Recovery of a Wild Rice Stand following Mechanical Removal of Narrowleaf Cattail

Prepared for:

International Joint Commission

By:

Kristi E. Dysievick, Peter F. Lee and John Kabatay

April, 2016

Seine River First Nation

Lakehead University

Table of Contents

Abstract

The exotic narrowleaf cattail, *Typhaangustifolia* and the hybrid *T. glauca*(*T. latifolia x T. angustifolia*) are known to be extremely successful invasive wetland plant species and were examined for their effect on wild rice in Rainy Lake and as well as methods to control them. Due to their dominance in habitat occupation, the cattails were shown to have displaced large areas of native wild rice stands in Rainy Lake. Rat River Bay in Rainy Lakewas used as a study area to determine effectiveness of mechanical control of cattails and recovery of wild rice. In the fall of 2014, Seine River First Nations (SRFN) conducted trials for cattail removal by cutting cattail culms with a mechanical harvester immediately above the sediment:water interface. The following spring, cattail survival in these cut areaswas negligible. The control mechanism was hypothesized to be a lack of oxygen supply from the culms to the rhizomes during ice cover. Wild rice in the seed bank of the cut areas germinated and renewed the former wild rice stands in terms of area of occurrence. However, total, extractable and pore water results for sediment nutrients, showed that cattails were depleting many macro and micronutrients in the former wild rice areas which may have long-term implications. Of particular importance was the lower nitrogen concentrations causing chlorosis in the wild rice plants growing in the cut cattail locations. If water levels were above average on Rainy Lake, this increase in depth was shown to favour the spread of cattails whereas a rule curve that allowed lower water levels during the growing season would favourwild rice. It was recommended that future studies concentrate on understanding seed bank dynamics for wild rice, the process by which cattails affect wild rice germination, the methods in which sediment nutrient depletion can be corrected and more efficient equipment for cutting cattails.

1.0 Introduction

A current and major problem for the natural ecosystems of Rainy Lake has been the invasion of exotic cattails, *Typha angustifolia,* and the hybrid, *T. glauca* (*T. latifolia x T. angustifolia*)into the lake's wild rice stands. These wild rice areas, together with those on Lake of the Woods, form the largest natural stands of wild rice in the world and are of immense historical and cultural importance to the First Nations of this region.

Exotic cattails are typical of most invasive species which can dramatically change the environment they invade and become a major threat to biodiversity and ecosystem stability (Ehrenfeld, 2003). Normally, exotics have some overriding advantage to the native species. In the case of these exotic cattails, they can tolerate depths of up to 1.5 m (Grace and Harrison, 1986) versus the native species (*T. latifolia*) with a depth tolerance of less than 15 cm (Apfelbaum, 1967; Travis et al., 2010). The 1.5 m depth limit of the cattail exotics falls into the same depth tolerance as wild rice and they therefore compete for the same niche. Invasive species, such as cattails, are normally very prolific and form dense mono-specific stands that can completely displace native species particularly if their depth tolerance exceeds the native species (Galatowitsch et al., 1999). They also produce abundant litter and decomposing biomass that can exert less noticeable changes. For example, the large amount of litter produced by *Typha angustifolia* can limit light, modify soil temperature and even change wetland hydrology (Tuchman et al., 2009). These effects aid in invasion and dominance of the system.

Once a wetland is invaded, exotic species act as drivers of change (Tuchman at al. 2009, Vitousek et al., 1997). There are consequences to this shift in species composition. For example, the production within a wetland is dependent on the flux of materials between living and non-living reserves. This biogeochemical process in wetlands depends on microbial, vegetation and fauna which quantify the exchange and transport of elements or compounds within the wetland and the surrounding environment (Reddy et al., 2010). Due to the change in microbial communities, nutrient dynamics and physical differences between species, once plant populations change the wetlands ability to retain or cycle nutrients has changed (Kao et al. 2003).Invasiveness by *Typha* spp. may also be aided by their allelophathic ability (Ervin and Wetzel, 2003) and have resulted in pronounced expansion and domination in wetlands in Eastern North America (Shih and Finkelstein, 2008).

Originally, *Typha angustifolia* was believed to have arrived on this continent with European settlement (Hotchkiss and Dozier, 1949, Woo and Zedler 2002). Recently Shih and Finkelstein (2008) haven proven through pollen records their presence before the European's arrival. They were first recorded on the east coast and then advanced through the United Stated and into the great lakes region in the late 19th century (Hotchkiss and Dozier, 1949; Shih and Finkelstein 2008). The herbarium at Lakehead University in Thunder Bay have examples of thespecies collected in northwestern Ontario as early as 1985. According to SRFN councilor, John Kabatay and Chief Tom Johnson, the plant was first noticedin the late 70's – early 80's but has only become prevalent in their wild rice stands in the last decade.

In terms of their taxonomy, the *Typha* genus has a perennial aquatic habit with approximately 30 species and representatives throughout most of the world (Apfelbaum, 1967, Nowinska et al., 2014) but occurs most abundantly in wetlands of the temperate northern hemisphere where it forms dense monocultures (Grace and Harrison, 1985). The various species have unisexual wind pollinated flowers with 20,000-700,000 fruits per inflorescence (Apfelbaum, 1967) which aids in colonization. Reproduction also occurs vegetatively via their rhizomes (Apfelbaum, 1967; Smith 1967) and these form dense mats in or above the sediment that prevent germination of native species (Grace and Harrison, 1985). In northwestern Ontario, *Typha latifolia* is being replaced as the dominant cattail species by *T. angustifolia* and the hybrid between the two species. In addition to its greater depth tolerance,*T. angustifolia*exhibits higher ramet densities and more rapid colonization abilities versus *T. latifolia* (McNaughton 1966). The exotichybrid cattail (*Typhaglauca*) is sterile and therefore only found in regions where both parents *Typha Latifolia* and *Typha angustifolia* are present (Waters and Shay, 1990; Shih and Finkelstein, 2008). The hybrid is able to out perform both its parents and is more tolerant to a wide range of water depths (Waters and Shay 1990). Together, the exotic and hybrid cattails, are considered some of the most problematic wetland invaders in the upper Midwest/great lakes regions and can advance at a rate of 5m a year (Galatowitsch et al. 1999).

Due to Cattail's ability to dominant and influence a system management strategies have been developed in attempt to reverse the resulting negative impacts. As reviewed by Sojda and Solberg (1993) control methods include physical control such as cutting, chemical use such as spraying herbicide, prescribed burning, shading and water level management. Chemical control is easy and cost effective but at this point there are no herbicides registered in Canada for commercial use on plants that compete with wild rice (Aiken at el.,1988) and there is no desire to use these in any case. Heavy equipment would be required for removal of cattails in the shallower areas. Burning during winter could be tried but this technique requires inundation with water during the early spring to cover the shoots and the water level regimes in the SRFN may not be suitable.Of these possibilities, the most feasible method on the SRFN sites seemed to be cutting and this method was chosen for our experiments.

The effectiveness of the cutting and burning techniques is based on the method in which the cattails spread vegetatively. The developing shoots rely on starch reserves in the rhizomes to be converted to sugars. This process (starch to sugars) occurs aerobically with the shoots providing a passageway for oxygen to the under rhizomes. If the shoots are cut off below the water line, the transport of oxygen ceases and the plant essentially dies from starvation (Beule, 1979). Sale and Wetzel (1983) showed that three underwater cuttings of the shoots during the growing season would kill the cattail rhizomes.

In Ontario, cutting or burning followed by water level increases were shown to be effective (Ball, 1990). On a commercial basis, cattail removal is done by Inland Aquatics, located in Uxbridge, Ontario (http://www.inlandaquatics.ca). More locally and of direct relevance to wild rice, the Fond du Lac Band of Lake Superior Chippewa in Minnesota is actively involved in cattail control for wild rice production. In their case, however, the cattail marshes being removed are floating and require the use of cookie cutters.

Zizaniapalustris L., northern wild rice, is an emergent annual aquatic grass that grows in shallow depths in lakes and rivers (Aiken at al., 1988). It is the only cereal native to North America with its natural distribution restricted to temperate eastern North America but has been successfully established in commercial quantities as far west as Saskatchewan and California. Wild rice forms dense continuous stands and prefers waters 15-30 cm in depth but does occur in depths of up to 2m. Northern wild rice prefers organic sediments but can survive in a wide range of sediment and water types (Aikens et al., 1988; Day and Lee 1989; Lee and McNaugthon 2004). Northern wild rice is an important cereal crop and has been harvested by First Nations People for centuries (Aiken et al., 1988). Due to disturbance and habitat requirements their historic range has been significantly reduced (Meeker 1993)

Wild rice is an annual and therefore reproduces from seed each year. Growth begins in spring after germination of the afterrippened seed. The shoot is formed first, and needs to reach the waters surface as quickly as possible for normal photosynthesis to occur. This is a very fragile stage since the plant has a limited root system and finite resources in the seed. If water depth is too great the plant will die or wash away. This submerged leaf phenophase may last up to six weeks. Upon reaching the waters surface the floating leaf stage occurs for approximately two weeks. The emergent stem and leaves form and at this stage tillering (production of many stems from one plant) occurs under optimum conditions. During July, flowering and pollination occurs followed by seed formation. The ripe seeds are ready to be harvested by late August and early September.

Since wild rice is annually re-established from seed in the seed bank, dormancy and germination play an important role in vegetation dynamics.Primary dormancy occurs in all wild rice seed following a cold treatment at 4^{o} C for approximately three months (Atkins 1986). It has been noted that even after a year of complete crop failure it was possible to have a stand the following year (Atkins 1989). This is attributed to the seeds' ability to enter secondary dormancy when after a single afterrippening season germination does not occur. The induction of secondary dormancy is not well understood. Oelke (1983) noted wild rice seed can persist in continually flooded conditions for up to 6 years.

Successful invasion of *Typha* into Seine River Watershed is attributed partially to the intense water level management on the system. Water levels and fluctuations influence native plant species as well as the persistence of invasive aquatic plants (Keddy, 2000; Boers and Zedler 2008). Since the first small dam constructed in 1873, there have been continuous additions of diversion and reservoirs that now control nearly the entire watershed mostly for purposes of power production. Neither the 2004 Seine River Management Plan or the Rainy Lake rule curve considers wild rice production. Since cattails can thrive in a larger range of water depths as opposed to other wetland species such as wild rice, large fluctuations in water levels will favour the dominance of invasive *Typha* (Farrell et al 2010; Boers and Zedler 2008).

The people of Seine River First Nation have traditionally harvested wild rice for generations and this activity is very sacred to the people and their way of life. Collecting wild rice brings the community together and up holds a tradition of immense importance to them. Due to the invasionof cattails their stands that have always been present are being eradicated. As their stands decline or disappear there is on-going concern among elderswhat this could mean for their culture and future generations. In 2014 there was no wild rice harvested from Rainy Lake or Seine River. This compares to historical commercial sales of over a million pounds. The goal of this project is to quantify the effects of cattail invasion on wild rice and develop control methods that can stop the spread of this invasive species.

2.0 Objectives

The objectives of this project were;

i. to determine the effect of invasive cattails on wild rice in the Rainy-Namakan system
ii. to determine the effect of the current rule curve on the spread of cattails in the Rainy-Namakan system
iii. to develop management strategies that will enhance the control of cattails coupled with rule curve regulations
iv. to integrate the results of the study into the water level model being developed by the IJC such that it will include the spread of cattails into wild rice stands

3.0 Materials and Methods

3.1.0 Study Area

Seine River First Nation (SRFN) is part of Treaty 3, with a population of 725 registered members with approximately 450 on reserve, and is located 60 km West of Atikokan Ontario on the shores of the Seine River (Figure 1). SRFN has large areas of reserve land on Rainy Lake as well as the Seine River. The Seine River is the source of the community drinking water for the residents and provides the fish, ducks, and wild rice that are staples to the communities' diet. Traditional land use areas for band members far exceed the boundaries of the community and are used for hunting, fishing, wild ricing, gathering, and ceremonies. These areas include the Turtle River and Seine River systems. Both systems have wild rice located within a few kilometers of the community.

There were two field study areas. Rat River Bay (-92.665, 48.594) on Rainy lake is located approximately 30 km from the Seine River community and is directly affected by water level control on Rainy Lake. Wild Potato (-92.501, 48.711), the second study area, is just west of the community (Figure 1). It is affected by water control on the Seine River. They are both located on traditional lands and havebeen harvested for wild rice for generations.

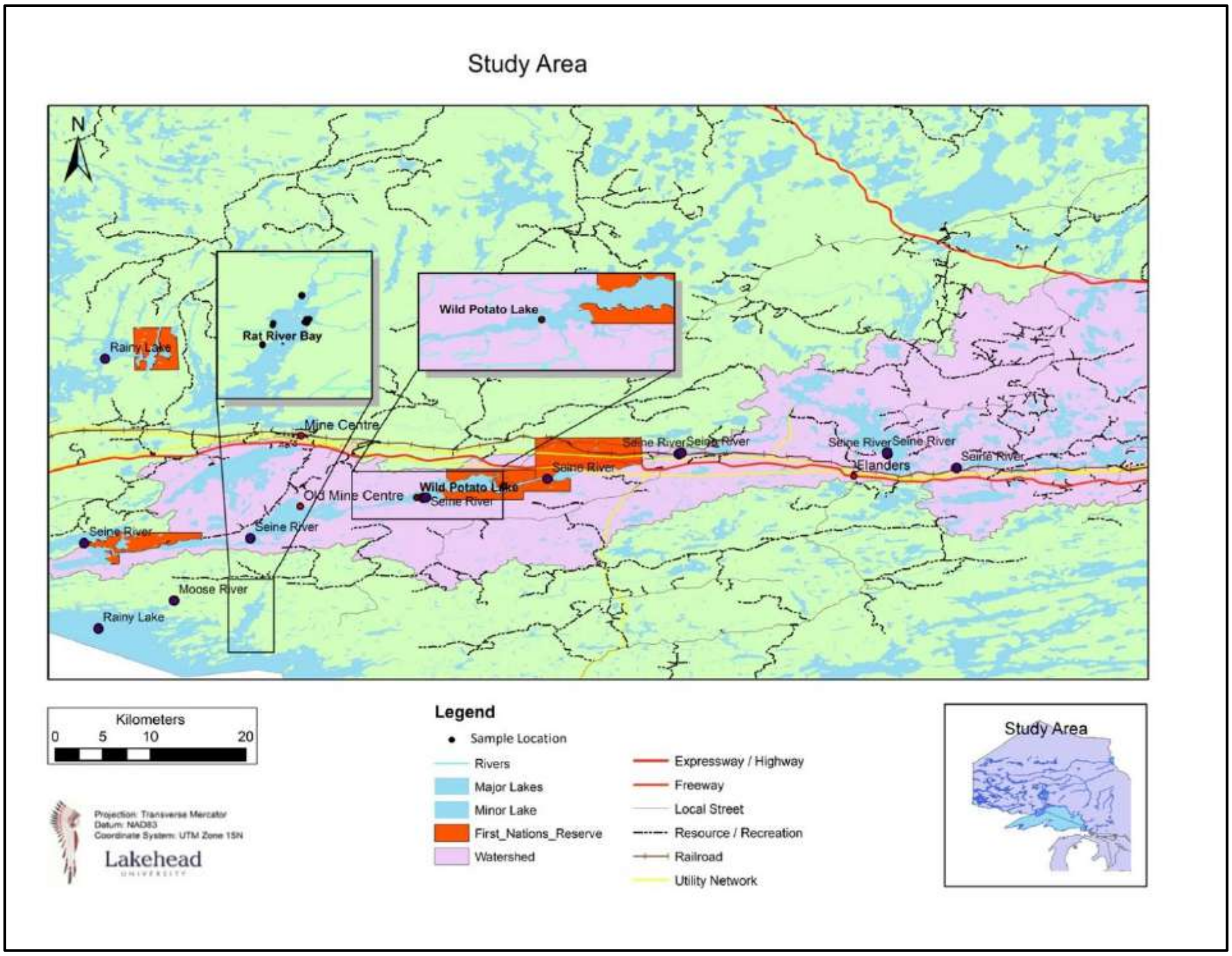


Figure 1. Location of study areas. Rat River Bay is at the bottom left on Rainy Lake and Wild Potato Lake is just below the Seine River Community. Both lakes are on Seine River's traditional land and are harvested for wild rice. The sample locations on the western shore of Rat River Bay are where cattails were cut.

3.2 Field Procedures

3.2.1 Cutting of Cattails

During the fall of 2014, three primary cattail dominated areas in Rat River Bay (RRB) were selected for cutting (Fig. 1). These treatment areas were in three different habitats: near an island on the western shore of the bay; along the shore just north of the island; and at the extreme north end of the bay where the Rat River enters the bay. The cutting was done using a cutting bar apparatus attached to an airboat as seen in Figure 2. The cutting bar is lowered into the water and cuts cattails just above the sediment:water interface. Within all three cutting locations, no aerial portions of cattail plants were visible following the harvest event.

Figure 2. Cutting bar apparatus attached to the SRFN airboat (left). The bar is lowered into the water and cutting of the cattails occurs (right). The system requires both an operator for the airboat and the cutting bar.

3.2.2 Pore water Collection

Porewater samples were collected using peepers. They were constructed using acrylonitrile butadiene styrene (ABS) pipes, which held the sample tubes three every 10 cm. Fisherbrand® 50 mL sample tubes were modified by drilling a 19 mm diameter hole in the cap and replaced with a 0.45 µm pore size Millipore Durapore® membrane filter. At deployment on August 9, 2015 sample tubes were filled with degassed distilled deionized water (DDW), capped with zero head space, and placed within the ABS pipe structure.They were located at the island cut site in Rat River Bay. The peepers were pushed vertically into the sediment with two in each treatment (cattail dominated, wildrice natural stand, and a cut (treated) area). Collection occurred on October 14, 2015 when the peepers were pulled vertically out of the sediment. All three tubes from each depth were combined into one composite sample.

3.2.3Sediment/Plant Tissue Collection

Sediment and plant tissue collection occurred in late August, 2015along transects thatran perpendicular to the shore line. Sample collection occurred near the island cut site at Rat River Bay in an existing wild rice stand, an area dominated by cattails, and an area where cattails were cut (treated) and was now wild rice. Additionally, a natural wild rice stand in Wild Potato Lake was sampled. Each study area had three transects and samples were collected at depth increases of 10 cm in 0.25m^2quadrats from the shore outward to the depth limit of wild rice. Sediment samples were collected in each quadrat using an corer to collect the top 20 cm of sediment.In each quadrat the number of plants were counted and collect by severing all plant culms just above the sediment water interface.All plants from each quadrat were placed into a labeled bag, and placed on ice in a cooler for transport to the laboratory.

3.3Laboratory Procedures

All sample analyses were conducted at the Lakehead University Environmental Laboratory (LUEL), a Canadian Association of Laboratory Accreditation (CALA) ISO 17025 accredited laboratory. All analyses followed standard operating procedures and included the use of blanks, quality control samples and replicates.

3.3.1Water Analysis

Water samples were mixed, allowed to settle for 5 to 10 minutes and then filtered.Water (surface and pore) samples were analyzed for P (total P and phosphate), N (nitrite, nitrate, ammonia, total N) dissolved organic carbon (DOC), and total Al, As, Ba, Ca, Fe, K, Mg, Mn, Na, S, Sr and Zn.

Following the addition of HNO3, water samples were digested and concentrated by microwave and analyzed by ICP spectrometry for Al, As, Ba, Ca, Fe, K, Mg, Mn, Na, S, Sr and Zn. Total N and P were analyzed by colourimetry using a SKALAR AutoAnalyzer®. Anions (Cl NO2, NO3, SO4) were measured using Dionex 1100 ion chromatograph and ammonia was measured with a Dionex 120ion chromatograph. Dissolved Organic Carbon was quantified by acidifying the sample and filtering it through a carbon dioxide permeable membrane prior to analysis on a SKALAR AutoAnalyzer®.

3.3.2Sediment Analysis

Sediment samples were air-dried, ground to pass through a 2 mm mesh and homogenized into uniform samples.

For total concentrations, samples were digested by microwave following the addition of HCl and HNO3. Samples were also analyzed for pH and conductivity using non-dried samples thoroughly mixed with DDW. Total P, Al, As, Ba, Ca, Fe, K, Mg, Mn, Na, S, Si, Sr, Ti and Zn analyses were conducted by ICP spectrometry.

Total carbon, total nitrogen and total organic carbon was analysed with the ElementarVario Cube analyzer (CHNS analyzer). In this instrument, combustion occurs forming gaseous products which is reduced and absorbed, and then transported by carrier gas into the measuring cell of the thermal conductivity detector.

Concentrations for extractable values for selected parameters were also determine. Ca, Mg, K and Na, were extracted with ammonium acetate solution (pH = 7) while Fe, Mn, Cu and Zn were extracted in a 0.1N HCl solution.Both cations and metals were determined by ICP.The available N as ammonia present in the sediment (as NH4-N) and nitrate was extracted with 1.0MKCl solution and determined by colorimetry and cadmium reduction on the SKALARAutoAnalyzer®. The available phosphorus in the sediment was determined using the BRAY P1 method (Bray & Kurtz, 1945), whereby NH4F dissolves Al and Fe phosphates and forms complexes with these metals in acid solution. P was then measured by ICP. Sediment bulk density was obtained by oven-drying 20 cc of sediment at 105°C until a constant weight was reached.

3.3.3Vegetation Analysis

Samples from each quadratwere weighed, number of tillers/culms counted and a disease ranking was assigned. The plant tissue samples werethen oven-dried at 35°C and ground to pass through a 2 mm mesh. All samples were analyzed for total P, N, Al, Ba, Ca, Fe, K, Mg, Mn, Na, S, Si, Sr, Ti and Zn. Total P, Al, Ba, Ca, Fe, K, Mg, Mn, Na, S, Si, Sr, Ti and Zn analyses were conducted by ICP spectrometry subsequent to their digestion and concentration by microwave following the addition of HNO3. Total Carbon and Nitrogen was analysed with the ElementarVarioCube analyzer (CHNS analyzer).

4.0 Results and Discussion

4.1.0 Effect of Invasive Cattails on Wild Rice

4.1.1 Wild Rice Production

The results indicated that primary production for cattails greatly exceeded wild rice at the study site (Table 1). Cattails had the fewest number of culms per 0.25 m^2 quadrat, but their dry weight per quadrat and weight per culm was higher than either wild rice treatment. These results support the theory that invaders are often much larger in size when compared to native species (Zedler and Kercher, 2004). This added production may influence the recovery of wild rice. Statistically there was a significant difference between plant density, total weight per quadrat and weight per plant between the natural and treated (cattail cut) wild rice treatments. There were more plants in the treated quadrats but they were lower in dry weight per quadrat and weight per plant compared to the natural wild rice area. The cause of the lower weights in the treated area may be related to lower nutrient concentrations following nutrient depletion by the larger invasive cattails (see sections 4.1.3 and 4.1.4). Similarly, the lower values in Wild Potato Lake may be related to lower nutrient concentrations in that site versus Rat River Bay.

Table 1. Meanvalues of plant density, dry weight per quadrat (0.25m^2), weight per plant in the three treatments. Collection occurred from a naturalwild rice dominated stand (natural),a previously cattail dominated stand which cutting occurred in 2014 (treated) and acattail dominated area (cattail) in Rat River Bay. Results also include a natural wild rice standlocated in Wild Potato Lake.

Treatment	No. of Culms/Plants		Dry Weight (g)		Weight/plant (gm)	
	Mean	SD	Mean	SD	Mean	SD
Cattail	8.08	2.31	347.40	107.81	44.13	11.4
Natural	13.05	7.7	177.13	49.88	17.66	8.89
Treated	26.68	16.00	123.93	50.57	5.68	2.89
Wild Rice Wild Potato	10.37	4.13	96.54	23.08	10.59	4.41

4.1.2Wild Rice Chlorosisand Incidence of Disease

The colouration of wild rice plants within natural wild rice stands and wild rice within the treated areas (treated) was noticeably different. Wild rice plants harvested from a natural wild rice stand had an outward appearance of a generally healthier plant with less brown spot disease (Table 2, Fig. 3, 4) compared to rice plants harvested from the treated areas of intense cattail removal which were slightly chlorotic and heavily disease infested (Fig. 3, 5). This suggests there was nutrient deficiency, specifically nitrogen, in the sediment of the treated areas (Day and Lee; 1990; Chaplin 1980). This is reinforced by our plant tissue analysis that did confirm significantly lower nitrogen in treated areas (Table 4).

Table 2. Disease ranking assigned to each wild rice quadrat. A rank of 1 was assigned to plants with no chlorosis and no brown spots increasing in chlorosis and brown spots to a rank of 5. See Figure 3 for a visual appearance of ranks.

	Disease Ranking (increasing brown spots and chlorosis 1 →5)				
%	1	2	3	4	5
Treated	0	6.25	12.5	37.5	43.75
Natural	30	45	20	5	0
Wild Potato	40	30	20	10	0

Figure 3. Visual appearance of disease ranking for wild rice infected with brown spot.

Rice Disease Evaluation Legend

Example	Rating
	1
	2
	4
	5

Figure 4. WR plants in a quadrat within a natural WR area (never dominated by cattails). NOTE the lower incidence of brown spots on leaves and stems of WR plants. This was the general observation throughout this natural WR plant area; water depth in this image was 60 cm (same as **Figure 5** below).

Figure 5. WR plants in a quadrat within a treated area of cattail cutting. NOTE high incidence of brown spots on leaves and stems of WR plants. Similar results occurred throughout the treated area; water depth in this image was 60 cm.

4.1.3 Sediment and Pore water

The effects of cattails on total and extractable nutrients are contained in Table 3 and Table 4 respectively.

Table 3. Average total values in sediment grab samples for study locations; a natural wild rice stand, a cattail dominated area (cattails) and an area where cattails were cut (treated) in Rat River Bay (RRB), as well as a natural wild rice stand in Wild Potato Lake.

	Wild Rice Wild Potato		Treated (RRB)		Wild Rice Natural Stand (RRB)		Cattails (RRB)	
Description	Average	SD	Average	SD	Average	SD	Average	SD
Tot. Ca (µg / g)	7679.2	937.6	10260.9	863.4	8157.1	843.8	9912.3	1470.1
Tot. Cu (µg / g)	36.3	6	57.6	8.4	63.4	11.8	73.0	5.8
Tot. Fe (µg / g)	28459	3339.8	10957.0	2705.5	11371.7	5015.7	14216.2	2656.2
Tot. K (µg / g)	1999.3	332.6	750.6	173.2	861.2	343.3	916.6	149.7
Tot. Mg (µg / g)	11568.9	1644.5	5550.0	1361.7	4510.1	2157.5	6743.8	743.5
Tot. Na (µg / g)	3550.3	395.3	2951.3	237.2	3227.2	206.1	3241.6	215.0
Tot. P (µg / g)	594.4	10.2	1454.4	242.7	1412.1	352.8	1023.3	259.9
Tot. S (µg / g)	379.7	87.6	2603.0	873.8	2473.5	690.1	2073.4	559.7
Tot. Si (µg / g)	184.4	22.1	236.2	25.3	321.7	219.8	209.9	18.4
Tot. Carbon (%C)	2.8	0.5	21.4	7.3	20.9	7.4	16.4	3.9
Tot. Nitrogen (%N)	0.2	0.05	1.8	0.5	1.8	0.6	1.4	0.4
Organic Carbon (%C)	2.7	0.4	20.2	6.7	20.1	7.0	15.6	3.8

Table 3. shows a trend for lower concentrations for total nitrogen, total carbon, total organic carbon and Si, S, P in the sediment of cattail dominated areas. The reverse is true for K, Fe, Cu, Mg which are higher in cattails. When comparing treated vs non treated stands of wild rice, Si, Fe, Na,Cu and K are lower in treated stands, while treated was higher in Ca and S. Wild Potato had total concentrations that were higher for most parameters but noticeably lower in total nitrogen.

The extractible values for sediment nutrients (Table 4) show much the same trends as the total concentrations for most parameters. Lower concentrations of P, NO_3, NH_4, and Mn occur in the cattail dominated area while Ca, K, Na, Cu, Fe and Zn are all highest in the cattail dominated area. Wild Potato again showed concentrations of most nutrients differed considerably from Rat River Bay, probably reflecting the variations for these parameters in its drainage basin.

The most significant effect is the variations in nitrogen that occurred among the four different treatments and locations (Fig. 6). For all three forms of nitrogen, the natural stand is the highest while the treated area values are intermediate to the natural stand and the cattail dominated stand.

Table 4. Extractable values for sediment grab samples for study location; a natural wild rice stand, a cattail dominated area (cattails) and an area where cattails were cut(treated) in Rat River Bay, as well as a natural wild rice stand in Wild Potato Lake.

	Wild Rice Wild Potato		Treated		Wild Rice Natural Stand		Cattails	
Description	Average	SD	Average	SD	Average	SD	Average	SD
Ext. Ca (µg / g)	1293.6	205.6	1023.1	181.9	817.2	134.1	1150.0	168.5
Ext. K (µg / g)	32.8	10.9	5.9	2.2	5.9	4.1	10.1	4.4
Ext. Na (µg / g)	23.2	9.7	2.6	0.7	3.9	2.2	15.1	25.0
Ext. Cu (µg / g)	3.5	0.5	1.4	0.4	1.4	0.6	2.3	0.5
Ext. Fe (µg / g)	200.3	51.7	52.4	19.1	61.9	22.0	93.4	79.9
Ext. Mn (µg / g)	72.2	39.5	7.5	0.8	10.8	5.7	9.4	5.2
Ext. Zn (µg / g)	3.3	0.3	0.8	0.2	1.0	0.9	1.2	0.3
NH3+NH4 (µg / g)	1	0.4	0.7	0.3	2.3	1.0	0.6	0.4
N-NO3 (µg / g)	0.5	0.4	0.9	0.7	1.2	1.3	0.8	1.1
pH	6	0.5	6.0	0.1	5.6	0.1	6.0	0.0
Ext. P (µg / g)	0.1	0.1	13.3	3.7	8.3	5.0	7.8	4.1
Bulk Density (g/cm^3)	0.7	0.1	0.2	0.1	0.2	0.1	0.3	0.1

Results from the peepers continued the observed trends shown for total and extractable nutrient values in the sediment. Table 4 presents the concentration averages and standard deviation from the water column immediately above the sediment:water interface and at depth intervals in the sediment column.

Concentrations of Ca, Mg, Sr, PO4 and total P were highest in the lower portion of the sediment profile for all 3 study areas. This was no true for NH4, K and total nitrogen which were higher in concentration in the upper 10cm for treated and natural areas but lowest in the top 10 cm in the cattail dominated area.In comparing treated to natural stand, it is noted that dissolved organic carbon, K, ammonia and total nitrogen were higher in treated then the natural wild rice area.

The values for the parameters in the water column above the sediment:water interface (Table 5) show the natural wild rice stand were highest in PO_4, total nitrogen, Cl, Ca, Fe, Mg,Mn and SO_4 but lowest in Na. The treated area generally had the lowest values for PO_4, total nitrogen, Cl, Ca and Fe but was highest in K and Na. The cattail dominated area had intermediate values for most parameters but showed the lowest values in SO_4, Mg, and K.

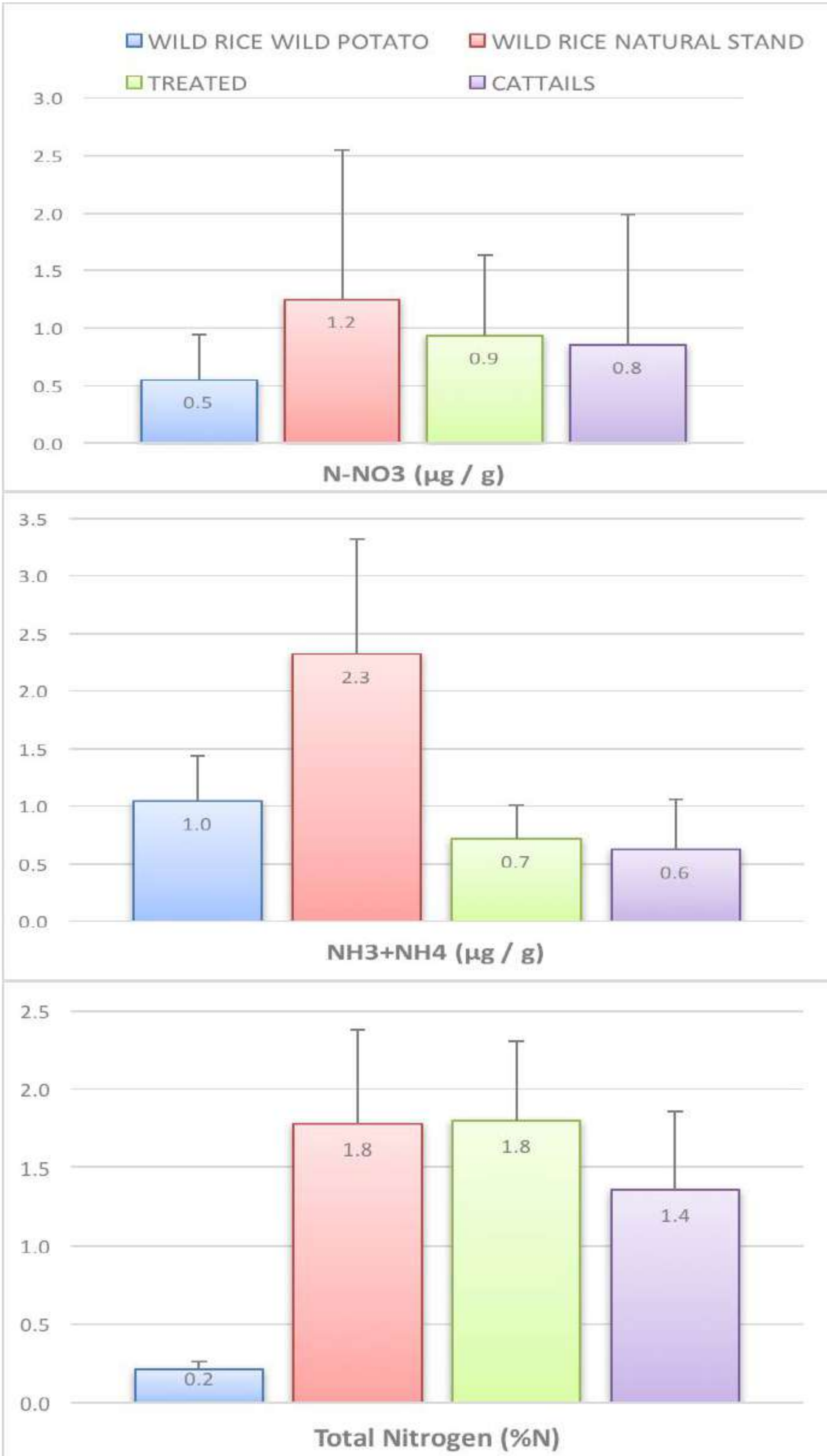


Figure 6. Mean values for ammonia, nitrate and total nitrogen from sediment core samples collected in transects in each of the treatment and location areas.

The sediment results from total, extractable and pore water in sediment all indicate a depletion of nitrogen caused by invasive cattails. These difference in nitrogen values (Fig. 6) between study areas is critical as wetlands are often nitrogen limited and therefore nitrogen determines rates invasion, eradication and recovery of native species (Bedford, 1999). Such changes in nutrient values can be attributed to a change in plant species (in this case wild rice to cattails) with associated difference in primary productivity, growth rate, chemical quality and rate of litter fall (Ehrenfeld, 2003) that all influences nutrient concentrations in the sediment. In all three sediment nitrogen parameters (Figure 6) the treated area values are intermediate to the natural wild rice and the cattail dominated stand. Live and decomposing biomass impact availability of nutrients (Vaccaro et al., 2009). Therefore, the removal of cattails by cutting and consequently the reduction in biomass in treated areas after one year is reducing the impact of the cattails on nutrient levels. Therefore, sequential years with little to no cattail biomass could eventually result in treated stands being as productive as natural wild rice stands.

Pore water is available immediately to a plants roots for their nutritional requirements but as they uptake nutrients into their tissues, concentrations of these nutrients decline in the sediment rhizosphere (En- Hua et al. 2010).As shown by Table 5, pronounced differences in pore water nutrients occurred between vegetation types and this influences pore water concentrations. Values for many nutrients increased as with increased depth of sediment, indicating the demand for both cattails and wild rice was in the upper rooting zone as shown previously by Lee, (2015). However, NH4, K, and total nitrogen were higher in concentration in the upper 10cm for treated and natural wild rice versus cattails indicating the increased demand for these nutrients for cattails and therefore reducing the amount of available nutrients for wild rice.

Water quality near aquatic vegetation can be influenced by plant density and species present (Lee and McNaughton, 2004). A similar trend was observed in this study with wild rice having higher concentration for total nitrogen, Cl, Ca, Fe, K, Mg, Mn, Na and SO4 versus cattails.

4.4.2 Plant Tissue

The impact of cattail invasion on nutrient depletion in the sediment can be assessed by examining its uptake of nutrients into plant tissue versus wild rice. Table 6 shows the concentrations in plant tissue per 0.25 m^2 for cattails, natural and treated wild rice stands. The value for 0.25 m^2 was used to normalize for plant density differences among study areas. Total carbon, total nitrogen, Ba, Ca, Cu, Mg, Mn, Na, P, S, Sr and Znper 0.25 m^2 were all higher in the cattails' plant tissue compared to the wild rice study areas. The reverse was true for Fe, Si andTiwhich were lowest in cattails. Comparing natural wild rice stands to treated stands, P, Mg, K, Ca, Zn, Cu, total carbon and total nitrogen were significantly higher in the natural wild rice stand.

Table 5. Mean total values of elements in water column and pore water from 0-10cm and 10 -20 cm samples for 3 study locations; a naturally occurring wild rice stand, a cattail dominated area and an area where cattails were cut and wild rice recovered (treated) in Rat River Bay.

	Treated Area						Natural Wild Rice Stand						Cattail Dominated					
-	Water Column		0-10cm		10-20cm		Water Column		0-10cm		10-20cm		Water Column		0-10cm		10-20cm	
Description (mg/L)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Dissolved Organic Carbon	27.20	1.8	12.55	1.2	15.30	7.4	24.60	4.5	21.00	2.8	17.60	1.8	23.60	6.2	18.90	4.4	14.75	2.9
Chloride	0.28	0.0	0.15	0.1	0.27	0.1	0.72	0.5	0.58	0.3	0.52	0.2	0.34	0.0	0.14	0.0	0.13	0.0
N-NH4+NH3	0.00	0.0	0.39	0.3	0.00	0.0	0.18	0.2	0.39	0.2	0.34	0.2	0.00	0.0	0.00	0.0	0.06	0.1
Dissolved Calcium	6.15	0.5	8.60	1.2	11.05	1.0	7.66	2.3	11.99	4.9	14.74	2.9	6.18	0.3	7.58	1.2	8.36	1.7
Dissolved Iron	0.62	0.2	0.39	0.1	1.19	1.3	1.81	2.2	3.51	4.3	5.18	5.0	0.70	0.6	1.97	0.4	3.77	1.8
Dissolved Potassium	1.67	0.1	0.37	0.2	0.16	0.2	1.06	0.1	0.48	0.3	0.16	0.1	0.91	0.1	0.43	0.0	0.27	0.2
Dissolved Magnesium	3.17	0.3	4.03	0.3	5.62	0.0	3.71	0.8	5.37	1.8	6.43	1.3	3.02	0.1	3.29	0.4	3.58	0.7
Dissolved Manganese	0.00	0.0	0.19	0.0	0.20	0.0	0.13	0.2	0.32	0.3	0.37	0.3	0.04	0.1	0.14	0.1	0.17	0.1
Dissolved Sodium	1.90	0.1	0.94	0.1	1.97	0.9	1.62	0.3	0.97	0.7	0.59	0.3	1.68	0.2	1.26	0.0	0.80	0.3
Dissolved Sulfur	0.33	0.1	0.16	0.0	0.15	0.0	0.34	0.1	0.30	0.1	0.27	0.0	0.32	0.1	0.26	0.1	0.23	0.0
Dissolved Strontium	0.02	0.0	0.03	0.0	0.04	0.0	0.03	0.0	0.05	0.0	0.05	0.0	0.02	0.0	0.03	0.0	0.03	0.0
Sulphate	0.18	0.0	0.14	0.1	0.08	0.0	0.26	0.1	0.09	0.1	0.11	0.1	0.17	0.0	0.10	0.0	0.05	0.1
Phosphates (as P)	0.03	0.0	0.04	0.0	0.06	0.0	0.10	0.1	0.11	0.1	0.13	0.1	0.04	0.0	0.10	0.1	0.17	0.1
Total Nitrogen	0.76	0.1	1.15	0.3	0.88	0.0	1.10	0.3	1.27	0.2	1.19	0.2	0.84	0.0	0.92	0.0	1.06	0.1
Total Phosphorous	0.04	0.0	0.03	0.0	0.04	0.0	0.08	0.1	0.09	0.1	0.12	0.1	0.03	0.0	0.08	0.0	0.16	0.1

Table 6. Averagevalues of elements in plant tissue from each study location; a natural wild rice stand, a cattail dominated area (cattails) and an area which cattails were removed in 2014 (treated) in Rat River Bay, as well as a natural wild rice stand in Wild Potato Lake. These results are the absolute concentration in plant tissue multiplied by mass per quadrat.

	Wild Rice Wild Potato		Wild rice Natural stand		Treated		Cattails	
Description mg	Average	SD	Average	SD	Average	SD	Average	Cattails
Aluminum	32.89	22.1	16.58	5.8	18.54	16.2	9.20	5.8
Barium	1.10	0.5	2.04	0.9	1.79	0.7	5.01	1.6
Calcium	925.81	520.9	1656.82	648.0	1481.34	629.1	1769.01	534.9
Chromium	0.07	0.1	0.04	0.0	0.04	0.1	0.03	0.1
Copper	0.56	0.2	0.61	0.2	0.49	0.2	1.10	0.4
Iron	68.98	33.7	54.44	15.7	48.20	28.1	21.44	13.5
Potassium	1950.82	541.3	2501.90	860.8	1503.19	577.0	2489.92	1032.1
Magnesium	223.48	135.8	508.93	231.3	358.73	158.8	842.62	231.0
Manganese	43.16	16.9	14.68	6.0	18.97	10.2	210.73	139.4
Sodium	398.80	150.8	460.78	231.8	447.49	164.8	621.56	259.6
Nickel	0.13	0.1	0.07	0.1	0.18	0.4	0.13	0.2
Phosphorus	340.81	102.3	402.94	92.0	289.66	97.2	608.59	219.4
Sulfur	242.76	86.6	393.78	131.2	273.15	90.0	480.93	184.9
Silicon	58.13	24.6	90.84	39.8	86.02	49.6	43.39	30.4
Strontium	1.96	1.1	3.72	1.6	3.05	1.3	5.68	1.4
Titanium	2.33	1.9	0.63	0.5	0.55	0.9	0.11	0.0
Zinc	1.52	0.6	2.23	0.8	1.81	0.6	4.73	2.0
Total Carbon	43438.72	17398.0	72104.89	21124.2	53235.50	14722.2	161937.32	51164.8
Total Nitrogen	2991.64	1007.8	4305.77	1271.9	2607.30	823.5	5861.66	2658.2

Nitrogen had the most pronounced difference in nutrient concentrations in plant tissue among the plantstudy areas (Table 6).The highest values for nitrogen, occurred in the cattail plant tissuequadrats. Previous studies haveshown that cattails are able to uptake excess amounts of nutrients (Larkin et al., 2012), and their ability to internally translocate high concentrations of nitrogen, may deprive other competing species of their nitrogen requirements (Davis et al.,1983). Nitrogen was lower in the cut (treated) versus natural wild rice areas suggesting that cattails have a long term effect on nutrient concentrations to due to their elevated uptake and the fact that they are present even under extremely high water level conditions (such as 2014). Certainly the lower values of nutrients in the sediment of the cut areas would contribute to lower primary production in these areas (Table 1); a similar effect of low nutrients on wild rice was described by Day and Lee (1990).

One noteworthy value in Table 6 is the high amounts of silica in the wild rice quadrates (both treated and natural) versus cattails. This was expected. Struyf and Conley (2009) state in their review that wild rice plants consistently uptake large amounts of silica. Silica is thought to provide plants with enhanced growth and protection from physical stress (Struyf and Conley, 2009).

4.2 Rule Curve Effect on Cattail Spread

4.2.1 Water Level Control and Historical Invasion of Cattails

Water levels on the Seine River and/or Rainy Lake are the major influence on crop success for the wild rice stands belonging to the Seine River First Nation.

The Seine River watershed has its headwaters in the Savanne River located near Upsala, ON. The river flows southwest some 250 kilometres, emptying into Rainy Lake. The watershed itself has an area of approximately 6,250 kilometres. Water level control within the system began in 1873 with the construction of a small dam on the outlet from Lac de Mille Lac and various dams, diversions, and reservoirs were added in the early and mid parts of the 20th century. The river system is used mostly for power generation and the flows controlled by various dams. The Lac de Mille Lac dam controls outflow from Lac de Mille Lac, the Raft Lake dam controls Upper Marion Lake while the Lower Marmion Sluiceway controls Lower Marmion Lake. Wagita Bay Dam is primarily used to separate the Seine River diversion (around the former Steeprock Iron Mine) from Steep Rock Lake. The Valerie Falls dam controls water levels in Colin Lake and Little Falls Lake which are a relatively small portion (0.2%) of the upstream watershed. The Calm Lake dam controls water levels from Calm Lake to Perch Lake while the Crilly Lake Dam (Sturgeon Falls Dam) controls the level on Crilly Lake (Laseine Lake) which is a small receiving lake just downstream from Calm Lake. Water levels in the Seine River are controlled by the 2004 Seine River Management Plan (2004) which essentially considers energy production and fish spawning. There is no management for wild rice production. The extent that the wild rice areas in the Seine River belonging are affected by water levels is largely dependent on the discharge from the Crilly Lake Dam although levels on Rainy Lake also have some effect. Daily peaking does sometimes occur from the Crilly Lake Dam, causing increases of water levels in wild rice areas.

The Rainy Lake Convention of 1938 authorized the IJC to control water levels on Rainy Lake during periods of drought or flooding. The water levels are controlled by the dam at Fort Frances. An annual rule curve was implemented in 1949 and revised in 1970 to contain both upper and lower recommended levels. This was slightly modified again in 2000. The 2000 rule curve does recommend that the water level be maintained in the middle of the range between the upper and lower levels. The overall effect of the rule curves has been much less fluctuation in water levels than prior to the rule curve.

Wild rice production was not considered when water level regulations for Rainy Lake were being developed by the Canadian and U.S. governments. Anecdotal information from First Nation elders suggests that harvests were at one time much greater and given that water levels were at times very much lower than at present this seems likely. Flug (1986) estimated that average water levels under natural conditions would have been approximately 0.5 m less than the lower rule curve during the growing season than they are now which would have increased wild rice production.

Although there are no specific studies on the effects of cattails on wild rice, it is well known that wild rice does not compete well against perennials (Aiken et al, 1989). Clay and Oelke, (1987) showed that wild rice yield was reduced by 60% from competition due to giant burred compared to weed free treatments. Perennials are better able to withstand increases in water levels. Unlike annuals(like wild rice) with limited carbohydrates in their seeds, perennials can rely on food reserves in their underwater rhizomes and tubers to supply needed energy to reach the water surface. If these water levels are maintained for several years at above average water levels, the perennials are able to displace the wild rice even if water levels drop to optimum depths for wild rice. On Lake of the Woods, Gilbert (1985) showed that water lilies had invaded bays previously occupied by wild rice to the extent that the rice was completely displaced. Field experiments by Atkins (1983) on Lake of the Woods demonstrated that lily pads, once established, could exclude wild rice regardless of water depth. Continued growth of the invading plants can eventually alter the nutrient levels in the sediment to be distinctly different from those typical of wild rice stands (Lee and McNaughton, 2004). Results from this study (Tables 3, 4, 5) suggest the same outcome is occurring in Rat River Bay.

Historical aerial photographs give an indication as to the spread of cattails in Rat River Bay between 1976 and 2010 (Figure 7). In 1976, there were approximately 14 hectare of cattails. By 2010, this had increased to 72 hectares. Invasion rate is certainly from year to year but recent data shows there is a distinct advantage for cattails over wild rice in high water level years.

4.2.2 Current Situation

In 2014 there was no wild rice harvested in Rat River bay and Wild Potato lake. In fact, there was no wild rice whatever in Rat River Bay. This compares to historical commercial sales of wild rice from Rainy Lake and the Seine River of up to 150,000 pounds. Figure 8 shows increased depth and a large water level increase spike in June and July of 2014 on Rainy Lake. No wild rice is visible in Figure 9. However, in 2015 under low water conditions with no water level increase spike in the growing season, wild rice was prevalent in the same area (Figure 10), and Rat River Bay had approximately 116.8 ha of wild rice.

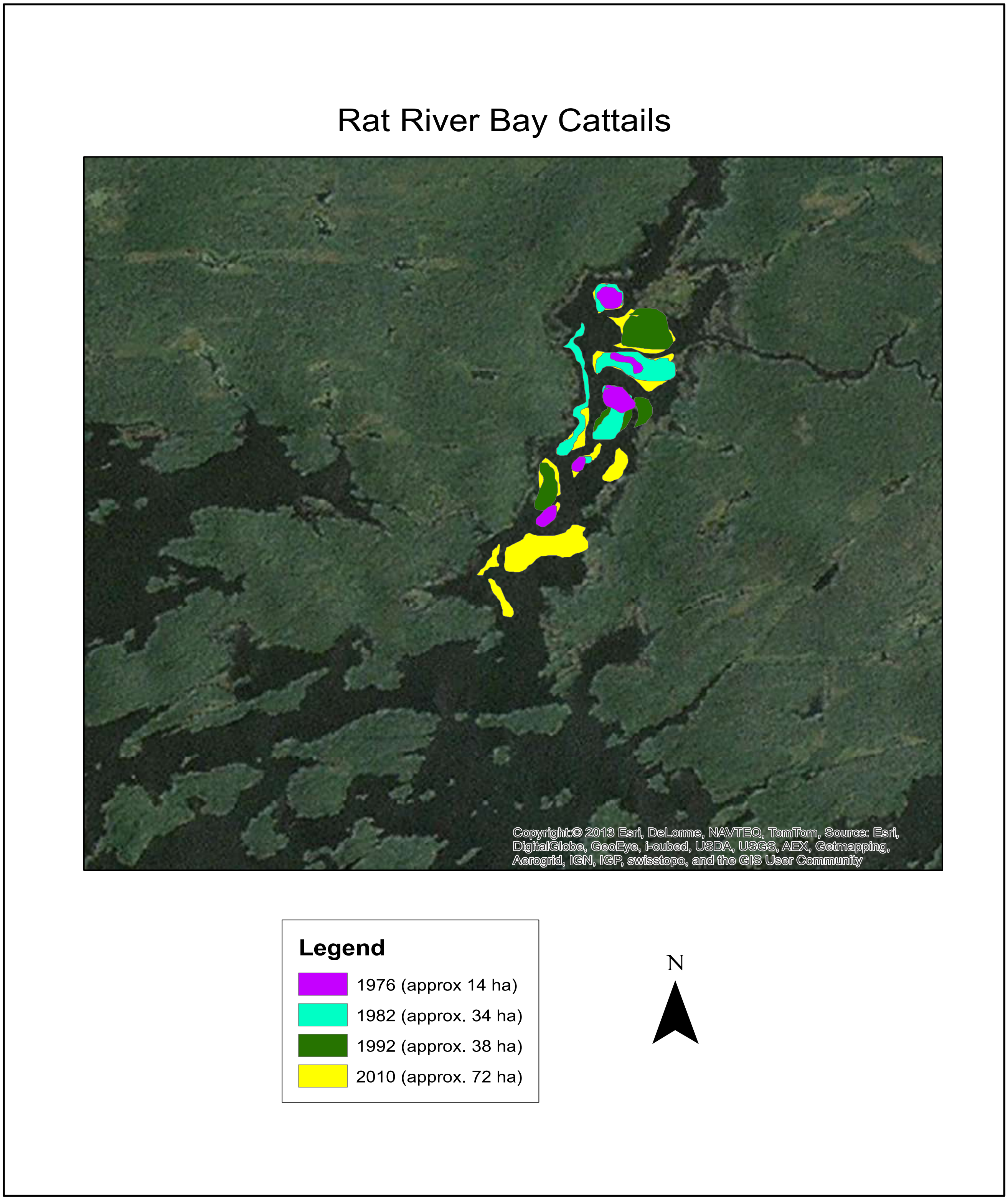


Figure 7. Spread of cattails determined from historical air photos. Data was from aerial photographs from 1976, 1982, 1992 which were used to overlay a 2010 Google Earth image.

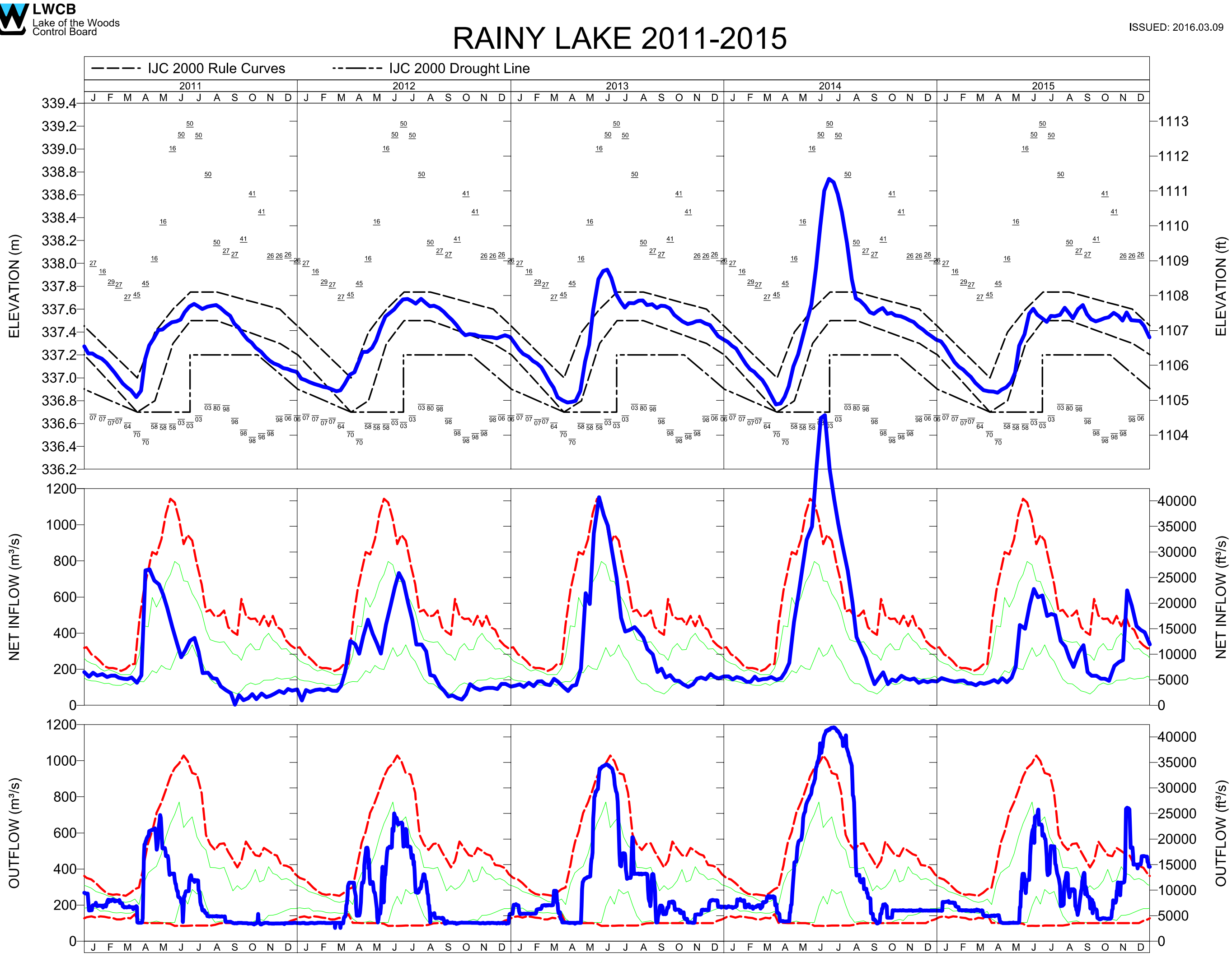


Figure 8. Water level and flow data for Rainy Lake for 2011-2015 from Lake of the Woods Control Board. In 2014, Rainy Lake had extremely high water levels during the growing season with a large water level spike in June-July. Water levels were lower in 2015 and there were no sudden peaks in water levels during the growing season.

Figure 9. Rat River Bay in 2014, this photo was taken off an island. NOTE the cattail domination and not a single wild rice plant in this area.

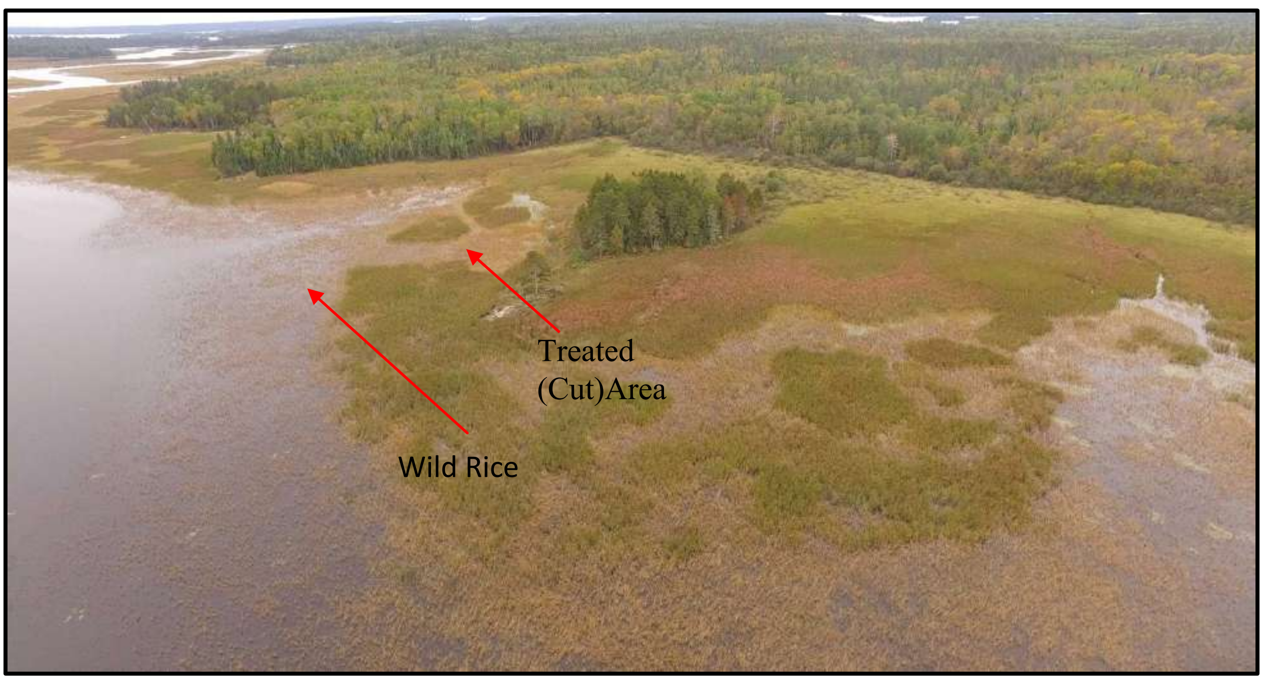


Figure 10. Rat River Bay in 2015, this is an aerial photo taken off the same island seen in Figure 9. NOTE the several meters of wild rice in front of the Treated area that was not present in the 2014 photo (Figure 9).

4.3Management Strategy-Cutting Cattails

Due to cattail's ability to dominate and influence a system, methods have been developed to eradicate the species and the resulting negative impacts. An objective wasto determine a suitable management strategy for the Rainy-Namakan system that would control cattails coupled with rule curve regulations.As reviewed by Sojda and Solberg (1993) control methods include physical control such as cutting, chemical use such as spraying herbicide, prescribed burning, shading and water level management. In this project, mechanicalcontrol by cuttingcattails just above the sedimen:water interface was used.

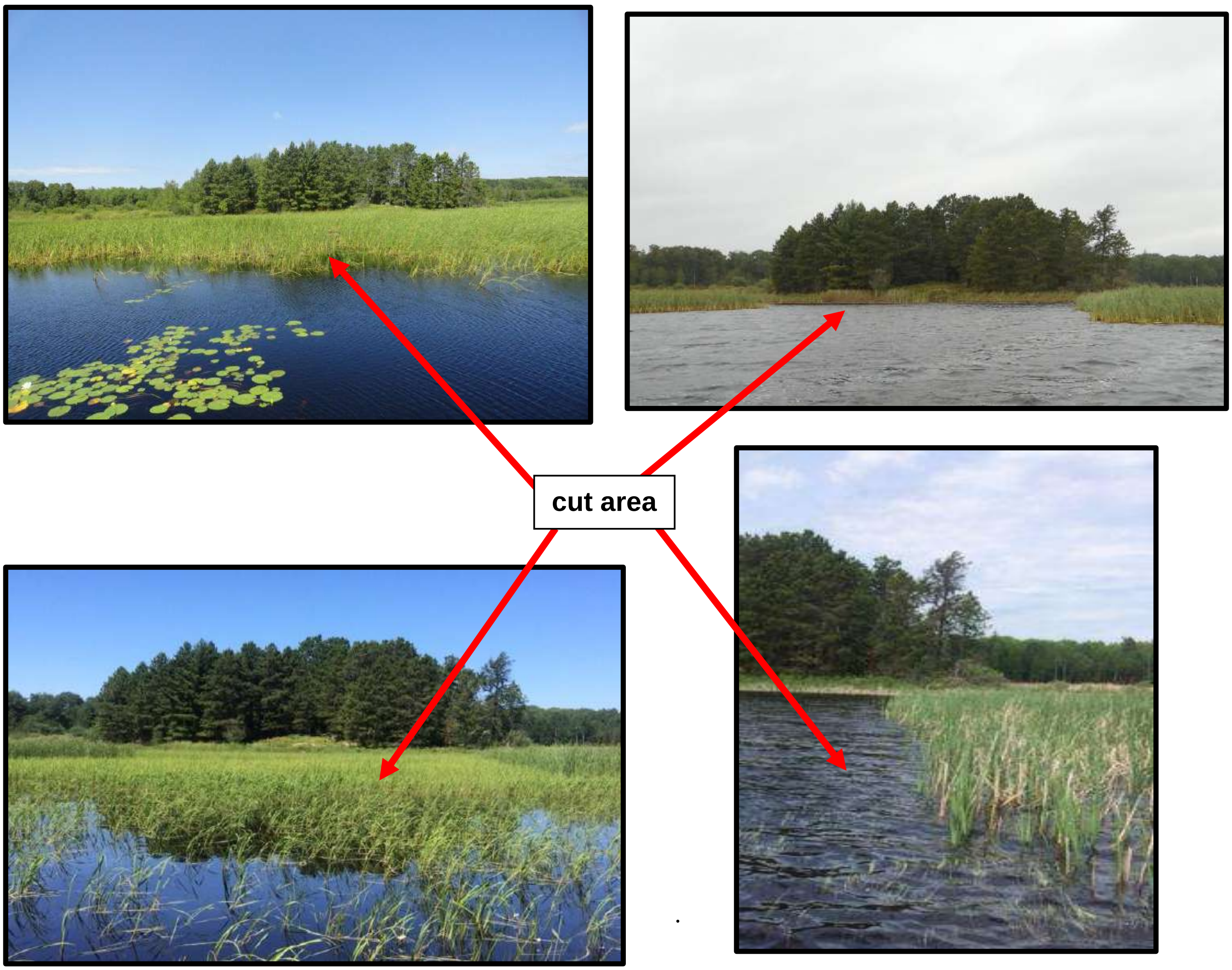


Figure 10. An area of cattails cut area on Rat River Bay. Upper left, prior to cutting, August, 2014. Upper right, after cutting, August, 2014. Lower left, rice in floating leaf stage in cut area, June, 2015. Lower right, rice in aerial stage in cut area, July, 2015.

The cutting procedure for cattail removal proved to be remarkably effective. In the areas that were cut, the cattails were completely eliminated (Figure 10). The theory is that the dead stems of the cattails provide oxygen to the rhizomes in the anaerobic sediment in winter. Cutting the cattail culms underwater prior to ice cover stops the flow of oxygen to the rhizomes in winter and successfully kills the species (Seago and Marsh 1989; Whigham and Simpson 1988).Additionally, the native species that were present in the cut areas (water lilies, soft stem bulrush) were not affected by cutting and since these species were in low density, they had little effect on wild rice production. Adding to the success of the procedure, rice apparently remained viable in the seed bank in the area previously occupied by cattails. The cut area became completely filled with wild rice in these cut areas without seeding.The net effect is shown by Figure 10the upper left shows the study area completely dominated by cattails in September, 2014 while clockwise to the bottom left is the study area in August, 2015 when it is completely dominated by wild rice.

The cattails appeared to prevent germination of wild rice although the mechanism is not known. Vaccaro et al. (2009) observed a similar relationship when cattail expansion reduced species diversity. Wild Rice only germinates under specific conditions after a required cold treatment, and, if conditions are not suitable for germination, secondary dormancy will result (Atkins 1989). Germination in wild rice may have be prevented by such changes as soil nutrient modification, reduced light, lower dissolved oxygen, or allelopathy from cattails (Atkins 1989). Additionally, there was increased accumulation of detrital matter from cattails in the rice areas. Sydes and Grime (1981b) stated abundant litter can alter germination signifiers such as temperature fluctuation.In any case, germination of wild rice was reduced or stopped after the invasion from cattails and there was sufficient viable seed left in the seed bank to enable a viable population of wild rice to re-establish itself without the need for seeding.

4.4 Integration into the IJC water level model

The invasion by cattails into Rainy Lake and its devastating impact on wild rice stands, is a major concern. Information and all data from this study will be shared with Dr. J. Morin of Environment Canada in his efforts to devise a water use model for Rainy Lake that considers all resources on the lake that are affected by depth. Any changes to the rule curve that will enhance production of wild rice by adversely affecting cattail invasion is a major priority for the Seine River First Nation.

5.0 Conclusions and Future Work

This study showed that cattails are increasingly displacing wild rice on the Seine Rive and Rainy Lake. Aside from theactual loss of the wild rice stands, the cattails were shown to alter the nutritional status of the sediment in which wild rice naturally grew. Of particular significance was the lower nitrogen levels in the sediment where cattails grew. The cattails were also shown to impede germination of wild rice but, when removed, there was sufficient wild rice in the seed bank to renew wild rice stands but under the altered nutrient regime.

The rule curve on the Rainy-Namakan system is not controlled for wild rice production. Aerial photographs revealed that there has been a continuous increase in cattails on Rat River Bay. Recent water levels in 2014 showed that high water levels favour cattail production. In 2015, the water levels were low and this caused a resurgence of wild rice. However, if high water level years occur continuously, the spread of cattails will impede the survival of wild rice likely by allelopathic effects limiting wild rice germination. For wild rice to return, the cattails must be removed.

The control technique tested was mechanical cutting of cattail culms under water prior to ice formation. This method was found to be highly effective with no survival of cattails in cut areas. Furthermore, the seed bank for wild rice was able to maintain sufficient seed to enable the wild rice stand to recover once the cattails were removed.

Cattail invasion and loss of wild rice areas are clearly affected by water levels on Rainy Lake. Prolonged occurrence of high water levels will favour the extirpation of wild rice and further spread of cattails. Data from the study can be used to help formulate an appropriate model to limit the detrimental effects of exotic cattails on wild rice.

Future studies are required to understand the mechanism for wild rice survival in the seed bank and the precise effect of cattails on seed germination. Long term impacts on wild rice of changed nutrient regimes in the sediment need to be examined and techniques developed to correct this condition. Finally, a more efficient method of cutting cattails needs to be perfected and a method for disposing of the enormous amount of cattail biomass determined.

Acknowledgements

This study was financially supported by the International Joint Commission. We would like to thank Seine River First Nation for their technical, logistic and financial support in this study. Lakehead University Environmental Laboratory provided high quality sample analysis and needed support ad assistance with this project. All are hereby gratefully acknowledged.

Literature Cited

Aiken, S.G., Lee, P.F., Punter, D., and Stewart, J.M. 1988. Wild Rice in Canada. Agriculture Canada and New Canada Publications, Toronto.

Atkins, T.A. 1983. The aquaculture of wild rice. Progress Year 2 Addendum. Lakehead University, Thunder Bay.

Bedford, B.L., Walbridge, M.R., Aldous, A., 1999. Patterns in nutrient availability and plant diversity of temperate North American wetlands. Ecology 80, 2151–2169

Boers, A. M., &Zedler, J. B. (2008). Stabilized water levels and Typha invasiveness. *Wetlands*, *28*(3), 676–685. http://doi.org/10.1672/07-223.1

Chapin, E. S. (1980). The Mineral Nutrition of Wild Plants. Annual Reviews Stable URL : http://www.jstor.org/stable/2096908 REFERENCES Linked, *11*(1980), 233–260.

Clay, S.A. and Oelke, E.A., 1987. Effects of giant burreed (Sparganiumeurycarpum) and shade on wild rice (Zizaniapalustris). *Weed Science*, pp.640-646.

Davis, C.B., van der Valk, A.G., 1983. Uptake and release of nutrients by living and decomposing TyphaglaucaGodr. tissues at Eagle Lake, Iowa. *Aquat. Bot.* 16, 75–89

Day, W.R., and Lee, P.F. 1990. Mineral Deficiencies of Wild Rice Grown in Flocculent Sediments. *J. Aquat. Plant Manage.* 28: 84-88.

Ehrenfeld, J. G. (2003). Effects of Exotic Plant Invasions on Soil Nutrient Cycling Processes. *Ecosystems*, *6*(6), 503–523. http://doi.org/10.1007/s10021-002-0151-3

Farrell, J. M., Murry, B. A., Leopold, D. J., Halpern, A., Rippke, M. B., Godwin, K. S., &Hafner, S. D. (2010). Water-level regulation and coastal wetland vegetation in the upper St. Lawrence River: Inferences from historical aerial imagery, seed banks, and Typha dynamics. *Hydrobiologia*, *647*(1), 127–144. http://doi.org/10.1007/s10750-009-0035-z

Fleming, J. P., & Dibble, E. D. (2014). Ecological mechanisms of invasion success in aquatic macrophytes. *Hydrobiologia*. http://doi.org/10.1007/s10750-014-2026-y

Flug, M. 1986. Analysis of lake levels at Voyageurs National Park. U.S. Dept. of Interior, National Park Service Water Resources Report No. 86-5.

Galatowitsch, S. M., Anderson, N. O., &Ascher, P. D. (1999). Invasiveness In Wetland Plants In Temperate North America. *Wetlands*, *19*(4), 733–755.

Gilbert, G.J. 1985. The relationship of wild rice to sediment chemistry and competing marcrophytes in four bays on Lake of the Woods. Hon. B.Sc. thesis, Dept. of Biology, Lakehead University.

Grace, J. B., & Harrison, J. S. (1986). The biology of Canadian weeds. 73. Typha latifoliaL., Typha angustifoliaL. andTyphaxglaucaGodr. *Can. J. plant Sci.* 66: 361-379.

Hotchkiss, N. and H.L. Dozier. 1949. Taxonomy and distribution of North American cattails. *Am. Midl. Nat.* 41: 237-254.

International Rainy-Lake of the Woods Watershed Board. (2016). Retrieved April 20, 2016, from http://ijc.org/en_/RLWWB/International_Rainy-Lake_of_the_Woods_Watershed_Board

Jordan, T. E., & Whigham, D. F. (1988). The importance of standing dead shoots of the narrow leaved cattail, Typha angustifolia L. *Aquatic Botany*, *29*(4), 319–328. http://doi.org/10.1016/0304-3770(88)90076-9

Keddy, P. A., 2000. Wetland Ecology Principles and Conservation. Cambridge University Press, Cambridge, UK.

Kao, J.T., Titus, J.E., and Zhu, W.X. 2003. Differential nitrogen and phosphorus retention by five wetland plant species. *Wetlands*. 23(4): 979-987.

Larkin, D. J., Lishawa, S. C., & Tuchman, N. C. (2012). Appropriation of nitrogen by the invasive cattail Typha??glauca. *Aquatic Botany*, *100*, 62–66. http://doi.org/10.1016/j.aquabot.2012.03.001

Lee, P. F., & McNaughton, K. A. (2004). Macrophyte induced microchemical changes in the water column of a northern Boreal Lake. *Hydrobiologia*, *522*(1-3), 207–220. http://doi.org/10.1023/B:HYDR.0000029987.64557.36

Oelke, E.A., J.K. Ransom, M.J. McClellan. 1983. Wild rice production research-1982 In: Minessota wild rice production 1982

Meeker, J. E. 1993. The ecology of ‘‘Wild’’ wild-rice (Zizaniapalustris var. palustris) in the Kakagon Sloughs, a riverine wetland on Lake Superior. Ph.D. dissertation, University of Wisconsin, Madison, Wisconsin, USA.

McNaughton, S.J. (1966) Ecotype function in the Typha community-type. EcologicalMonographs, 36, 297–325

Mitsch, W. J. and J. G. Gosselink. 2007. Wetlands. 4th Edition, Wiley, New York. 920 pp.

Raskin, I. and Kende, H., 1985. Mechanism of aeration in rice. *Science,* 228: 327-329.

Reddy, K. R., Delaune, R. D., & Craft, C. B. (n.d.). White Paper on Nutrients in Wetlands : Implications to Water Quality under Changing Climatic Conditions.

Sojda, R. S., & Solberg, K. L. (n.d.). Waterfowl Management Handbook and Control of Cattails, 1–8.

Seago J. L. and Marsh L. C. (1989). Adventitious Root Development in Typhaglauca , with Emphasis on the Cortex Author (s): Published by : Botanical Society of America , Inc .

Shih, J. G., & Finkelstein, S. A. (2008). Range dynamics and invasive tendencies in typhalatifolia and typha angustifolia in eastern North America derived from herbarium and pollen records.

Smith, S. (1967). Experimental and natural hybrids in North American Typha (Typhaceae). *American Midland Naturalist*, *78*(2), 257–287.

Struyf, E., & Conley, D. J. (2009). Silica: An essential nutrient in wetland biogeochemistry. *Frontiers in Ecology and the Environment*, *7*(2), 88–94. http://doi.org/10.1890/070126

Sydes, A. C., & Grime, J. P. (2016). Effects of Tree Leaf Litter on Herbaceous Vegetation in Deciduous Woodland : I . Field Investigations Published by : British Ecological Society Stable URL : http://www.jstor.org/stable/2259828 Accessed : 0305-2016 14 : 09 UTC Your use of the JSTOR archive indicates your acceptance of the Terms & Conditions of Use , available at, *69*(1), 237–248.

Tuchman, N. C., Larkin, D. J., Geddes, P., Wildova, R., Jankowski, K., & Goldberg, D. E. (2009). Patterns of environmental change associated withTyphaxglauca invasion in a Great Lakes coastal wetland. *Wetlands*, *29*(3), 964–975. http://doi.org/10.1672/08-71.1

Travis, S. E., Marburger, J. E., Windels, S., &Kubátová, B. (2010). Hybridization dynamics of invasive cattail (Typhaceae) stands in the Western Great Lakes Region of North America: A molecular analysis. *Journal of Ecology*, *98*(1), 7–16. http://doi.org/10.1111/j.1365-2745.2009.01596.x

Vaccaro, L. E., Bedford, B. L., & Johnston, C. A. (2009). Litter Accumulation Promotes Dominance of Invasive Species of Cattails (TyphaSpp .) in Lake Ontario Wetlands, *29*(3), 1036–1048.

Venterink, H., Davidsson, T., Kiehl, K., &Leonardson, L. (2002). Impact of drying and re-wetting on N, P and K dynamics in a wetland soil. *Plant and Soil*, *243*, 119–130. http://doi.org/10.1023/A:1019993510737

Waters I, Shay J (1990) A field study of the morphometric response of Typhaglauca shoots to a water depth gradient. *Canadian Journal of Botany* 68:2339–2343

Whillans, T. H., 1982. Changes in marsh area along the Canadian shore of Lake Ontario. *Journal of Great Lakes Research* 8: 570–577.

Wilcox, D. A., Thompson, T. A., & Booth, R. K. (2007). *Lake-Level Variability and Water Availability in the Great Lakes*. *US Geological Survey Circular* (Vol. 1311).

Woo, I., &Zedler, J. B. (2002). Can nutrients alone shift a sedge meadow towards dominance by the invasive Typha × glauca. *Wetlands*, *22*(3), 509–521. http://doi.org/10.1672/0277-5212(2002)022[0509:CNASAS]2.0.CO;2

Zedler, J.B., Kercher, S., 2004. Causes and consequences of invasive plants in wetlands: opportunities, opportunists, and outcomes. Crit. Rev. Plant Sci. 23, 431–452.

Appendix A: IJC Oral Presentation

Presented by Kristi Dysievick at the 2016 Rainy Lake Watershed Conference

NUTRIENT ANALYSIS IN WILD RICE RE-ESTABLISHMENT PROJECT

KRISTI DYSIEVICK-LAKEHEAD UNIVERSITY
DR. PETER LEE – LAKEHEAD UNIVERSITY ENVIRONMENTAL LABORATORY
COUNCILOR JOHN KABATAY – SEINE RIVER FIRST NATION

INVASION HISTORY

- *Typha Angustifolia (narrowleaf)* is believed to have arrived on this continent with European settlement
- First seen strictly in salt marshes on the Atlantic coast
- *Typha glauca* is the hybridization of the native *Typha latifolia (broad leaf)* and invasive *Typha angustifolia*
- *Typha Angustifolia* migration inland occurred in 1900
- By 1949 *Typha angustifolia* spread into Canada and was first reported in Quebec and Ontario
- *Typha glauca* followed this range expansion and was in Ontario shortly after.
- Was observed in the Seine River watershed in the early 1990's

WHAT MAKES CATTAILS SUCH EFFECTIVE INVADERS

- They form dense, nearly monospecific stands
- Larger and more productive than the species they displace
- leave behind abundant litter
- subjected to relatively little herbivory
- slow to decompose
- thrives in anthroprogenically disturbed and eutrophic environments
- Typha spp. can spread quickly and widely both through aggressive rhizomatous growth and sexual reproduction

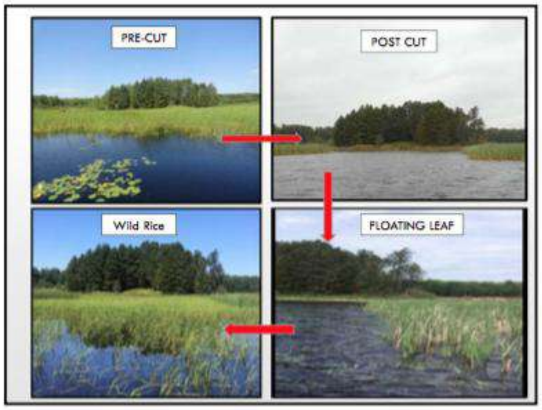
THE PROBLEM

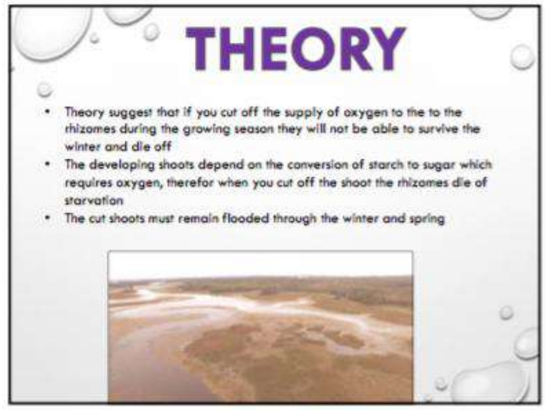
- Occupy the same water depths as Wild Rice
- In 2013/2014 there was no Wild rice to harvest
- In contrast to historical commercial wild rice sales from Rainy Lake and Seine River of up to 150,000 pounds and over 1,000,00 pounds on Lake of the Woods
- Water level management in the Rainy-Namakan system has been detrimental effects on existing historical stands of wild rice
- Continued concern of the Seine River First Nation and other First Nations in the Basin

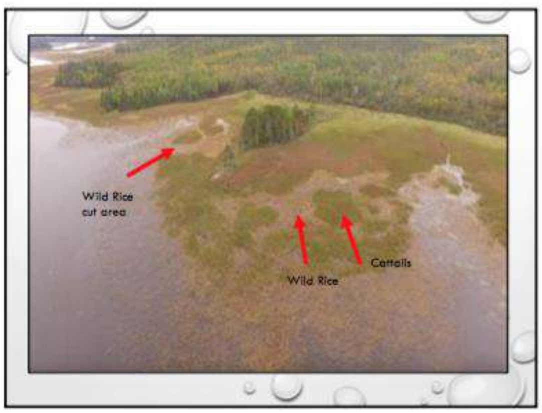
STUDY AREA

CUTTING TRAILS

- In August of 2014 SRFN members conducted cutting trails
- 4 cut areas within Rat River Bay
- The cattails are harvested just above the sediment water interface


PRE-CUT
POST CUT
Wild Rice
FLOATING LEAF


THEORY
• Theory suggest that if you cut off the supply of oxygen to the to the rhizomes during the growing season they will not be able to survive the winter and die off
• The developing shoots depend on the conversion of starch to sugar which requires oxygen, therefor when you cut off the shoot the rhizomes die of starvation
• The cut shoots must remain flooded through the winter and spring


Wild Rice cut area
Wild Rice
Cattails

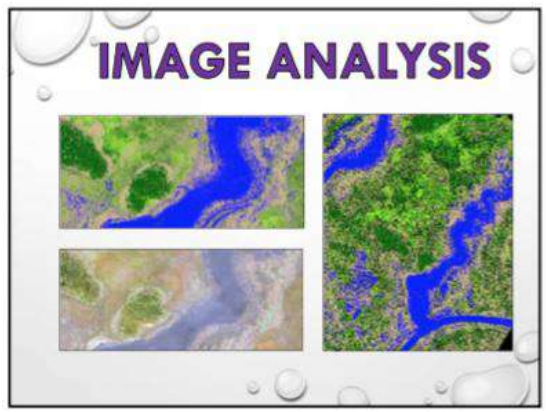
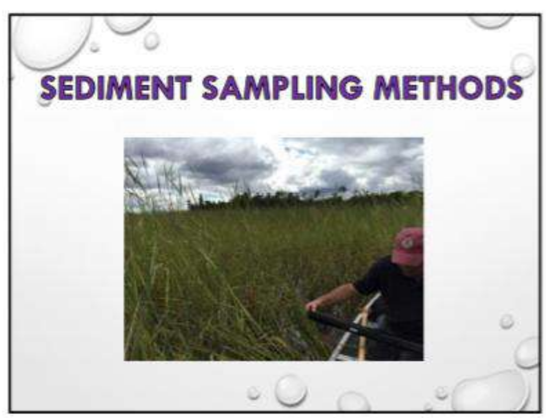
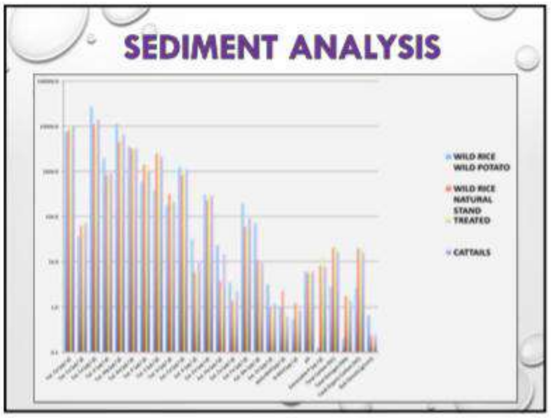
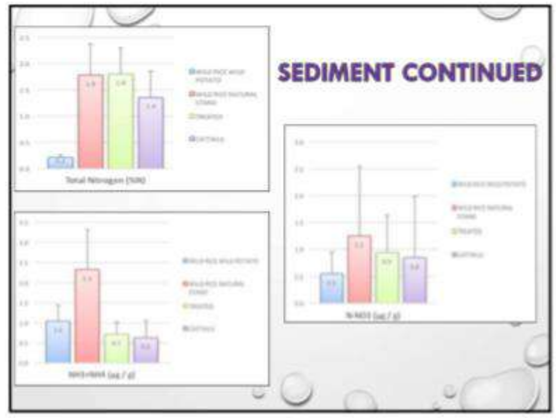


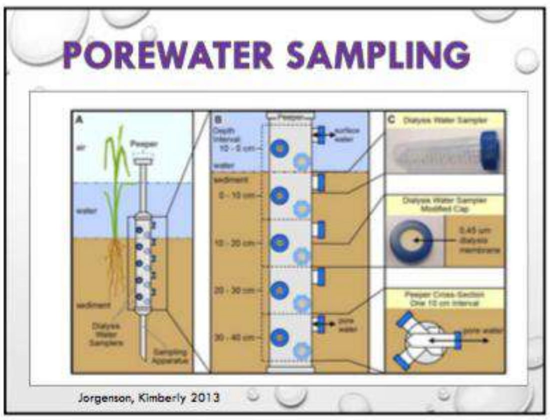
IMAGE ANALYSIS

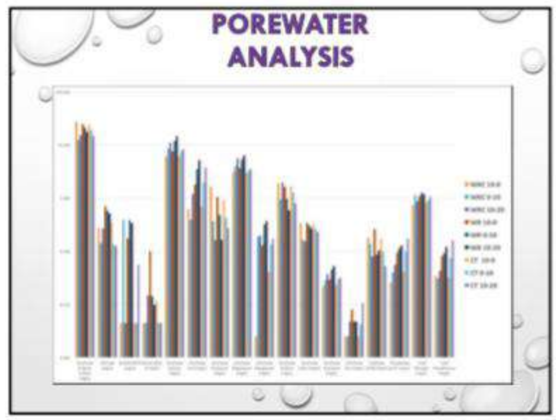

OBJECTIVES
• Return as many acres as we can back to natural wild rice habitat
• Quantify the Cattail invasion
• Comparison of nutrient analysis of invaded vs uninvaded areas
• Most effective cutting time
• Determine what is occurring in treated areas;
• Seed bank
• What is preventing germination
• Nutrient levels

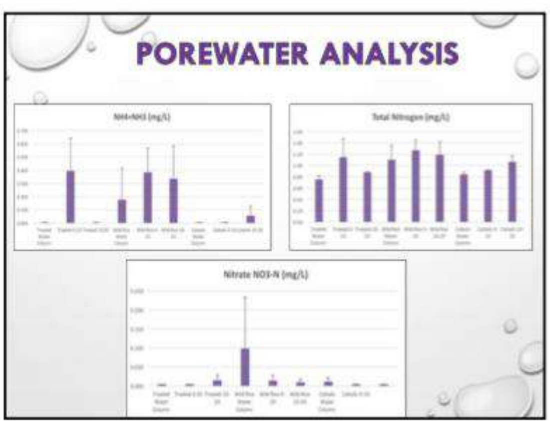

SEDIMENT SAMPLING METHODS


SEDIMENT ANALYSIS
WILD RICE WILD POTATO
WILD RICE NATURAL STAND
TREATED
CATTAILS

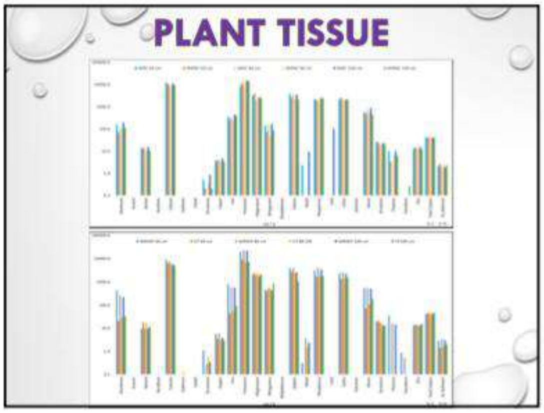

SEDIMENT CONTINUED
Total Nitrogen (%N)

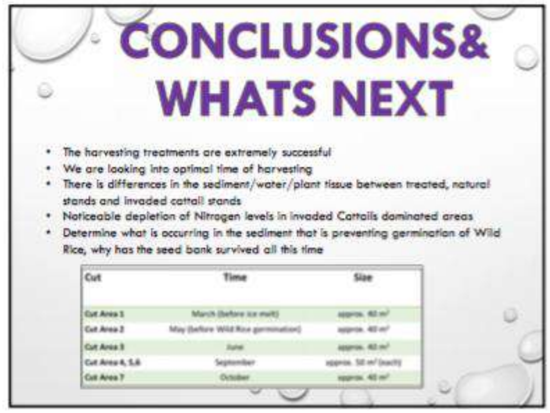

POREWATER SAMPLING
A
B
C
air
Peeper
water
sediment
Dialysis Water Samplers
Sampling Apparatus
surface water
pore water
Dialysis Water Sampler
Dialysis Water Sampler Modified Cap
0.45 µm dialysis membrane
Peeper Cross-Section One 10 cm interval
Jorgenson, Kimberly 2013


POREWATER ANALYSIS


POREWATER ANALYSIS
NH4+NH3 (mg/L)
Total Nitrogen (mg/L)
Nitrate NO3-N (mg/L)


PLANT TISSUE SAMPLING





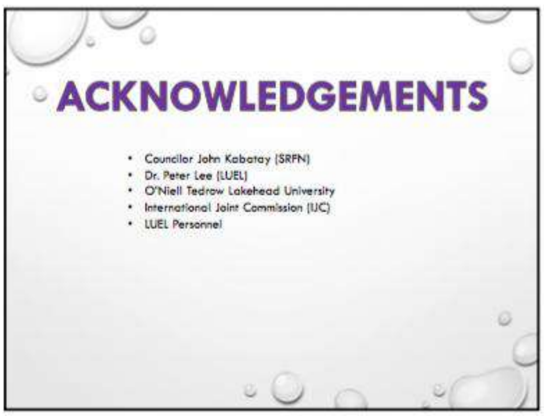
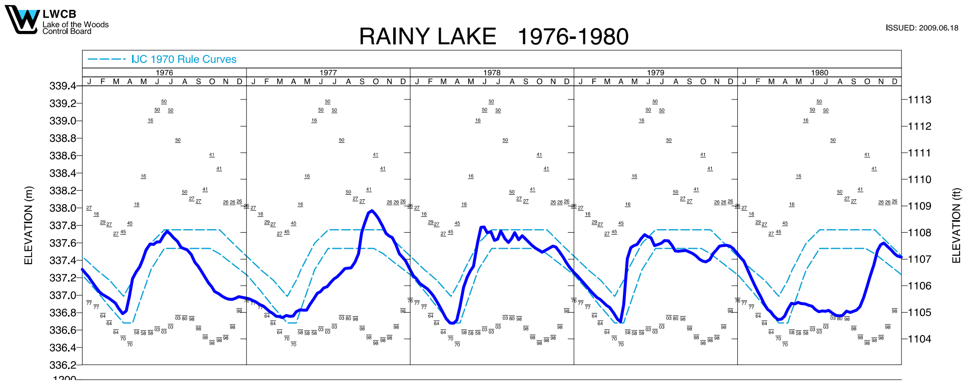
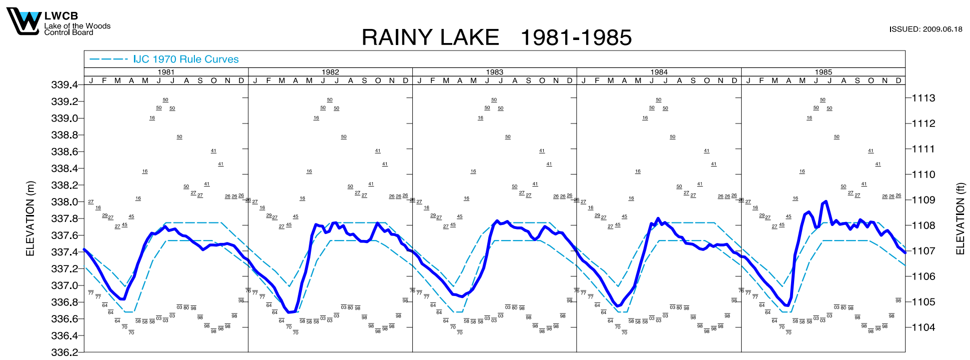


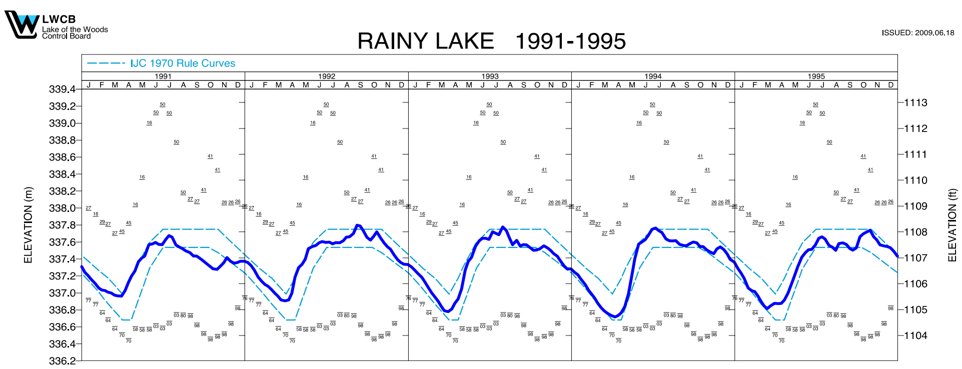
Figure One. Slideshow presentation for 2016 Rainy-Lake of the Woods Watershed Forum presented by Kristi Dysievick

APPENDIX B: WATER LEVEL DATA

Lake of the Woods Water Control Board







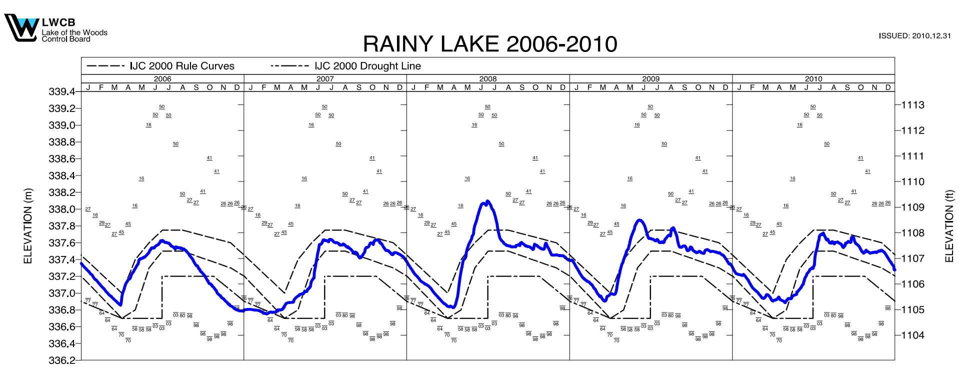


Figure Two. Water level graphs for Rainy lake created by the International Rainy-Lake of the Woods Watershed Board

<u>Appendix C: IJC Initial Report</u>

Initial 2015 Progress Report

Effects of Water Management Regime of Rainy Namakan System on Wild Rice Production and Cattail Invasion into Wild Rice

Prepared for

International Joint Commission

Prepared by

Dr. Peter Lee, Lakehead University
Councilor John Kabatay, Seine River First Nation
O'Niell Tedrow, M.S., Lakehead University

Table of Contents

Appendices

- **A.** Seasonal Monitoring of Wild Rice Experimental Depth Rafts
- **B.** Collection of Samples and Data for Sediment, Wild Rice Productivity from Rafts, and Field Sites
- **C.** Cutting of Cattails

1.0 Seasonal Monitoring of Wild Rice Experimental Depth Rafts

During May 2014, nine (9) rafts of approximate 11'W x 11'L x 5'D were constructed on-site at the Seine River First Nation Community (**Appendix A; Figures 1 – 3**). During May and June 2014, these rafts were sequentially deployed in groups of three (3). Each raft was divided into quadrants; and each quadrant contained nine (9) tubs containing formulated sediment ('black earth') with a specific amount of amended fertilizer suspended at a different water depth or water depth regime. The control depth was 40 cm and did not change during the experimental duration. Three different initial depths were also chosen; 40, 60, and 80 cm. These three depths were held constant until a specific wild rice (WR) phonological development stage was achieved; submerged, floating leaf, or emergent. Following observance of one of these stages the tubs in that particular raft quadrant were lowered 10 cm approximately every five (5) days until these tubs had been lowered an additional 30 cm. The final depths for three of the raft quadrants were 70, 90, and 110 cm. Due to lack of WR seedling growth in rafts four through nine, the only rafts used for this portion of the research were rafts one through three. One likely cause of decreased WR seedling survival in rafts four through nine is exposure to an increased amount of fertilizer; 20 grams in rafts four through six, and 40 grams in rafts seven through nine. Differences in select measured chemical characteristics is one potential source of increased WR seedling mortality in rafts four through nine (**Appendix A; Table 1**) Therefore, the following discussion will focus on responses of WR plants exposed to only five grams of fertilizer in rafts one through three.

The first three rafts deployed (rafts 1, 2, and 3) were classified as emergent (raft 1), floating leaf (raft 2), and submerged (raft 3). Sediment used for rafts one through three was formulated sediment containing five grams of pelletized fertilizer (select characteristics of sediments detailed in **Appendix A; Table 1**). Initially, 10 WR seedlings were planted in each tub, which were subsequently culled to five to seven plants once the majority of tubs in each raft achieved their target WR phenological developmental stage. Two weeks following the third of three 'tub lowering' events (i.e., increasing the tub water depth by 10 cm of those tubs in quadrants with treatments requiring lowering), an initial WR plant harvest event was completed. All plants, and a sediment sample, were removed from a random sample of tubs in each quadrant. **[**NOTE: WR plants in each raft (1 – 3) achieved their respective phenological stage at different times, and were therefore sampled at different times and time intervals.**]** WR plants and sediment samples were obtained from a random sample of tubs from each quadrant of each raft approximately every two weeks following the final tub lowering event for each specific raft quadrant.

During August 2014, raft 5 was re-planted using WR seedlings and field-collected sediment from Wild Potato Lake (WPL) and Rat River Bay (RRB) (**Appendix A; Figures 5, 6**). Although WPL and RRB were the initial proposed sediment sources for the raft WR growth experiments, increased water depths, and continued precipitation and flooding during Spring / early-Summer 2014 prohibited collection of sediment from WPL and RRB for use in these rafts. Nine (9) replicates of each field-collected sediment were used. Eighteen (18) replicates of formulated sediment, nine containing five grams and nine containing 40 grams of pelletized fertilizer, were also used to test the question of influences on WR seedling survival and growth from fertilizer amendments. All 36 tubs / replicates were suspended at 40 cm depth. The overall conclusions from this re-planted raft 5 experiment were that **1)** both WPL and RRB sediment exposures supported nearly all WR seedlings to emergent stage; and **2)** WR plants in both five and 40 gram exposures of fertilizer in formulated sediment appeared to result in adverse WR seedling responses compared to WPL and RRB sediment exposures (**Appendix B; Table 2; Figure 9**). Statistical characterization of these data will include comparisons / contrasts between specific plant components (roots, shoots, leaves) and the number of seeds per plant. Comparisons and contrasts of select sediment characteristics and measured plant components (roots, shoots, leaves) and the number of seeds per plant will also be completed.

2.0 Collection of Samples and Data for Sediment, Wild Rice Productivity from Rafts, and Field Sites

During the portion of this research using floating rafts to quantify influences of water depth manipulations on WR plant growth responses, a sediment sample was obtained from at least one (1) replicate per quadrant (**Appendix B; Figure 6**); additional sediment samples were obtained from multiple quadrants during initial WR plant harvesting events on rafts one through three. All observed viable plants in each of the submerged tubs randomly selected for sampling were completely removed, including roots, shoots, and all associated leaves and seeds (if present) (**Appendix B; Figures 6, 7**). All plant and sediment samples were sealed in Ziploc® bags, and stored and transported to Lakehead University Environmental Laboratory (LUEL) under refrigeration. Data available at the time of reporting are presented in **Appendices A and B**. Additional WR plant measurements and sediment characterization data will be available for future progress and accomplishments reports, including applicable statistical treatments.

3.0 Set-Up of Germination Experiment

This initial research objective involved **1)** during Fall 2014 deploying permeable bags of WR seeds along transects within WR-containing areas of Wild Potato Lake and Rat River Bay from the shore outward; **2)** during Spring 2015 retrieving these bags of WR seeds; and **3)** using seeds from the retrieved bags in WR laboratory germination experiments.

During the 2014 field season, no WR beds were observed in either Wild Potato Lake or Rat River Bay areas. Some WR plants were observed in Wild Potato Lake during late August 2014; however, the density of these plants as observed was insufficient to classify the area as a 'WR bed' or 'WR stand.' The WR seed germination portion of this research as described will be re-scheduled for completion during the 2015 – 2016 field season.

4.0 Sample Analysis / Analyses

All plant- and sediment- samples obtained during the 2014 field season were sealed in Ziploc® bags at the time of collection, and stored and transported to Lakehead University Environmental Laboratory (LUEL) under refrigeration.

Various measurements of physical WR plant characteristics involving root mass / length, shoot mass / length, leaf mass / length, and number of seeds per plant (if present) have been, and will be, completed on all WR plant samples. Statistical treatments of these data will include comparisons and contrasts between plant metrics (responses) and select sediment characteristics and water depths (exposures).

5.0 Data Analysis / Analyses

All data obtained during the course of this research will be organized into Excel® data sheets and appropriate figures and charts. Tentatively, SigmaPlot-SigmaStat® (Systat® Software, Inc.), and / or other applicable statistical software, will be used to complete appropriate statistical comparisons. Following completion of all plant and sediment analyses, all data will be organized and appropriate statistical comparisons will be initiated.

6.0 Cutting of Cattails

During June – July 2014, an airboat-mounted, mechanical cattail harvesting assembly was constructed and used to remove cattails in identified areas in Rat River Bay area. This mechanical removal system is height-adjustable, which allows for sequential removal of cattails at variable heights. The overall purpose of this research objective is to use this mechanical catting assembly to 'cut' cattails below the surface of the water sufficiently to result in cattail mortality in harvested areas.

The initial cattail harvest / removal event was completed on August 12, 2014, in the Rat River Bay area (**Appendix C**). The cuttings occurred in depths ranging from less than 40 cm to 120 cm. Multiple cattail-infested areas were harvested using this method; little to no re-growth was observed on a subsequent site visit on August 24, 2014 (**Appendix C**).

Monitoring of areas in which cattails were harvested during August 2014 will continue through the 2015 field season. In particular, we will be examining the effects of cattails in the harvested areas on wild rice development during the submerged, floating leaf and emergent phases of wild rice at depths ranging from 40 cm to 120 c. The various depth regimes are desired to emulate the effects of the rule curve on cattails versus wild rice production. Within each of the depth x cutting x seeding treatments, three 0.25 m^2 quadrats will be randomly collected without replacement. Water depth, wild rice and cattail densities, will be recorded and the plants removed for biomass determination. The net outcome of this experiment will be an assessment of the effect of water depth emulating the rule curve on potential cattail control by cutting.

7.0 2015 Planned Activities

Throughout the 2014 field season, several adjustments were made to the initial research plan for **1)** using raft assemblies to measure influences of water depth and sediment source on WR plant development; **2)**measuring influence of water depth on WR seed survival and germination rates; and **3)** measuring efficacy of a mechanical harvesting technique on cattail removal. The overall reason for amending original plans for these research objectives during 2014 was the extraordinary Spring melt volume, followed by precipitation and flooding events continuing into June – July 2014 at field sites chosen for this research.

For the 2015 field season, we plan to begin collection of site-sediment from Wild Potato Lake and Rat River Bay area as soon as possible following ice out. Specific locations within these water resources have been identified for sediment collection, which will expedite this portion of 2015 research. The continued 2015 WR plant growth, development, and productivity raft research will use information from 2014 re: exposure of the more critical and sensitive phenological stage to water depth fluctuations more representative of the International Joint Commission (IJC) rule curve for Rainy Lake. An additional raft will be used to measure influences of water depth fluctuations in Rat River Bay due to releases of water from Kettle Falls.

Associated with site-collected sediment events, areas which may be used for the WR seed survival and germination portion of this research will be identified. This may involve selecting areas in Rat River Bay, which have historically contained harvest-able densities of WR, where permeable bags of WR seed may be deployed for overwintering and ripening in variable water depths.

Cattail removal and their effects on wild rice production will continue in 2015. In addition to monitoring the effects of 2014 removal of cattails, areas will be seeded with wild rice in some cut areas from 2014 to determine if re-establishment of rice can occur. These will be compared with non-harvested areas in an effort to answer questions about cattail presence / absence and the efficiency of WR seed germination and growth between areas of cattail harvest and areas of no cattail harvest.

There is also a question about the changes in the sediment chemistry of former wild rice areas caused by the invasion of cattails and whether management strategies can be developed to stop this situation. For example the time of cutting of the cattails may be critical. If they can successfully be removed or at least slowed in growth early in the growing season, then they will not be able to trap as much suspended matter during later spring run-off. Similarly, just the removal of the old culms from the previous year's growth may well prove beneficial in stopping sediment accumulation early in the growing season.

The effects of the previous year's growth on sediment accumulation will be assessed by cutting the culms off at the ice level and burning the above ice biomass. Since the current rule curve increases in depth during the spring, a large proportion of the plants should be able to be removed at this time.

In order to assess the effects of cattails on the sediment of former wild rice areas,a series of transects (four per treatment) will be established along depth gradients running from the shore outward to the edge of rice colonization at the Rat River Bay site. There will be three "treatments" within each main wild rice area consisting of a monospecific area of wild rice, a monospecific area of cattails, and a mixed area of wild rice and cattails. The treatment areas will each be 5 m wide. Sampling will proceed as follows: **a.)**during the emergent (maximum biomass) phase of wild rice development, 5, 0.25m^2 quadrats will be sampled at regular intervals along the transects in each of the wild rice "treatment" areas; **b.)** wild rice population densities will be recorded in each quadrat, dry weight of wild rice and any competing plants determined, and a sediment sample collected within each quadrat; and **c.)** sediment will be collected from the upper 20 cm of the soil column and analyzed for pH, conductivity, bulk density and total N, P, K, Ca, Mg, Fe, Mn, Zn, Cu, Al, As, Ba, Be, Cd, Co, Cr, Mo, Na, Ni, Pb, S, Se, Sr, Ti, V, and Zn. Interstitial water will be analyzed for the same parameters. This investigation will show if cattails are altering the nutrient regime of the sediment formerly growing wild rice and whether there is a correlation of the nutrient regime with the depth gradient. Management strategies will be hypothesized to reduce the impact of cattails on sediment changes as much as possible.

APPENDIX A
SEASONAL MONITORING OF WILD RICE EXPERIMENTAL DEPTH RAFTS

Table 1. Select measured characteristics of sediment used in (select) rafts. Sediment used in rafts one, two, and three was a formulated sediment with five grams of amended pelletized fertilizer. Wild rice seedlings in rafts one through three appeared to thrive and were used for the initial field portion of this study. Sediment used in rafts seven, eight, and nine was also the formulated sediment, but was amended with 40 grams of pelletized fertilizer. Complete wild rice seedling mortality was observed in rafts seven through nine. Rafts four through six (data not shown) also used the formulated sediment with 20 grams of amended fertilizer; complete mortality of wild rice seedlings was also observed in these rafts. Raft 5 was re-planted mid-season using field collected sediment from Rat River Bay and Wild Potato Lake; and two formulated sediment treatments of five and 40 grams of fertilizer (data shown in **Appendix 2; Table 2**).

	RAFT 5		RAFT 1	RAFT 2	RAFT 3	RAFT 7	RAFT 8	RAFT 9
ANALYTE	**RAT RIVER BAY**	**WILD POTATO LAKE**						
CONDUCTIVITY (µS / CM)	62	65	789	606	834	1560	1341	1452
POTASSIUM (MG / KG)	16.5	24.4	45.8	49.0	53.5	228	205	208
AMMONIA / AMMONIUM (MG / KG)	9.4	14.0	26.2	17.5	22.2	75.7	85.8	79.7
NITRATE (MG KG)	1.1	0.8	17.6	9.1	9.3	163.1	227.2	159.2
PH (SU)	5.96	5.91	5.96	5.95	5.95	5.92	5.78	5.74
PHOSPHATE (MG / KG)	13.5	7.6	5.4	4.0	4.6	31.4	27.6	25.8

Figure 1. WR raft without hanging tubs in each quadrant.

Figure 2. WR raft assembly and tubs of sediment; some deployed, some awaiting WR seedling plants.

Figure 3. All nine (9) rafts constructed and deployed in Wild Potato Lake.

Figure 4. Sediment obtained from Wild Potato Lake for use in the replanted Raft 5. Not pictured is the Rat River Bay sediment sampling event. Sediment from both locations was sampled for use in the replanted Raft 5 set-up.

Figure 5. 2014-09-06: WR plants thriving in Rat River Bay sediment.

Figure 6. 2014-09-06: WR plants thriving in Wild Potato Lake sediment.

APPENDIX B
COLLECTION OF SAMPLES AND DATA FOR SEDIMENT, WILD RICE PRODUCTIVITY FROM RAFTS, AND FIELD SITES

Figure 7. Example sediment sample obtained from 'Raft 2,' tub 'C7.'

Figure 8. September 28, 2014: WR plant harvesting and sediment sampling event.

Table 2. Average measured characteristics of WR plants harvested from the re-planted 'Raft 5.' WR seedling exposures included **1)** formulated sediment with five and 40 grams of amended fertilizer; **2)** sediment sampled from Wild Potato Lake; and **3)** sediment sampled from Rat River Bay (see '**Figure 9**' below).

	FIVE GRAMS FERTILIZER	40 GRAMS FERTILIZER	WILD POTATO LAKE SEDIMENT	RAT RIVER BAY SEDIMENT
NUMBER OF PLANTS (TOTAL)	13	4	15	18
AVERAGE NUMBER OF SEEDS PER PLANT	6.4	0	19	13
AVERAGE ROOT DRY WEIGHT (MG)	47.6	12.4	95.4	64.7
AVERAGE ROOT LENGTH (MM)	106	106.8	138.6	144.4
AVERAGE SHOOT DRY WEIGHT (MG)	105.3	16.5	306.8	166.3
AVERAGE SHOOT LENGTH (MM)	351	203.8	712.8	533.1
AVERAGE LEAF DRY WEIGHT (MG)	110.3	65.1	217.7	154.2
AVERAGE LEAF LENGTH (MM)	450.1	453.8	666.9	593

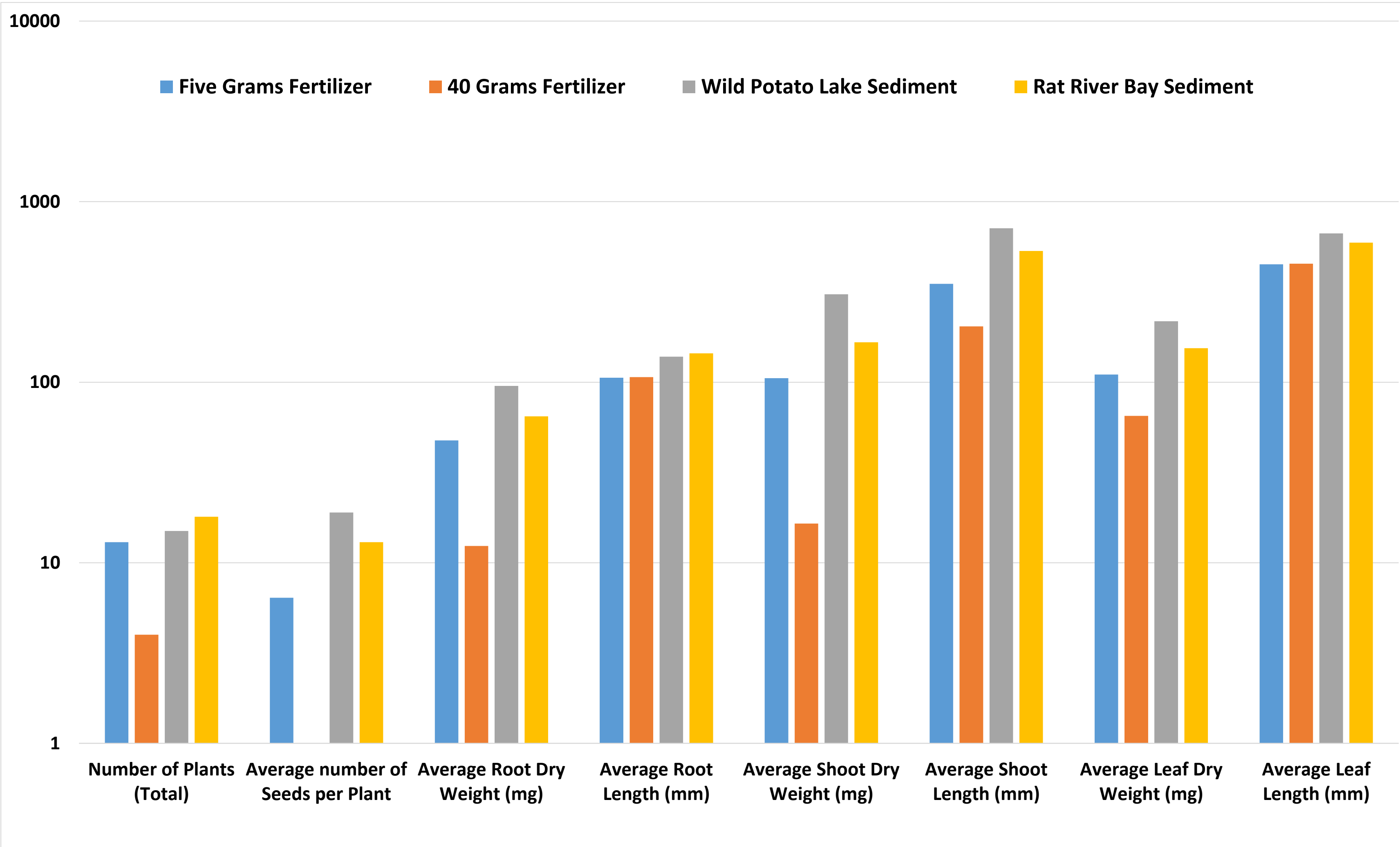


Figure 9. Average, measured characteristics of WR plants harvested from the re-planted 'Raft 5.' WR seedling exposures included **1)** formulated sediment with five and 40 grams of amended fertilizer; **2)** sediment sampled from Wild Potato Lake; and **3)** sediment sampled from Rat River Bay (see '**Table 1**' above).

Table 2. Average measured characteristics of WR plants harvested from Raft 1 (emergent phenological stage) and Raft 3 (floating leaf phenological stage). Treatments labeled with '+30' were those treatments lowered 10cm approx. every five days following target phenological stage achievement.

	R1 40cm Ctl Trt	**R3 40cm Ctl trt**	**R1 40+30cm Trt**	**R3 40+30cm Trt**	**R1 60+30cm Trt**	**R3 60+30cm Trt**	**R1 80+30cm Trt**	**R3 80+30cm Trt**
Total Number of Plants	19	6	19	17	14	5	11	3
Avg. # of Seeds per Plant	77	0	59	13	9	0	23	0
Avg. Root Dry Wt. (mg)	255.1	6.4	142.9	52.3	28.4	86.6	77.1	50.7
Avg. Root Length (mm)	271	83	219	167	151	71	193	65
Avg. Shoot Dry Wt. (mg)	334.3	1.5	320.4	117.9	86.6	4.7	96.0	3.5
Avg. Shoot Length (mm)	532	132	845	513	292	102	360	180
Avg. Leaf Dry Wt. (mg)	784.3	8.2	494.5	248.0	133.3	10.2	394.0	6.8
Avg. Leaf Length (mm)	696	159	1045	560	389	191	510	258

R1 = Raft 1; emergent phenological stage. These WR plants were allowed to achieve an emergent developmental phase prior to initiating the lowering events (i.e., water depth of the tubs in which WR seedlings were planted were maintained at a 40cm depth until the majority of WR plants achieved emergent development; water depth of all tubs was increased by 10cm every approx. five days following emergent development).

R3 = Raft 3; submerged phenological stage. These WR plants were only allowed to achieve a submerged developmental phase prior to initiating the lowering events (i.e., water depth of the tubs in which WR seedlings were planted was increased 10cm every approx. five days prior to plants reaching the surface of the water; approximately 15 – 25 cm in height).

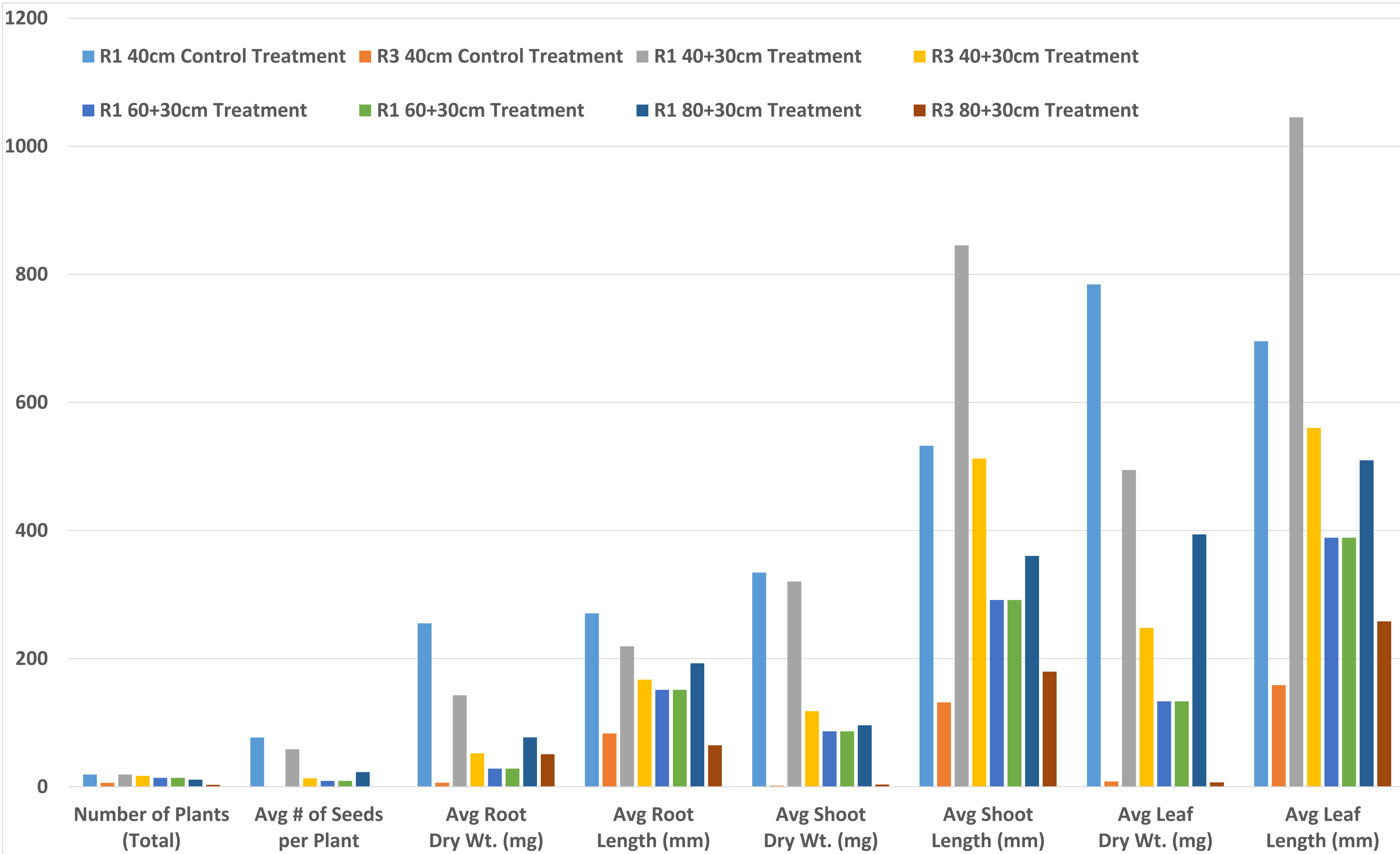


Figure 10. Average measured characteristics of WR plants harvested from Raft 1 (emergent phenological stage) and Raft 3 (submerged phenological stage). Treatments labeled with '+30' were those treatments lowered 10cm approx. every five days following target phenological stage achievement.

APPENDIX C
CUTTING OF CATTAILS

Figure 9. Airboat mounted mechanical cattail removal assembly.

Figure 10. August 12, 2014: Using mechanical cattail removal assembly for cattail removal - during operation.

Figure 11. August 12, 2014: Using mechanical cattail removal assembly for cattail removal - after operation.

Figure 12. August 24, 2104: Same area as Figs. 10 – 11; cattail re-growth not observed. Few observed cattail plants 'missed' during initial harvest event. Appears this mechanical cattail harvest method is effective and efficient.

Figure 13. August 24, 2014: Open area approaching island harvested on August 12, 2014. Re-growth not observed; very few cattails 'missed' during initial harvest. Appears this mechanical cattail harvest method is efficient and effective.

APPENDIX D: IJC JANUARY UPDATE

January 2016 Update Summary

Effects of Water Management Regime of Rainy Namakan System on Wild Rice Production and Cattail Invasion into Wild Rice

Prepared for

International Joint Commission

Prepared by

Dr. Peter Lee, Professor, Lakehead University
Councilor John Kabatay, Seine River First Nation
O'Niell Tedrow, M.S., Lakehead University
Kristi Dysievick, B.S., Lakehead University

TABLE OF CONTENTS

APPENDICES

EXECUTIVE SUMMARY

During the 2014 field season, multiple portions of the research detailed in the Work Plan (Plan) were initiated. However, due to extraordinary field conditions early in the 2014 field season (increased water depths throughout the study areas; heavy rains and continued flooding into June / July 2014) some components of the Plan were re-scheduled to the 2015 field season. Surprisingly, no wild rice (WR) was observed within the Wild Potato Lake (WPL) and Rat River Bay (RRB) study areas; therefore, no field measurements of wild rice density, or other characteristics, were possible during 2014. The field component of the research was completed during the 2015 field season; densities of WR plants specifically within the RRB study area were measured as described later in this update.

The WR Experimental Depth Raft study was initiated early Summer 2015 using four rafts; two used WPL sediment and two used RRB sediment. Each raft's discreet water depth treatments were designed to mimic the current upper and lower Rule Curve water depth limits. Likely due to an acute, controlled upstream release of water from a beaver impoundment during the submerged / seedling WR phenological stage, near complete mortality was observed in the 2015 Experimental depth Raft portion of this research. Fungal infection also occurred on some of the seedlings after germination which may also have contributed to their poor performance. This experiment is scheduled to be repeated during the 2016 field season. The few data which were obtained from the 2015 portion of this research are summarized and appended to this update.

Exceptional WR plant densities were observed within the RRB study area; specifically, within areas having received an intensive cattail harvest event during August 2014. This allowed an extensive survey of WR plant density in a cattail harvest area, natural WR area (without cattails), and cattails from a cattail dominated area. WR plants were typically present in cattail dominated areas, albeit at much lower densities than in cattail harvested areas or natural WR areas. WR plants were also observed in the WPL study area. WR plant density estimates and other metrics were obtained from a WPL WR area as well. Sediment, sediment pore water, and WR plants were sampled from the RRB study area for measurement of select chemical and physical characteristics. Data obtained from the 2015 portion of this research are summarized and included in various appendices at the end of this update.

At this time, we believe it is premature to draw any definitive conclusions with respect to specific objectives detailed within this ongoing study. Discussion of preliminary results will be included in individual sections as appropriate. Additional data, as they become available, will be included in subsequent Plan updates.

1.0 SEASONAL MONITORING OF WILD RICE EXPERIMENTAL DEPTH RAFTS

1.1 RAFT CONFORMATION SET-UP AND INITIATION

Based on data obtained during the 2014 'Experimental Depth Raft' study, four additional rafts were sequentially deployed for the 2015 field season in the same area as for the 2014 field season (**seeAppendix A, Figures 1-3** for 2014:2015 raft deployment area contrast). The overall objective for this portion of the 'Experimental Depth Raft' research was to measure the influence of upper and lower (current) Rule Curve water depth limits on WR growth, development, and productivity; obtaining the same measurements of these parameters as during the 2014 field season.

Each of the four rafts was deployed with four quadrats; each quadrat contained nine tubs suspended in the water column at specific depths. Two rafts' tubs were filled approximately ¾ full with sediment obtained from WPL (rafts one and two); the other two rafts were deployed similarly, but using sediment obtained from RRB (rafts three and four). No sediment amendments in the form of fertilizer additions were used during 2015.

1.2 Raft Water / Tub Depth Treatments and Adjustments

Each of the four quadrats within each raft was assigned a specific depth treatment. Water depth changes within each of the four rafts were designed to mimic the prescribed water depth limits (upper and lower) of the current Rule Curve. Therefore, not all tubs within each raft were treated similarly; rather, some tubs were lowered more deeply into the water column; other tubs were raised towards the water's surface.

Tub depths within the water column on 'Raft 1' containing WPL sediment was initiated at 40 cm, and adjusted upward by 15 cm (Q1); no change (40 cm control; Q2); or downward by 15 cm (Q4). Five tubs in Q3 on Raft 1 were used as depth peaking tubs, receiving a depth increase of 30 cm. Four tubs in Q3 of Raft 1 were used as a shallow treatment, receiving a water depth decrease of 30 cm. Tub depths within the water column on 'Raft 3' were identical to those used on 'Raft 1;' the difference being the sediment type – WPL sediment for Raft 1 and RRB sediment on Raft 3.

Water depth treatments for tubs in quadrats on Raft 2 and Raft 4 were initiated at 60 cm, and received identical depth treatment changes as Rafts 1 and 3. WPL sediment was used in tubs on Raft 2, and RRB sediment was used in tubs on Raft 4.

WR seedlings were prepared as in 2014; WR seeds were cleaned using hydrogen peroxide, a portion of the seed coat was scraped from the embryo to promote germination, and seeds were then stored and germinated (approx. 5-7 days) in aerated distilled water in a light (16h light:8h dark) and temperature (24°C ±2°C) controlled incubator. All rafts associated with this research were initiated and deployed on June 26, 2015, using WR seedlings prepared as described above (**Appendix B, Figure 4**).

Although the WR seedlings were prepared and germinated as in 2014, very sparse WR plant development was observed during the 2015 field season (**Appendix B, Figure 5**). However, 'field' WR plants were observed within the channel in which rafts were deployed, as well as throughout the study areas (**Appendix B, Figure 6**). Regardless of the water depth treatment within any of the four rafts, few if any WR seedlings achieved the floating leaf phenological stage; fewer achieved the aerial / emergent phenological stage. Due to this lack of observed WR plant development, no plants were sampled until an October 14, 2015, site visit. Data obtained from sample-able plants during this visit are detailed in **Appendix C, Figure 7**.

Between the date of raft planting, initiation, and deployment, a 'large volume' of water was released upstream of the raft deployment channel due to beaver dam removal efforts. It is likely that this event was detrimental to WR plant development in 'Experimental Depth Rafts.'

Based on data obtained during the 2014 field season, the more likely sensitive phenological stage is the seedling stage. Since these plants would have likely been seedlings at the time of this upstream water release, they would be more likely to suffer adverse developmental influences (from this release). Fungal infection was also noted on some of the young seedlings which likely impeded root development causing further stress on the young plants. 'Field' WR which had achieved the floating leaf phenological stage at the time of raft deployment is more likely to have 'survived' this upstream water release, and continued to develop (**Appendix A, Figures 2 and 3; Appendix B, Figures 4-6**).

2.0 Collection of Samples for Sediment, Wild Rice Productivity from Rafts

All WR plant samples obtained during the 2015 field season were sealed in Ziploc® bags at the time of collection, and stored and transported to Lakehead University Environmental Laboratory (LUEL) on ice.

Due to the lack of WR growth, development, and productivity from wild rice within the deployed 'Experimental Depth Rafts,' no sediment samples were obtained during this portion of the research. The near complete mortality of WR plants observed in the 2015 Experimental Depth Rafts was likely due to an acute, controlled inflow of water released from an upstream beaver impoundment. Based on observations immediately following initiation and deployment of the rafts, the WR phenological stage that would have been exposed to this rapid inflow of water was likely the submerged / seedling stage; the stage typically more sensitive to rapid water depth fluctuations.

During a sit visit on October 14, 2015, harvestable plants were obtained from rafts 1 and 3 (**Appendix C, Figure 7**). Unfortunately, due to the low density of harvestable plants in these rafts, no statistical treatment or definite statements re: the data may be concluded.

3.0 Sample Analyses

Future samples of sediment and WR plants from 'Experimental Depth Raft' studies will be organized using Microsoft Excel®, with statistical analyses completed using SigmaPlot-SigmaStat® (Systat, Inc.), or equivalent.

4.0 Collection of Samples and Data from Transects for Sediment, Wild Rice, and Cattail Productivity

During the 2014 field season, three primary cattail dominated areas in Rat River Bay (RRB) were selected for harvest of cattails. These areas were: **1)** near an island; **2)** along shore upstream from the island location; and **3)** further upstream from the island location nearer the steel bridge. These areas were intensely harvested for cattails; specifically, to sever the cattail plants below the water's surface. This objective was achieved; within these three areas, no aerial portions of cattail plants were visible following the harvest event. Also, within these areas of cattail harvest no wild rice (WR) plants were observed prior to or following the 2014 cattail harvest (**Appendix D, Figures 9 and 11**). Furthermore, no WR plants were observed throughout the RRB (and WPL) field study areas during the 2014 field season; this was true for areas dominated by cattails and areas not dominated by cattails. This was likely due to the increased water depth in all areas of WPL and RRB, specifically during Spring and early Summer 2014, the time of year during which WR is more vulnerable to adverse water depth influences (specifically, the seedling stage)

Less precipitation was received during the 2014-2015 Winter and 2015 Spring. This resulted in observably decreased water depths throughout the WPL and RRB study areas. Although this decreased water depth would be a benefit to WR plants, quite unpredictably, during the 2015 field season, WR plants were observed in outstanding densities throughout the RRB (and to a lesser degree WPL) field study areas (**Appendix D, Figures 8, 10, and 12; Appendix A, Figures 1-3**). Observations of unexpectedly high WR plant densities within areas of intense cattail harvest resulted in a re-evaluation of the necessity of WR seeding activities (WR was also observed growing within areas dominated by cattails, but at much lower plant densities).

NOTE: All WR plants harvested from RRB and WPL during the 2015 field season were well into their emergent / aerial phenological stage; also well into the seed bearing stage; at the time of harvest. Growth of WR plants during 2015 in areas dominated by cattails in 2014 indicates a viable, extensive, and abundant WR seed bank within the RRB (and WPL) sediment.

WR plants were harvested from up to three quadrats in four areas **[**WR plants from an area of intense 2014 cattail harvest (WRC), cattails from a cattail dominated area (CT), WR from an area lacking intense 2014 cattail harvest (WRNC), WR plants from a WR dominated area in WPL (WRWP)**]**. Overall above ground weight of WR plants harvested, biomass of WR plants harvested, and average weight of individual harvested WR plants were measured. These data are summarized in **Appendix D, Figures 14-16**. These data will be used to assess the effect of water depth versus wild rice production under natural production in the areas of concern.

5.0 SAMPLE ANALYSIS

All plant (cattail; wild rice) and sediment samples obtained during the 2015 field season were transported on ice to LUEL for analysis.

6.0 DATA ANALYSIS FROM 'TREATED' QUADRATS

All data obtained from plant (cattail; wild rice) and sediment samples were / will be organized using Microsoft Excel®. All statistical analyses will be completed using appropriate statistical software.

7.0 WILD RICE SEDIMENT SAMPLE AND PLANT TISSUE CHARACTERIZATION

7.1 SEDIMENT CORE SAMPLER COLLECTION

Sediment core samples were obtained from three specific areas within the WPL and RRB. These three areas coincided with the three areas in which peepers (sediment pore water sampling devices) were deployed (see description in **Section 8.2**below). Sediment cores were obtained in clear, 1.88" internal diameter cellulose acetate butyrate (CAB) sleeves. Cores were stored in the upright position and transported to LUEL for analyses. Select data are summarized in **Appendix**

D, Figure 13 and Table 1. NOTE: In **Table 1**, 'Wild Rice' refers to the area containing wild rice plants; 'Wild Rice Cut' refers to the area of intense cattail harvest; and 'Open Water' refers to the area of open water where neither wild rice nor cattails were observed. See **Table 1** description in **Appendix D** for a brief explanation of the sediment core characterization data.

7.2 Peeper Construction and Deployment

Dialysis pore water samplers, commonly known as peepers, are designed to collect pore water samples along a depth gradient within the sediment. Acrylonitrile butadiene styrene (ABS) pipes and fittings were used to construct the structure, which held the sample tubes. Holes were drilled to allow three sample tubes every 10cm. Fisherbrand® 50 mL sample tubes were modified by drilling a 18 mm diameter hole in the cap and replaced with a 0.45 µm pore size Millipore Durapore® membrane filter. At deployment sample tubes were filled with degassed distilled deionized water (DDW), capped with zero head space, and placed within the ABS pipe structure.

All peepers were deployed September 9, 2015, on Rat River Bay; a Large Bay within the Seine River Water Shed that is an area of interest due to the typical abundance of wild rice. In total six peepers were deployed; two within a natural wild rice stand; two within a cattail stand; and two within an area from which cattails had been harvested during August 2014.

7.3 Pore Water Sample Collection and Analysis

Peepers were retrieved on October 14, 2015, which allowed 35 days of deployment. Each peeper was pulled vertically from the sediment noting how many 50 mL sample tubes remained within the water column. Sample tubes within 10 cm intervals were combined in one clean labeled sample bottle, which resulted in 150 mLs ofpore water sample volume per 10 cm sediment interval. All samples were placed in an ice filled cooler and transported to LUEL for analysis. Select data are summarized in **Appendix D, Table 2**. See **Table 2** description in **Appendix D** for a brief explanation of the sediment pore water data.

Pore water results from the peepers were organized using Microsoft Excel®; statistical analyses will be completed using appropriate statistical software.

7.4 Wild Rice Plant Tissue Analysis

Within the three areas from which sediment and sediment pore water were sampled (described above), with an additional site in WPL (labelled 'WRWP'), multiple 0.25 m^2 areas (quadrats) in specific water depths (primarily 40, 60, 80, and 100 cm depths) were selected for harvest of WR plants in an effort to compare and contrast characteristics of WR plant tissue; the deepest water sampled for the cattail area was 90 cm, which is represented as a 100 cm depth in **Appendix E, Table 3 / Figure 17, and Table 4 / Figure 18**. WR plants in each of the selected quadrats were harvested, quantified, stored in plastic bags, and transported to LUEL for analysis. Due to variability in field-site conditions, not all water depths were equally represented in the study area. Therefore, select data from coinciding water depths (60, 80, and 100 cm) are summarized in **Appendix E, Table 3 / Figure 17, and Table 4 / Figure 18.**

No WR plants were observed throughout the RRB and WPL study areas during 2014. WR plants were observed in astounding densities throughout the RRB study area, and to a lesser degree the WPL study area. This complete transformation of WR populations was compounded by extraordinary WR plant density within areas intensely harvested for cattails during 2014. However, the outward appearance of WR plants within natural WR areas and within cattail harvested areas was noticeably different. WR plants harvested from a natural WR stand had an outward appearance of a generally healthier plant; plants generally lacked appearance of (potential) brown spot disease (**Appendix E, Figure 19**). WR plants harvested from areas of intense cattail removal during 2014 typically had an unhealthier appearance; specifically, more extensive and intensive appearance of potential brown spot disease (**Appendix E, Figure 20**). This could indicate a nutrient deficiency, specifically nitrogen, in the sediment of cattail areas. Additional sediment sampling is scheduled for the 2016 field season to further investigate this theory.

8.0 2016 Planned Activities

8.1 Experimental Depth Rafts

Due to observed, decreased WR plant development and productivity in the 'Experimental Depth Raft' portion of this research, a repeat version of this experiment will be completed during the 2016 field season. The design of the rafts for the 2016 field season are targeted to be the same as those during the 2015 field season. Sediment will be obtained from WPL and RRB, as was completed for initial raft experiments during 2013, and these follow-up raft experiments during 2014.

Potential changes to the raft initiation and deployment will include an earlier deployment date in an effort to **1)** more closely associated with 'field' WR plant development; and **2)** if problems are again observed in terms of WR plant growth and development (i.e., observations of suspected 'failure to thrive' throughout the deployed rafts), allow time for a potential 're-initiation' of one or more rafts during the WR growing season.

8.2 Cattail Harvest and WR Re-Establishment

The density of WR plant growth within all areas of intense 2014 cattail harvest indicate a viable and extensive WR seed bank in the RRB study area. WR plants were also observed in the WPL study area, but at lower densities contrasted to RRB, which is normal for the WPL system.

Due to the exceptional success in 2015 of WR re-establishment in areas of intense cattail harvest, additional areas for intensive cattail harvest events have been, and will be, selected specifically within the RRB area (an area of heavy cattail growth impeding WR growth in areas historically known for their dense WR stands). These additional cattail harvest areas will be specifically chosen to coincide with Plan objectives. Discussion about the need to broadcast WR seeds within the RRB areas of intense cattail harvest is currently a topic of discussion; seeding areas within RRB following cattail harvest may not be necessary.

One component that may be focused on for the 2016 field season will be the harvesting of cattails in areas of specific water depths. Although this may also be difficult to complete as designed due to the dynamism of water depths in fairly small areas; add to that water depth fluctuations on a more short-term temporal basis (i.e., daily; weekly; monthly) due to rainfall. Furthermore, additional sediment samples are scheduled to be obtained from areas used for the ongoing field study portions of the research (WR growth in cattail harvested areas; cattail dominated areas; natural WR areas; open water areas). Specifically, to add to the dataset designed to answer questions about cattails' potential influence on sediment characteristics; some of which may be detrimental for WR plant development, growth, and productivity. Sediment samples are also scheduled to be obtained from areas sampled during the 2015 field season described above. These will help to answer questions about if and how sediment characteristics change following cattail removal and WR re-growth.

8.3 WR and Cattail Plant Tissue Characterization

As described in **Section 8.4** (above), general observations of WR plants harvested from areas of cattail harvest and WR plants harvested from natural WR areas generally had contrasting outward appearances of 'health.' The more extensive and intensive appearance of brown spots on leaves and stems of WR plants harvested from cattail harvest areas may indicate a nutrient deficiency, likely nitrogen, in sediment of cattail harvest areas (cattail areas in general). This could decrease productivity of WR plants in these areas, and potentially result in increased susceptibility to other diseases and worse, mortality.

For the 2016 field season, additional sediment samples from cattail areas (harvested or non-harvested), natural wild rice areas, and open water areas are scheduled. These additional samples will help to answer questions about the potential for cattail infestations to problematically alter sediment characteristics; and also, in areas sampled during 2015 if and how critical sediment characteristics such as nitrogen forms and concentrations change following cattail removal, and (unexpectedly) WR re-establishment.

In an effort to continue evaluation of the health of WR plants re-established in areas following intense cattail harvest, repeat sampling of WR plants in 0.25 m^2 quadrats within the four areas previously described, as close to WR plant sampling locations used during 2015 as possible, is scheduled for completion during the 2016 field season. However, this is dependent on water depth, which in these areas can measurably fluctuate on a daily basis.

APPENDIX A
SEASONAL MONITORING OF WILD RICE EXPERIMENTAL DEPTH RAFTS

Figure 1. 2014-07-18: 'Experimental Depth Rafts' deployed during the 2014 field season (facing south). NOTE date, and lack of wild rice in raft deployment channel.

Figure 2. 2015-07-22: 'Experimental Depth Rafts' deployed for the 2015 field season (facing south). NOTE date, and presence of wild rice on periphery of raft deployment channel.

Figure 3. 2015-07-22: 'Experimental Depth Rafts' deployed for the 2015 field season (facing north). NOTE date and presence of wild rice on periphery of raft deployment channel.

APPENDIX B

COLLECTION OF SAMPLES FOR SEDIMENT, WILD RICE PRODUCTIVITY FROM RAFTS (SHOWN – INITIATION AND DEPLOYMENT OF 2015 RAFTS)

Figure 4. 2015-06-26: Planting, initiation, and deployment of 2015 'Experimental Depth Rafts.' NOTE beginning of floating-leaf stage of wild rice development along periphery of raft deployment channel. Wild rice used in raft study only in seedling stage; 'field' wild rice already in floating leaf stage.

Figure 5. 2015-08-03: Very sparse wild rice plant growth in 'Experimental Depth Rafts.'

Figure 6. 2015-08-03: Note density of 'field' wild rice along periphery of 'Experimental Depth Raft' deployment channel.

APPENDIX C
(EXPERIMENTAL DEPTH RAFT) HARVESTABLE WR PLANT SAMPLE ANALYSIS

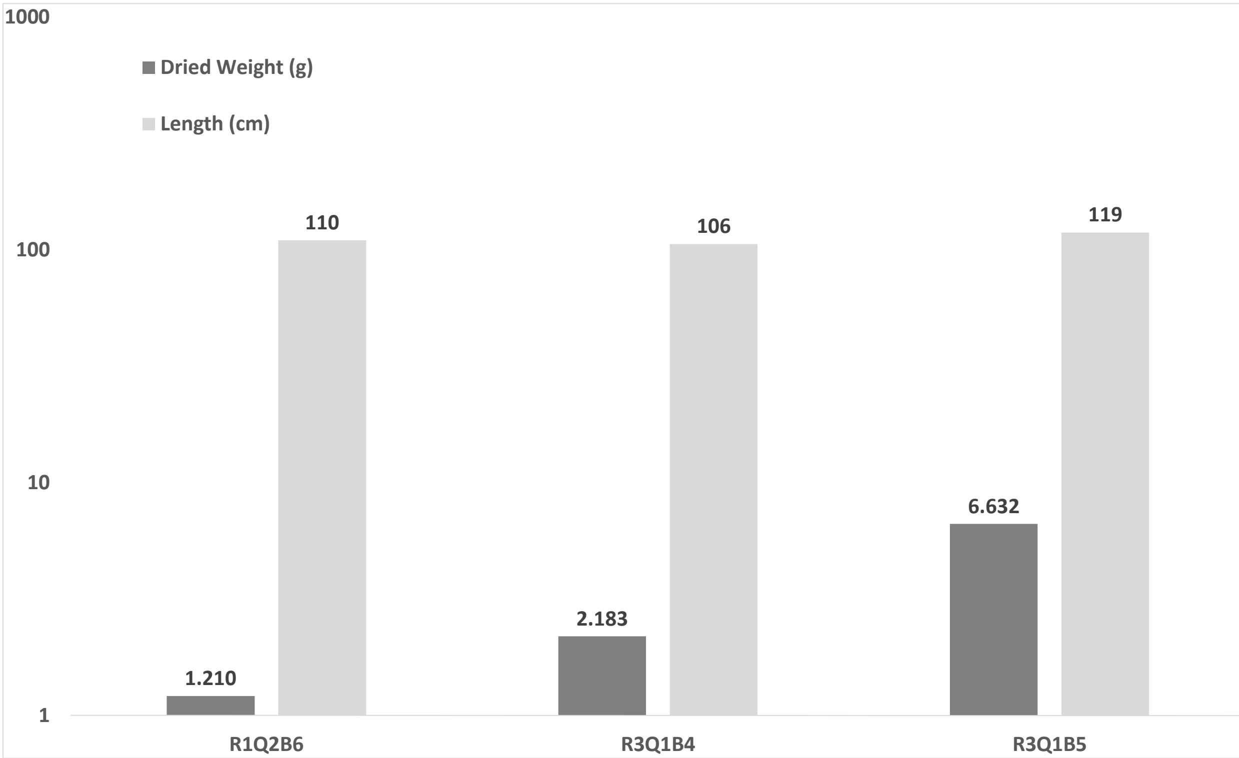


Figure 7. Average dried weight (g) and length (cm) of harvestable WR plants from two rafts; raft 1 and raft 3. Key to x-axis labels is as follows:

R1 = Raft 1 (WPL sediment); **Q2** = Quadrat 2 (25 cm depth); **B6** = bucket / tub 6.
R3 = Raft 3 (RRB sediment); **Q1** = Quadrat 1 (45 cm depth); **B4** = Bucket / tub 4.
R3 = Raft 3 (RRB sediment); **Q1** = Quadrat 1 (45 cm depth); **B5** = Bucket / tub 5.

APPENDIX D

COLLECTION OF SAMPLES AND DATA FROM TRANSECTS FOR SEDIMENT, WILD RICE, AND CATTAIL PRODUCTIVITY

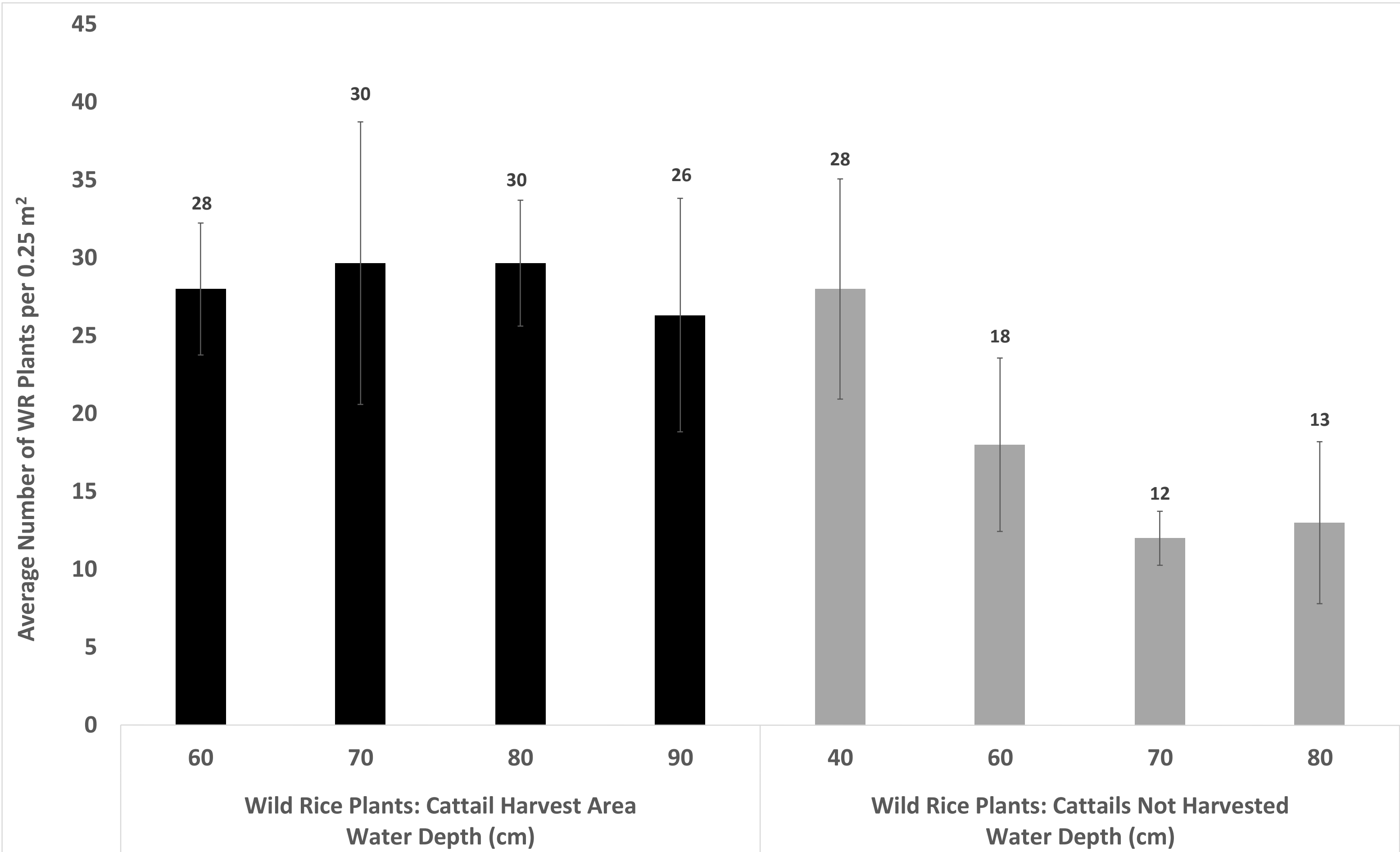


Figure 8. Average number of wild rice (WR) plants harvested from discreet 0.25 m^2 sections in Rat River Bay areas where cattails had been harvested and where cattails had not been harvested. Error bars represent one standard deviation (n = 2 in the 60 cm in cattail harvest area and 40 cm depth in cattail non-harvest area; other depths: n = 3). WR plants were sampled from the area where cattails had been harvested was on the south side of the island (as seen in **Appendix E, Figures 9 and 10** below).

Figure 9. 2014-08-24: South of an island; area of cattail harvest approaching the island. NOTE the appearance of the 'pathway' cut through the cattails approaching the island.

Due to the absence of wild rice (WR) plants throughout the Rat River Bay (RRB) and Seine River (SR), no WR plants samples, density estimates, or sediment samples were obtained during the 2014 field season.

Figure 10. 2015-08-03: South of an island; area of cattail harvest approaching the island. NOTE the density of WR plants in the area of cattail harvest; and the area in the foreground of the photo. Cattails were only removed from the pathway approaching the island.

WR plants were sampled, and density estimates obtained, from 0.25 m^2 quadrats within the area of cattail harvest, and from the area containing WR outside the cattail harvest area.

Sediment core samples were also obtained from areas containing WR plants within and outside the area of cattail harvest.

Figure 11. 2014-08-24: Cattail harvest area along shore, downstream from the near-island cattail harvest area. NOTE lack of aerial portion of cattail plants, and dead-fall tree along shore in distance (circled).

Area of cattail removal is in the foreground, and is nearly identical to that of the area containing wild rice plants (see **Figure 12**).

Figure 12. 2015-07-03: Cattail harvest area along shore, downstream from the near-island cattail harvest area. NOTE presence of wild rice plants in area of cattail harvest, and dead-fall tree along shore in distance (circled).

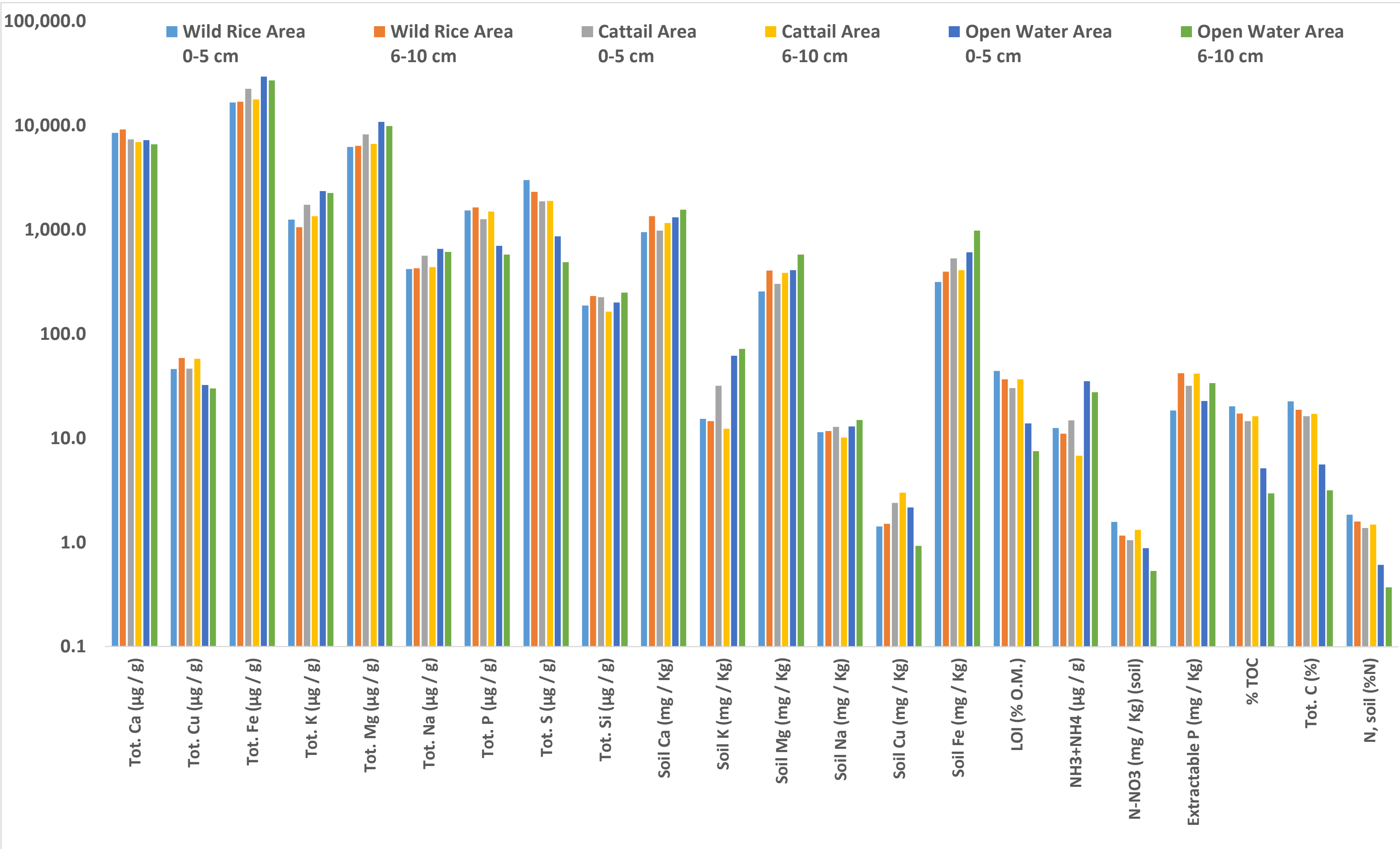


Figure 13. Measured chemical characteristics of two sediment depth intervals; sampled from three areas, WR dominated area, cattail dominated area, and open water area (see description of areas in caption for **Table 1** below).

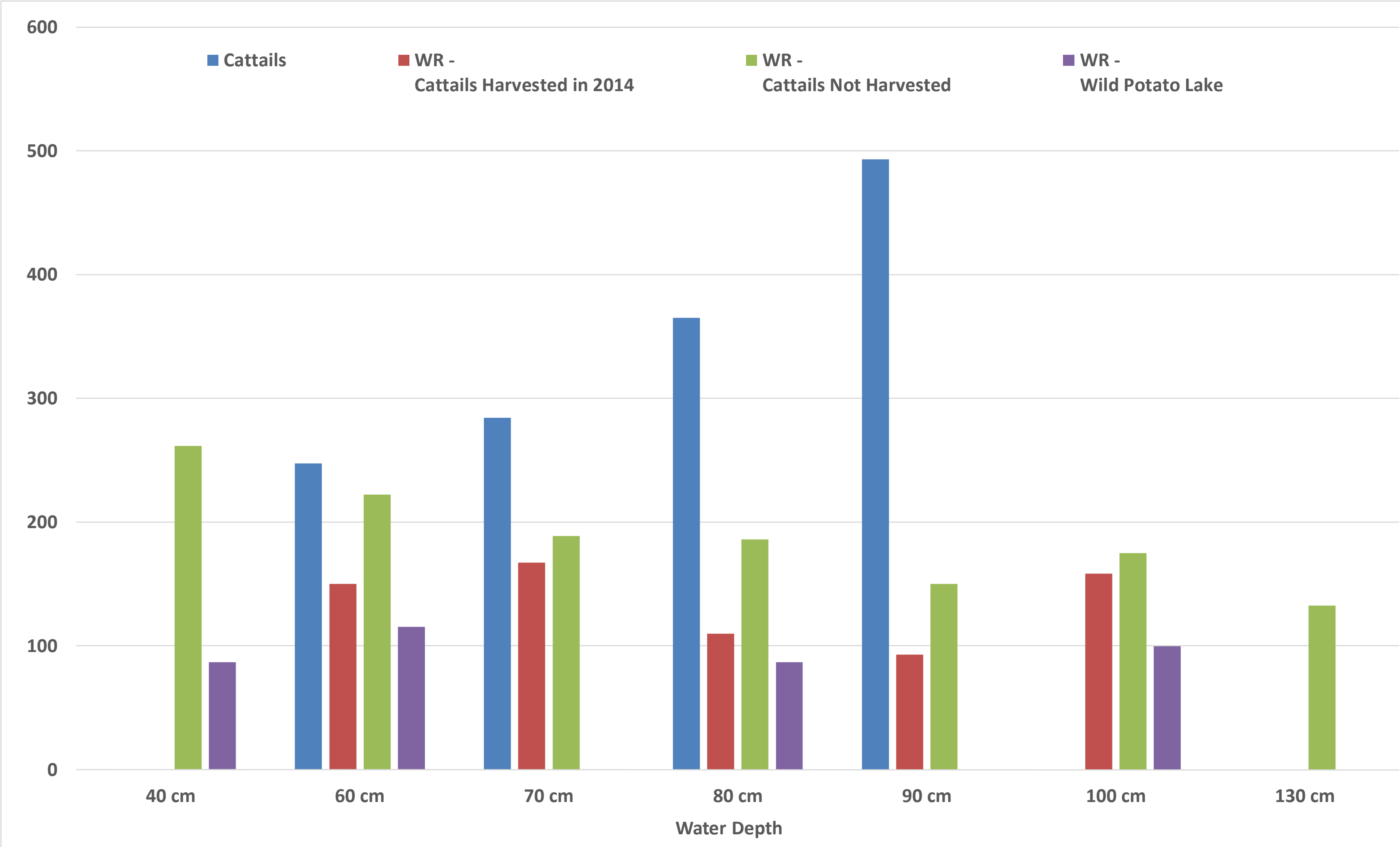


Figure 14. Average measured above ground weight (grams) of all WR plants harvested from three quadrats in four specific areas. Cattails were harvested from a cattail dominated area (CT). Not all water depths were sample-able in all four specific areas in the two systems' (RRB, WPL) study areas.

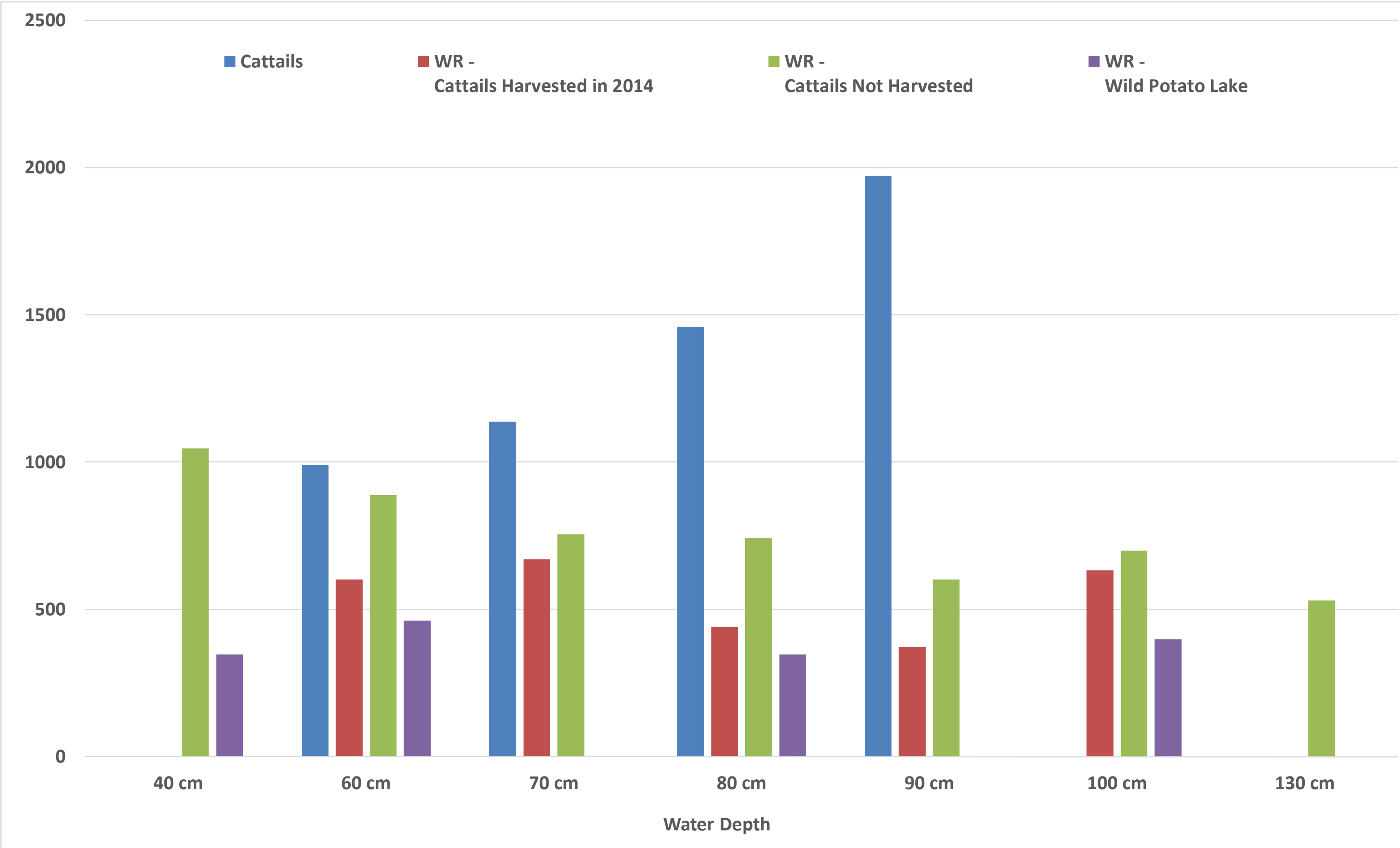


Figure 15. Average measured above ground biomass (grams / m^2) of WR plants harvested from three quadrats in three specific areas. Cattails were harvested from a cattail dominated area (CT) Not all water depths were sample-able in all four specific areas in the two systems' (RRB, WPL) study areas.

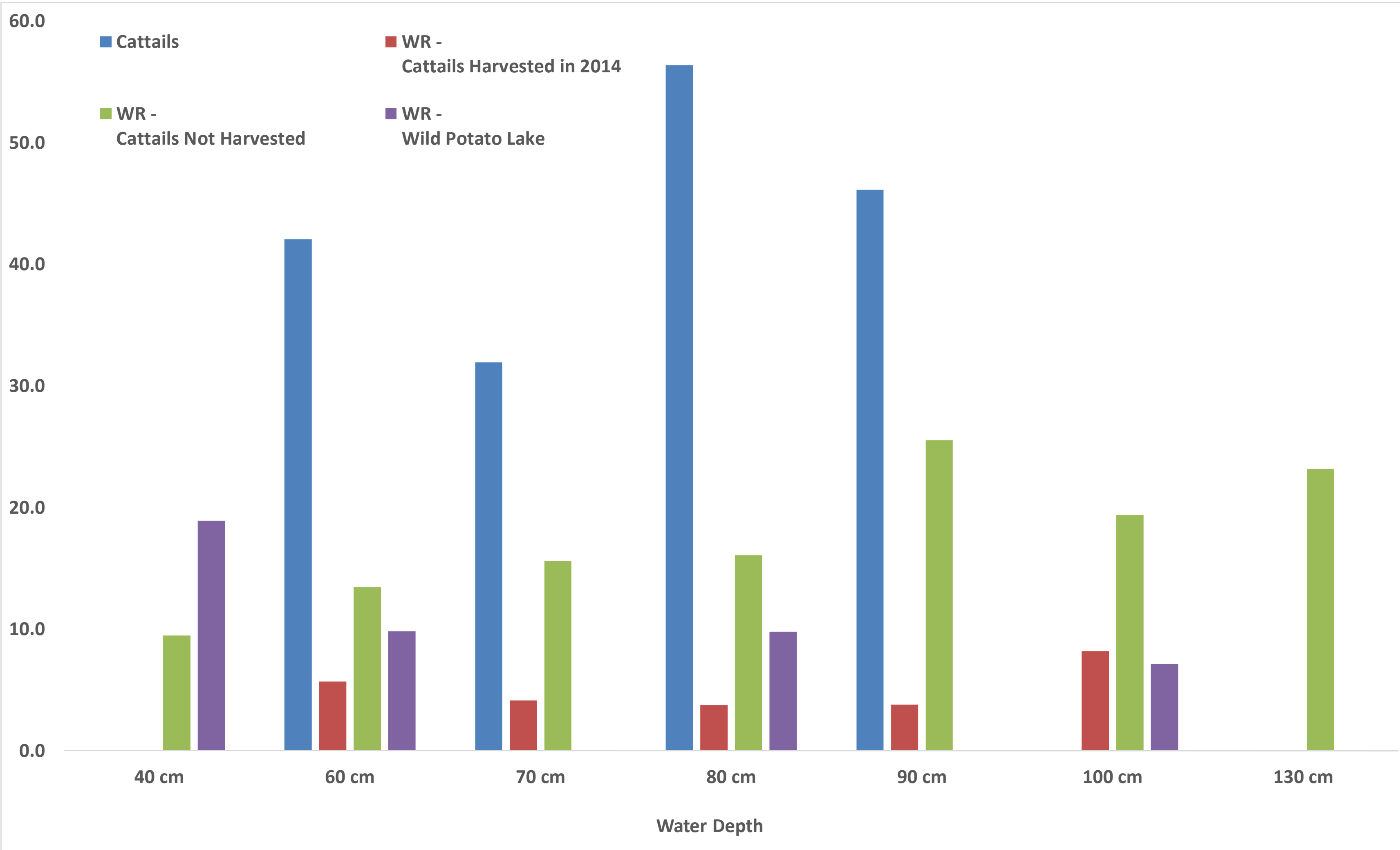


Figure 16. Average measured above ground weight (grams) per WR plant harvested from three quadrats in three specific areas. Cattails were harvested from a cattail dominated area (CT). Not all water depths were sample-able in all four specific areas in the two systems' (RRB, WPL) study areas.

Table 1. Average total values of elements from two depths in sediment cores collected within natural wild rice in Rat River Bay, areas where cattails were cut and now contain wild rice, and open water adjacent to the rice area. 'Wild Rice' refers to a natural WR dominated area; 'Wild Rice Cut' refers to the area of intense cattail harvest; and 'Open Water' refers to the area of open water where neither WR nor cattails were observed.

Parameter	Wild Rice		Wild Rice Cut		Open Water	
	0-5 cm	5-10 cm	0-5 cm	5-10 cm	0-5 cm	5-10 cm
Aluminum (%)	2.06	2.38	2.54	2.89	2.45	2.36
Barium	143.17	162.8	161.94	157.26	157.11	158.86
Berillium	0.57	0.72	0.62	0.74	0.45	0.41
Calcium (%)	0.85	0.91	0.74	0.69	0.72	0.66
Cadmium	0.69	0.65	0.2	0.56	0.13	0.13
Cobalt	9.27	8.80	12.28	9.32	15.75	15.29
Chromiujm	36.78	44.96	48.67	51.18	54.01	59.04
Copper	45.73	58.38	46.13	57.45	32.19	29.84
Iron (%)	1.66	1.69	2.24	1.77	2.93	2.70
Potassium (%)	0.12	0.11	0.17	0.13	0.23	0.22
Magnesium (%)	0.62	0.64	0.82	0.66	1.08	0.98
Manganese	220.93	201.73	294.87	165.21	332.21	286.35
Sodium	419.43	424.87	560.52	434.43	651.37	609.19
Nickel	39.81	46.26	38.56	43.69	37.91	36.5
Phosphorus (%)	0.15	0.16	0.13	0.15	0.07	0.06
Lead	9.90	9.09	12.43	10.3	11.90	10.46
Sulphur (%)	0.30	0.23	0.19	0.19	0.09	0.05
Silica	186.99	230.73	223.79	163.50	199.47	247.76
Strontium	30.18	31.55	28.59	28.02	26.63	24.83
Zinc	53.51	43.69	65.03	46.16	90.87	94.26

Table 1 shows that concentrations for Al, Ba, and Si are in higher concentrations in the lower portion of the sediment profile in the natural wild rice area. Si changes likely represent the demand by the rice plants in the upper rooting zone. The reverse trend occurred for Si in the cut wild rice area. Otherwise, concentrations of elements were quite similar between depths and between wild rice treatments (uncut cattail area, former cattail area, and open water). Noticeable differences did occur in the open water area where levels of Fe, K, and Na were higher than in the rice growing areas, possibly since there was no demand for these elements

from plants. On the other hand, both P and S were noticeably lower suggesting that recycling from plants was occurring for these elements in the rice growing sections.

Table 2, below, shows the concentrations of extractable (available) nutrients from the same area.

Table 2. Extractable values for sediment from natural, cut areas, and open water in Rat River Bay.'Wild Rice' refers to a natural WR dominated area; 'Wild Rice Cut' refers to the area of intense cattail harvest; and 'Open Water' refers to the area of open water where neither WR nor cattails were observed.

Parameter	**Wild Rice**		**Wild Rice Cut**		**Open Water**	
	0-5 cm	**5-10 cm**	**0-5 cm**	**5-10 cm**	**0-5 cm**	**5-10 cm**
Conductivity	53.3	69.9	64.8	64.6	65.2	81.0
Bulk Density	0.1	0.2	0.3	0.2	0.4	0.7
CA	941.1	1347.9	977.1	1152.2	1309.5	1554.3
K	15.2	14.5	31.6	12.2	61.6	71.6
MG	253.8	404.8	300.6	385.4	406.1	576.5
NA	11.3	11.6	12.7	10.1	12.9	14.8
CU	1.4	1.5	2.4	3.0	2.1	0.9
FE	313.7	394.4	527.3	408.8	603.6	975.7
MN	19.0	22.9	33.1	16.4	44.7	47.4
ZN	1.8	1.4	1.9	1.0	4.8	5.4
Loss on Inition	43.9	36.4	30.0	36.4	13.8	7.5
NH42	12.4	11.0	14.8	6.7	34.9	27.3
NO3	1.6	1.2	1.0	1.3	0.9	0.5
PH	5.9	6.0	6	5.9	6.4	6.6
PO4	18.4	41.8	31.6	41.4	22.6	33.6

Concentrations for Ca and Mg were higher in the lower 5 cm of the sediment profile in both the natural rice and cut wild rice areas. Noticeable differences included higher between the natural and cut areas included higher Fe concentrations in the cut area and of particular significance lower N levels. The wild rice in the cut areas was noticeably chlorotic (yellowish) and lower N values were a suspected cause. Comparing the open water area to the rice areas, concentrations were higher for Ca, K, Fe, Zn, NH4, NO3, and pH, and lower for loss on ignition.

Differences for the nutrients can be attributed to the lack of uptake by plants. The higher pH and lower LOI signifies the lower amount of organic build up in the non-rice producing sections.

APPENDIX E

WILD RICE SEDIMENT SAMPLE AND PLANT TISSUE CHARACTERIZATION

Table 3. Average measured concentration of select characteristics in WR plant tissue samples obtained from two areas **[**WR from an area without having had cattails harvested (WRNC), and WR from an area having had cattails harvested during August 2014 (WRC)**]** at three water depths (60, 80, and 100 cm) common between both areas; two additional areas summarized in **Table 4** below.

ug / g (unless noted)	WRC			WRNC		
	WRC 60 cm	WRC 80 cm	WRC 100 cm	WRNC 60 cm	WRNC 80 cm	WRNC 100 cm
Al	153.1	103.6	192.1	69.1	100.4	112.2
As						
Ba	13.3	12.9	15.0	13.7	9.8	10.2
Be						
Ca	12491.4	8798.1	11287.4	10652.9	8170.7	9459.8
Cd						
Co						
Cr	0.5		0.8	0.2	0.4	0.2
Cu	3.6	3.8	4.6	3.7	3.7	3.4
Fe	351.5	356.3	445.1	269.9	248.2	381.5
K	8441.1	9338.9	15255.4	12351.9	14310.4	13874.9
Mg	3201.3	1939.3	2681.0	3742.6	2505.0	2374.5
Mn	140.2	150.3	169.9	72.3	44.9	86.1
Mo						
Na	3901.3	3404.8	3587.9	2485.6	2308.4	2193.0
Ni	2.3		9.4			
P	2225.3	1718.5	2368.6	1961.0	2542.7	2461.3
Pb			101.1			
S	2162.4	1795.8	2072.8	2528.7	2091.9	2090.7
Se						
Si	556.4	772.5	861.2	476.6	514.0	438.0
Sr	26.2	18.8	22.8	23.6	18.0	20.8
Ti	9.7		10.3	3.3	6.1	6.2
V						0.3
Zn	12.9	13.4	15.0	14.2	12.7	11.8
C, Tot. (%)	40.7	40.9	39.3	41.6	42.0	40.7
N, Sed. (%)	2.2	1.8	1.8	2.7	2.5	2.3

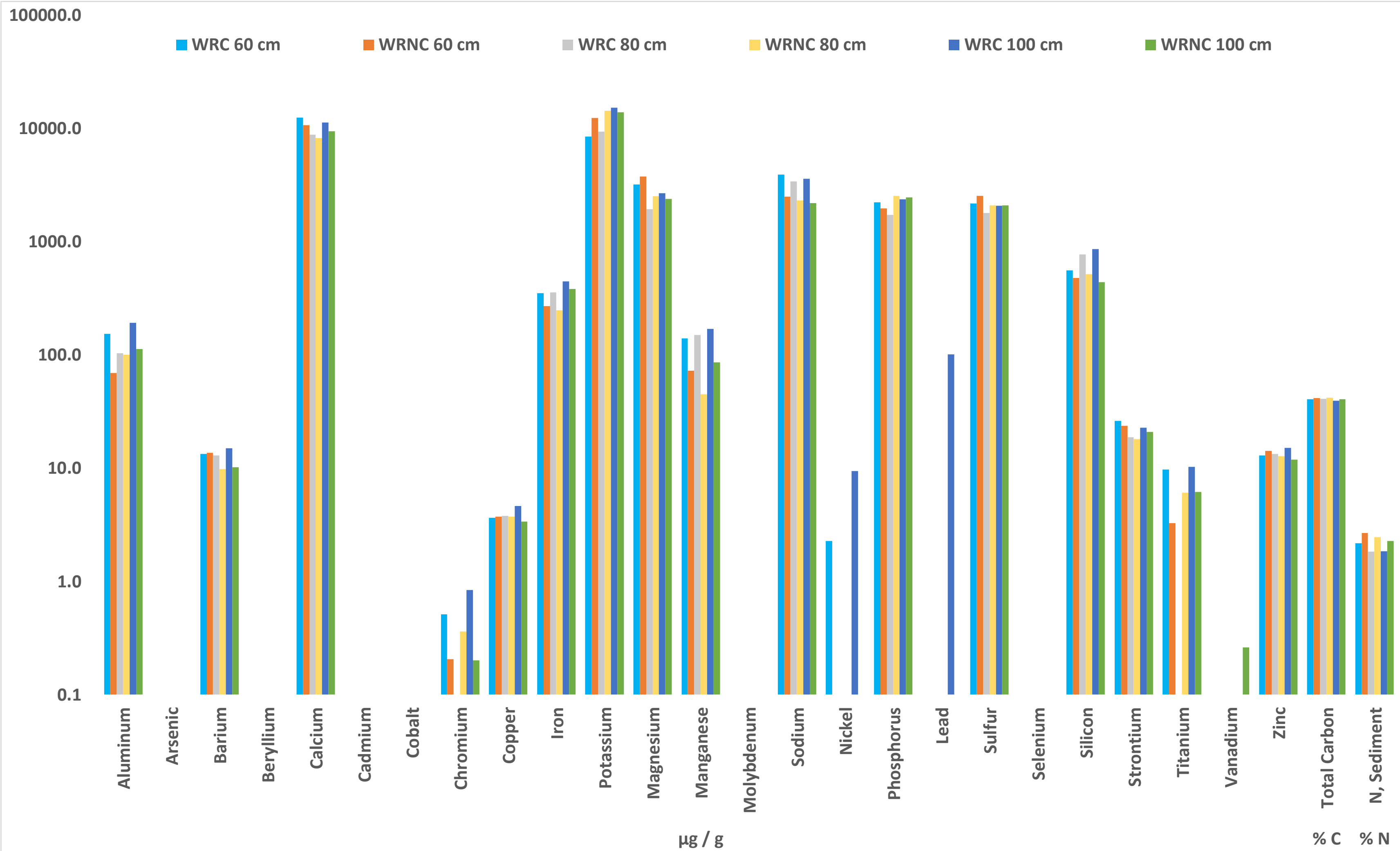


Figure 17. Average measured concentration of select characteristics in WR plant tissue samples obtained from two areas **[**WR from an area without having had cattails harvested (WRNC), and WR from an area having had cattails harvested during August 2014 (WRC)**]** at three water depths (60, 80, and 100 cm).

Table 4. Average measured concentration of select characteristics in WR and cattail plant tissue samples obtained from two areas (WR from an area within WPL, and cattails from a cattail dominated area in RRB) at three water depths (60, 80, and 100 cm) common between both areas; two additional areas summarized in **Table 3** above.

ug / g (unless noted)	WRWP			CT		
	WRWP 60 cm	WRWP 80 cm	WRWP 100 cm	CT 60 cm	CT 80 cm	CT100 cm
Al	423.4	254.8	220.0	20.1	27.6	33.0
As						
Ba	9.5	9.6	9.4	17.6	16.2	11.9
Be						
Ca	9028.1	7548.5	5550.7	6235.9	5328.3	4770.5
Cd					0.1	
Co						
Cr	1.1	0.3	0.3		0.6	
Cu	5.7	6.0	3.8	3.5	3.0	3.0
Fe	768.4	570.6	568.6	42.5	52.4	89.1
K	19458.6	22611.1	21695.5	8858.9	6592.1	7034.4
Mg	2094.9	1906.2	1729.6	2500.6	2491.5	2195.1
Mn	452.3	545.8	417.9	400.7	522.7	849.1
Mo						
Na	3878.6	3832.7	2500.0	2667.5	2482.8	1069.0
Ni	0.3	3.7	2.4			
P	3152.2	3888.3	3363.4	1706.0	1712.6	1811.1
Pb						
S	2310.0	2552.5	2251.5	1297.2	1374.2	1482.4
Se						
Si	538.3	564.3	513.1	71.1	104.7	185.3
Sr	18.8	16.8	12.6	21.7	17.4	13.4
Ti	35.2	16.1	14.0			
V	0.9	0.5				
Zn	14.0	14.4	13.5	13.4	12.4	15.2
C, Tot. (%)	40.0	40.5	41.2	45.7	46.6	47.0
N, Sed. (%)	2.8	3.3	3.0	1.4	1.6	2.0

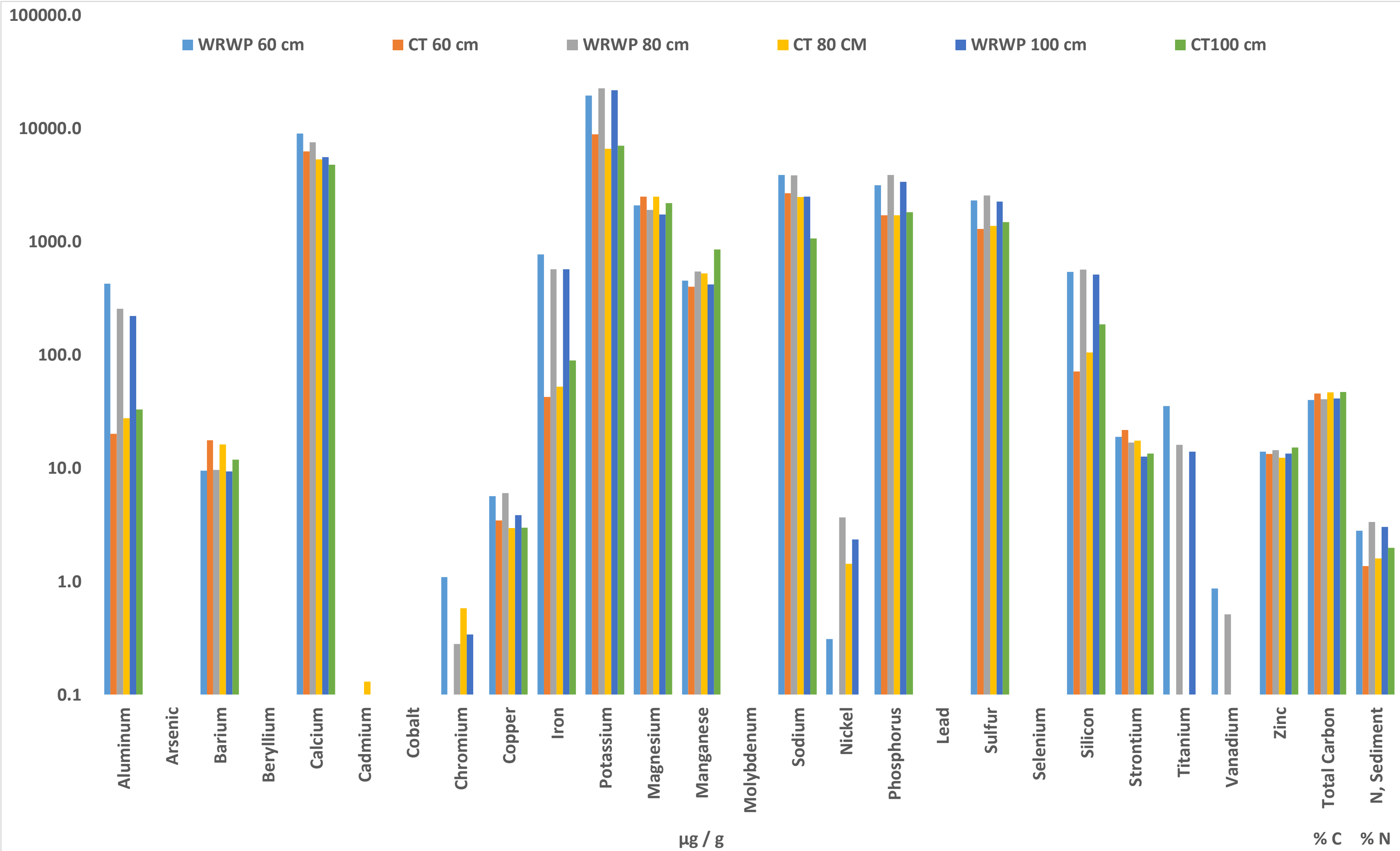


Figure 18. Average measured concentration of select characteristics in WR and cattail plant tissue samples obtained from two areas (WR from an area within WPL, and cattails from a cattail dominated area in RRB) at three water depths (60, 80, and 100 cm) common between both areas.

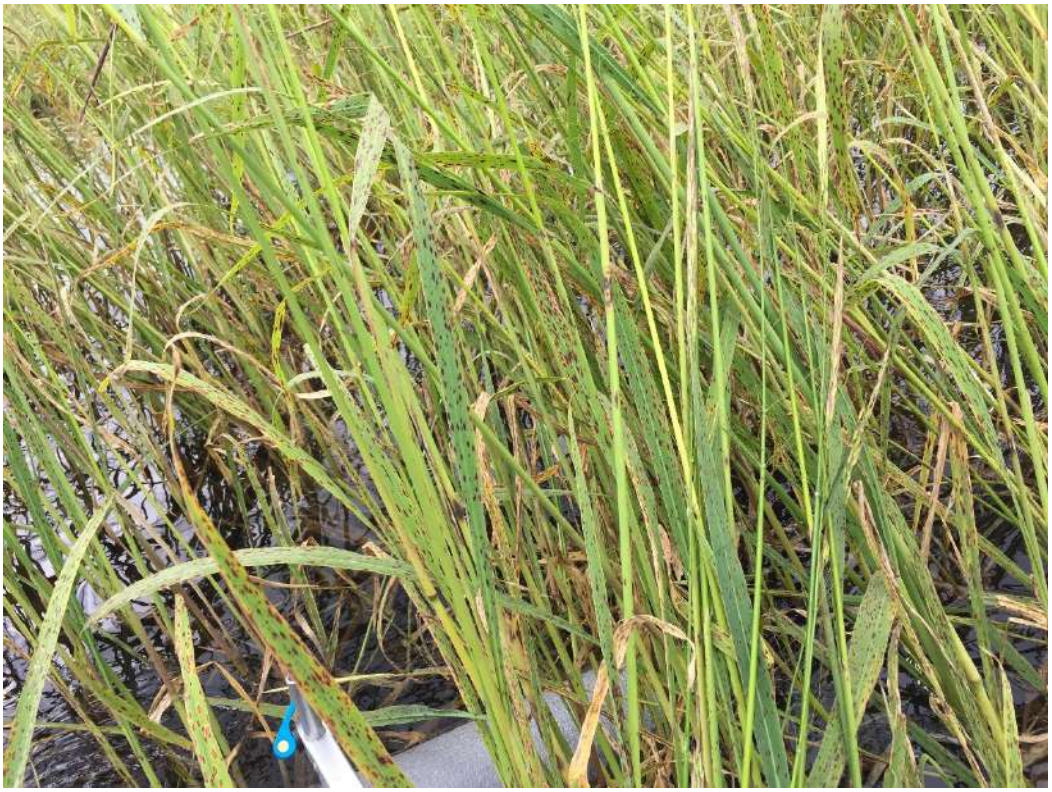


Figure 19. 2015-08-20: WR plants harvested from within the 'near island' area of intense 2014 cattail harvest. NOTE appearance of brown spots on leaves and stems of plants, generally throughout the sample area. This WR harvest quadrat was in approximately 60 cm of water in the near island cattail harvest area (same water depth as **Figure 20** below).

Figure 20. 2015-08-20: WR plants harvested from a natural WR area; one in which cattails do not dominate, and therefore an area not in need of cattail harvest. NOTE the decreased observance of brown spots on leaves and stems of WR plants. This was the general observation throughout this natural WR plant area; water depth in this image = approximately 60 cm (same as **Figure 19** above).

APPENDIX E: IJC FEBUARY UPDATE

FEBRAURY 2016 UPDATE SUMMARY: DATA ANAYLSIS OF TREATED QUADRATS

EFFECTS OF WATER MANAGEMENT REGIME OF RAINY NAMAKAN SYSTEM ON WILD RICE PRODUCTION AND CATTAIL INVASION INTO WILD RICE

PREPARED FOR
INTERNATIONAL JOINT COMMISION

PREPARED BY
DR. PETER LEE, PROFESSOR, LAKEHEAD UNIVERSITY
COUNCILOR JOHN KABATAY, SEINE RIVER FIRST NATION
O'NIELL TEDROW, M.S., LAKEHEAD UNIVERSITY
KRISTI DYSIEVICK, B.S., LAKEHEAD UNIVERSITY

TABLE OF CONTENTS

EXCUTIVE SUMMARY

During the 2014 field season, three primary cattail dominated areas in Rat River Bay (RRB) were selected for harvest of cattails. These areas were: **1)** near an island; **2)** along shore upstream from the island location; and **3)** further upstream from the island location nearer the steel bridge. These areas were intensely harvested for cattails; specifically, to sever the cattail plants below the water's surface. This objective was achieved; within these three areas, no aerial portions of cattail plants were visible following the harvest event. Also, within these areas of cattail harvest no wild rice (WR) plants were observed prior to or following the 2014 cattail harvest. Furthermore, no WR plants were observed throughout the RRB (and WPL) field study areas during the 2014 field season seen in **Figure one Appenddix A**. This was likely due to the increased water depth in all areas of WPL and RRB, specifically during Spring and early Summer 2014, the time of year during which WR is more vulnerable to adverse water depth influences (specifically, the seedling stage)

Less precipitation was received during the 2014-2015 Winter and 2015 Spring. This resulted in observably decreased water depths throughout the WPL and RRB study areas. Although this decreased water depth would be a benefit to WR plants, quite unpredictably, during the 2015 field season, WR plants were observed in outstanding densities throughout the RRB (and to a lesser degree WPL) field study areas. Observations of unexpectedly high WR plant densities within areas of intense cattail harvest resulted in a re-evaluation of the necessity of WR seeding activities (WR was also observed growing within areas dominated by cattails, but at much lower plant densities).

All WR plants harvested from RRB and WPL during the 2015 field season were well into their emergent / aerial phenological stage; also well into the seed bearing stage; at the time of harvest. Growth of WR plants during 2015 in areas dominated by cattails in 2014 indicates a viable, extensive, and abundant WR seed bank within the RRB (and WPL) sediment.

WR plants and sediment were harvested from up to three quadrats in four areas **[**WR plants from an area of intense 2014 cattail harvest (WRC), cattails from a cattail dominated area (CT), WR from an area lacking intense 2014 cattail harvest (WRNC), WR plants from a WR dominated area in WPL (WRWP)**]**. Overall above ground weight of WR plants harvested, biomass of WR plants harvested, and average weight of individual harvested WR plants were measured. This data is summarized in January's progress report**.** Also collected at that time were sediment grab samples and these results are summarized in **TABLE 1,2,3** This data will be used to assess the effect of water depth versus wild rice production under natural production in the areas of concern.

At this time, we believe it is premature to draw any definitive conclusions with respect to specific objectives detailed within this ongoing study. Discussion of preliminary results will be included in individual sections as appropriate. Additional data, as they become available, will be included in subsequent Plan updates.

1.0 Sediment Samples

1.1 Sediment Grab Sample Collection

Within the four areas described above (WRC, WRNC, WRWP, CT), multiple 0.25 m2 areas (quadrats) in specific water depths (primarily 40, 60, 80, and 100 cm depths) were selected for harvest of WR plants and sediment collection in an effort to compare and contrast characteristics of WR plant tissue. Sediment and WR or CT plants in each of the selected quadrats were harvested, quantified, stored in plastic bags, and transported to LUEL for analysis. Due to variability in field-site conditions, not all water depths were equally represented in the study area.

All plant (cattail; wild rice) and sediment samples obtained during the 2015 field season were transported on ice to LUEL for analysis.

2.0 Porewater

2.1 Peeper construction and Deployment

Dialysis pore water samplers, commonly known as peepers, are designed to collect pore water samples along a depth gradient within the sediment. Acrylonitrile butadiene styrene (ABS) pipes and fittings were used to construct the structure, which held the sample tubes. Holes were drilled to allow three sample tubes every 10cm. Fisherbrand® 50 mL sample tubes were modified by drilling a 18 mm diameter hole in the cap and replaced with a 0.45 µm pore size Millipore Durapore® membrane filter. At deployment sample tubes were filled with degassed distilled deionized water (DDW), capped with zero head space, and placed within the ABS pipe structure.

All peepers were deployed September 9, 2015, on Rat River Bay; a Large Bay within the Seine River Water Shed that is an area of interest due to the typical abundance of wild rice. In total six peepers were deployed; two within a natural wild rice stand; two within a cattail stand; and two within an area from which cattails had been harvested during August 2014.

2.2 Pore Water Sample Collection and Analysis

Peepers were retrieved on October 14, 2015, which allowed 35 days of deployment. Each peeper was pulled vertically from the sediment noting how many 50 mL sample tubes remained within the water column. Sample tubes within 10 cm intervals were combined in one clean labeled sample bottle, which resulted in 150 mLs of pore water sample volume per 10 cm sediment interval. All samples were placed in an ice filled cooler and transported to LUEL for analysis. Select data are summarized in **Appendix A, Figure 8,9**.

Pore water results from the peepers were organized using Microsoft Excel®; statistical analyses will be completed using appropriate statistical software

APPENDIX A

DATA ANAYLSIS OF TREATED QUADRATS

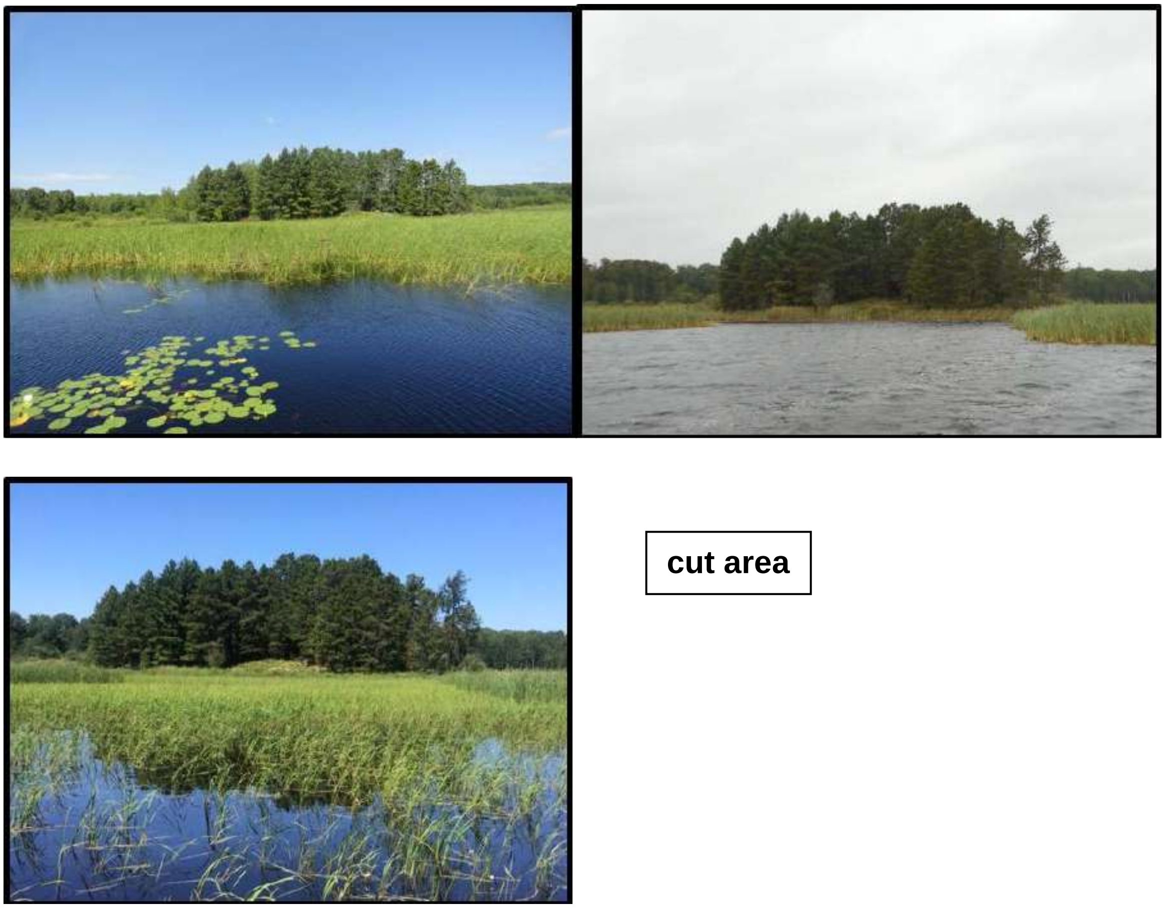


Figure 1. Test cutting area on Rat River Bay. Upper left, prior to cutting, August, 2014. Upper right, after cutting, August, 2014. June, 2015. Lower right, rice in aerial stage in cut area, July, 2015.

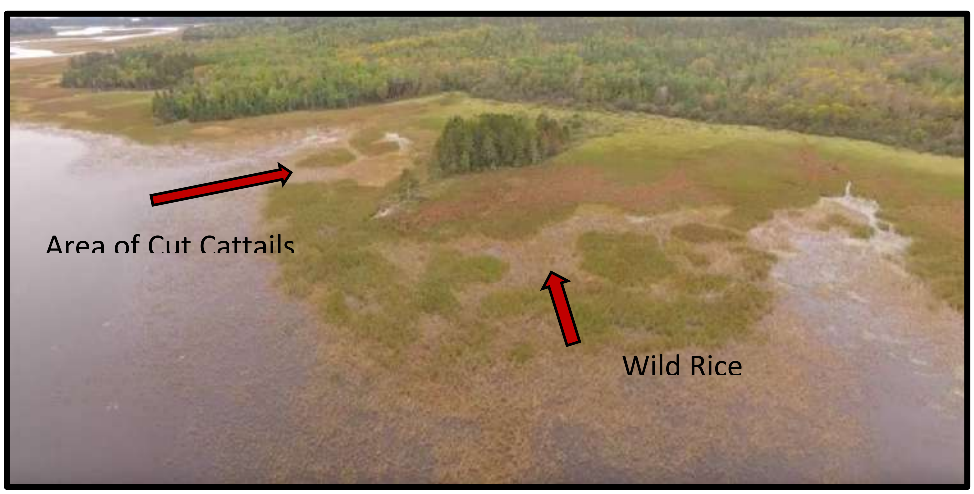


Figure 2. Aerial view of portion of Rat River Bay in fall, 2015. The dark areas are cattails. The arrow indicates the cut area shown in Fig. 25.

Table 1. Average measured concentration of select characteristics in sediment samples obtained from the four study areas. First without having had cattails harvested (WRNC), and from an area having had cattails harvested during August 2014 (WRC), and a cattail dominated area (CT) all from transects in RRB and lastly a transect from a wild rice dominated area in Wild Potato; additional parameters summarized in **Table 2 and 3** below.

Description	Total Recoverable Calcium (ug/g)	Total Recoverable Copper (ug/g)	Total Recoverable Iron (ug/g)	Total Recoverable Potassium (ug/g)	Total Recoverable Magnesium (ug/g)	Total Recoverable Sodium (ug/g)	Total Recoverable Phosphorus (ug/g)	Total Recoverable Sulfur (ug/g)	Total Recoverable Silicon (ug/g)
WRWP40	6914.9	31.4	25226.5	1743.0	10606.6	3497.0	606.9	473.8	156.4
WRWP60	6865.6	30.9	25939.1	1683.9	9750.9	3213.8	594.7	432.3	192.8
WRWP80	8738.6	40.7	31578.5	2325.9	13051.1	4117.2	581.9	288.3	208.7
WRWP100	8197.6	42.3	31091.8	2244.3	12867.0	3373.0	594.0	324.3	179.8
WRNC40	8960.2	58.7	7540.6	515.3	2490.8	3440.7	1370.2	3095.3	163.1
WRNC60	8133.5	49.8	7016.1	498.2	2557.8	3048.0	1522.8	2992.7	220.9
WRNC70	8955.0	67.6	9868.1	956.9	4253.3	3338.3	1748.5	2462.3	210.2
WRNC80	8533.6	78.7	11827.8	1073.7	5091.9	3012.0	1500.0	2862.8	179.8
WRNC90	8509.9	68.4	9968.4	756.7	3757.5	3169.9	1821.5	2851.2	776.6
WRNC100	6824.4	73.3	11386.2	751.4	4542.5	3059.4	1097.1	1757.6	432.5
WRNC130	7183.4	47.5	21995.0	1476.3	8876.7	3522.3	824.6	1292.7	268.9
WRC 60	11463.1	48.4	6211.9	451.7	3277.1	3302.0	1892.6	3910.4	262.8
WRC 70	10173.0	48.2	9088.5	654.3	4792.0	2883.4	1555.7	3090.7	231.3
WRC 80	10663.5	62.7	10572.5	744.1	5580.7	2743.7	1520.5	2340.8	207.0
WRC 90	9405.9	62.9	12645.7	862.0	6489.4	2976.6	1305.5	1926.3	255.6
WRC 100	9599.2	65.8	16266.6	1040.8	7610.8	2850.9	997.6	1746.7	224.4
CT 60	8184.1	75.9	17096.2	823.5	6762.7	3372.7	729.2	1558.9	233.1
CT 70	11659.0	70.2	11394.7	800.2	6047.2	2921.4	1342.4	2792.8	190.2
CT 80	10375.1	79.5	12620.2	913.9	6395.9	3359.0	1094.7	2232.1	201.9
CT 90	9431.0	66.4	15753.8	1128.8	7769.3	3313.2	927.0	1709.8	214.6

Table 2. Average measured concentration of select characteristics in sediment samples obtained from the four study areas. First without having had cattails harvested (WRNC), and from an area having had cattails harvested during August 2014 (WRC), and a cattail dominated area (CT) all from transects in RRB and lastly a transect from a wild rice dominated area in Wild Potato.

Description	Ext. NH3+NH4 (µg / g)	Extractable N-NO3 (µg / g)	Extractable P (µg / g)	Total Carbon (%C)	Total Nitrogen (%N)	Total Organic Carbon (%C)	Bulk Density (g/cm^3)
WRWP40	0.5	0.4	0.2	3.3	0.3	3.1	0.7
WRWP60	1.4	0.4	0.2	3.1	0.2	3.0	0.6
WRWP80	1.3	0.2	0.0	2.3	0.2	2.2	0.8
WRWP100	0.9	1.2	0.1	2.5	0.2	2.4	0.7
WRNC40	1.6	0.3	0.3	29.5	2.4	28.2	0.2
WRNC60	3.4	0.8	5.7	28.6	2.3	27.3	0.2
WRNC70	1.6	3.9	13.6	20.5	1.8	19.9	0.2
WRNC80	1.5	1.7	14.1	20.4	1.8	19.4	0.2
WRNC90	2.0	1.3	11.3	23.8	2.0	22.8	0.2
WRNC100	2.1	0.4	5.5	15.2	1.3	14.7	0.4
WRNC130	4.0	0.4	7.3	8.5	0.8	8.2	0.4
WRC 60	1.0	0.4	13.3	32.6	2.7	30.5	0.1
WRC 70	0.4	1.9	14.6	25.0	2.1	23.6	0.1
WRC 80	0.5	0.7	20.8	19.1	1.7	18.0	0.2
WRC 90	1.0	0.5	12.6	16.2	1.4	15.5	0.3
WRC 100	0.6	1.2	5.4	14.1	1.2	13.2	0.3
CT 60	1.1	0.2	5.9	13.3	1.0	12.3	0.3
CT 70	0.9	0.2	12.7	21.6	1.9	20.6	0.2
CT 80	0.3	0.5	9.3	17.4	1.5	16.6	0.2
CT 90	0.3	2.6	3.4	13.4	1.1	12.9	0.3

Table 3. Average measured concentration of select characteristics in sediment samples obtained from the four study areas. First without having had cattails harvested (WRNC), and from an area having had cattails harvested during August 2014 (WRC), and a cattail dominated area (CT) all from transects in RRB and lastly a transect from a wild rice dominated area in Wild Potato.

Description	Extraactable Ca (ug/g)	Extractable K (ug/g)	Extractable Mg (ug/g)	Extractable Na(ug/g)	Extractable Cu (ug/g)	Etractable Fe (ug/g)	Extractable Mn (ug/g)	Extractable Zn (ug/g)
WRWP40	1100.8	24.3	269.5	17.8	3.0	149.0	35.6	3.5
WRWP60	1131.3	22.5	266.1	13.2	3.3	163.3	40.6	3.5
WRWP80	1460.0	40.3	362.6	26.7	3.8	252.4	107.5	2.9
WRWP100	1482.2	43.9	353.1	35.0	4.1	236.3	105.3	3.4
WRNC40	716.0	5.3	183.0	8.3	0.7	69.6	19.6	0.3
WRNC60	723.5	3.4	178.6	5.3	1.1	54.8	13.4	0.3
WRNC70	791.8	4.2	219.4	2.8	1.1	32.2	5.0	1.0
WRNC80	646.0	3.0	165.4	1.7	0.9	37.7	3.2	2.4
WRNC90	925.7	4.0	239.8	3.4	1.8	65.9	10.1	0.4
WRNC100	899.2	6.9	262.6	3.3	2.4	79.4	14.8	0.5
WRNC130	1018.3	14.7	330.4	2.7	1.6	93.8	9.2	2.0
WRC 60	772.2	2.9	163.1	1.3	0.8	34.5	6.1	0.6
WRC 70	892.4	4.5	215.0	2.6	1.0	34.4	6.0	0.5
WRC 80	1076.7	7.6	277.6	2.7	1.5	39.0	6.6	0.8
WRC 90	1177.5	7.1	346.5	2.7	1.7	73.9	7.7	0.8
WRC 100	1196.9	7.3	369.7	3.6	2.0	80.4	11.1	1.5
CT 60	1175.1	13.9	269.2	52.6	2.8	212.9	16.8	1.3
CT 70	933.2	4.9	225.2	1.6	1.6	61.1	5.9	0.9
CT 80	1147.9	7.9	302.1	3.2	2.2	51.5	5.8	1.3
CT 90	1343.9	13.6	398.7	2.8	2.5	48.0	9.1	1.5

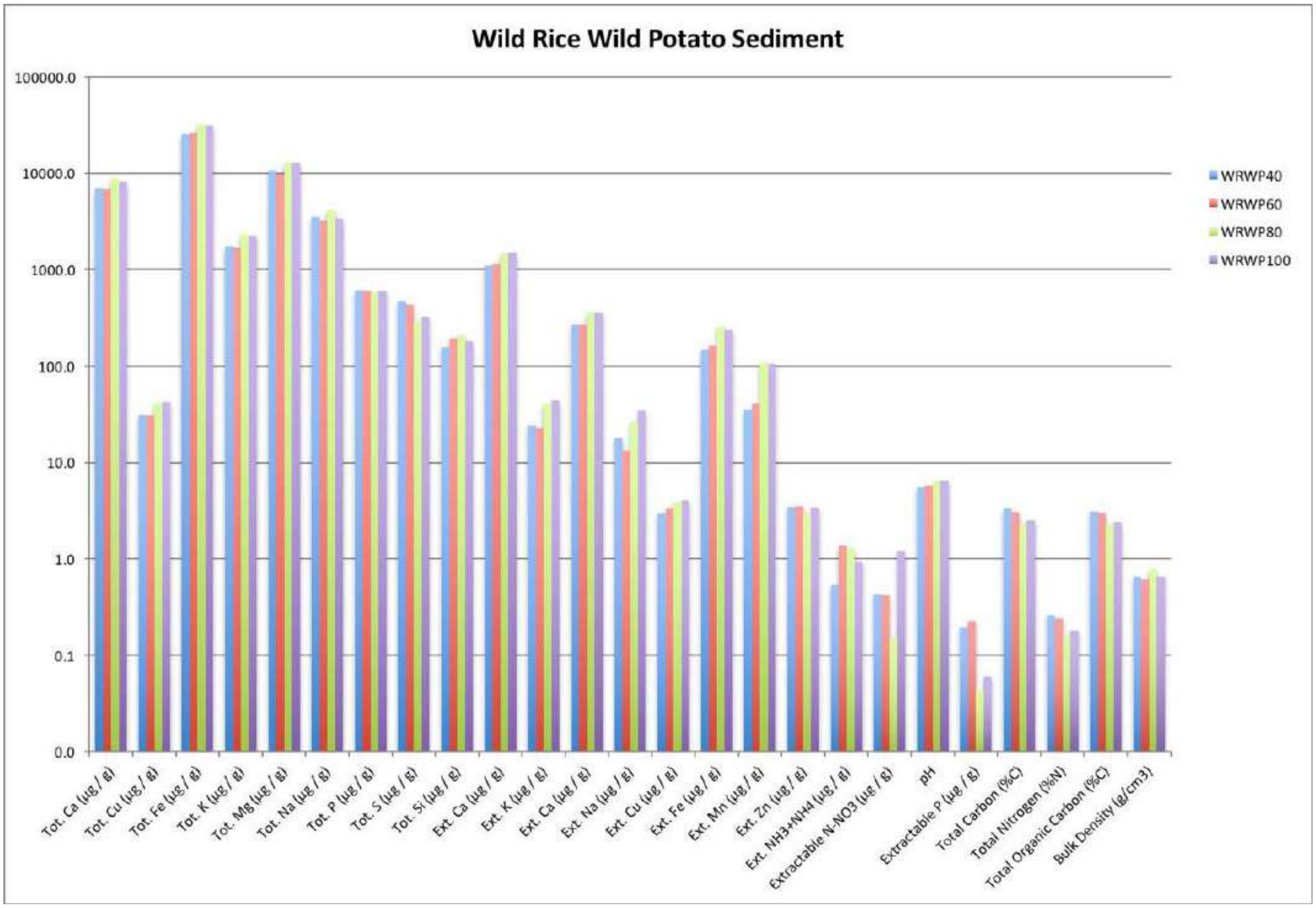


Figure 3. Average measured concentration of select characteristics in sediment samples obtained from transects in a wild rice dominated area of Wild Potato at four water depths (40, 60, 80, and 100 cm)

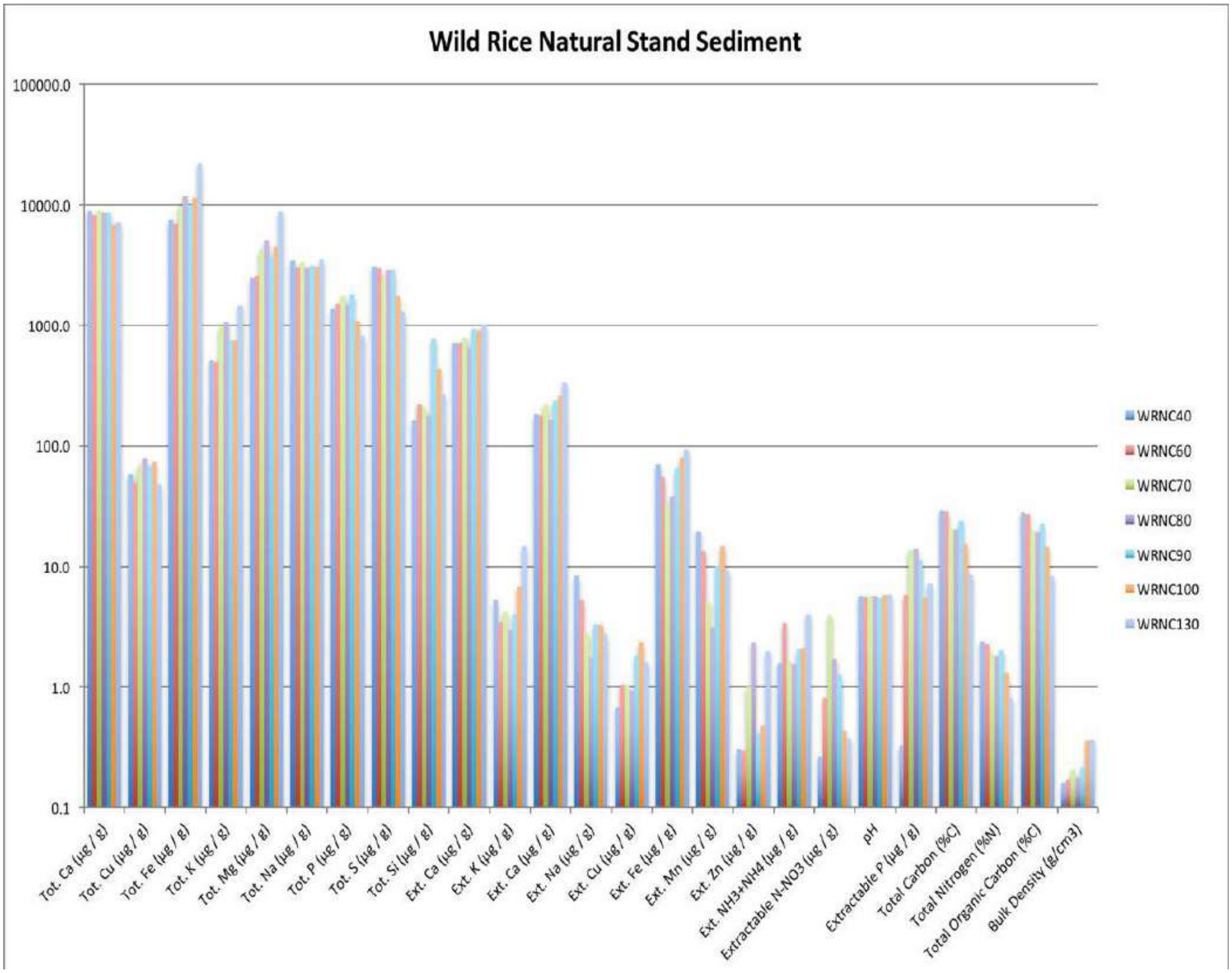


Figure 4. Average measured concentration of select characteristics in sediment samples obtained from transects in a wild rice dominated area of Rat River Bay at seven water depths (40, 60, 70, 80, 90, 100 and 130 cm)

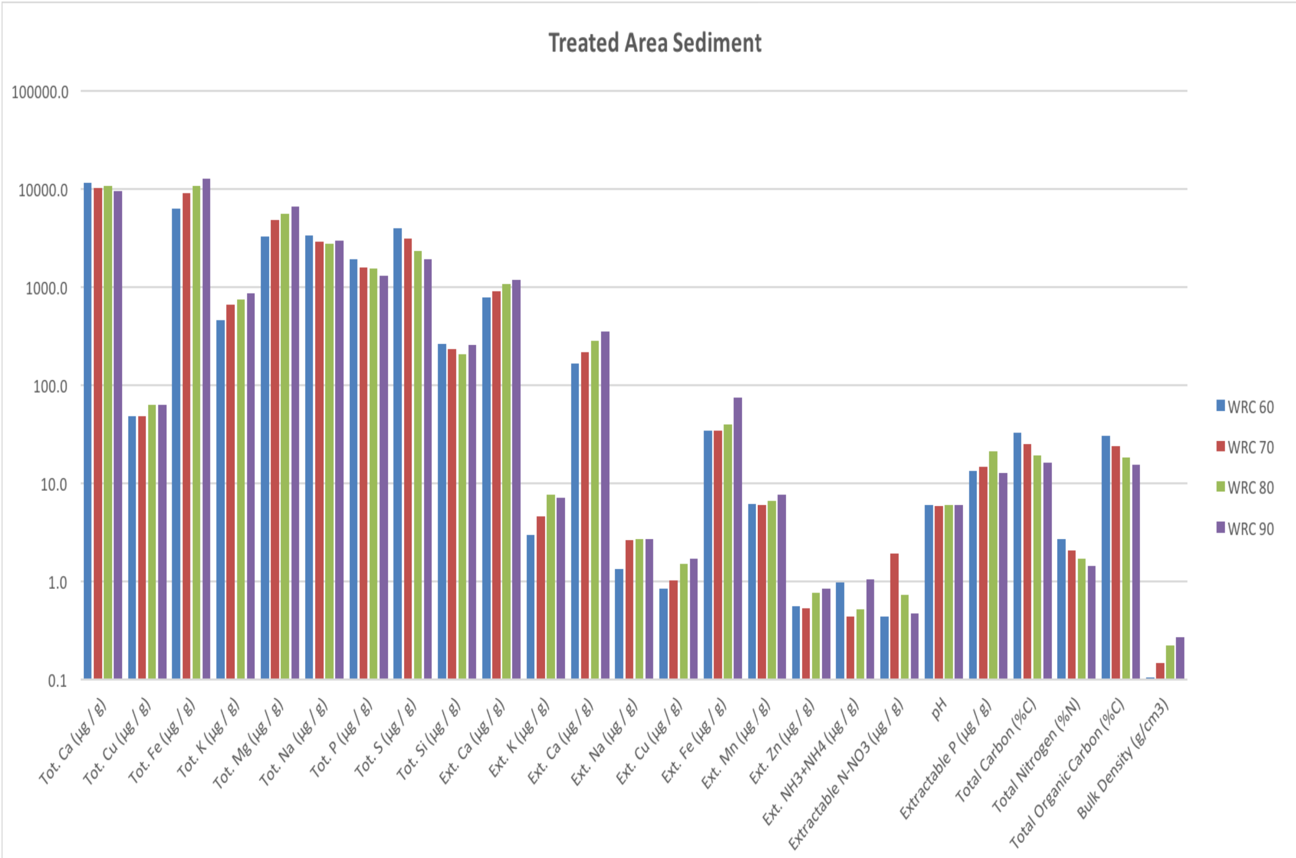


Figure 5. Average measured concentration of select characteristics in sediment samples obtained from transects in a previously cattail dominated area which was cut (treated) in August 2014 and currently wild rice dominated at four water depths (40, 60, 80, and 100 cm) in RRB

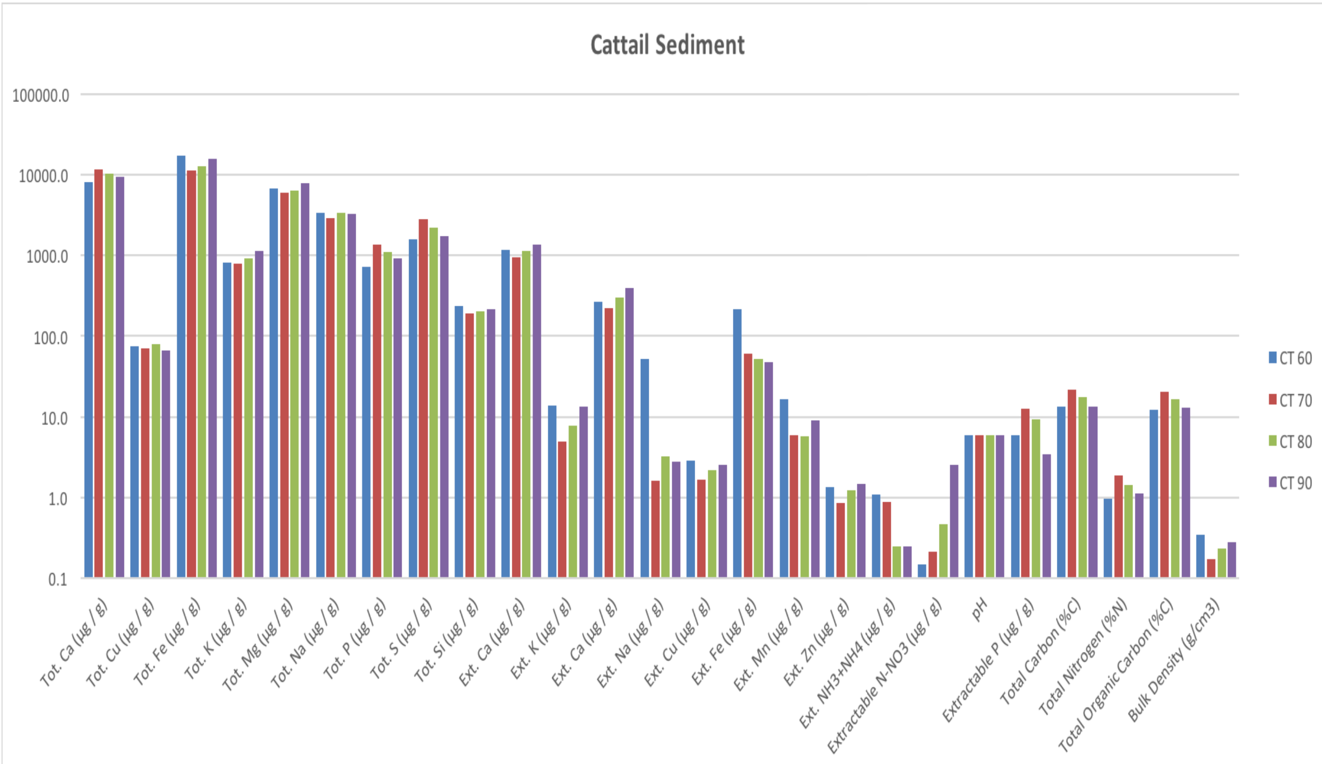


Figure 6. Average measured concentration of select characteristics in sediment samples obtained from transects in a cattail dominated area in RRB at four water depths (60, 70, 80, and 90 cm)

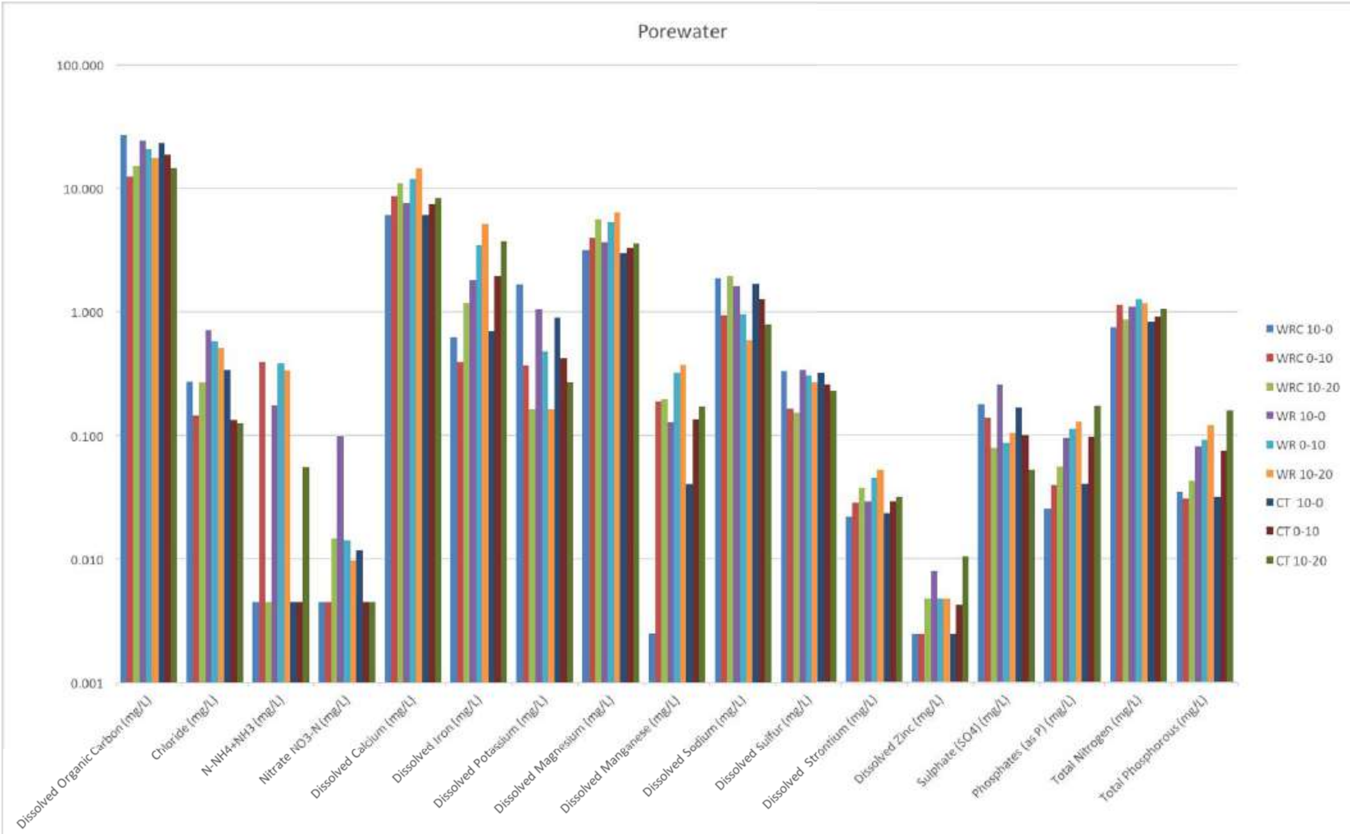


Figure 7. Average measured concentrations of select characteristics in porewater samples

Figure 8. Averaged measured concentrations of a) Nitrate b) Ammonium c) Total Nitrogen of pore water