<u>Examination of Comparative Manual Removal Strategies for Non-Chemical Control of Invasive Non-Native *Phragmites australis subsp. australis*: PHASE II</u>

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Research Site – June 9, 2017

Research Site – July 20, 2017 – Note Great Blue Heron visitor!

Introduction

Species Taxonomy and Distribution

Known as European Common Reed, or simply Phragmites, *Phragmites australis* is a perennial wetland grass in the Arundinoideae subfamily (which includes reeds and canes). As a species, *Phragmites australis* is distributed throughout the world in temperate and subtropical wetlands (Haslam 1972).

Invasive Phragmites -Lineage and History of Invasion

Invasive Phragmites is an extraordinarily prolific haplotype of the European subspecies *Phragmites australis* subsp*. australis.* This haplotype, identified as Haplotype M, and hereafter referred to as Invasive Phragmites, was accidentally introduced to Eastern North America near the turn of the last century (Saltonstall 2002). It persisted in small, isolated populations in the Northeastern United States, and in Southeastern Canada, along the St. Lawrence Seaway, for most of the 20th century. However, about 40 years ago, Invasive Phragmites began spreading aggressively north and westward out of its historically documented range (Catling and Mitrow 2011).

Currently, Invasive Phragmites is found as far west as Manitoba, with isolated populations further west, and as far North as Sudbury, Ontario (Catling and Mitrow 2011). Populations are recorded throughout the Great Lakes Basin, and are known to be encroaching on ecologically sensitive wetlands (OMNR 2011). It is predicted to continue spreading west and north throughout Canada (Catling and Mitrow 2011). The aggressive spread of Invasive Phragmites across Canada and the damage it causes to native wetlands, has led Agriculture and Agri-Food Canada to name it 'Canada's Worst Invasive Species' (Catling and Carbyn 2006).

Colonization and Dispersal

Once Invasive Phragmites arrives in a new area, it displaces native and naturalized wetland communities, and forms clonal stands composed exclusively of Invasive Phragmites. These stands can cover several square kilometres (OMNR 2011). Invasive Phragmites has a high degree of phenotypic and genotypic plasticity, giving it a broad range of tolerances for environmental conditions (Haslam 1972). This allows it to establish successfully on lake and stream margins, water meadows and seasonally flooded lands, as well as freshwater and brackish wetlands and estuaries (Marks and Lapin 1994). Perhaps most critically, Invasive Phragmites has demonstrated a strong affinity for urban stormwater catchments, and agricultural runoff and irrigation ditches. Encroachment of Invasive Phragmites into a previously unaffected area typically begins in places with high levels of human disturbance. It often establishes populations on roadsides, and from there invades less disturbed sites (Catling and Carbyn 2006).

The success of Invasive Phragmites is greatly facilitated by human activity. Distribution of seeds and viable rhizome fragments occurs when the stands are damaged or disturbed from road maintenance and construction or agricultural activities, and then dispersed along roads, railways, and waterways (Brisson et al. 2006). The plant also gains a significant competitive advantage from the use of road salts, which has a twofold effect: the waterway becomes inhospitably saline for native freshwater plants, and the increased acidity of water is favourable for Invasive Phragmites (Catling and Carbyn 2006). Additionally, the high concentration of nitrogen in agricultural and urban runoff also benefits Invasive Phragmites by providing the plant with a surplus of a normally limiting nutrient (Ravit *et al*. 2007). Increased average annual temperatures, and changes in precipitation patterns in the impacted regions are also thought to be facilitating its spread (Guo *et al*. 2013).

Relevant Biology

Invasive Phragmites is best understood as a perennial grass where the majority of its mass, upwards of 80%, is located underground (Hazelton *et al.* 2014). That is, the sight of a stand that extends over kilometres, bearing stalks 4 metres high and laden with seed heads, represents less than one quarter of the whole plant. The largest part of the plant is its extensive network of rhizomes- underground stems- that extend both horizontally and vertically through the soil. Rhizomes account for between 60% and 80% of the plant's total biomass (Cross and Fleming, Granholm and Chester 1994).

Rhizomes

The rhizomes, together with the roots, make-up the perennial tissues of Invasive Phragmites. Rhizomes are the functional and structural core of the plant. They are responsible for the storage of food reserves and hormones, as well as the development and support of shoots and roots (Klimeš *et al.*1999). Rhizome growth into new territory is also the primary means by which Invasive Phragmites propagates itself (Marks *et al* 1993).

The rhizomes of Invasive Phragmites are thick-walled, mostly hollow stems, although they may be solid at the nodes. Each node on the rhizome possesses at least two auxiliary buds, capable of producing shoots, roots, or more rhizomes (Haslam 1972). Rhizome segments with two or more nodes are capable of surviving separation from the parent plant and can, over time, propagate a new stand (Marks *et al* 1993). Under ideal growing conditions, rhizomes can grow more than 10 metres horizontally each year, and may grow down to depths greater than a metre (Mal and Narine 2004). Under these growing conditions, a single 'plant', more properly called a genet, and consisting of the parent plant and its clonal offspring, may grow to cover areas as great as 1.0 km^2 (Marks *et al* 1993). The parent and offspring remain connected by the rhizomes, allowing them to share and direct resources to optimize the competitiveness of the stand. While individual segments of rhizomes may live 5 years on average, the entire plant may live for decades. Collectively, clonal stands, composed of many genets, may cover several square kilometres (Cross and Fleming 1989).

Rhizome samples taken from research site

Shoots, Flowers and Seeds

The shoots of Invasive Phragmites are produced annually, emerging early in the spring, and remain photosynthetically active until late October or early November. Under ideal conditions, shoots may grow at a rate of 4cm/day and reach heights in excess of 4 metres (Mal and Narine 2004). Early spring shoots emerge from buds that were developed at the tips of rhizomes over the course of the previous year. These shoots are typically large in diameter. Once these shoots emerge the node at the base of each shoot will direct resources to the development of several smaller lateral buds. These buds, called 'spring-formed' buds remain dormant unless the initial shoot is damaged. The shoots of spring-formed buds are typically smaller than the shoot from the initial bud, but are more numerous (Cross and Fleming 1989).

Flowering occurs late in the summer. On mature stands, generally less than 50% of the stalks will produce flowers. The flowers are borne on panicles that are typically 20 cm long or more (Haslam 1972). Seeds mature throughout the fall. In favourable conditions, each flowerhead will produce 2000+ seeds. However, the seed viability is typically quite low: often less than 5% of the seeds produced will be capable of germinating (Granholm and Chester 1994). Seed viability varies greatly depending on the growing conditions throughout the season (Cross and Fleming 1989).

Rhizome growth occurs throughout the growing season, but peaks in May through August (Aseada *et al* 2006). Following flowering a greater proportion of the plant resources are dedicated to expansion at the edges of the stand. Overwintering buds are also formed at this time (Marks *et al*. 1993). Rhizome resources are depleted throughout the winter and into the early spring (Aseada *et al* 2006).

Seed head found in water on site in early spring
Phragmites seedlings growing in the wet plant material

Snorkeling

At the end of the growing season, the shoots die back. Often, dead stalks will shed their leaves, but remain erect (Mal and Narine 2004). These stalks will continue standing throughout the winter and subsequent growing season, and remain connected to the rhizome for as long as it remains standing. The presence of these stalks is thought to help the plant to transport oxygen throughout its underground tissues, in a process known as pressurized ventilation, or snorkeling. In this process, the influx of oxygen into the rhizomes from photosynthetic tissues causes a pressure gradient to form, wherein the gas pressure within the rhizomes is greater than that of the atmospheric pressure. Since the dead, hollow stalks are both connected to the rhizomes, and open to the air above ground, they act as a conduit for allowing air to the escape from the rhizomes, thus allowing the influx of oxygen to continue (Vretare and Weisner 2007). Without this mechanism, gas exchange in underground tissues is restricted to diffusion from the roots and rhizomes to the soil, which happens at a much slower rate. As a result, wetland plants that use pressurized ventilation have significantly higher oxygen levels in their underground tissues (310g of O_2/m^2/day) than plants that do not (10g O_2/m^2/day) (Mal and Narine 2004). This process increases the metabolic activity of the underground tissues, and supports the production of underground biomass.

Environmental Factors
In its native range, Invasive Phragmites is most significantly limited by the availability of nitrogen in its habitat (Modzer and Zieman 2010). Thus, its invasive spread in North America has been linked, in part, to the widespread use of fertilizers in agricultural systems, which has greatly increased the concentrations of nitrogen in surrounding waters and soils (Ravit *et al.* 2007).
Given sufficient nitrogen and sunlight, Invasive Phragmites is capable of photosynthesis at a rate that is two times greater than that seen in native Phragmites (Modzer and Zieman 2010). As a result of this significant advantage, invasive Phragmites is capable of acclimating or adapting to a wide range of environmental conditions.

Substrate Tolerances
Invasive Phragmites is able to acclimate and adapt to an enormous range of substrate conditions. Typically, young shoots are most vulnerable to damage from unusually harsh conditions, with tolerance increasing as the stand matures. Invasive Phragmites will tolerate periodically dry soils, as well as standing water as deep as 1 m (Tilley and St. John 2012). Its salinity tolerance ranges from freshwater to brackish water with salt contents as high as 4%. Most seedlings, however, will fail to germinate in soils with a salinity greater than 2%. (Marks at al. 1994). The plant favours acid soils, and has been found to be growing, in stunted form, on Acid Mine Tailings with a pH of 2.9 (Mal and Narine 2004). Most commonly, however, healthy stands are found in substrates with a pH range of 3.7, up to 8.7 (Tilley and St. John 2012). It is found in substrates with organic matter contents ranging from 3-97% (Haslam 1972).

Climatic Tolerances
On its native range, it is found from sea level up to altitudes as high as 3000m (Haslam 1972). Globally, it is found in temperate regions from the equator as far as 70^{o} north, and as far south as New Zealand (Haslam 1972, Mal and Narine 2004).

Disturbance and Stress Tolerances
Invasive Phragmites is also well-adapted to survive seasonal disturbances and poor growing conditions. Plants regenerate readily following early spring frosts, floods and fires (Hazelton 2014). Damage done to the winter-formed buds stimulates the development of the otherwise dormant spring-formed buds, often resulting in increased shoot density for the stand. In the case of drought, root systems can penetrate to a depth of 3m, allowing stands to survive conditions that kill most other wetland plants (Marks et al 1993). Alternatively, in standing water and waterlogged soils, the plant will produce specialized ‘water roots’ that grow at the surface of the water to prevent the roots from suffocating (Haslam 1972). Additionally, the increased airflow through the rhizomes from snorkeling, allows the plant to survive low-oxygen, or anoxic soils. In the case of soil disturbance, even small fragments of rhizomes are capable of regeneration (Cross and Fleming 1989).

Competition with other Plants
Invasive Phragmites moving into an area will outcompete and displace both native Phragmites (*Phragmites australis* subsp. *americanus*) and other native or naturalized

wetland plants (Saltonstall 2002). In most cases, the establishment of a colony of Invasive Phragmites will result in the total loss of all other plant species within the stand (Marks *et al* 1993). It has even been observed to displace other invasive plants, such as the narrow-leaf cattail (*Typha angustifolia*) (Chun and Choi 2009).

The success of Invasive Phragmites over its native counterparts appears to be due to several subtle differences in its physiology, all of which combine to greatly enhance its photosynthetic capacity. The photosynthetic tissues of Invasive Phragmites contain, on average, twice the amount of chlorophyll than that found in Native Phragmites. In addition to this, the rate of photosynthesis in the tissues of Invasive Phragmites remains constant throughout the growing season. By contrast, the rate of photosynthesis in Native Phragmites varies over the course of the growing season, beginning slowly and peaking in the late summer (Ravit *et al.* 2007). Finally, the growing season of Invasive Phragmites is itself about two months longer than that of Native Phragmites, as the shoots of Invasive Phragmites emerge earlier in the spring, and remain active later into the fall (Saltonstall 2002). Collectively, these adaptations, allow Invasive Phragmites to accumulate biomass at a greater rate than other wetland plants.

This capacity to rapidly produce a tall, dense canopy, and its robust expansion of underground tissues allows Invasive Phragmites to suppress the growth of others. This is the plant's *competitive effect*- a predictable measure of a given plant's likelihood of dominating its niche, based on its biomass, and canopy height and density (Keddy *et al*. 1998). Invasive Phragmites' competitive effect can be observed in Chun and Choi's 2009 study of the plant's movement into an Invasive Cattail wetland. Their study found that, while the productivity of both competitors was reduced where they shared a space, the Invasive Cattail was far more greatly affected- the total biomass for Invasive Cattail was 82% lower in mixed stands than in pure Cattail stands, whereas the total biomass for Invasive Phragmites was only 34% lower. Invasive Phragmites also maintained greater shoot densities and shoot height in the mixed stands. From these findings, Chun and Choi predicted that the Invasive Cattail would eventually be replaced by Invasive Phragmites.

Once established, an invasive Phragmites stand is extremely inhospitable to other species of wetland plants. Dead leaves and stalks create a persistent, impenetrable thatch that suppresses the seeds and shoots of others plants (Marks et al 1993). Emerging shoots of Phragmites itself are rigid and sharply pointed, allowing them to pierce the thatch. Mature shoots are tall enough and dense enough that they shade out any undergrowth (Chun and Choi 2009). Large stands can extend for kilometres, and can alter the local water table and water chemistry, reinforcing the dominance of the Invasive Phragmites (Cross and Fleming 1989). In addition to these factors, Invasive Phragmites also appears to have some allelopathic capacity (Rudrappa *et al* 2007), although the exact nature and effectiveness is not yet fully understood (Uddin and Robinson 2017).

As an additional advantage, the near total absence of any natural predators or pests on Invasive Phragmites may also be enabling its dominance over native wetland plants (Blossey and Nötzvold 1995). In its native range, more than 170 species are known to feed on Phragmites. In North America, only 26 species have been recorded feeding on Invasive Phragmites, of which only five are native species (Tewksbury *et al*. 2002).

Currently, no single predator reduces Invasive Phragmites stands for any significant length of time. As a result, it is able to expand unchecked (Cross and Fleming 1989).

Impacts:

A) On The Water Cycle

On a broad scale, Invasive Phragmites can alter the water cycle in a watershed. The plant's high productivity requires high transpiration rates, and thus the plant draws more water out of the system than other plant communities would (Marks *et al* 1993). This increased demand in water can also change the level of the water table. On shallow wetlands, dense underground growth can support the buildup of sediments, which will eventually cause the wetland to fill in. This dense growth may also block channels, slowing or diverting stormwater runoff, causing increased risk of flooding in some areas, and effecting the recharge rate of groundwater in others (Cross and Fleming 1989, Catling and Carbyn 2006).

B) On Plant Species

The displacement of native plants caused by invasive Phragmites, may be putting many at risk of extirpation or even extinction. It is believed that several native haplotypes of Phragmites have already been lost (Saltonstall 2002).

C) On Wildlife

Incursion into native or naturalized wetlands by Invasive Phragmites generally heralds a decline in biodiversity (Mal and Narine 2004). The plant is not regularly used as food or as nesting sites by any native North American wildlife (Cross and Fleming 1989). The density of these stands can make them impassable for wildlife, resulting in significant loss of habitat for mammals, birds, turtles and amphibians, fish and invertebrates (Marks et al. 1993). As it primarily colonizes the margins of waterbodies, it is especially harmful to animals that rely on the shallow water and shoreline for feeding, nesting or egg-laying sites. The destruction of this niche by Invasive Phragmites can have a wide-ranging impact on the food web by causing a collapse of the populations of the insects and vertebrates that are reliant on the shallow water zones (Ailstock *et al.* 2001). Invasive Phragmites is also of significant concern in migratory corridors, where the loss of habitat in a small area may have an amplified negative impact on the birds or animals relying on the habitat as a resting site (Cross and Fleming 1989).

D) On Humans

Stands of Phragmites may be a nuisance in many developed areas, as it blocks access to waterfronts, clogs waterways and invades naturalized and recreational lands. Its presence on roadsides can affect visibility. Dead standing stalks and the build-up of thatch also increases the risk of fire (Hazelton *et al.* 2014). Public Health Units have expressed concerns that the stands are too impenetrable to be effectively treated for mosquitoes, and that this may allow potential populations of disease-carrying mosquitoes to grow unchecked. In agriculture, there is great concern that its spread into the Prairie Provinces may pose a significant threat of invading and displacing cash crops in low-lying croplands, and that its presence may block run-off ditches and irrigation channels (Christie 2014).

Culturally, the displacement of native ecosystems may result in the loss of traditional fishing and hunting grounds, migratory pathways, as well as the loss of native plants that may have dietary, medicinal or cultural value (Cross and Fleming 1989).

Management of Invasive Phragmites

The scope of Invasive Phragmites often makes its management a community concern. It spreads readily between public and private lands, without regard for boundaries, and it is easily introduced into new areas. In areas where control has been attempted, incomplete removal often permits stands to regenerate from remnant populations (Mal and Narine 2004). For these reasons, any management plan for Invasive Phragmites must be comprehensive in including all affected areas, must be coordinated among all affected community members, and must be on-going.

Complete eradication of Invasive Phragmites requires the killing or physical removal of all the rhizomes in the stand. Often, eradication is not feasible as the impacted area may be too large, or too topographically varied, for complete removal to work. The size of many stands may also make total removal prohibitively expensive (Marks *et al* 1993). Intensive removal methods may also damage or destroy non-target species. In addition, complete eradication often comes at the cost of a high degree of environmental disturbance (Granholm and Chester 1994).

Current management plans for the control of Invasive Phragmites rarely include eradication, but rather seek to reduce the competitive effect of the plant to the point that other wetland plants are able to reestablish in the affected area. A management plan may be considered successful when the community diversity and richness of the impacted areas have returned to pre-disturbance levels. For some projects, success may mean that the wetland is restored to its native state. For other projects, especially those in urban areas, successful recovery may mean that desired ecosystem functions are restored, although the post-recovery plant community may be composed of introduced species. Once an area has been restored, ongoing monitoring and management is essential to prevent Invasive Phragmites from re-establishing on the site (Marks *et al* 1993, Cross and Fleming 1989).

Current Methods of Control:

1) **Mechanical Removal Methods**

Mechanical methods of control seek to reduce the competitive effect Invasive Phragmites, through the direct removal or suppression of plant biomass. There are a large number of methods that can be employed, but they can all be broadly broken down into two categories: methods that target the above-ground shoots' biomass, and methods that target the underground biomass.

Shoot-focused control reduces or removes the shoots in the stand, with the aim of reducing the productivity of the stand, and opening the canopy up enough for other plants to be able to reestablish in the impacted area. These methods include: mowing and cutting, tarping, flooding and burning (Cross and Fleming 1989).

Mowing and cutting are perhaps the simplest methods of controlling Invasive Phragmites. Both methods need to be repeated over the course of the growing season, as the initial removal of shoots stimulates the development of secondary shoots (Granholm and Chester 1994). Mowing and cutting do result in an increase in plant community diversity (Marks *et al*. 1993), but do little to reduce the overall vigour of the stand. These methods will need to be employed for multiple growing seasons before a reduction in stand size and productivity occurs (Cross and Fleming 1989).

Tarping, flooding and burning all seek to reduce the competitive effect of Invasive Phragmites by the total suppression of the shoots. In tarping, the stand is covered, early in the season with a heavy black plastic that prevents the shoots from growing. In addition, heat absorbed by the black plastic ‘cooks’ the shoots over the course of the growing season. Flooding is undertaken very early in the spring, and works by drowning the emerging shoots. Effective control by flooding is difficult. A water depth of at least 1m above the rhizomes must be maintained for several weeks in order to kill the nascent shoots, and flooding must be undertaken at the correct time, as after the shoots are established they become less vulnerable to high water levels (Marks *et al* 1994). Controlled burns may also be an effective management method, but again, timing must be precise to avoid stimulating secondary shoot development (Cross and Fleming 1989).

With the exception of hand-cutting individual stalks, all of these methods have a very broad impact. All species of plants growing within the impacted area is likely to be suppressed or killed off by these methods.

Underground-focused mechanical methods include disc-harrowing and digging. Disc-harrowing breaks up the roots and rhizomes in the soil using a tilling machine. Marks *et al* (1993) recommend waiting until late fall to harrow the stand, so that exposed rhizomes may freeze or dry out before they can reestablish themselves. Digging entails the complete removal of the roots and rhizomes from the soil, and can be done either using hand tools or heavy equipment, depending on the size of the impacted area (Granholm and Chester 1994).

Attempts to remove the plants through digging out the rhizomes can be prohibitively expensive, and again, if the entire plant is not removed may encourage renewed growth. Similarly, breaking up stands through harrowing or trenching the stand can increase the dispersal of viable rhizomes (Hazelton et al 2014). In both cases, large-scale disturbances of the soil may be untenable.

2) Removal of Thatch

Removal of thatch is a method that can be incorporated into other control methods, and is simply done by raking up fallen plant matter. Phragmites suppresses the seeds and shoots of other plants through the buildup of thatch into an impenetrable mat. The removal of thatch allows these seeds and shoots to develop (Mal and Narine 2004). Care is needed in the disposal of the thatch, as it may contain viable Invasive Phragmites seeds and living plant matter that could then be dispersed into new areas.

3) Chemical Application

Glyphosate, and imazapyr are proven to be effective chemical controls for Invasive Phragmites (OMNR 2011). Treatments may be applied through broadcast methods, such as aerial spraying, or the chemicals may be applied directly to the plants. It is recommended that chemical treatments follow cutting or mowing of the stand, so that the stalks are more receptive to the application of the chemicals (Hazelton *et al*. 2004).

The use of chemical controls however, is stringently regulated in North America. In Ontario, for example, the use of herbicides over wetlands and open water is not permitted except under extraordinary circumstances (OMNR 2011). As all these herbicides are broad-spectrum, they will also effect non-targeted plant species, so their use in ecologically sensitive areas is discouraged. In addition, a recent increase in public concern about the long-term effects of these chemicals may make their use undesirable, especially when the management plan is a community-based initiative (Cross and Fleming 1989).

4) Biological Control

Currently, Invasive Phragmites has few predators in North America. 26 species of insects have been found feeding on Invasive Phragmites, but of these, only three species are known to use Phragmites as a primary food source (Tewksbury *et al*. 2001). Two predators, a stem-boring moth and a rhizome-boring moth have been found to have a modest impact on stand densities, which can be reduced by up to 20% (Marks *et al* 1993). Additionally, the rhizome-boring moth, *Rhizedra luteosa*, appears to limit the expansion of Phragmites stands, by targeting new rhizome growth. Tewksbury *et al*. (2001) suggest that a larger suite of predator insects, all of which target different parts of the plant, could be introduced into North American wetlands as an effective form of biological control. There are significant concerns, however, that the introduced predators may spread to Native Phragmites, which may cause a further decline of their already vulnerable populations (Cronin *et al* 2016) .

Rationale for this Research

An Alternate Mechanical Control Method: Spading

The methods for controlling Phragmites that are currently in use are non-specific. Removal of Phragmites by the above mentioned methods does not preserve the biodiversity of other desirable plant species present. Those methods remove all plant material.

We propose the use of an innovative spading technique to effectively control Invasive Phragmites. This method has been employed for several years on Wymbolwood Beach in Tiny Township, Ontario to control Phragmites infestations on private property along the beachfront.

Use of this technique has numerous advantages over traditional control methods. The tools are readily available to the public. The technique is low-tech, and easily taught, and so can be implemented by most people. The disturbance to the soil, and surrounding wildlife is minimized, allowing for the fastest possible recovery of the site. This technique uses a sharpened spade to separate the shoot and its attendant buds from the rhizome. The shoot is then discarded, and the rhizome remains undisturbed in the soil. The plant is controlled through the attrition of its resources: the rhizome is deprived of photosynthetic products, and must use stored material to produce new shoots. In addition, the removal of both living and dead stalks deprives the underground tissues of the oxygen that is transferred from the shoots to the rhizomes and roots, creating further stress. It is believed that, by repeating this spade cutting of the shoot from the rhizome over the course of the growing season and for several seasons, the rhizome will eventually exhaust its resources and die off.

Spade Cut Technique Illustrated:

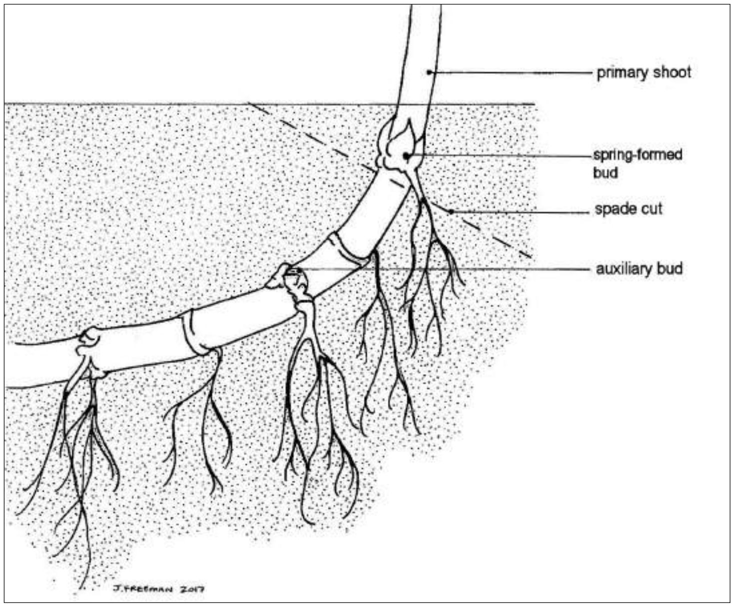


Figure 1. Initial Spade Cut. The initial cut is made at a roughly 45^{o} angle, to a minimum depth of 5cm. The aim of this cut is to sever both the primary shoot (the shoot that has emerged from the over-wintering bud) and its attendant spring-formed buds from the rhizome.
The removal of the primary shoot will stimulate the development of auxiliary buds into new shoots.
The loss of the photosynthetic capacity caused by the removal of the shoot, and the development of the new shoots will force the rhizome to expend some of its reserved resources.

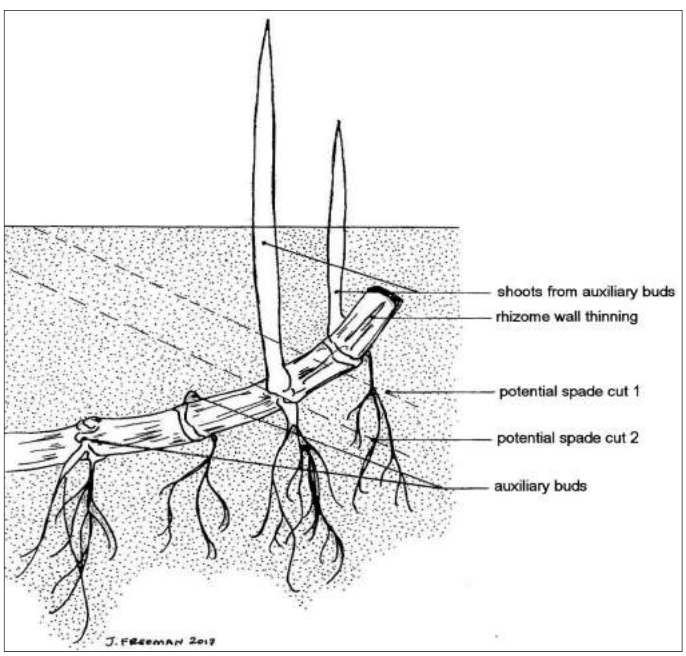


Figure 2. Second Spade Cut. The second spading period should be undertaken after the emergence of the shoots from the auxiliary buds. Again the cut is made at a roughly 45^{o} angle, at a minimum depth of

5cm.
The shoots emerging from these auxiliary buds will be notably thinner than the primary shoot, and may not attain the same height. These shoots will often be quite numerous, however.
Two potential spading cuts are shown in the illustration. If the cut is made to the shoot on the left first, both shoots will be removed at the same time. However, if the shoot on the right is removed first, a second cut will be need to remove the shoot on the left. The number of cuts needed will depend on the density of the shoots, and the position of the shoots on the rhizome.
A study of the rhizome segments removed during this spading period should show that the rhizome walls are thinner than they were prior to the first spading. In undisturbed stands, a rhizome typically expends up to 38% of its mass during the winter and early spring in the development of new shoots (Asaeda *et al* 2006). The removal of the shoots by spading is believed to place a similar stress on the rhizome.

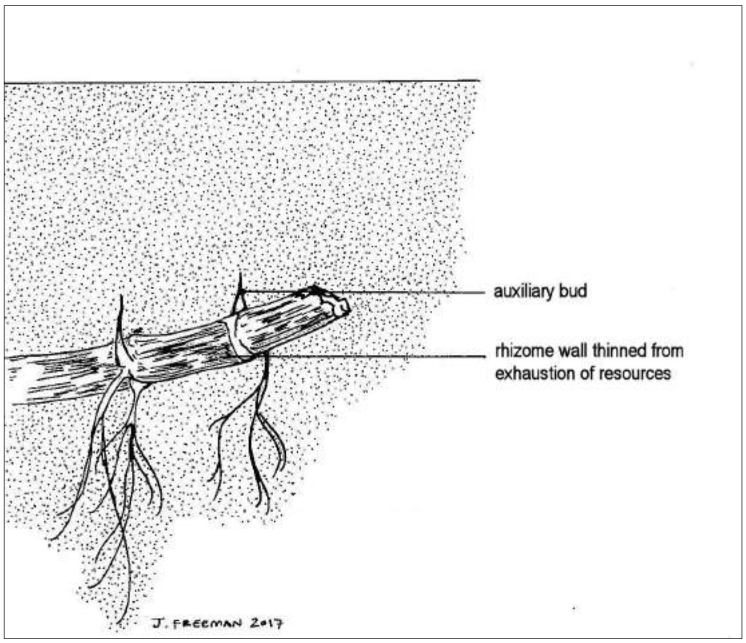


Figure 3. Shoots developing following the second spading.   Removal of the shoots during the second spading period will again stimulate the remaining auxiliary buds on the rhizome. The shoots developing from these buds will again be thinner and less robust than the primary shoot. The shoot density and vigour will depend on the reserved resources of the stand. A third spading period is required if these shoots emerge.
The rhizome will continue to be depleted of resources following each subsequent spading period. The ultimate aim of the spade cut technique is to completely exhaust the rhizomes' resources, causing the eventual death of the plant.


Rhizome with stalk attached

Procedure
Last spring (2016), a site was selected in Tiny Township at Wymbolwood Beach on the private property of Joanne Lelovic and Richard Weldon. The owners generously agreed to allow the research to occur on their property. The property has an unusual shape. It is triangular with the wide base of the triangle at the beach side. The property at the two extreme corners of the triangle are not in often in use. There is a dune at the beach edge with shrub willows present and Phragmites behind the willows. This site was selected on the basis that Phragmites was the dominant species present and there had not been any control methods applied to the site prior to this research project. The Phragmites had been growing undisturbed for at least ten years. The test site measured approximately 12.5 metres by 8 metres in size.
The owners generously gave permission for the property to be used for research again this summer (2017).

To prepare the site for the research project initially, the owners gave permission for the property management company to prepare the site. Peter Ford of Wysechoice Property Services directed the removal and disposal of last year's standing stalks. The stalks were very strong and had to be cut using a brush cutting saw. Once the stalks were removed from the site, the remaining thatch on the ground was raked away from the site using hard rakes by volunteers. This plant debris was raked to the edges of the site and packed in bags for the Township to pick up.

Last summer, the site was then divided into four test sections, side by side, measuring 2.5m by 8m. Tall wooden stakes were used to mark the corners of each section. Diagonals were calculated to ensure that the sections were square. Strings were used to define the boundaries of each section.

The test sections were identified as:
- Section 1 - the control that would remain undisturbed except for data collecting;
- Section 2 - the section where the stalks would be cut 5cm below the soil surface using a sharpened spade in July;
- Section 3 - the section where the stalks would be cut 5cm below the soil surface using a sharpened spade in July and August;
- Section 4 - the section where the stalks would be cut 5cm below the soil surface using a sharpened spade in June, July and August.

Within each test section, four plots, each measuring 1m x 1m and labelled A, B, C, and D, were staked out for data collection throughout the summer. Short wooden stakes and strings around the perimeter of each test plot were used to define the boundaries of these test plots. Each entire test section was treated according to our plan but only the four test plots were counted and measured for data collection. It was felt that it would be important to remove the Phragmites using the same protocol in the zones surrounding the measured test plots within each test section to minimize the influence of the treatments in the adjacent test sections and the surroundings areas.

This spring (2017), the few standing dead stalks were individually removed using secateurs to cut them at the soil surface. Missing stakes and strings were replaced in order that the test plots and sections were restored to their original positions. At this time, a composite soil sample was taken from the site. The soil sample was analyzed at Agrifood Laboratories in Guelph.

Prior to the initial data collection, core samples measuring 10cm x 10cm x 25cm deep containing rhizomes were taken from each test section (5 samples each). These samples were cut out using a pruning saw with a blade 25cm long. The core samples were levered out of the ground using a trenching shovel. The rhizomes were isolated from the core samples by rinsing them with water to remove the sand. The rhizome samples were collected from outside the four test plots but within the test section and in different locations from the samples taken last season. Each sample was bagged separately and labelled. They were kept cool and transported to Rebecca Rooney's Laboratory in the Biology 2 Building at the University of Waterloo for analysis.

At the end of the summer, when the removal of stalks and data collection were complete, five samples were taken from each test section in the same manner but in different locations than the samples had been taken previously. These samples were also brought to the University of Waterloo for analysis. The results of this analysis will not appear in this report.

One week before each cutting of the stalks was begun, the number of stalks, the height of the stalks and the diameter of the stalks were recorded in all test plots at both sites. On the same days that the density, heights and diameters of the Phragmites stalks were measured and recorded, numbers and identity of other plant species present in each test plot were recorded. It is important to note that the other plant species became established on their own as a result of the removal of the Phragmites, they were not planted there.

Each square metre was divided into four quadrats using dead Phragmites stalks cut into 1 metre lengths. This made it easier to count the stalks. All stalks were counted in each test plot. To measure the heights, a metre stick or tape measure was used, depending on the height of the stalk. The measuring device was placed beside the stalk touching the soil surface and the leaves of the plant were extended straight up beside the measuring device to determine the height to the tip of the leaves. The diameter of the stalks was measured at 5 cm above the soil surface using calipers. If there were more than 100 stalks/m^2, the stalks in the south and north quadrats of each test plot were measured for height and diameter.


Test Plot divided into 4 Quadrats   Measuring Stalk Heights


Data recorders for Control test plot height measurement
(note: volunteer in the tall stalks in photo on left)

Removal of the Phragmites stalks was done using a sharpened spade. In Test Sections 2, 3 & 4, on the scheduled dates, each individual stalk was cut at 5 centimetres below the soil surface using a sharpened spade. The spades were sharpened on a rotating grinding wheel to create a slight bevel on the front edge of the spade blade.


Volunteers removing Phragmites stalks using a sharpened spade

It is important to remember that the goal of this technique is to remove the Phragmites stalk but to avoid disturbing the surrounding soil or other nearby plants, if possible. The spade blade is placed a few centimeters away from the base of the Phragmites stalk and held at approximately a 45° angle. The foot is placed on the footrest of the blade and the leg is used to thrust the blade of the spade into the soil to cut the stalk below the soil surface. The stalks can then be easily removed from the soil. Sometimes the stalk is curved below the surface. In those instances, there will need to be adjustments in the angle or direction of approach in order to successfully cut the stalk. In situations where other plant species are present near the Phragmites stalks, it may be necessary to use just the corner of the blade rather than the entire width of the blade to remove an individual stalk. This minimizes the damage to the surrounding plants.

The schedule of rhizome sampling, stalk removal and data collection was as follows:

Date	Action Taken
May 5, 2017	Remove standing dead stalks, Replace missing stakes and strings, Obtain soil samples
May 19, 2017	Collect Rhizome Core Samples (20 samples)
May 26, 2017	Data Collection (density, heights and diameters, plant ID)
June 9, 2017	Data Collection (density, heights and diameters, plant ID)
June 16, 2017	Spade all stalks in Section 4
July 7, 2017	Data Collection (density, heights and diameters, plant ID)
July 14, 2017	Spade all stalks in Sections 2, 3 & 4
July 28, 2017	Data Collection (density, heights and diameters, plant ID)
August 4, 2017	Spade all stalks in Sections 3 & 4
August 18, 2017	Data Collection (density, heights and diameters, plant ID)
August 25, 2017	Collect Rhizome Core Samples (20 samples)
Sept 30, 2017	Observe Test Plots for formation of Flowerheads
Oct 20, 2017*	Spade removal of all living stalks in Test Sections 2,3, & 4

*NOTE: Based on observations at a site at a Toronto City Park Phragmites removal, a change in the procedure from last year was implemented in the fall of this year. All standing live stalks in Test Sections 2, 3 & 4 were spade removed on October 20, 2017 to test the effect on the spring regrowth (see discussion in Next Steps section).

Results

Soil Analysis:

The soil texture results were 97% sand, 2% silt and 1% clay, identifying this soil texture as a sandy soil. The soil pH was 7.7 and the organic matter present was 5.0%. This soil pH will support many different types of plant growth. The soil does not contain much organic matter which is typical of beach ecosystems.

Measurement Data Results

May 26, 2017

Test Section 1 - Control

Plot	A	B	C	D
Density (stalks/m^2)	46	61	94	88
Average Height (cm)	53.6	59.6	87.7	52.9
Average Diameter (cm)	0.55	0.63	0.72	0.56

Test Section 2 – Spade cut 5cm below soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	82	175	87	131
Average Height (cm)	58.7	54.8	61.5	54.6
Average Diameter (cm)	0.45	0.39	0.44	0.39

Test Section 3 – Spade cut 5cm below soil surface in July & August

Plot	A	B	C	D
Density (stalks/m^2)	112	88	38	81
Average Height (cm)	42.1	48.9	45.1	36.7
Average Diameter (cm)	0.36	0.35	0.35	0.37

Test Section 4 – Spade cut 5cm below soil surface in June, July & August

Plot	A	B	C	D
Density (stalks/m^2)	120	68	47	116
Average Height (cm)	47.8	36.4	32.3	42.3
Average Diameter (cm)	0.40	0.34	0.28	0.31

June 9, 2017

Test Section 1 - Control

Plot	A	B	C	D
Density (stalks/m^2)	89	102	111	125
Average Height (cm)	82.4	94.8	130.8	100.1
Average Diameter (cm)	0.53	0.57	0.66	0.54

Test Section 2 – Spade cut 5cm below soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	111	192	142	173
Average Height (cm)	84.3	89.2	76.4	85.1
Average Diameter (cm)	0.42	0.43	0.41	0.43

Test Section 3 – Spade cut 5cm below soil surface in July & August

Plot	A	B	C	D
Density (stalks/m^2)	111	120	90	104
Average Height (cm)	75.2	79.2	72.3	66.8
Average Diameter (cm)	0.38	0.39	0.37	0.38

Test Section 4 – Spade cut 5cm below soil surface in June, July & August

Plot	A	B	C	D
Density (stalks/m^2)	149	89	70	148
Average Height (cm)	86.2	69.8	66.9	78.0
Average Diameter (cm)	0.43	0.35	0.36	0.42

July 7, 2017

Test Section 1 - Control

Plot	A	B	C	D
Density (stalks/m^2)	108	103	134	133
Average Height (cm)	174.7	223.9	183.4	170.2
Average Diameter (cm)	0.46	0.53	0.63	0.54

Test Section 2 – Spade cut 5cm below soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	121	207	116	201
Average Height (cm)	148.9	152.1	145.5	162.2
Average Diameter (cm)	0.38	0.37	0.37	0.41

Test Section 3 – Spade cut 5cm below soil surface in July & August

Plot	A	B	C	D
Density (stalks/m^2)	166	136	90	106
Average Height (cm)	146.0	130.6	137.8	138.5
Average Diameter (cm)	0.35	0.39	0.39	0.36

Test Section 4 – Spade cut 5cm below soil surface in June, July & August

Plot	A	B	C	D
Density (stalks/m^2)	3	4	5	4
Average Height (cm)	60.1	45.1	64.1	66.9
Average Diameter (cm)	0.43	0.33	0.34	0.25

July 28, 2017

Test Section 1 - Control

Plot	A	B	C	D
Density (stalks/m^2)	106	104	131	124
Average Height (cm)	200.9	204.5	239.6	208.4
Average Diameter (cm)	0.49	0.57	0.64	0.53

Test Section 2 – Spade cut 5cm below soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	1	1	1	1
Average Height (cm)	43	56	10	12
Average Diameter (cm)	0.20	0.2	0.5	0.1

Test Section 3 – Spade cut 5cm below soil surface in July & August

Plot	A	B	C	D
Density (stalks/m^2)	6	0	1	2
Average Height (cm)	43.2	NA	78	84.5
Average Diameter (cm)	0.18	NA	0.20	0.50

Test Section 4 – Spade cut 5cm below soil surface in June, July & August

Plot	A	B	C	D
Density (stalks/m^2)	7	9	6	15
Average Height (cm)	40.6	29.2	38	59.1
Average Diameter (cm)	0.19	0.22	0.22	0.39

August 18, 2017

Test Section 1 - Control

Plot	A	B	C	D
Density (stalks/m^2)	94	98	129	117
Average Height (cm)	199.6	222.8	254.8	225.2
Average Diameter (cm)	0.51	0.56	0.65	0.58

Test Section 2 – Spade cut 5cm below soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	10	6	3	12
Average Height (cm)	37.0	31.3	62.7	43.3
Average Diameter (cm)	0.30	0.25	0.37	0.35

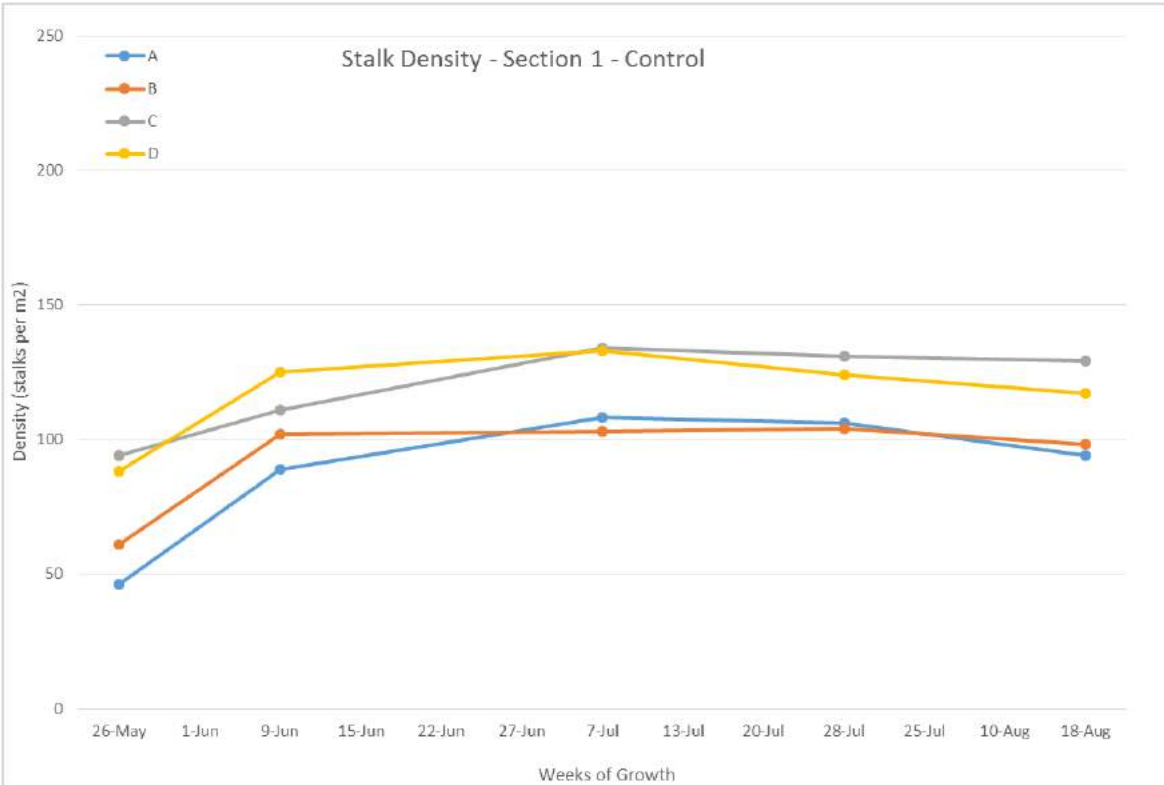
Test Section 3 – Spade cut 5cm below soil surface in July & August

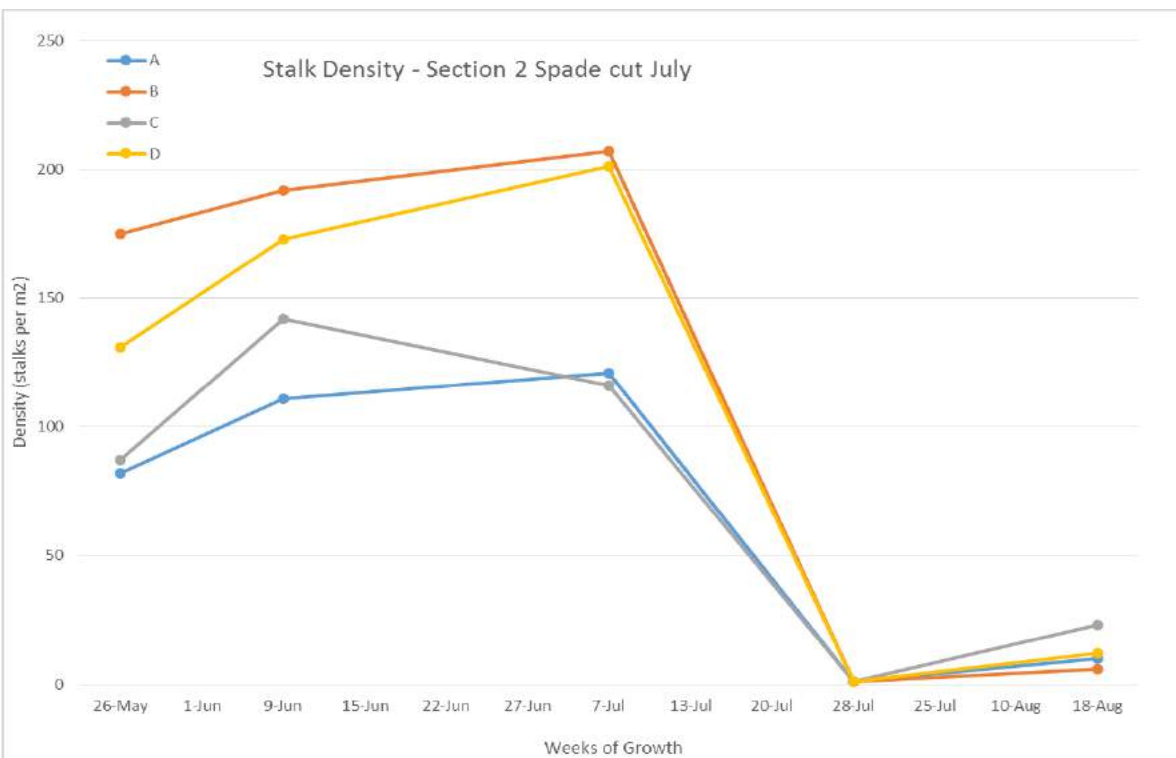
Plot	A	B	C	D
Density (stalks/m^2)	3	2	8	5
Average Height (cm)	34.0	43.9	63.5	39.0
Average Diameter (cm)	0.37	0.51	0.45	0.40

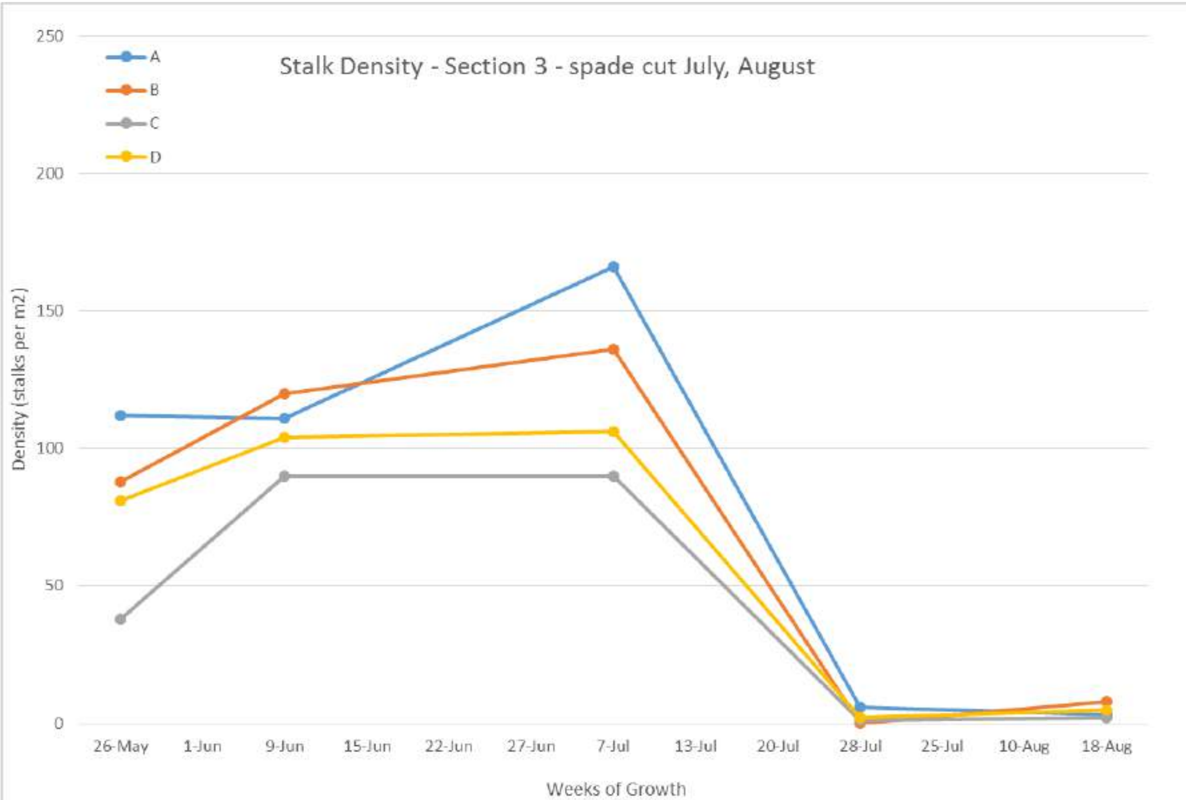
Test Section 4 – Spade cut 5cm below soil surface in June, July & August

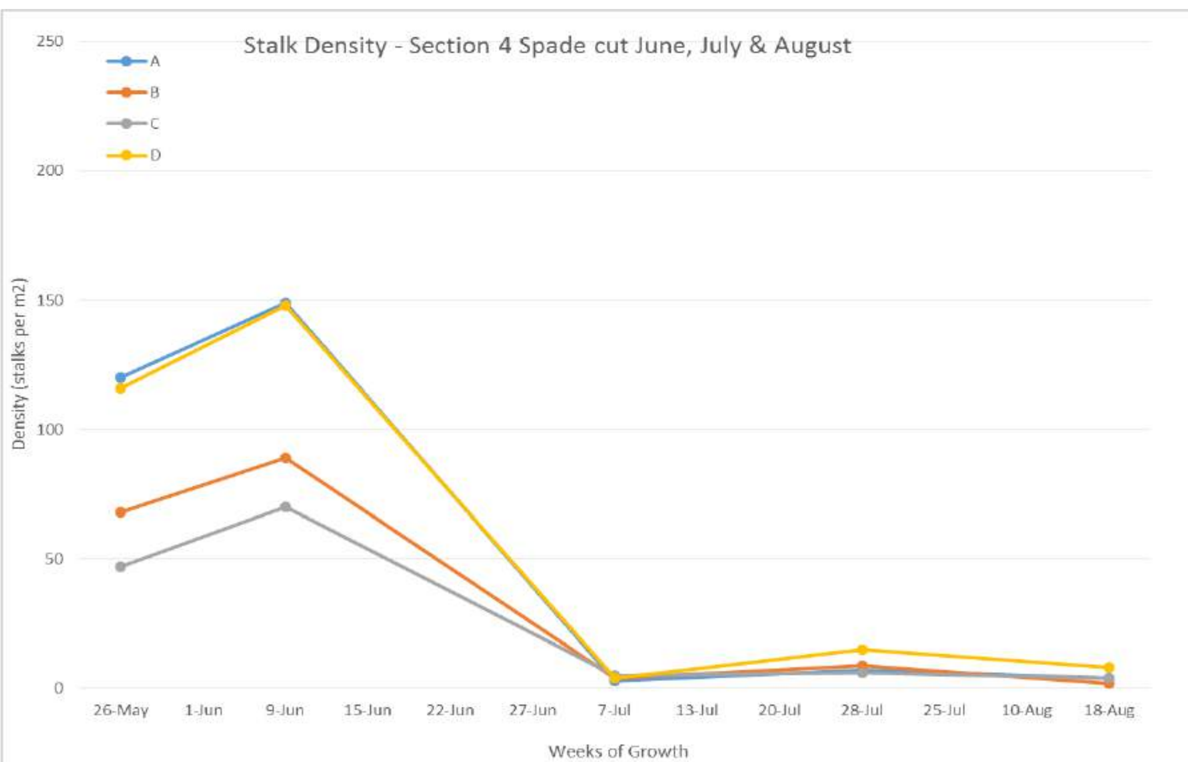
Plot	A	B	C	D
Density (stalks/m^2)	4	2	4	8
Average Height (cm)	39.0	45.5	37.8	49.5
Average Diameter (cm)	0.25	0.35	0.23	0.35

Graphic Representation of Measurement Data
Stalk Densities

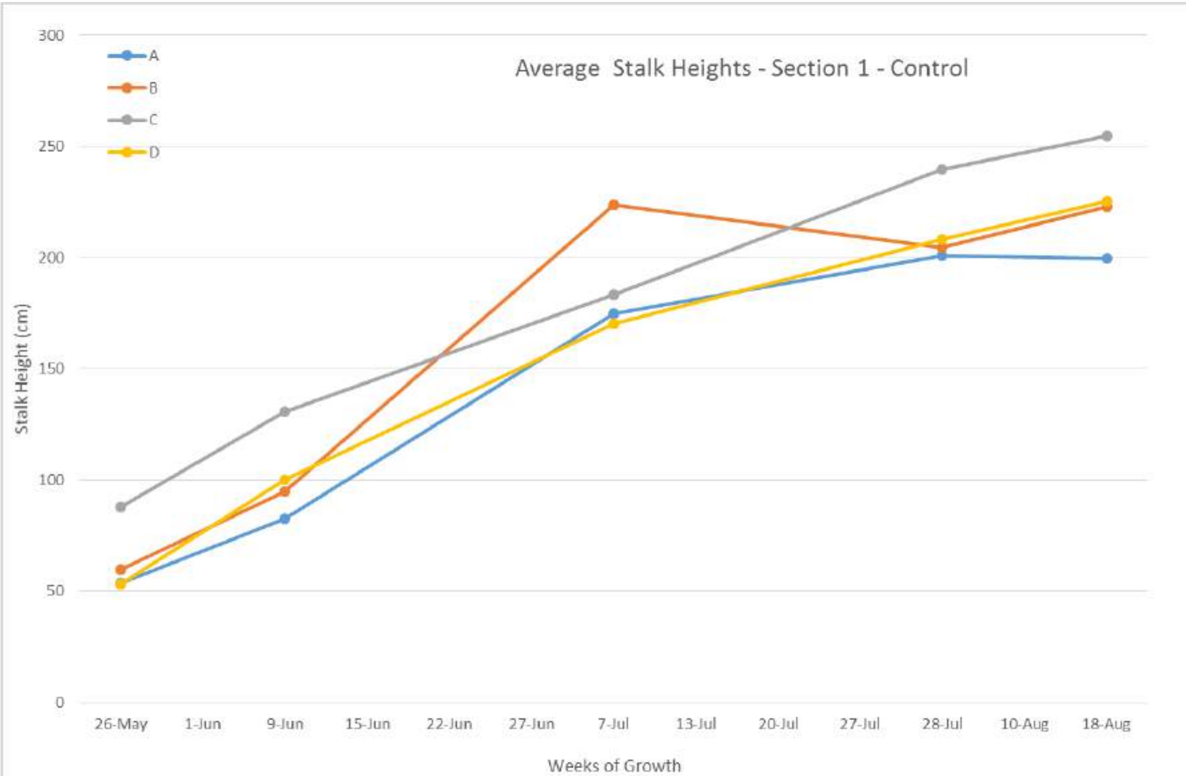


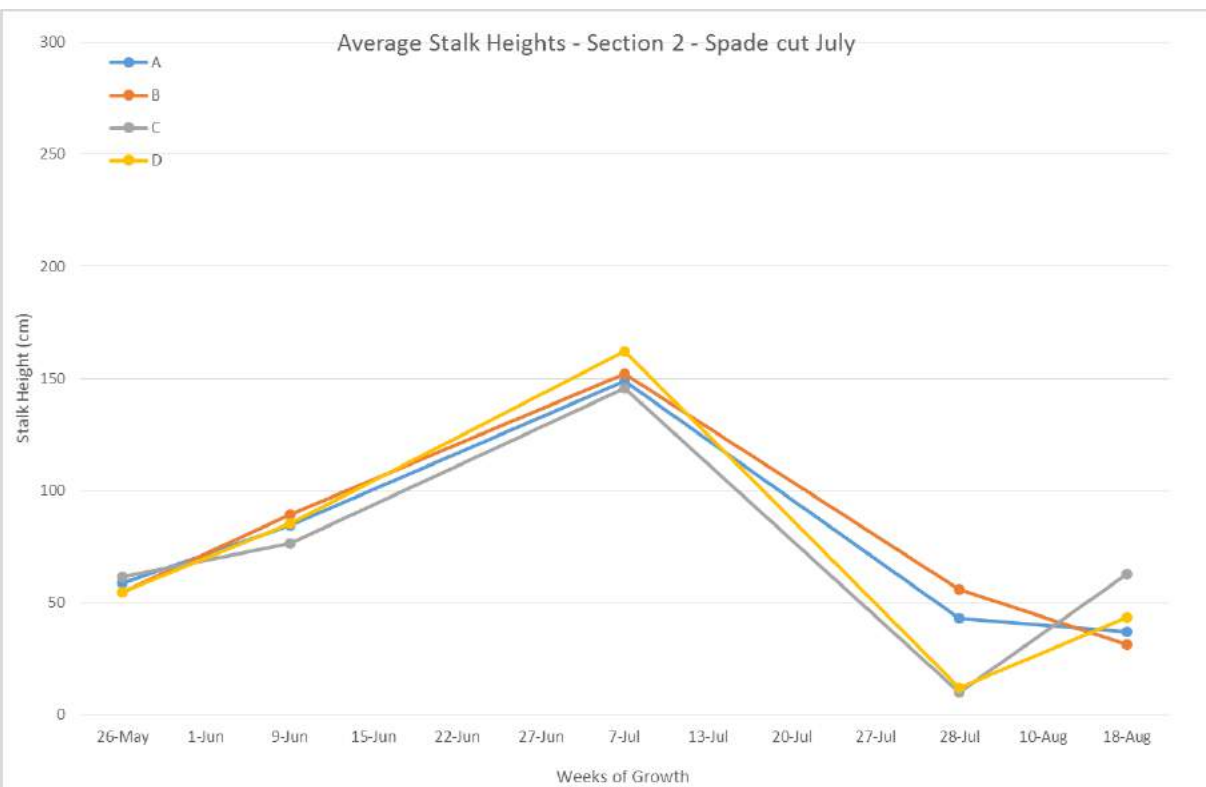


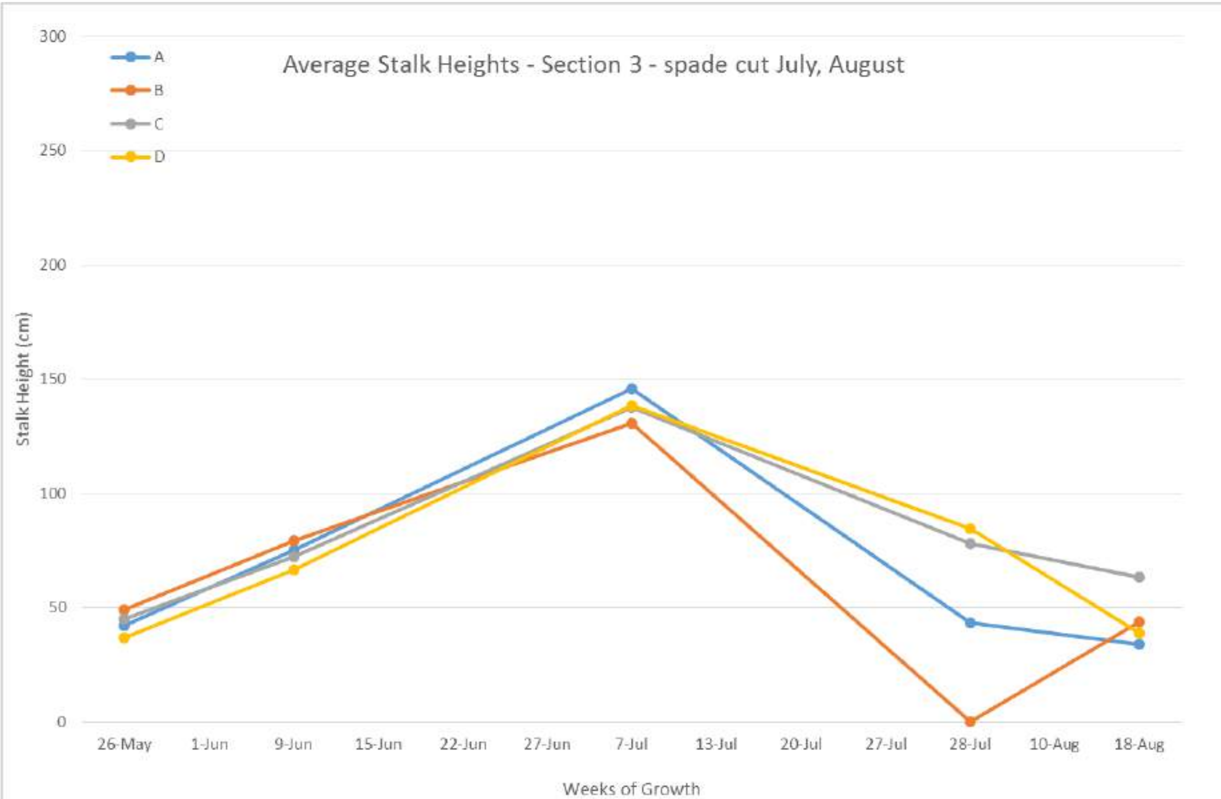

Stalk Density - Section 3 - spade cut July, August
A
B
C
D
Density (stalks per m2)
250
200
150
100
50
0
26-May
1-Jun
9-Jun
15-Jun
22-Jun
27-Jun
7-Jul
13-Jul
20-Jul
28-Jul
25-Jul
10-Aug
18-Aug
Weeks of Growth

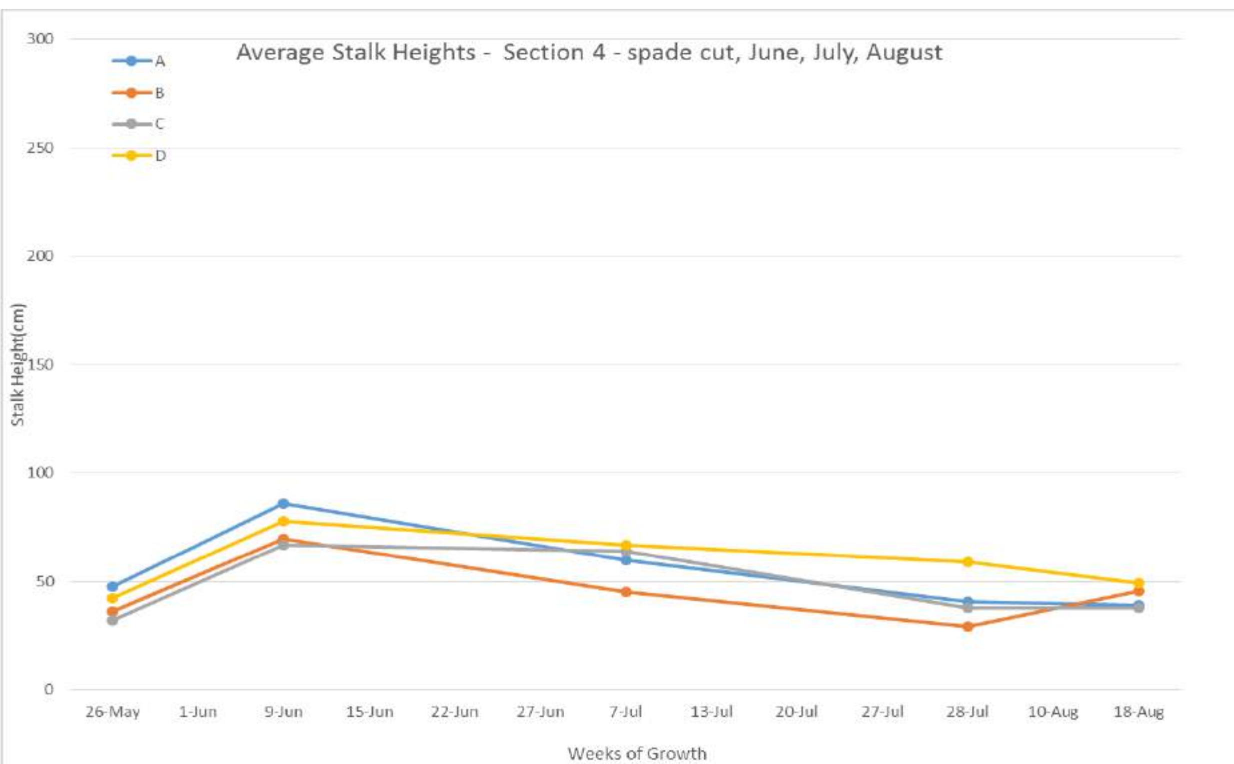

Stalk Density - Section 4 Spade cut June, July & August
A
B
C
D
Density (stalks per m2)
250
200
150
100
50
0
26-May
1-Jun
9-Jun
15-Jun
22-Jun
27-Jun
7-Jul
13-Jul
20-Jul
28-Jul
25-Jul
10-Aug
18-Aug
Weeks of Growth

Stalk Heights

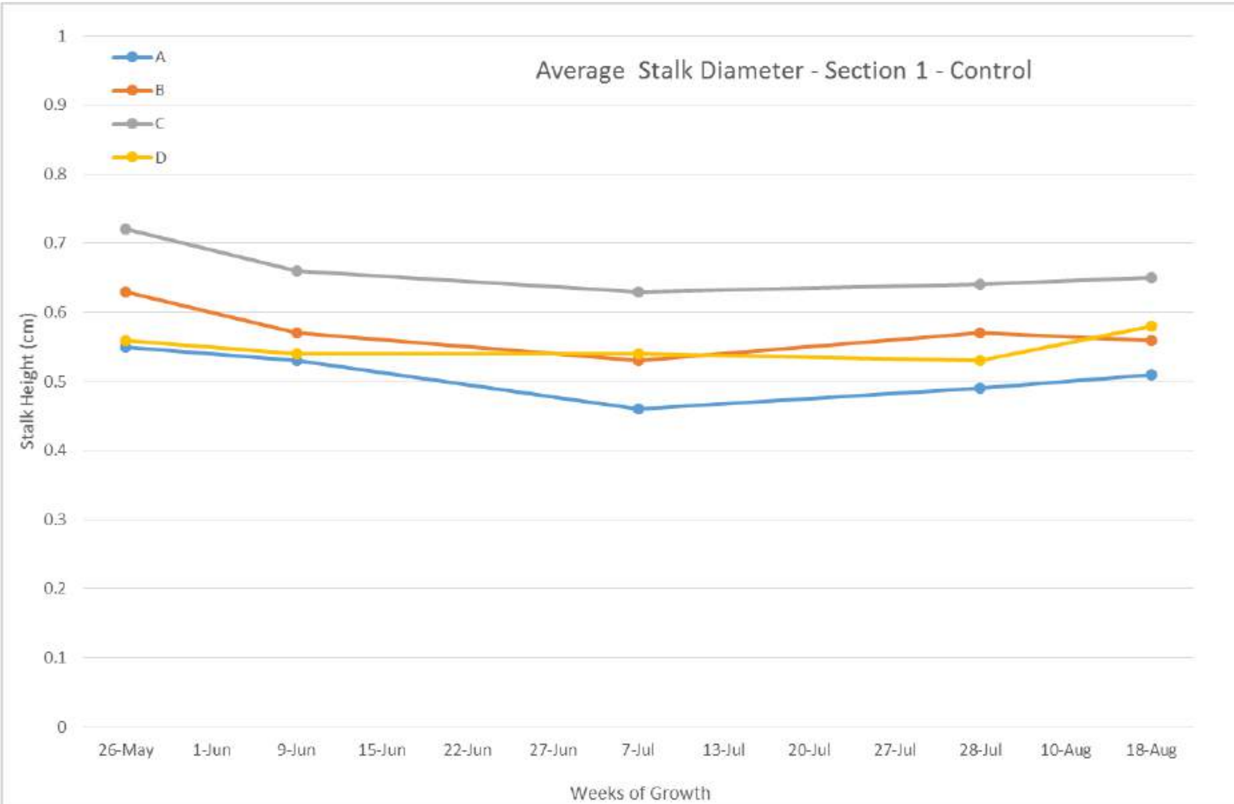


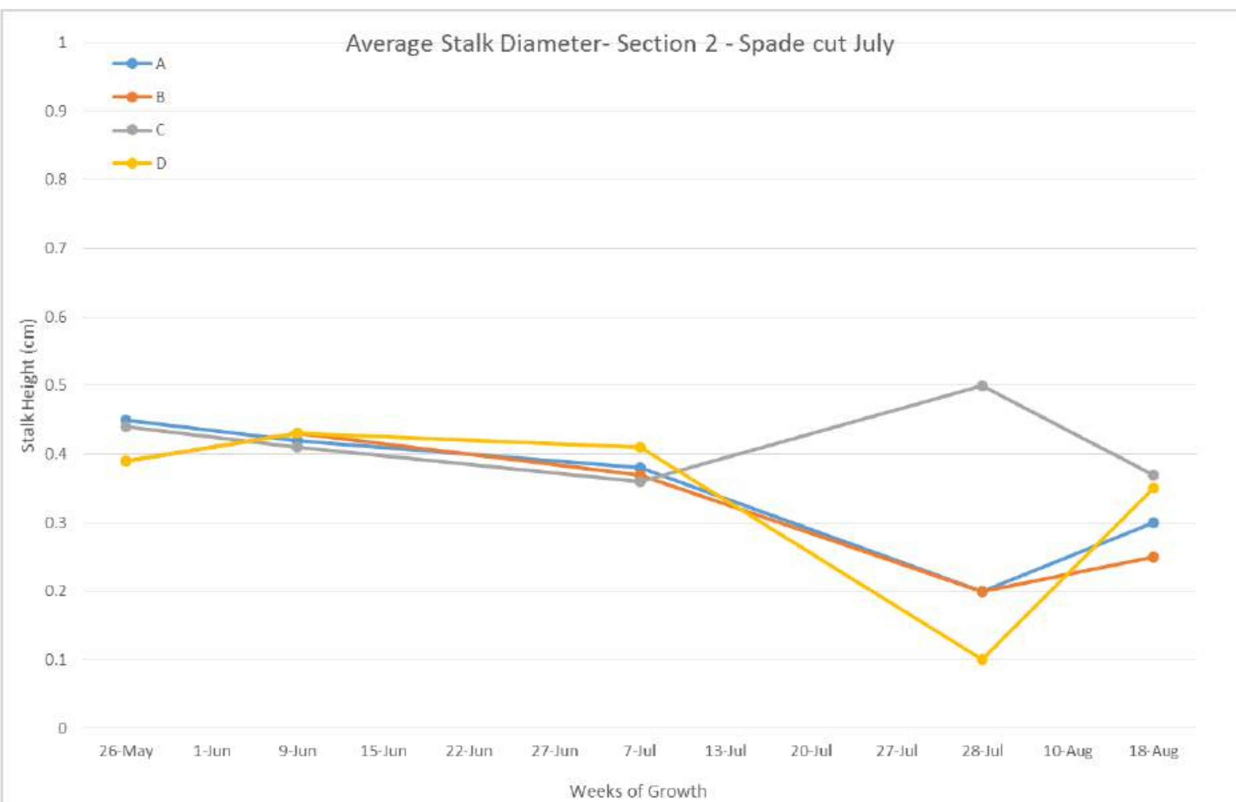


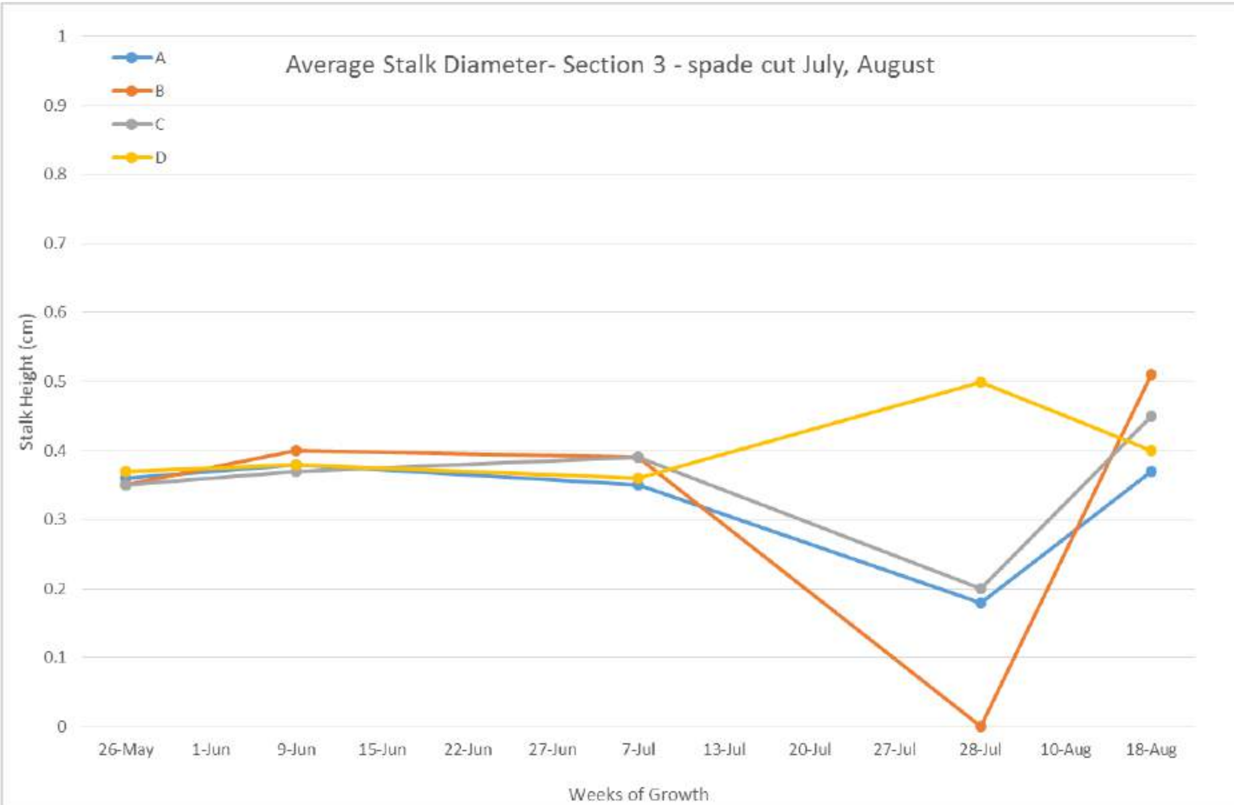

Average Stalk Heights - Section 3 - spade cut July, August
A
B
C
D
Stalk Height (cm)
300
250
200
150
100
50
0
26-May
1-Jun
9-Jun
15-Jun
22-Jun
27-Jun
7-Jul
13-Jul
20-Jul
27-Jul
28-Jul
10-Aug
18-Aug
Weeks of Growth

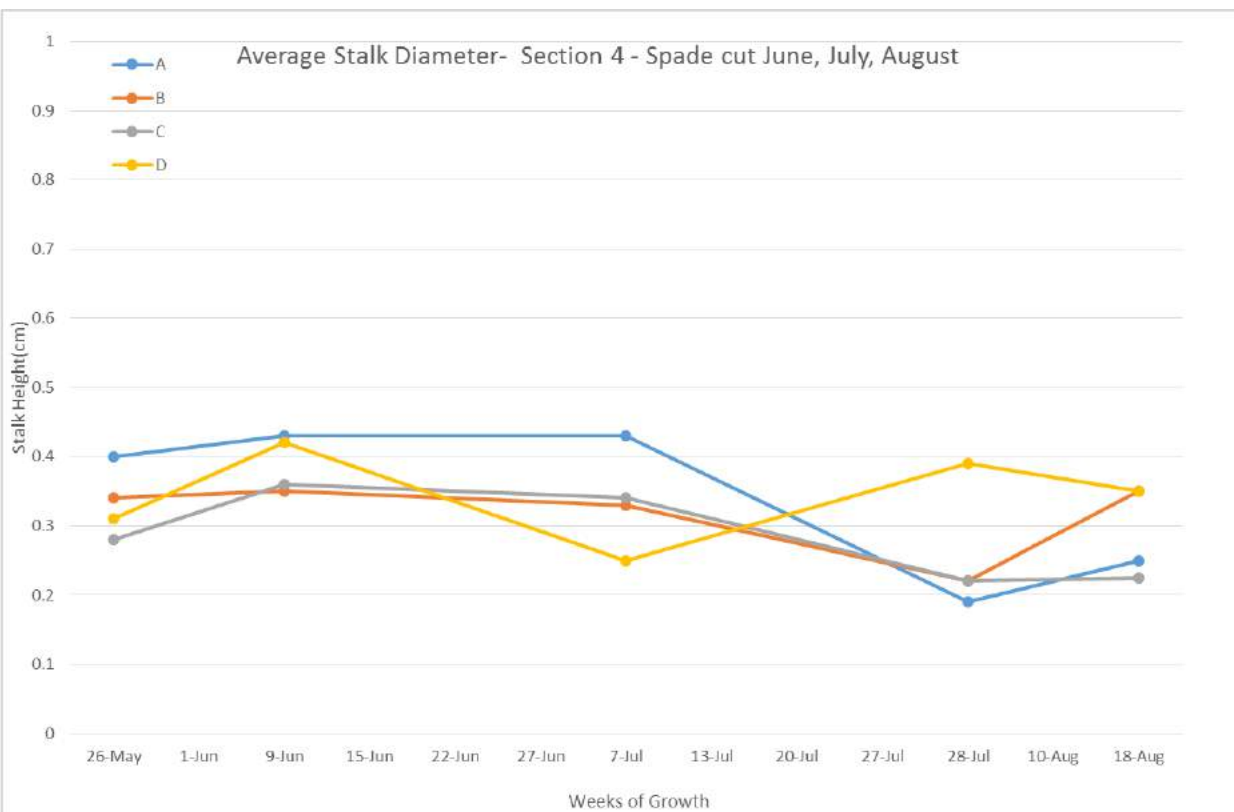

Average Stalk Heights - Section 4 - spade cut, June, July, August
A
B
C
D
Stalk Height(cm)
300
250
200
150
100
50
0
26-May
1-Jun
9-Jun
15-Jun
22-Jun
27-Jun
7-Jul
13-Jul
20-Jul
27-Jul
28-Jul
10-Aug
18-Aug
Weeks of Growth

Stalk Diameters






Average Stalk Diameter- Section 3 - spade cut July, August
A
B
C
D
Stalk Height (cm)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
26-May
1-Jun
9-Jun
15-Jun
22-Jun
27-Jun
7-Jul
13-Jul
20-Jul
27-Jul
28-Jul
10-Aug
18-Aug
Weeks of Growth


Average Stalk Diameter- Section 4 - Spade cut June, July, August
A
B
C
D
Stalk Height(cm)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
26-May
1-Jun
9-Jun
15-Jun
22-Jun
27-Jun
7-Jul
13-Jul
20-Jul
27-Jul
28-Jul
10-Aug
18-Aug
Weeks of Growth

Wymbolwood Plant Species Data Summer 2017
Native species – green
Non-Native species - black

Section 1 – Control – no removal of Phragmites stalks

	Plant Species	May 26	June 9	July 7	July 28	Aug 18
1	Narrow leafed willow	4	5	8	4	1
2	Northern bedstraw	33	22	22	30	25
3	Joe Pye Weed	4	10	14	10	8
4	Boneset					
5	Northern Bugleweed	35	30	57	27	67
6	Horsetail	4	4	6	14	9
7	Dogwood	1	1	1	1	
8	Aster					
9	Beach goldenrod					
10	Canada goldenrod		2	1	1	2
11	Porcupine sedge					
12	Tussock sedge					
13	Bebb's sedge					
14	Small Rushes					
15	Torrey's Bulrush					
16	Grapevine					
17	Purple Gerardia					
18	Cattail					
19	Canada thistle					
20	Grasses					
21	Dandelion					
22	Poplar	2	3	3	3	3
23	Phragmites	289	427	478	465	438
24	Loosestrife		*			
25	Hairy Willow Herb	51	*			
	Number of Species	**8**	**9**	**9**	**8**	**8**

* Loosestrife and Hairy Willow Herb removed from site on June 2 due to invasive nature of these plants.

Section 2 – Phragmites stalks spaded once in July

	Plant Species	May 26	June 9	July 7	July 28	Aug 18
1	Narrow leafed willow	12	11	12	15	18
2	Northern bedstraw	23	10	15	8	30
3	Joe Pye Weed	2	4		2	3
4	Boneset	1	1			
5	Northern Bugleweed	76	100	120	105	150
6	Horsetail	3	3	8	2	11
7	Dogwood					
8	Aster	7			1	7
9	Beach goldenrod					
10	Canada goldenrod					
11	Porcupine sedge		3	2	9	9
12	Tussock sedge					
13	Bebb's sedge					
14	Small Rushes			3	5	6
15	Torrey's Bulrush					
16	Grapevine			1	2	
17	Purple Gerardia	1	1	1	1	1
18	Cattail		2	3	2	6
19	Bull thistle	1	1	1	1	
20	Grasses		2	3	2	
21	Dandelion					
22	Poplar					
23	Phragmites	475	618	645	4	31
24	Loosestrife	8	*			
25	Hairy Willow Herb	375	*			
	Number of Species	**9**	**10**	**10**	**12**	**11**

* Loosestrife and Hairy Willow Herb removed from site on June 2 due to invasive nature of these plants.

Hairy Willow Herb dominated this test plot, May 26, 2017 – Removed June 3, 2017

Section 3 – Phragmites stalks spaded twice, in July and August

	Plant Species	May 26	June 9	July 7	July 28	Aug 18
1	Narrow leafed willow	3	12	6	21	13
2	Northern bedstraw	22	17	10	4	10
3	Joe Pye Weed	5	8	6	6	6
4	Boneset	19	31	36	33	39
5	Northern Bugleweed	249	219	210	110	186
6	Horsetail	6	8			4
7	Dogwood	1	1	1	1	1
8	Aster	9	6	5	1	
9	Beach goldenrod					12
10	Canada goldenrod		6			
11	Porcupine sedge	13	18	10	23	19
12	Tussock sedge				3	
13	Bebb's sedge			3		
14	Small Rushes			8	1	7
15	Torrey's Bulrush					
16	Grapevine					
17	Purple Gerardia					
18	Cattail					
19	Canada thistle					
20	Grasses			3		10
21	Dandelion	1	1	1	1	1
22	Poplar	12	7	7	8	10
23	Phragmites	319	425	498	9	18
24	Loosestrife	2	*			
25	Hairy Willow Herb	334	*			
	Number of Species	**14**	**13**	**14**	**13**	**14**

* Loosestrife and Hairy Willow Herb removed from site on June 2 due to invasive nature of these plants.

Section 4 – Phragmites stalks spaded three times, in June, July and August

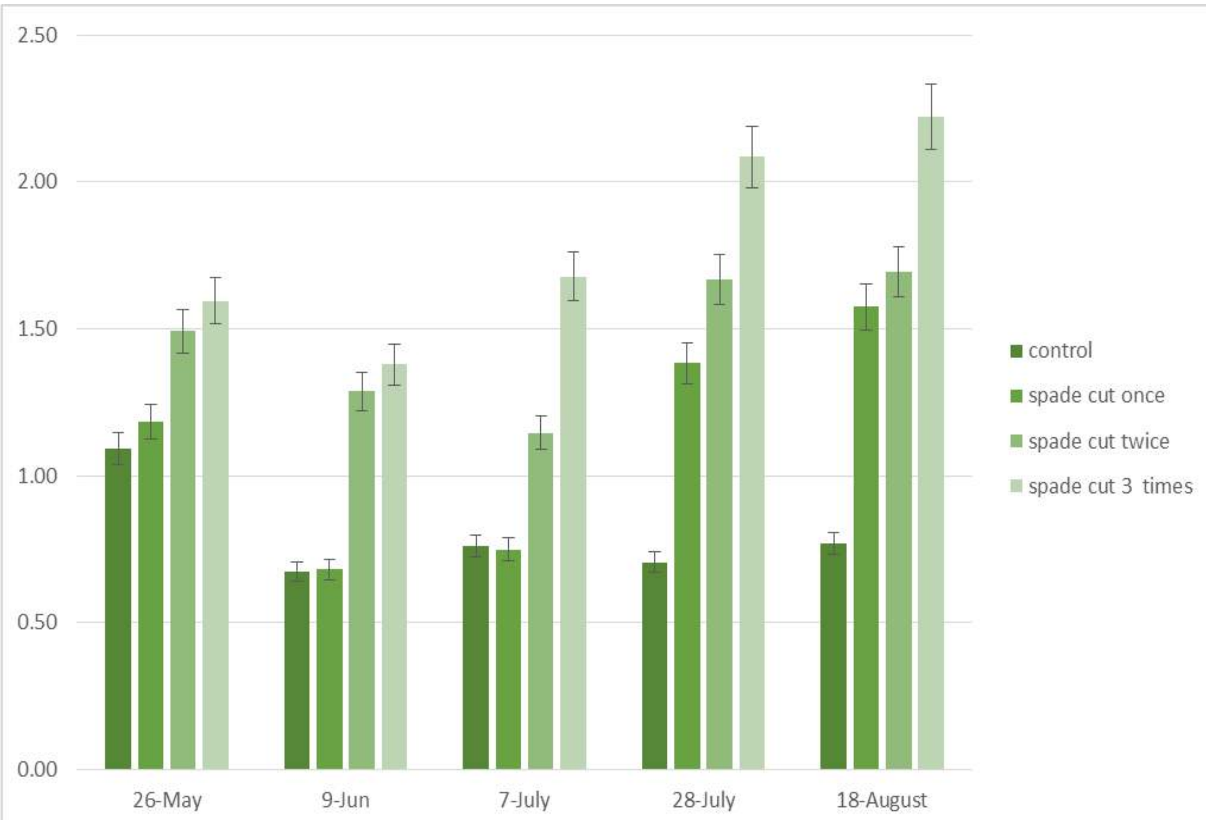
	Plant Species	May 26	June 9	July 7	July 28	Aug 18
1	Narrow leafed willow	18	21	49	30	46
2	Northern bedstraw	9	6	9	5	5
3	Joe Pye Weed	33	46	49	43	34
4	Boneset	69	57	61	65	56
5	Northern Bugleweed	207	177	225	125	128
6	Horsetail	20	28	22	20	27
7	Dogwood					
8	Aster					3
9	Beach goldenrod	10			15	24
10	Canada goldenrod	1	2	1	1	1
11	Porcupine sedge	16	17	16	16	16
12	Tussock sedge				3	3
13	Bebb's sedge			1	1	1
14	Small Rushes			5	17	23
15	Torrey's Bulrush				1	3
16	Grapevine					
17	Purple Gerardia					3
18	Cattail					5
19	Canada thistle					
20	Grasses					
21	Dandelion					
22	Poplar	7	5	5	5	5
23	Phragmites	351	456	16	37	18
24	Loosestrife		*			
25	Hairy Willow Herb	23	*			
	Number of Species	**11**	**10**	**12**	**15**	**18**

* Loosestrife and Hairy Willow Herb removed from site on June 2 due to invasive nature of these plants.

Table 1. Shannon Index values for the Wymbolwood Site, Summer 2017.

Plot	26-May	9-June	7-July	28-July	18-August
control	1.09	0.67	0.76	0.70	0.77
spade cut once	1.18	0.68	0.75	1.38	1.57
spade cut twice	1.49	1.29	1.15	1.67	1.70
spade cut 3 times	1.59	1.38	1.68	2.08	2.22

Figure 1. Shannon Index Values for the Wymbolwood Site, Summer 2017. All values are presented with a 5% margin of error.



Observations and Discussion

Phragmites Control

Stalk Density

The stalk density in the test plots in each test section was measured five times throughout the growing season. The initial and final densities from last year's and this year's results were compared.

Control – The initial stalk densities were about the same from last year and this year. This year, the stalk density increased a little from May to June and then remained consistent for the rest of the growing season. The final stalk densities were a little less this year compared to last year. This may be explained by the slight disturbance (unavoidable) caused by removing the standing stalks at the beginning of the season this year or by entering the test section (walking within the section) in order to perform the measurements during the testing season.

Section 2 – ***spade cut once- July, 2017***. The initial stalk densities were about the same from last year and this year. This year, the stalk density compared with the control measurements prior to the spade removal in July. After the removal, the stalk density was drastically reduced and remained less than 15 stalks/m^2 until the end of the testing period. It appears as though removal of stalks for two consecutive growing seasons has had a noticeable effect on Phragmites stalk density.

Section 3 – ***Spade cut twice- July and August, 2017***. The initial stalk densities were about the same from last year and this year. This year, the stalk density prior to the spade removal in July was about the same when compared with the control measurements. After the removal, the stalk density was drastically reduced and remained less than 10 stalks/m^2 until the end of the testing period. It appears as though removal of stalks for two consecutive growing seasons has had a noticeable effect on Phragmites stalk density.

Section 4 – ***Spade cut three times- June, July and August, 2017***. The initial stalk densities were about the same from last year and this year. This year, the stalk density prior to the spade removal in June was about the same when compared with the control measurements. After the removal, the stalk density was drastically reduced and remained less than 10 stalks/m^2 until the end of the testing period. It appears as though removal of stalks for two consecutive growing seasons has had a noticeable effect on Phragmites stalk density.

Stalk Height

The stalk heights in the test plots in each test section were measured 5 times throughout the growing season. In test plots with more than 100 stalks/m^2, a representative sample was measured (as described in the Procedure section).

Control – The initial range of stalk heights in May was 50cm to 100cm. The stalk heights increased throughout the season to a final stalk height range of 200cm to 250cm. Most of the stalks were in flower by late August.

Section 2 – ***spade cut once- July, 2017***. The stalk height increased at the same rate as the Control but, after the spade removal in July, the stalk heights in August were reduced to heights comparable to the May heights. No stalks were in flower by late

August.
***Section 3** – **Spade cut twice- July and August, 2017**.* The stalk height increased at the same rate as the Control but, after the spade removal in July, the stalk heights were reduced to heights comparable to the May heights and remained so until the end of the test period in August. No stalks were in flower by late August.
***Section 4** – **Spade cut three times- June, July and August, 2017**.* The stalk height increased at the same rate as the Control initially but, after the spade removal in June, the stalk heights were reduced to heights comparable to the May heights and remained so until the end of the test period in August. No stalks were in flower by late August.
NOTE: The site was visited on September 30, 2017, one month after the final data measurements were completed. There were no flowers observed on any of the stalks in any of the test plots. Most of the stalks in the Control section still had large flower/seed heads.

Stalk Diameter
The stalk diameters in the test plots in each test section were measured 5 times throughout the growing season. In test plots with more than 100 stalks/m^2, a representative sample was measured.
Control – The stalk diameter ranged between 0.5cm and 0.8cm consistently throughout the growing season.
***Section 2** – **spade cut once- July, 2017**.* The stalk diameters ranged between 0.4cm and 0.5cm until the spade removal in July. After the removal, the range of measurements was between 0.1cm and 0.5cm. There were very few stalks to measure after the July removal.
***Section 3** – **Spade cut twice- July and August, 2017**.* The stalk diameters ranged between 0.3cm and 0.4cm until the spade removal in July. After the removal, the range of measurements was between 0.1cm and 0.5cm. There were very few stalks to measure after the July and August removals.
***Section 4** – **Spade cut three times- June, July and August, 2017**.* The stalk diameters ranged consistently between 0.2cm and 0.4cm throughout the growing season.
NOTE: It appears as though the removals of the previous year have affected the diameters of the initial spring growth this season. The stalk diameters remained smaller than the stalk diameters measured in the control section throughout this summer.

Plant Biodiversity
Wymbolwood Beach is located on Georgian Bay, Lake Huron, Ontario. The plant community is relatively undisturbed by human activity as compared to an urban area. There are very few non-native plant species in the surrounding areas. Invasive Phragmites has appeared within the last 20 years at the same time that the water levels on Georgian Bay began dropping, resulting in exposing more sand to plant colonization. The test site is located on privately-owned land where no previous efforts have been undertaken to control the local Phragmites invasion. Diversity counts were performed five times from May through August, 2017.
The plant community at the Wymbolwood site is almost entirely composed of native species, with 18 native species and 7 introduced. Of the introduced species, four are considered invasive species, including Invasive Phragmites. Hairy Willow Herb and Purple Loosestrife are

both pernicious enough that they were removed from the test site at the beginning of June. The naturalized species on this site do not make significant contributions to the community, making this site a good candidate for full restoration to a native wetland community.

Table 2. Plant Species observed at the Wymbolwood Site, Summer 2017.

Native Plant Species	Introduced	Introduced - Significant Invasive
Narrow leafed willow	Grasses	*Phragmites australis* subsp. a*ustralis*
Northern bedstraw	Dandelion	Canada thistle
Joe Pye Weed	Poplar	Hairy Willow Herb
Boneset		Loosestrife
Northern Bugleweed		
Horsetail		
Dogwood		
Aster		
Beach goldenrod		
Canada goldenrod		
Porcupine sedge		
Tussock sedge		
Bebb's sedge		
Small Rushes		
Torrey's Bulrush		
Grapevine		
Purple Gerardia		
Cattail		

Control- Overall, plant community diversity in the Control section was the lowest of all the sections. Diversity was highest at the outset of the season (H'= 1.09), likely due to the shorter Phragmites stalks allowing light into the area. As the Phragmites stalks increased in height, the other plants became shaded out and the diversity of this Plot dropped significantly (H'=0.67, June 9) and remained consistently low for the rest of the season (H'=0.77, August 18).
Section 2- spade-cut once, July 2017. Prior to the removal of the Invasive Phragmites in July, the diversity in this section mirrored the diversity observed in the Control section, suggesting that the single spade-cutting event, that took place in the previous growing season, had little effect on the initial spring growth of Invasive Phragmites. The increase in diversity observed following this year's July spade-cutting (from H'=0.75 on July 7, to H'= 1.38 on July 28) was substantial, and diversity continued to increase slightly (up to H'= 1.57) in August.
Section 3- spade-cut twice, July and August, 2017. Diversity for this section was consistently the second highest out of all the sections. Diversity at the start of the season was relatively high (H'= 1.49), but decreased through June and into July (H'=1.15, July 7). This may be due to two factors: the presence of invasive Hairy Willow Herb and Purple Loosestrife on the section which were removed in late June, and the effect of spade-cutting done in the previous season. Diversity rebounded following the July spade-cut event (up to H' =1.67) and continued to increase modestly following the August spade-cut event (H'=1.70).
Section 4- spade-cut three times, June, July, August, 2017. Diversity in this section was the

highest of all the sections, for the entire season. Diversity was substantially greater than that found in the Control section, in particular. Overall, we observed a slight decrease in diversity between May (H'= 1.59) and June (H'= 1.38). Diversity increased dramatically following the June spade-cut (H'=1.68 on July 7) and continued to increase substantially following the subsequent July (H'= 2.08) and August (H'=2.22) spade-cuttings. This section experienced a longer period of decreased influence of the presence of Phragmites over the summer, due to the initial removals beginning in June.

Conclusions

With regards to community diversity and recovery, spade-cutting appears to be an effective method of controlling Invasive Phragmites. Spade-cutting was shown to improve community diversity and reduce Phragmites stalk densities when compared against the Control section. This suggests that spade-cutting is significantly impacting the viability and productivity of the rhizomes, as hypothesized. Generally, spade-cutting three times over course of the growing season was the most effective in increasing community diversity, reducing stalk density and maintaining improved community diversity throughout the growing season.

Phragmites Control

It is not possible to determine if there is any interference from the Phragmites growth that surrounds each of the research sites. Every effort to minimize this influence has been made by creating a buffer zone around the measured test plots in each section. The stalks in the buffer zone are treated the same way as the stalks inside the test plots, however, it is known that the rhizomes can reach long distances underground so it is possible that the stalks outside the perimeter of the site influence the growth on the inside the site. When treating an area using the spading technique, it is important to remove all the stalks present in the entire stand to prevent any photosynthesis within the stand. This was not possible for the purposes of this research but the effects seen in this study are very encouraging even with this as a consideration.

Spade removal of Phragmites stalks has been shown to reduce stalk density, height and diameter as compared to the control sections.

It would be expected that the stalk height would be adversely affected by removing the stalks at various times throughout the season, since the stalks must regrow after removal and have a shortened period of time to reach their final height. It would also seem reasonable that the amount of resources available for regrowth would be diminished since the plant had already been utilizing the resources to develop the initial growth.

It appears that, in addition to the effect on the height, the density of the regrowth and the diameter of the regrowth stalks are also affected. It appears that the rhizomes are not able to support the same dense sturdy growth after the initial stalks have been removed.

Removal of stalks, even once during the growing season affects the final density at the end of the season by reducing the number of stalks present. It also appears that repeated removal for two consecutive seasons also weakens the sustainability of the plant growth. In all test sections at the end of the second year, the final densities were drastically reduced compared to the Control section. Also, the stalk diameters were

much smaller than the stalks in the Control section.
One of the factors that may have contributed to the drastic reduction of stalk densities in Sections 2, 3 & 4 by the end of the growing season was the repeated flooding of the site due to the wet summer season. Since the dead standing stalks and the live stalks were removed, the process of snorkeling (gas exchange to the rhizomes) would have been interrupted. This may have reduced the viable shoots that were able to regrow.

On the days when there are high winds and large waves on Georgian Bay, the site becomes flooded. August 6, 2017.

Flooded test plot

Comparison of **Initial** Densities Summer 2016 & 2017

Control	Test Plot A	Test Plot B	Test Plot C	Test Plot D
June 24, 2016	133	119	104	84
June 9, 2017	89	102	111	125

Section 2	Test Plot A	Test Plot B	Test Plot C	Test Plot D
June 24, 2016	103	154	122	131
June 9, 2017	111	192	142	173

Section 3	Test Plot A	Test Plot B	Test Plot C	Test Plot D
June 24, 2016	120	117	71	125
June 9, 2017	111	120	90	104

Section 4	Test Plot A	Test Plot B	Test Plot C	Test Plot D
June 24, 2016	132	97	64	124
June 9, 2017	149	89	70	148

Comparison of **Final** Densities Summer 2016 & 2017

Control	Test Plot A	Test Plot B	Test Plot C	Test Plot D
September 2, 2016	145	183	155	143
August 18, 2017	94	98	129	117

Section 2	Test Plot A	Test Plot B	Test Plot C	Test Plot D
September 2, 2016	39	65	64	67
August 18, 2017	10	6	3	12

Section 3	Test Plot A	Test Plot B	Test Plot C	Test Plot D
September 2, 2016	23	25	21	8
August 18, 2017	3	2	8	5

Section 4	Test Plot A	Test Plot B	Test Plot C	Test Plot D
September 2, 2016	18	33	12	20
August 18, 2017	4	2	4	8

Plant Biodiversity

We anticipated that the control of Invasive Phragmites through the spading technique would allow the native and naturalized plant community to recover. In previous studies, (Mal and Narine 2004, Farnsworth and Meyerson 1999) removal of Invasive Phragmites has been shown to positively impact the diversity and richness of the effected plant community. To quantify this hypothesis, the Shannon Index was chosen, which is commonly used in ecological studies to compare species richness and diversity within communities. The index is measured by comparing the number of species and their

relative abundance within a representative sample. In the case of our study, all plants within each test plot were counted. Values in the Shannon Index may range between 0 and 4, where 0 represents a pure monoculture, and 4 represents an extremely diverse community. Healthy communities typically fall within the range of 1.5 and 3.5. A detailed explanation of the criteria for Healthy Communities and the formula used is attached in Appendix A (Smith and Smith 2002).
For our study, the Shannon Index was calculated for each test section on each site throughout the growing season.

General trends – Plant Community diversity was consistently lowest in the Control sections, and highest in the section that was spade-cut three times over the entire growing season. In all sections, diversity was relatively high at the outset of the season. This may be attributable to two factors. The removal of thatch and last year's standing stalks at the beginning of the season may have allowed for greater-than-anticipated germination success for other plant species. The relative lack of shade provided by the young Phragmites shoots provided for the germination of seeds that were present in the soil. In most of the sections, the diversity of the communities decreased slightly at the end of the growing season. This may be due to the fact that, as most of the plants studied were forbs and grasses, many were coming to the end of their growing season, and were dying back. Phragmites tends to have a longer growing season than many of the native plants, thus extending the time that it is able to produce resources for storage for the next season.

Selective Removal Effect. In most other commonly-used control methods, all living plants within the affected area are damaged, killed, or removed as a side-effect of Invasive Phragmites control. One of the great benefits of the spade-cut method is that only Invasive Phragmites is selectively removed, leaving the rest of the plant community, alive, on the site. This increases the rate of the recovery of the site, and preserves vulnerable species or populations.
In all of the sections, where removal of Phragmites occurred, the diversity of the community appeared to increase dramatically immediately following the removal. It is important to note that this apparent increase is not due to an influx of species. Rather, this value represents the baseline diversity of the site prior to actual recovery. The community observed at this point is composed of only those species that had been able to tolerate the competitive effect of Invasive Phragmites. We would expect that, with ongoing control of Invasive Phragmites and recovery of the site, the diversity values for the site will either remain constant at the baseline value, or will continue to increase.

Increased plant biodiversity allows for increased animal diversity!


Toad and Toad Eggs on site in spring

Juvenile Great Blue Heron visiting the site


Ladybug Larva

Viceroy Butterfly on native Joe Pye Weed

Next Steps
Repeated annual removal and data collection should be undertaken to establish the number of years that it will take to control Phragmites to a sustainable state. This would require that the above protocols be repeated annually on the same site. From previous experience of spade removal of Phragmites on residential properties at Wymbolwood Beach, it is predicted that it would take 3 to 7 years to reach a sustainable control of Phragmites using the spading technique. This research would benefit from at least one more year of scheduled removals and data monitoring.

Also, while working this fall with the City of Toronto, Parks, Recreation and Forestry stewardship groups, an interesting discovery was made that would benefit from more investigation. A decision was made to remove mature Phragmites stalks from a previously undisturbed stand in October of this year at Charles Sauriol Conservation Area near the East Don River. The goal was to reduce the amount of thatch and dead standing stalks that would otherwise be present next summer. The hope was that this would make spade removal easier next year since only new growth would have to be spaded.
When the mature stalks were spaded and removed from the ground, it was observed that there were often 3 to 5 new sprouts at the base of the stem **below the soil surface**. A similar removal of late October growth was tested on Wymbolwood Beach at a location away from the research site and with similar findings. (see photos below) It appears as though, at this time of the year, new buds are formed that will begin to develop into the initial stalks early in the spring.



Below soil surface sprouts (left photo – Toronto; right photo – Wymbolwood Beach)

On the basis of these observations, I removed the live standing stalks from the test sections in late October to test the effects of spading this late in the season on the initial density of the spring growth in the next season. Many of the stalks had one or two new shoots formed below the soil surface. I want to compare the regrowth in the spring for the test and control sections and continue to document the growth after the scheduled spade removals over the summer. This should provide valuable information for manual control strategies for Phragmites.

Below soil surface sprouts taken from research site – October 20, 2017

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Happy Volunteers working together!

 

The challenges of Phragmites Stalk Density in the Control Section!

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Appendix A

Healthy Community' and Recovery

For the purpose of this discussion, a 'healthy community' refers to a plant community composition that meets these three conditions (Adapted from Grubmine 1994):

1) the community is made up of sustainable populations of naturalized and native species,

2) the community tends towards a stable or increasing degree of diversity, with changes occurring gradually,

3) the ecosystem functions performed by the community remain stable, even allowing for natural changes in species composition. On our sites, these functions include habitat and food resources for wildlife, including pollinators, and the regulation of the local water cycle. (Costanza *et al.* 1997)

A recovering community is assessed according to how well the community is able to meet these criteria.

Shannon Index Expanded Definition

Diversity: In ecology, diversity is defined as a measure of the number of different species found in a given community. In undisturbed systems, communities will generally become more diverse over time. Highly diverse communities are typically more resilient when disturbed, and more stable. High diversity in one community also promotes increased diversity in connected communities. For example, a highly diverse marsh plant community will provide a greater range of food and habitats for insects, birds and mammals.

Diversity may be measured in a number of ways. One of the most common is the Shannon (or Shannon-Wiener) Index which quantifies diversity through measuring community *richness* and *evenness*.

Richness: the total number of species in a community. A community with a large number of different species is said to be species-rich.

Evenness compares the number of individuals of each species in a community to determine whether there are similar numbers of each species (high evenness) or whether one species is present in significantly higher numbers than the others (low evenness, one species is dominant).

Shannon Diversity Index

Purpose: The Shannon Diversity Index combines richness and evenness to give a diversity value (H') for a community. The value of one community can then be compared to the value of another community to give us a relative measure of the difference in diversity between the communities. The index can also be used to measure how a single community's diversity is changing over time.

Data needed: A full count of every individual of every species found within the community (or representative sample for that community) is required for this calculation. The total number of individuals for each species is represented as a fraction of the total number of individuals in the community.

Sample Data:

Species	Community 1	Community 2
A	25 = 0.25	85 = 0.85
B	20 = 0.20	15 = 0.15
C	25 = 0.25	0 = 0
D	30 = 0.30	0 = 0
Total	100 = 1.00	100 = 1.00

Sample Calculation:
These values can be put into the equation:
$H' = \mathbf{-\sum(} p_i \ln p_i)$
Where H' is the diversity index
p_i is the number of individuals of a given species

The equation reads: The diversity index is equal to the negative sum of all the number of individuals of a given species multiplied by the ln (logarithmic function of e) of that number.

For our example H' for Community 1 would be:
$H'_1 = -[(A_1 * \ln A_1) + (B_1 * \ln B_1) + (C_1 * \ln C_1) + (D_1 * \ln D_1)]$
$H'_1 = -[(0.25 * \ln 0.25) + (0.20 * \ln 0.20) + (0.25 * \ln 0.25) + (0.30 * \ln 0.30)]$
$H'_1 = -[-1.376]$
$H'_1 = 1.376$

And H' for Community 2 would be:
$H'_2 = -[(A_2 * \ln A_2) + (B_2 * \ln B_2) + (C_2 * \ln C_2) + (D_2 * \ln D_2)]$
$H'_2 = -[(0.85 * \ln 0.85) + (0.15 * \ln 0.15) + (0 * \ln 0) + (0 * \ln 0)$
$H'_2 = -[-0.423]$
$H'_2 = 0.423$

Interpretation:
For our example: The Diversity indices for community 1 and community 2 are:
$H'_1 = 1.376$, $H'_2 = 0.423$, respectively.
The larger H' value reflects the higher number of species, and the greater evenness found in community one compared to community 2.

Adapted from*:* Smith, R.L and T.M Smith (2002) **Ecology and Field Biology**- 6th ed. Prentice-Hall, Cambridge, Ma.