<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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Introduction

Species Taxonomy and Distribution

Known as 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).

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).

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 of 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:

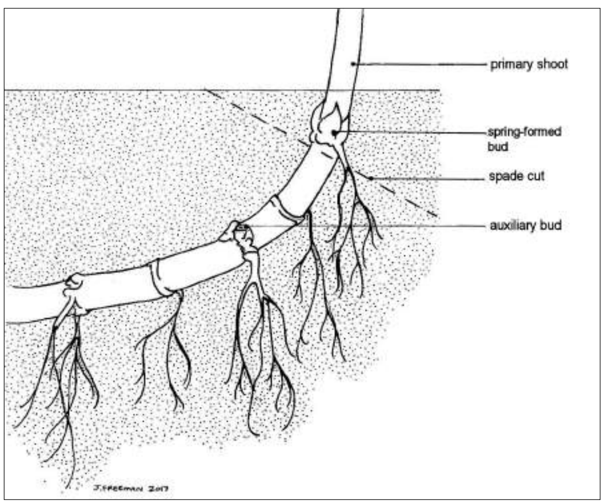


Figure 1. Initial Spade Cut. The initial cut is made at a roughly 45^{o} angle, to a minimum depth of 5cm. The aim of this cut is to sever both the primary shoot (the shoot that has emerged from the over-wintering bud) and its attendant spring-formed buds from the rhizome.
The removal of the primary 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.

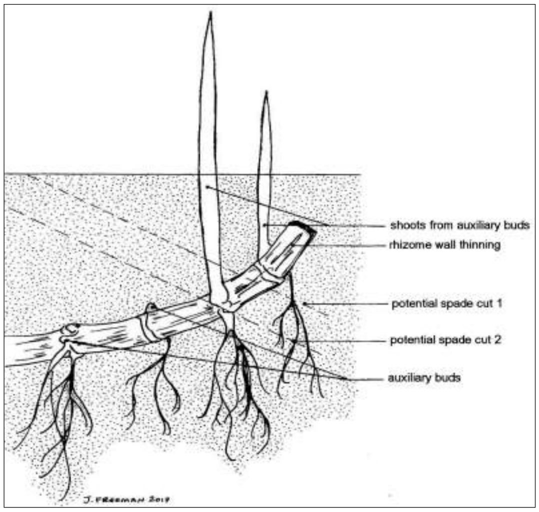


Figure 2. Second Spade Cut. The second spading period should be undertaken after the emergence of the shoots from the auxiliary buds. Again the cut is made at a roughly 45^{o} angle, at a minimum depth of 5cm.

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.

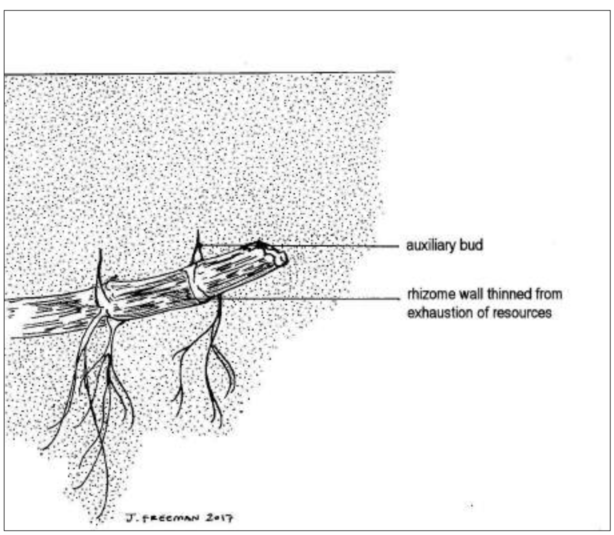


Figure 3. Shoots developing following the second spading. Removal of the shoots during the second spading period will again stimulate the remaining auxiliary buds on the rhizome. The shoots developing from these buds will again be thinner and less robust than the primary shoot. The shoot density and 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.

Jana holding a rhizome with multiple shoots growing from the nodes where the auxiliary buds were located.

Procedure

Last spring (2016), two sites were selected in the Humber Arboretum adjacent to the Humberwood Community Centre at 850 Humberwood Blvd., Toronto. These sites were selected on the basis that Phragmites was the dominant species present and that they had not had any control methods applied to the site to date. The Phragmites had been growing undisturbed for at least ten years. One site had standing water in the spring and was established at the edge of a stand of narrow-leaved cattails near a wetland (storm water collection zone) with open water. This was labelled the Wet Patch. The other site was dry, located in a meadow nearby. This was labelled the Dry Patch. The test sites measured approximately 12.5 metres by 10 metres in size. Approval to use the sites was obtained from the TRCA.

Last spring (2016) each site had been divided into five test sections, side by side, each section measuring 2.5m by 10m. T-bars 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 above the soil surface using secateurs in July;
- Section 3 - the section where the stalks would be cut 5cm below the soil surface using a sharpened spade in July;
- Section 4 - the section where the stalks would be cut 5cm below the soil surface using a sharpened spade in July and August; and
- Section 5 - 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 were used to define the boundaries of these test plots. 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 surrounding areas. Therefore, each entire test section was treated according to the plan but only the four test plots were counted and measured for data collection.

This spring (2017), standing dead stalks were 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 each site. The two soil samples were analyzed at Agrifood Laboratories in Guelph.

Removing standing dead stalks – May 2017

Prior to the initial data collection this summer (2017), core samples measuring 10cm by 10cm by 25cm deep containing rhizomes were taken from each site. These samples were cut out using a pruning saw with a blade 25cm long. The core samples were then levered out of the ground using a trenching shovel. Five samples were taken from within each test section but outside the four test plots 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 again from each test section in the same manner but in different locations from the previously removed samples. These samples were also brought to the University of Waterloo for analysis. This analysis will not be part of this report.

One week before each removal 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, the identity and numbers of other non-Phragmites plant species present in each test plot were recorded. It is important to note that these 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 test plot 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 in a test plot, then the stalks in the south and north quadrats of each test plot were measured for height and diameter to provide a representative sample.

Test Plot divided into four quadrats

Collecting Measurement Data

Dry Patch - Collecting Measurement Data – June 2017 – Wet Patch

Removal of the Phragmites stalks was done in one of two ways. In Test Section 2 of both the Dry Patch and the Wet Patch Sites, on the scheduled date, each individual stalk was cut at 5 centimetres above the soil surface using secateurs. The stalks were removed from the sites and piled in a remote location. In Test Sections 3, 4, and 5 of both the Dry Patch and the Wet Patch Sites, 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.

Spade removal of Phragmites stalks in Wet Patch – July 2017

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 plants in the area, 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 below the soil surface. In situations where other plant species are present near the Phragmites stalks, it may be necessary to use only 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.

Native Wetland Mint – Selective Spade removal preserved this plant in the Wet Patch

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

Date	Action Taken
May 9 & 10, 2017	Remove standing dead stalks, Replace missing stakes and strings, Obtain soil samples
May 16 & 17, 2017	Collect Rhizome Core Samples from Wet and Dry Patch (25 from each patch)
May 23 & 24, 2017	Data Collection for the Wet and Dry Patches (density, heights and diameters, plant ID)
June 6 & 7, 2017	Data Collection for the Wet and Dry Patches (density, heights and diameters, plant ID)
June 13 & 14, 2017	Spade all stalks in Section 5 of the Wet and Dry Patches
June 27 & 28, 2017	Data Collection for the Wet and Dry Patches (density, heights and diameters, plant ID)
July 4 & 5, 2017	Cut all stalks in Section 2 above the soil surface, Spade all stalks in Sections 3,4 & 5 of the Dry Patch
July 11 & 12, 2017	Cut all stalks in Section 2 above the soil surface, Spade all stalks in Sections 3,4 & 5 of the Wet Patch
July 25 & 26, 2017	Data Collection for the Wet and Dry Patches (density, heights and diameters, plant ID)
August 1 & 2, 2017	Spade all stalks in Sections 4 & 5 of the Wet and Dry Patches
August 15 & 16, 2017	Data Collection for the Wet and Dry Patches (density, heights and diameters, plant ID)
August 22 & 23, 2017	Collect Rhizome Core Samples from Wet and Dry Patch (25 from each patch)
Sept 30, 2017	Observe Test Plots for formation of Flowerheads

Results

Soil Analysis:

Wet Patch: The soil texture results were 56% sand, 40% silt and 4% clay, making this soil texture to be classified as a sandy loam. The soil pH was 6.8 and the organic matter present was 5.3%.
Dry Patch: The soil texture results were 50% sand, 43% silt and 7% clay, making this soil texture to be classified as a loam. The soil pH was 7.6 and the organic matter present was 11.6%.

Measurement Data:

Phragmites Measurements

Dry Patch May 23, 2017

Test Section 1 - Control

Plot	A	B	C	D
Density (stalks/m^2)	55	85	71	55
Average Height (cm)	64.0	64.3	62.8	64.0
Average Diameter (cm)	0.55	0.58	0.51	0.49

Test Section 2 - Secateur cut 5cm above soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	101	103	96	68
Average Height (cm)	66.3	75.6	74.4	68.9
Average Diameter (cm)	0.44	0.50	0.49	0.45

Test Section 3 - Spade cut 5cm below soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	115	89	93	90
Average Height (cm)	67.4	70.6	70.6	70.1
Average Diameter (cm)	0.51	0.51	0.49	0.53

Test Section 4 - Spade cut 5cm below soil surface in July & August

Plot	A	B	C	D
Density (stalks/m^2)	120	66	92	123
Average Height (cm)	63.8	64.9	70.5	72.4
Average Diameter (cm)	0.37	0.47	0.43	0.49

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

Plot	A	B	C	D
Density (stalks/m^2)	53	70	42	26
Average Height (cm)	75.0	79.1	66.7	67.9
Average Diameter (cm)	0.52	0.50	0.53	0.53

Dry Patch June 6, 2017

Test Section 1 - Control

Plot	A	B	C	D
Density (stalks/m^2)	155	88	75	90
Average Height (cm)	134.5	118.2	121.3	100.7
Average Diameter (cm)	0.63	0.53	0.54	0.43

Test Section 2 - Secateur cut 5cm above soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	106	104	88	66
Average Height (cm)	134.6	136.5	129.2	111.6
Average Diameter (cm)	0.47	0.52	0.48	0.41

Test Section 3 - Spade cut 5cm below soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	133	111	118	98
Average Height (cm)	124.8	124.4	124.5	114.4
Average Diameter (cm)	0.49	0.59	0.52	0.52

Test Section 4 - Spade cut 5cm below soil surface in July & August

Plot	A	B	C	D
Density (stalks/m^2)	151	87	95	150
Average Height (cm)	99.3	107.7	112.8	130.6
Average Diameter (cm)	0.35	0.41	0.39	0.45

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

Plot	A	B	C	D
Density (stalks/m^2)	56	91	54	37
Average Height (cm)	117.4	123.1	123.7	125.4
Average Diameter (cm)	0.55	0.54	0.46	0.48

Dry Patch June 27, 2017

Test Section 1 - Control

Plot	A	B	C	D
Density (stalks/m^2)	99	94	112	67
Average Height (cm)	203.8	183.9	172.4	139.9
Average Diameter (cm)	0.61	0.56	0.56	0.44

Test Section 2 - Secateur cut 5cm above soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	120	89	85	72
Average Height (cm)	192.9	187.2	175.9	165.8
Average Diameter (cm)	0.48	0.49	0.51	0.42

Test Section 3 - Spade cut 5cm below soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	95	66	92	99
Average Height (cm)	179.3	198.7	180.2	192.1
Average Diameter (cm)	0.49	0.54	0.49	0.56

Test Section 4 - Spade cut 5cm below soil surface in July & August

Plot	A	B	C	D
Density (stalks/m^2)	111	71	49	86
Average Height (cm)	152.6	174.4	179.0	190.4
Average Diameter (cm)	0.38	0.49	0.45	0.51

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

Plot	A	B	C	D
Density (stalks/m^2)	0	1	1	1
Average Height (cm)	8	8	8	8
Average Diameter (cm)	NA	NA	NA	NA

Dry Patch July 25, 2017

Test Section 1 - Control

Plot	A	B	C	D
Density (stalks/m^2)	86	77	75	56
Average Height (cm)	203.7	199.8	186.1	146.4
Average Diameter (cm)	0.62	0.57	0.51	0.46

Test Section 2 - Secateur cut 5cm above soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	17	38	21	2
Average Height (cm)	23.6	22.0	27.8	12.5
Average Diameter (cm)	0.27	0.23	0.24	0.15

Test Section 3 - Spade cut 5cm below soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	51	24	53	51
Average Height (cm)	26.8	22.1	27.4	22.3
Average Diameter (cm)	0.32	0.34	0.37	0.35

Test Section 4 - Spade cut 5cm below soil surface in July & August

Plot	A	B	C	D
Density (stalks/m^2)	35	17	40	46
Average Height (cm)	24.7	31.8	26.3	14.4
Average Diameter (cm)	0.26	0.27	0.26	0.26

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

Plot	A	B	C	D
Density (stalks/m^2)	21	12	22	16
Average Height (cm)	58.2	66.9	47.4	79.2
Average Diameter (cm)	0.29	0.31	0.27	0.28

Dry Patch August 15, 2017

Test Section 1 - Control

Plot	A	B	C	D
Density (stalks/m^2)	70	67	60	39
Average Height (cm)	213.5	194.8	179.8	147.9
Average Diameter (cm)	0.66	0.55	0.53	0.45

Test Section 2 - Secateur cut 5cm above soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	29	56	42	11
Average Height (cm)	62.9	71.4	70.9	41.5
Average Diameter (cm)	0.31	0.30	0.27	0.25

Test Section 3 - Spade cut 5cm below soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	79	35	78	69
Average Height (cm)	78.1	82.5	88.6	82.4
Average Diameter (cm)	0.27	0.33	0.35	0.33

Test Section 4 - Spade cut 5cm below soil surface in July & August

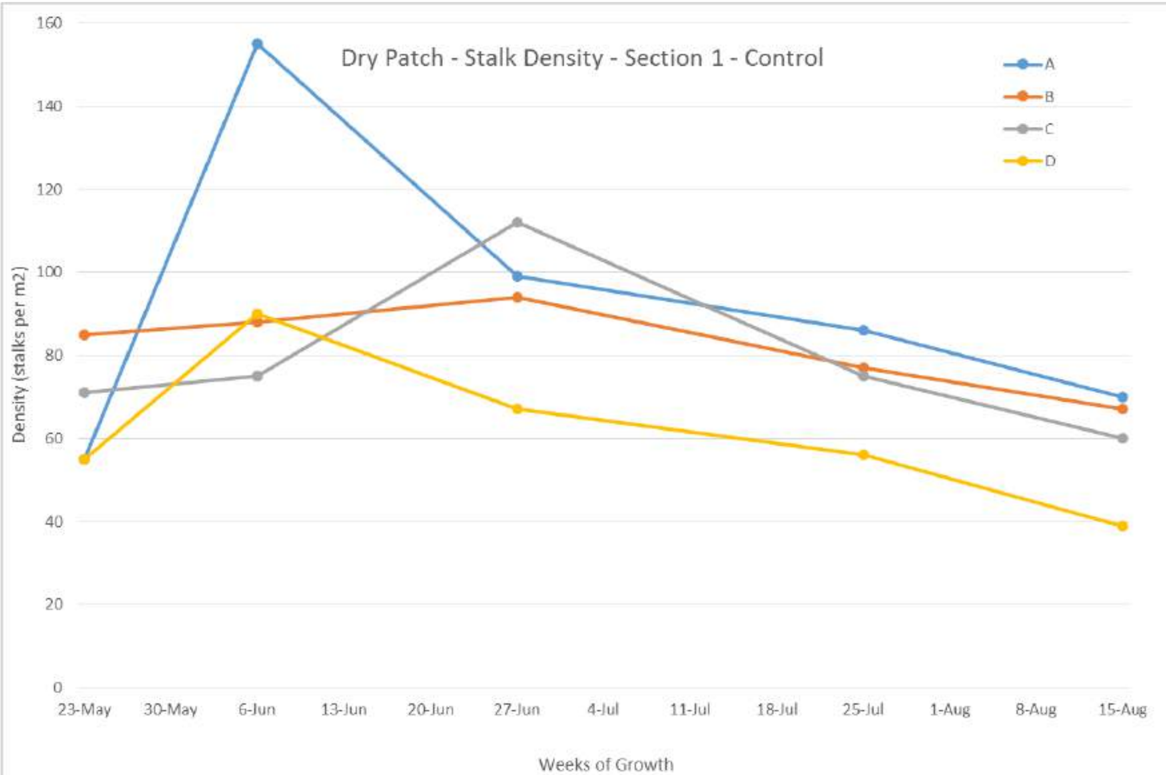
Plot	A	B	C	D
Density (stalks/m^2)	30	22	20	22
Average Height (cm)	35.8	21.1	15.5	11.2
Average Diameter	0.18	0.17	0.20	0.16

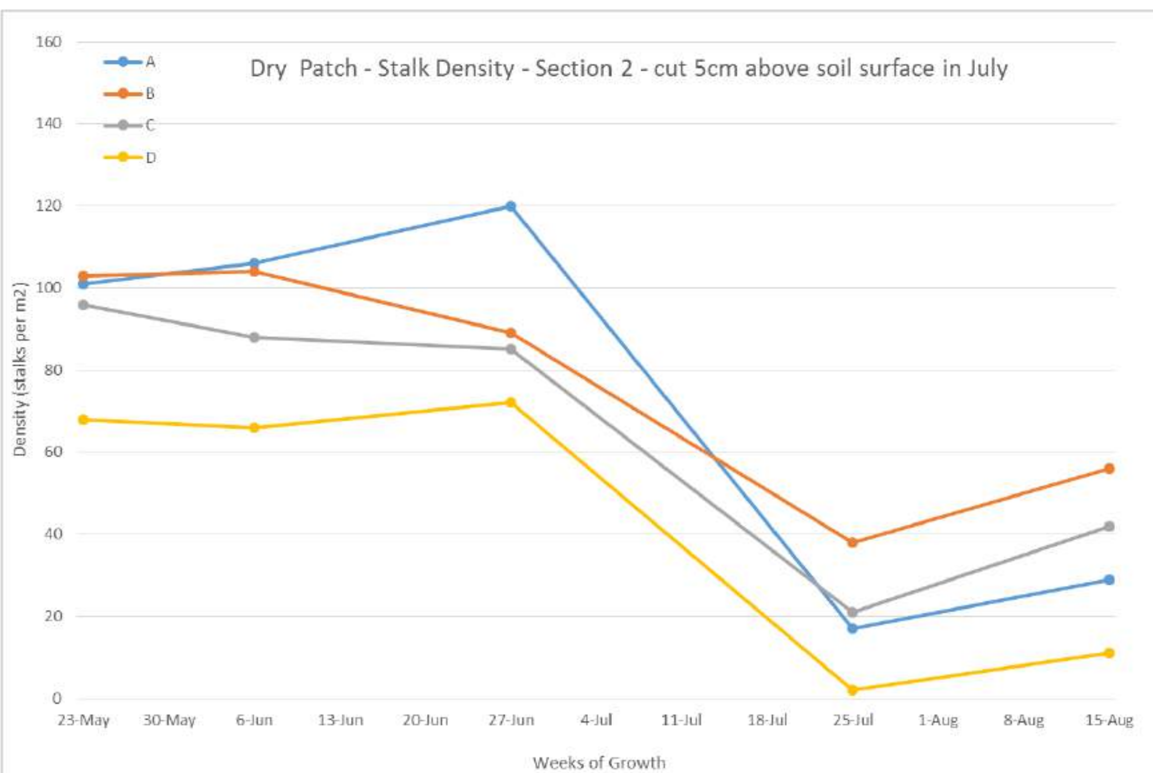
Test Section 5 - Spade cut 5cm below soil surface in June, July & August

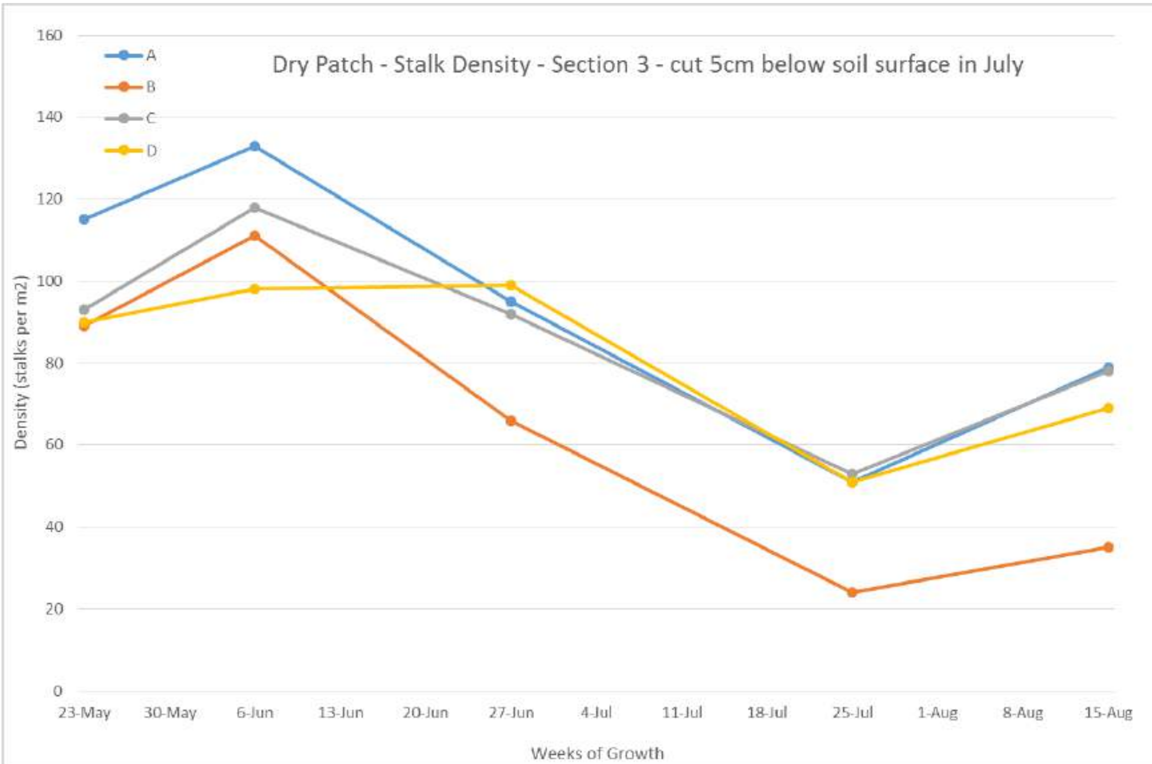
Plot	A	B	C	D
Density (stalks/m^2)	7	9	4	6
Average Height (cm)	36.9	28.1	5.5	30.3
Average Diameter (cm)	0.26	0.23	0.13	0.18

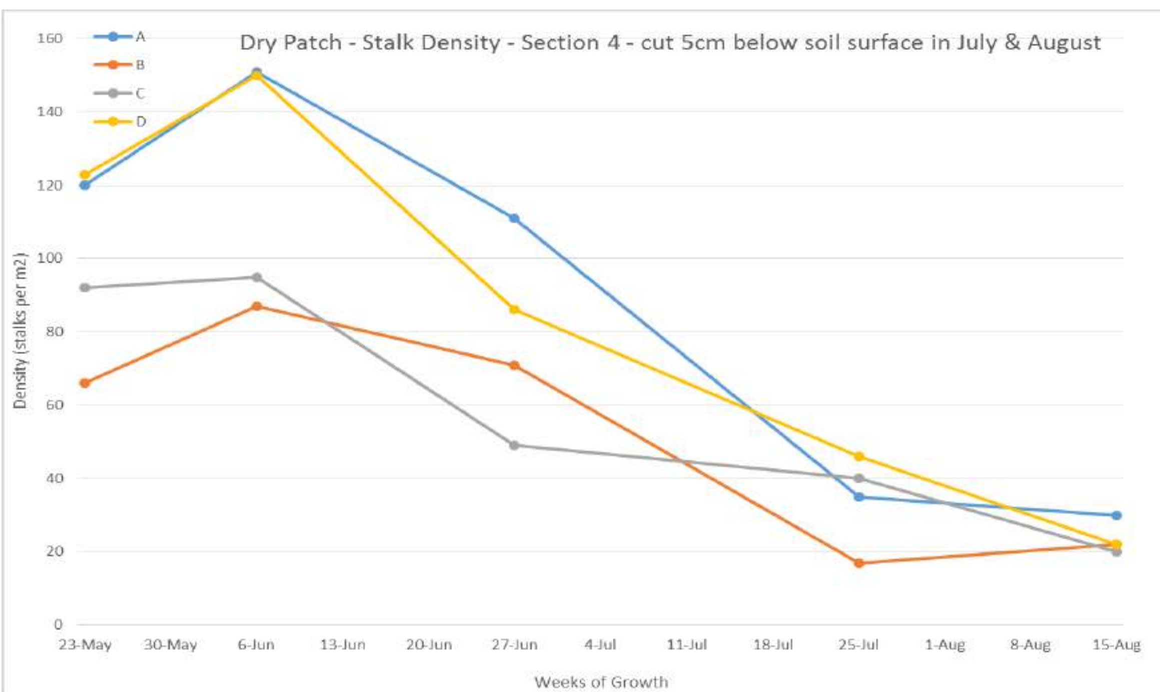
Graphic Representation of Measurement Data for Dry Patch

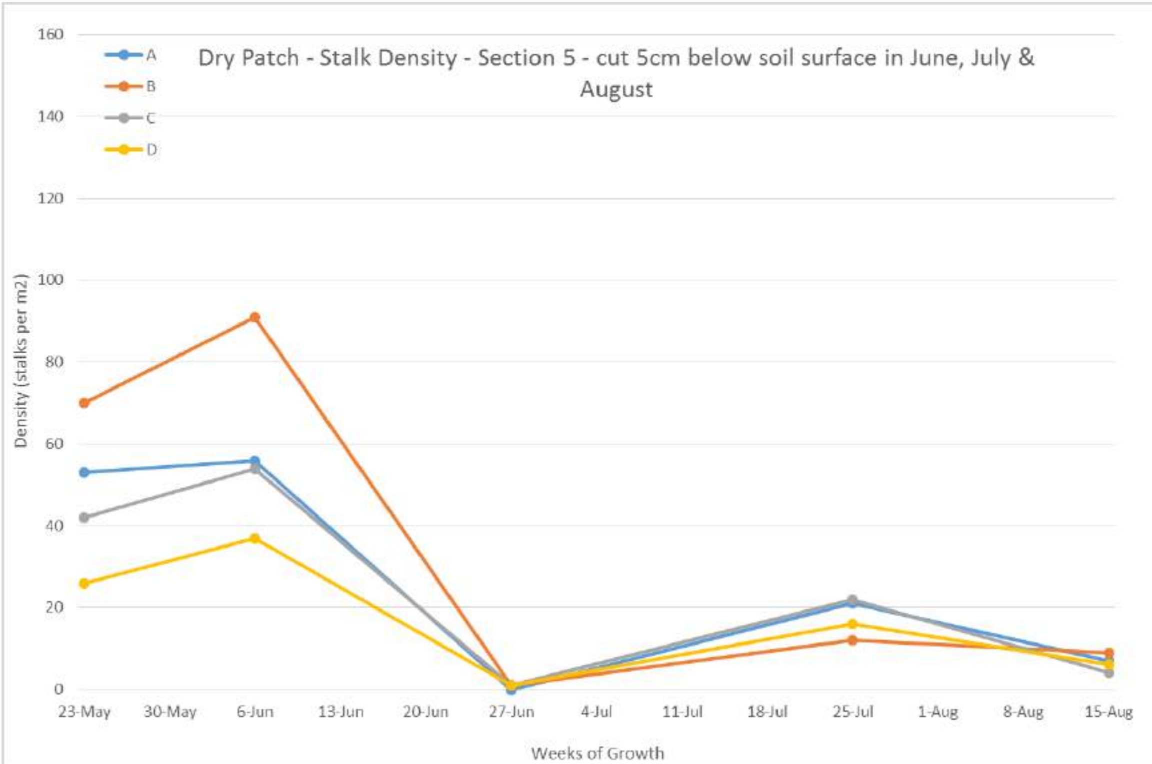
Dry Patch Stalk Density:



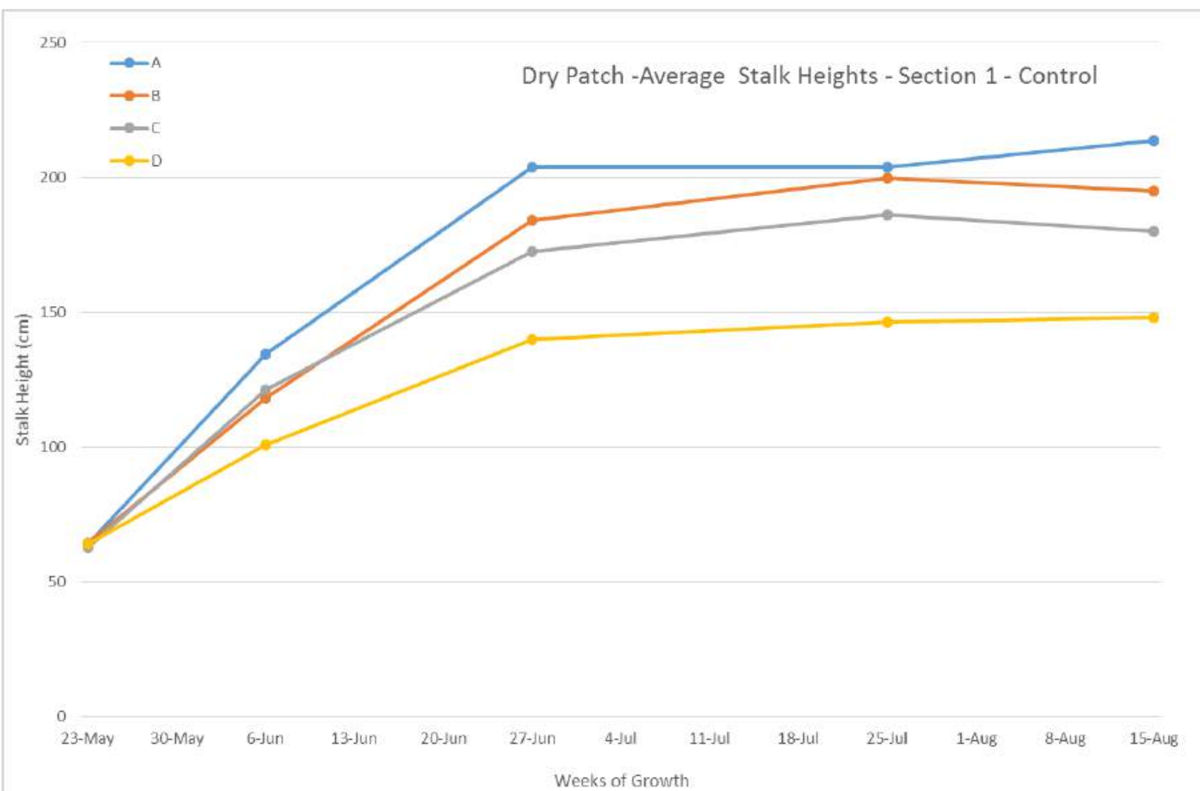


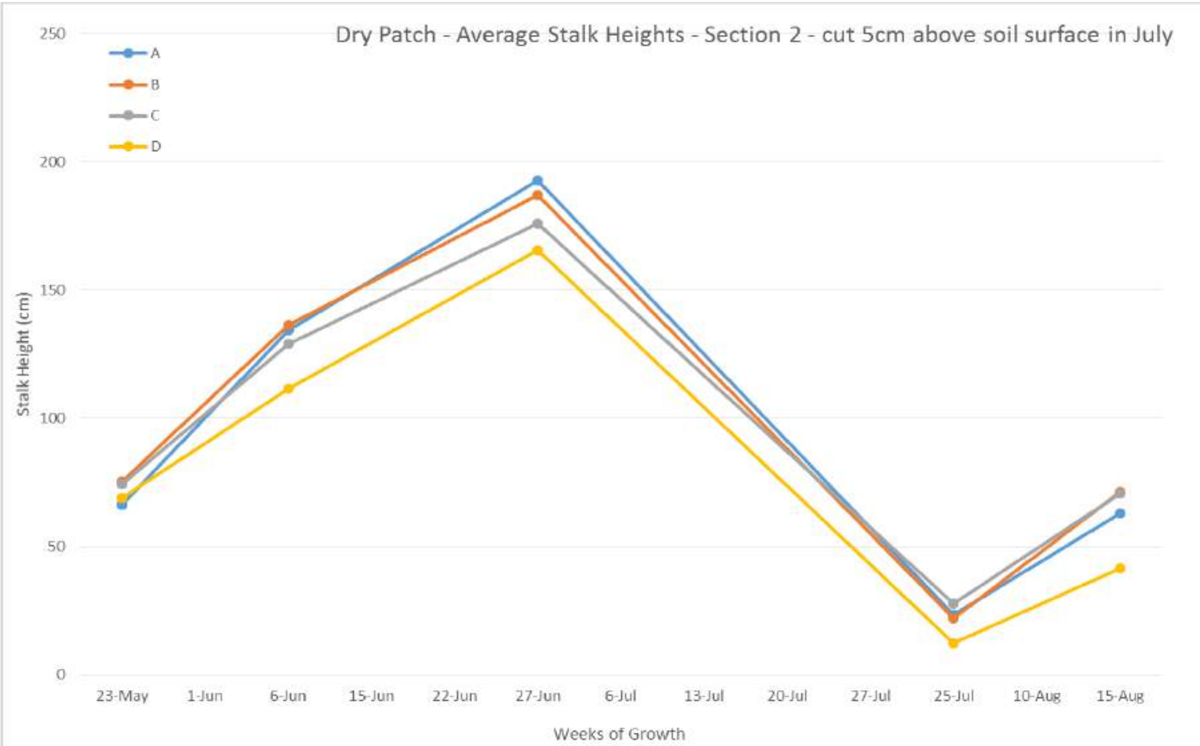

Dry Patch - Stalk Density - Section 3 - cut 5cm below soil surface in July
A
B
C
D
Density (stalks per m2)
Weeks of Growth
23-May 30-May 6-Jun 13-Jun 20-Jun 27-Jun 4-Jul 11-Jul 18-Jul 25-Jul 1-Aug 8-Aug 15-Aug
0 20 40 60 80 100 120 140 160

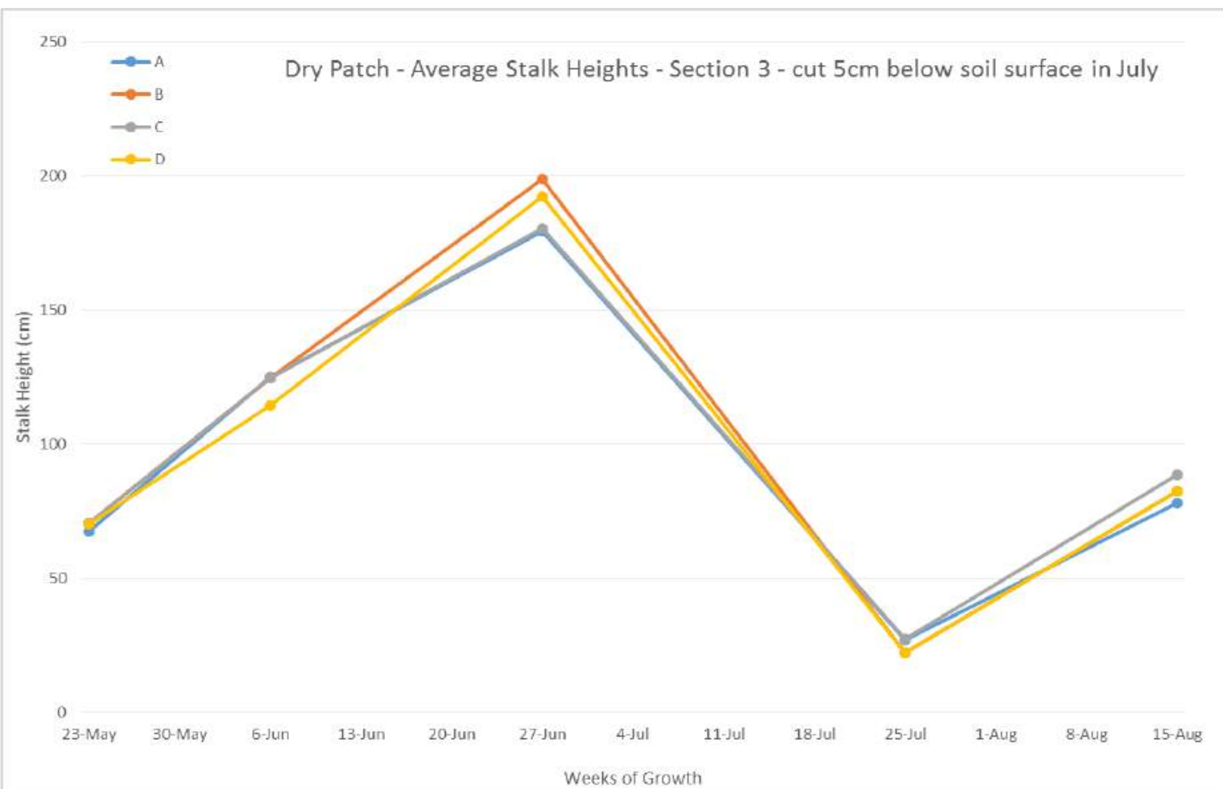

Dry Patch - Stalk Density - Section 4 - cut 5cm below soil surface in July & August
A
B
C
D
Density (stalks per m2)
Weeks of Growth
23-May 30-May 6-Jun 13-Jun 20-Jun 27-Jun 4-Jul 11-Jul 18-Jul 25-Jul 1-Aug 8-Aug 15-Aug
0 20 40 60 80 100 120 140 160

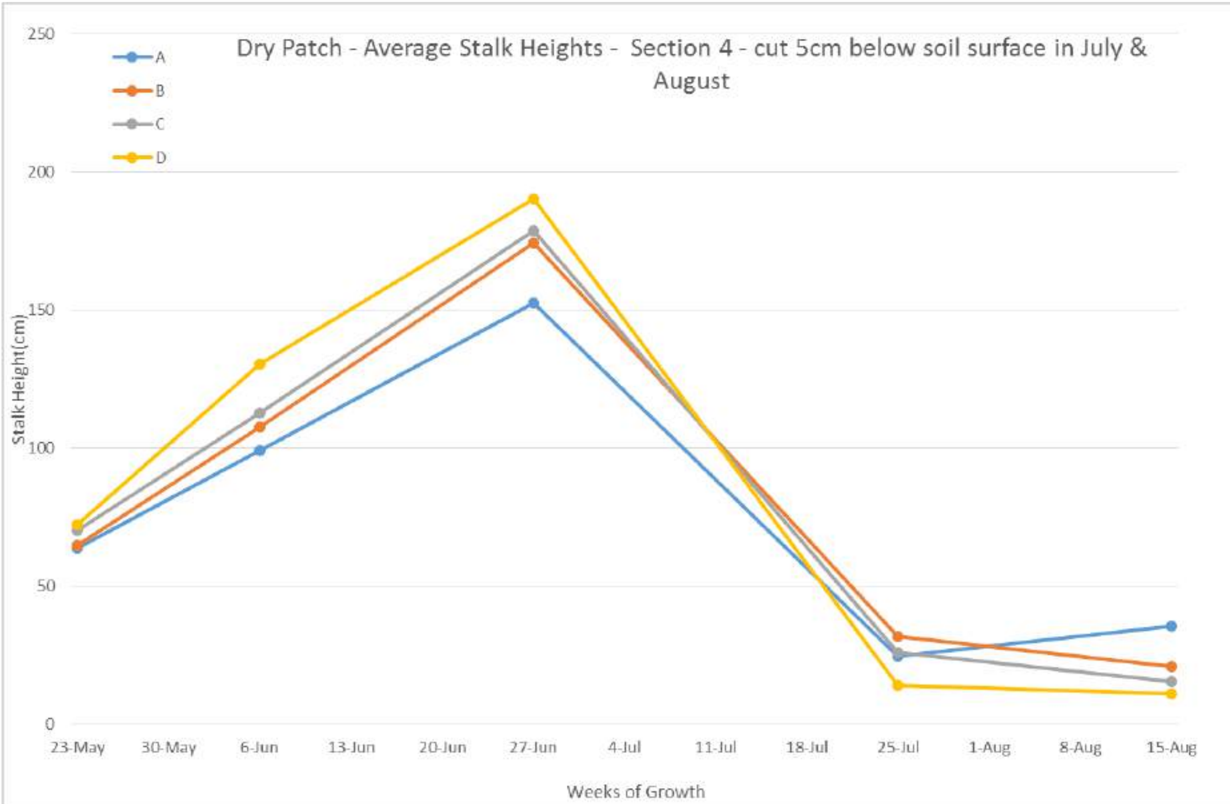


Dry Patch Stalk Heights




Dry Patch - Average Stalk Heights - Section 2 - cut 5cm above soil surface in July
A
B
C
D
250
200
150
100
50
0
Stalk Height (cm)
23-May
1-Jun
6-Jun
15-Jun
22-Jun
27-Jun
6-Jul
13-Jul
20-Jul
27-Jul
25-Jul
10-Aug
15-Aug
Weeks of Growth

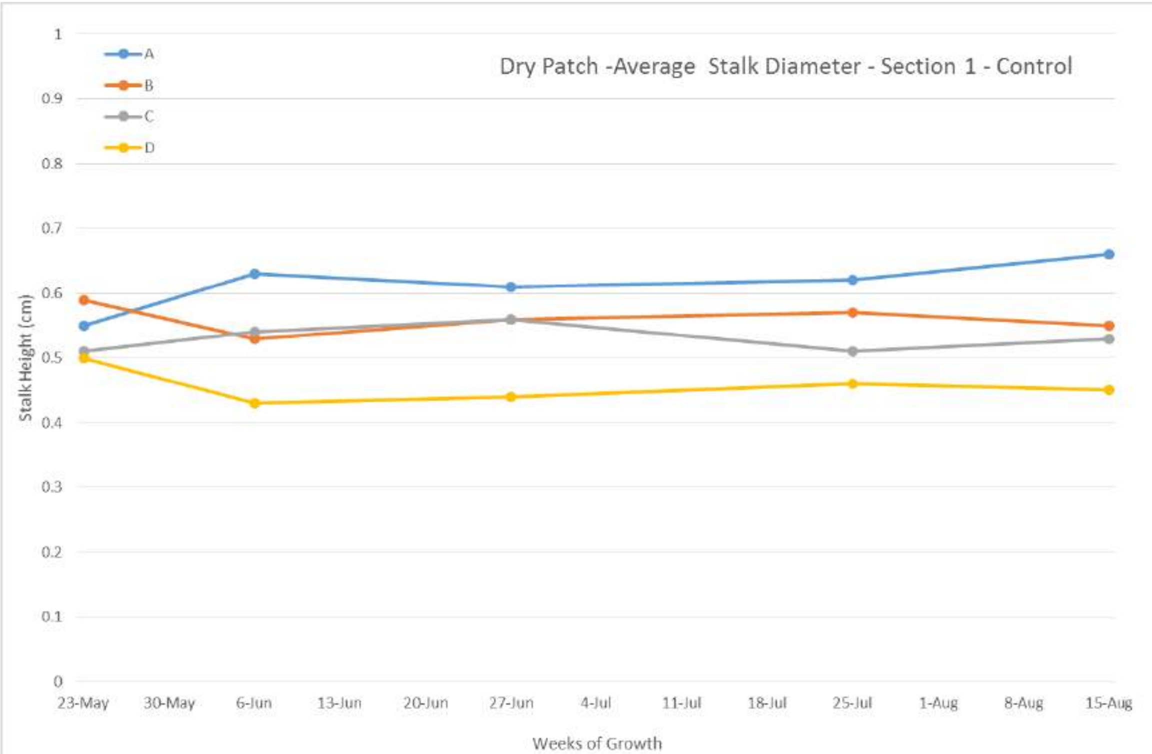

Dry Patch - Average Stalk Heights - Section 3 - cut 5cm below soil surface in July
A
B
C
D
250
200
150
100
50
0
Stalk Height (cm)
23-May
30-May
6-Jun
13-Jun
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
1-Aug
8-Aug
15-Aug
Weeks of Growth

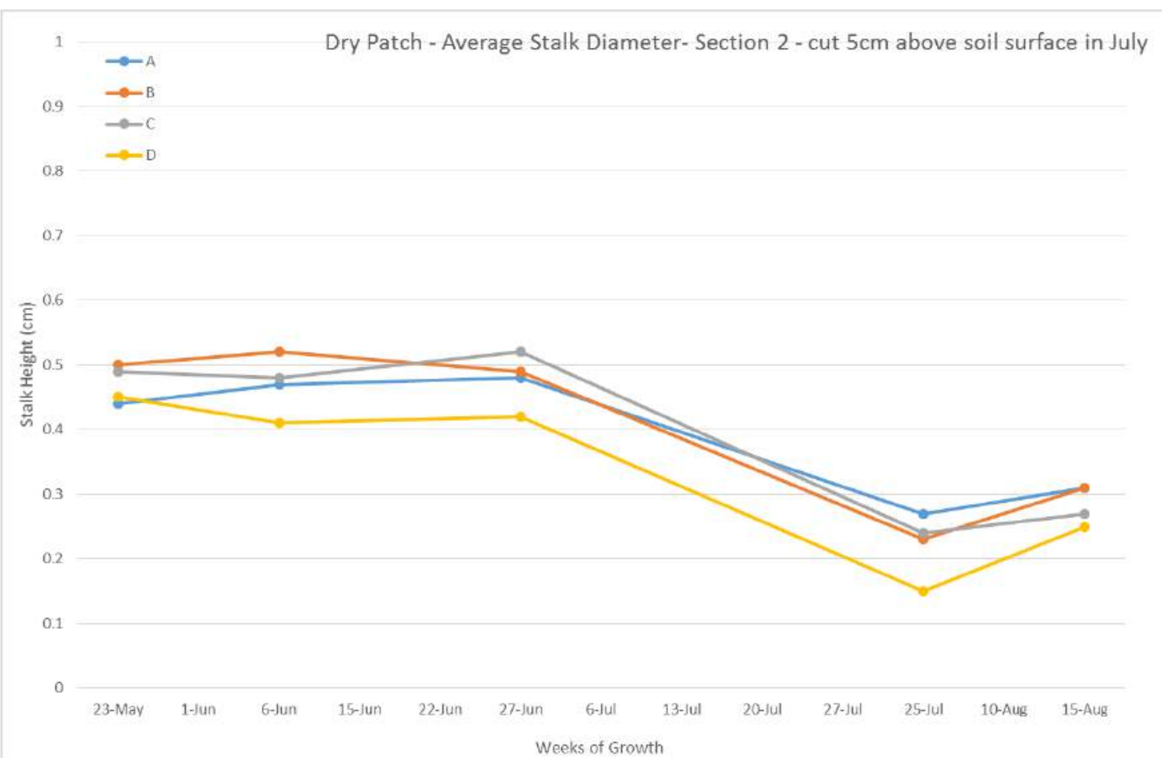


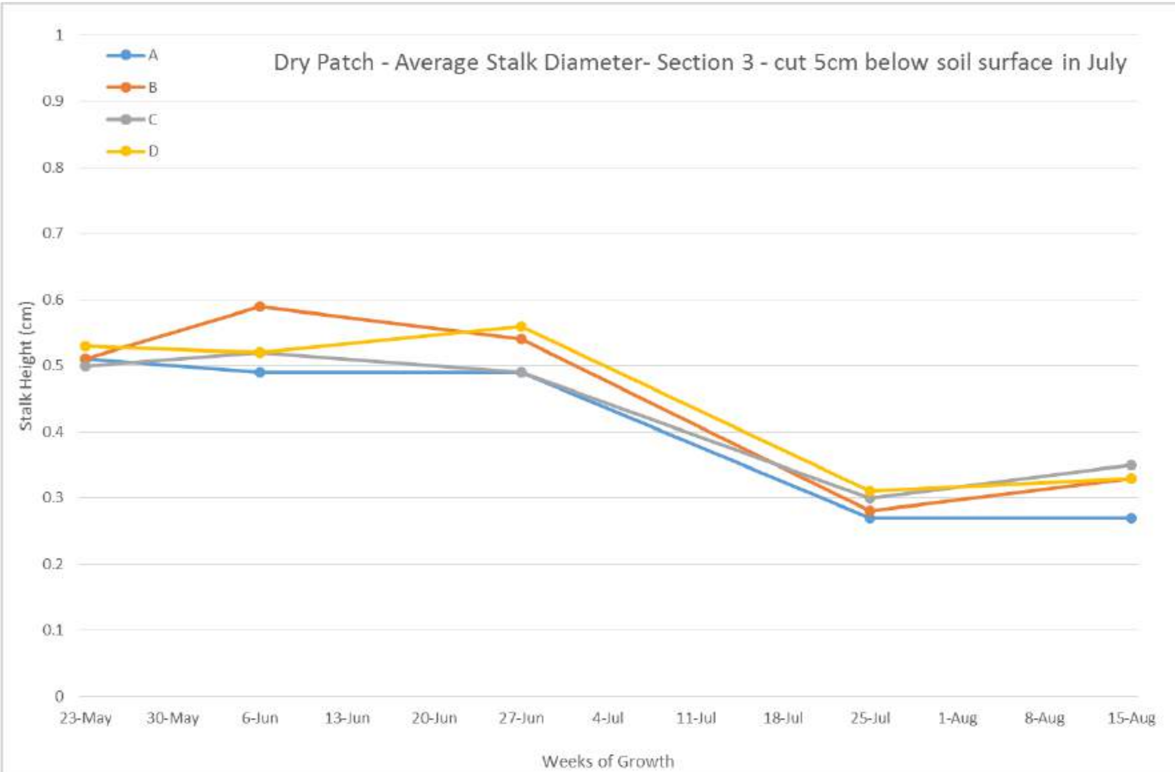
Dry Patch - Average Stalk Heights - Section 4 - cut 5cm below soil surface in July & August
A
B
C
D
Stalk Height (cm)
0
50
100
150
200
250
23-May
30-May
6-Jun
13-Jun
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
1-Aug
8-Aug
15-Aug
Weeks of Growth

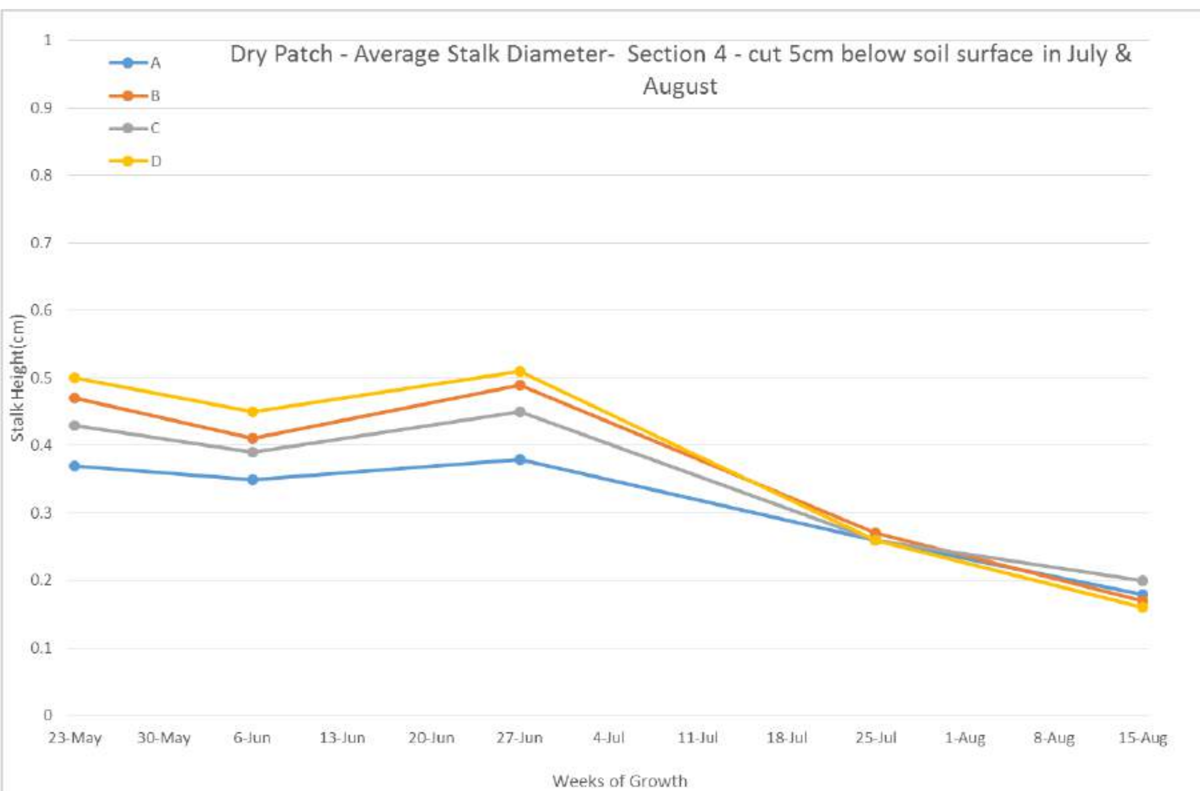
Dry Patch - Average Stalk Heights - Section 5 - cut 5 cm below soil surface in June, July & August
A
B
C
D
Stalk Height (cm)
0
50
100
150
200
250
23-May
30-May
6-Jun
13-Jun
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
1-Aug
8-Aug
15-Aug
Weeks of Growth

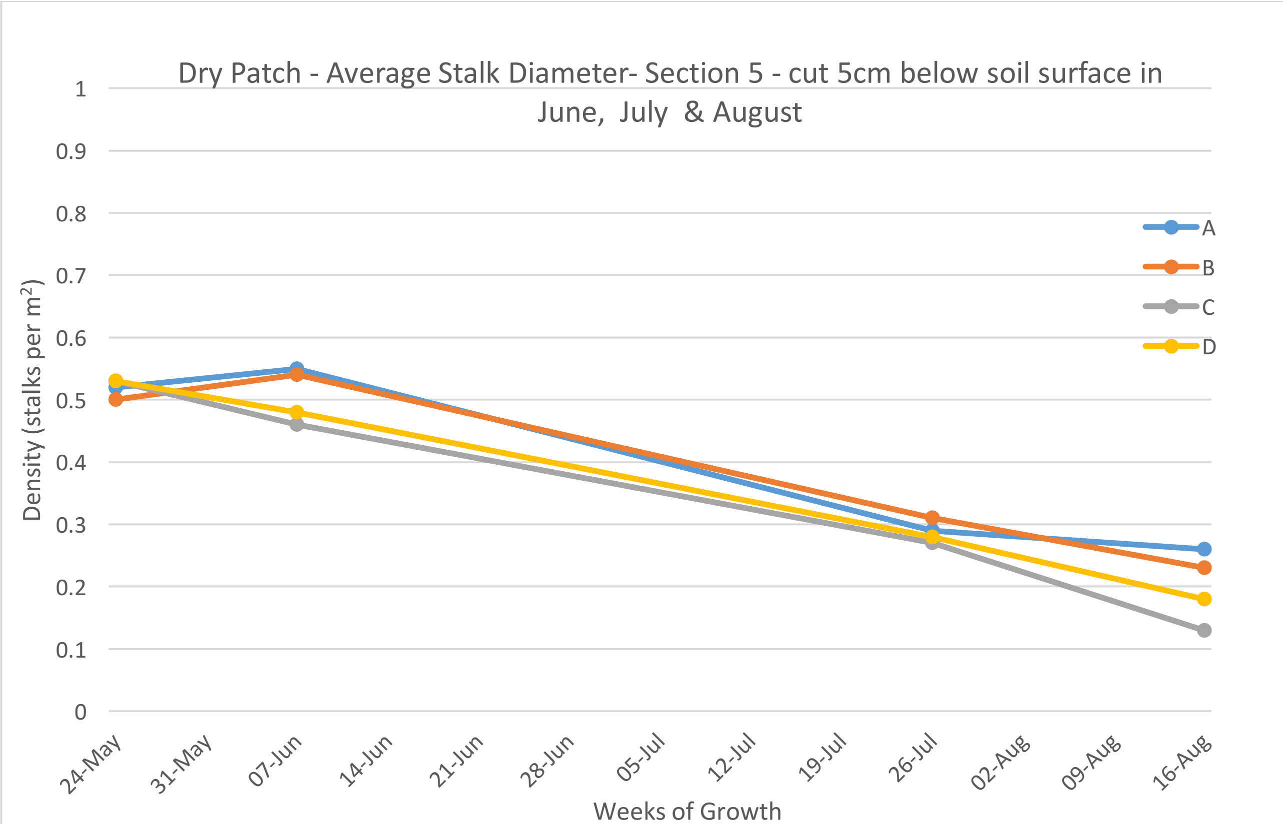
Dry Patch Stalk Diameters






Dry Patch - Average Stalk Diameter- Section 3 - cut 5cm below soil surface in July
A
B
C
D
Stalk Height (cm)
Weeks of Growth
23-May
30-May
6-Jun
13-Jun
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
1-Aug
8-Aug
15-Aug


Dry Patch - Average Stalk Diameter- Section 4 - cut 5cm below soil surface in July & August
A
B
C
D
Stalk Height(cm)
Weeks of Growth
23-May
30-May
6-Jun
13-Jun
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
1-Aug
8-Aug
15-Aug


Dry Patch - Average Stalk Diameter- Section 5 - cut 5cm below soil surface in June, July & August
Density (stalks per m2)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
24-May
31-May
07-Jun
14-Jun
21-Jun
28-Jun
05-Jul
12-Jul
19-Jul
26-Jul
02-Aug
09-Aug
16-Aug
Weeks of Growth
A
B
C
D

Dry Patch Plant Species Data - Summer 2017

Section 1 – Control – Total number in test plots A, B, C, D

	Plant Species	May 23	June 6	June 27	July 25	Aug 15
1	Burdock	40	19	3	3	14
2	Dandelion	2	1			
3	Catnip	4	3	2	3	3
4	Dame's Rocket	70	53	26	11	17
5	Motherwort	8	5	2	3	8
6	Common Vetch	4	6			
7	Wintercress	2	1			
8	Wild Parsnip	7	4	4	7	9
9	Spiny Plumeless Thistle	3	5	3	3	5
10	Sweet Clover	3				
11	Butter and Eggs	3				
12	Garlic Mustard	250	86	28	23	21
13	Canada Thistle	3	1			
14	Bull Thistle					
15	Queen Anne's Lace					
16	Aster	2				19
17	Teasel					
18	Curly Dock					
19	DSV					2
20	Mullein					
21	Poplar Sprout					
22	Grasses					6
23	Bitter Nightshade					10
24	"stick to your socks" plant					
25	Barren Strawberry					
26	Grape Vine seedling					
27	Yellow Wood Sorrel					
28	Cinquefoil					
29	Raspberry Seedlings					1
30	Evening Primrose					
31	Daisy Fleabane	3				
32	Canada Goldenrod	5				
33	Manitoba Maple	1	1	**1**	**1**	**1**
34	Phragmites	319	408	**372**	**294**	**236**
	Number of species	**18**	**13**	**9**	**9**	**14**

Dry Patch Plant Species Data - Summer 2017

Section 2 – 5cm above soil, once - Total number in test plots A, B, C, D

	Plant Species	May 23	June 6	June 27	July 25	Aug 15
1	Burdock	42	14	10	23	30
2	Dandelion	7				
3	Catnip	2		3	2	4
4	Dame's Rocket	77	54	29	18	29
5	Motherwort	3	1	1	1	3
6	Common Vetch	13	7	3		
7	Wintercress	5	2			
8	Wild Parsnip	9	6	8	14	9
9	Spiny Plumeless Thistle	10	27	16	23	20
10	Sweet Clover	1	1			
11	Butter and Eggs					
12	Garlic Mustard	14	2		3	
13	Canada Thistle	7	1	2	6	6
14	Bull Thistle					
15	Queen Anne's Lace	2	1	1	2	2
16	Aster	15			5	21
17	Teasel	2	5	2	1	1
18	Curly Dock					
19	DSV					2
20	Mullein					
21	Poplar Sprout				1	
22	Grasses					
23	Bitter Nightshade					
24	"stick to your socks"					1
25	Barren Strawberry					
26	Grape Vine seedling					
27	Yellow Wood Sorrel					
28	Cinquefoil				2	1
29	Raspberry Seedlings				1	1
30	Evening Primrose					
31	Daisy Fleabane					
32	Canada Goldenrod	12	1	1	2	14
33	Manitoba Maple	1			4	1
34	Phragmites	368	364	366	78	138
	Number of species	**17**	**14**	**12**	**17**	**17**

Dry Patch Plant Species Data - Summer 2017

Section 3 - 5cm below soil, once - Total number in test plots A, B, C, D

	Plant Species	May 23	June 6	June 27	July 25	Aug 15
1	Burdock	20	17	8	17	35
2	Dandelion					
3	Catnip	44	30	19	15	19
4	Dame's Rocket	92	53	17	12	17
5	Motherwort	12	1	5	4	7
6	Common Vetch	1				
7	Wintercress	4	1			
8	Wild Parsnip	4	6	4	3	2
9	Spiny Plumeless Thistle	3	3	2	3	3
10	Sweet Clover					
11	Butter and Eggs					
12	Garlic Mustard	1			5	12
13	Canada Thistle	7	5		2	3
14	Bull Thistle					
15	Queen Anne's Lace					
16	Aster	20		3	11	16
17	Teasel					
18	Curly Dock	2				
19	DSV				2	2
20	Mullein					
21	Poplar Sprout					
22	Grasses					
23	Bitter Nightshade					
24	"stick to your socks"					
25	Barren Strawberry					1
26	Grape Vine seedling					
27	Yellow Wood Sorrel					2
28	Cinquefoil					
29	Raspberry Seedlings					
30	Evening Primrose					
31	Daisy Fleabane					
32	Canada Goldenrod	25			5	13
33	Manitoba Maple	1			5	1
34	Phragmites	387	460	352	179	261
	Number of species	**15**	**9**	**8**	**13**	**15**

Dry Patch Plant Species Data - Summer 2017

Section 4 - 5cm below soil, twice - Total number in test plots A, B, C, D

	Plant Species	May 23	June 6	June 27	July 25	Aug 15
1	Burdock	19	8	4	9	22
2	Dandelion	10				1
3	Catnip	31	47	17	18	20
4	Dame's Rocket	89	68	16	21	22
5	Motherwort	10	8	5	7	11
6	Common Vetch	7	8	3	2	2
7	Wintercress	14	2			
8	Wild Parsnip	1			3	3
9	Spiny Plumeless Thistle	1	1	1	1	1
10	Sweet Clover	1				
11	Butter and Eggs					
12	Garlic Mustard				10	7
13	Canada Thistle	36	23	14	17	15
14	Bull Thistle					
15	Queen Anne's Lace					
16	Aster	13			11	8
17	Teasel					
18	Curly Dock	2	1	1	1	1
19	DSV				1	
20	Mullein	10				
21	Poplar Sprout					
22	Grasses					
23	Bitter Nightshade					
24	"stick to your socks"					
25	Barren Strawberry					
26	Grape Vine seedlng					2
27	Yellow Wood Sorrel					
28	Cinquefoil					1
29	Raspberry Seedlings					
30	Evening Primrose	1	1			
31	Daisy Fleabane	2				
32	Canada Goldenrod	96	35	27	31	19
33	Manitoba Maple				4	2
34	Phragmites	401	483	317	138	94
	Number of species	**18**	**12**	**10**	**15**	**17**

Dry Patch Plant Species Data – Summer 2017

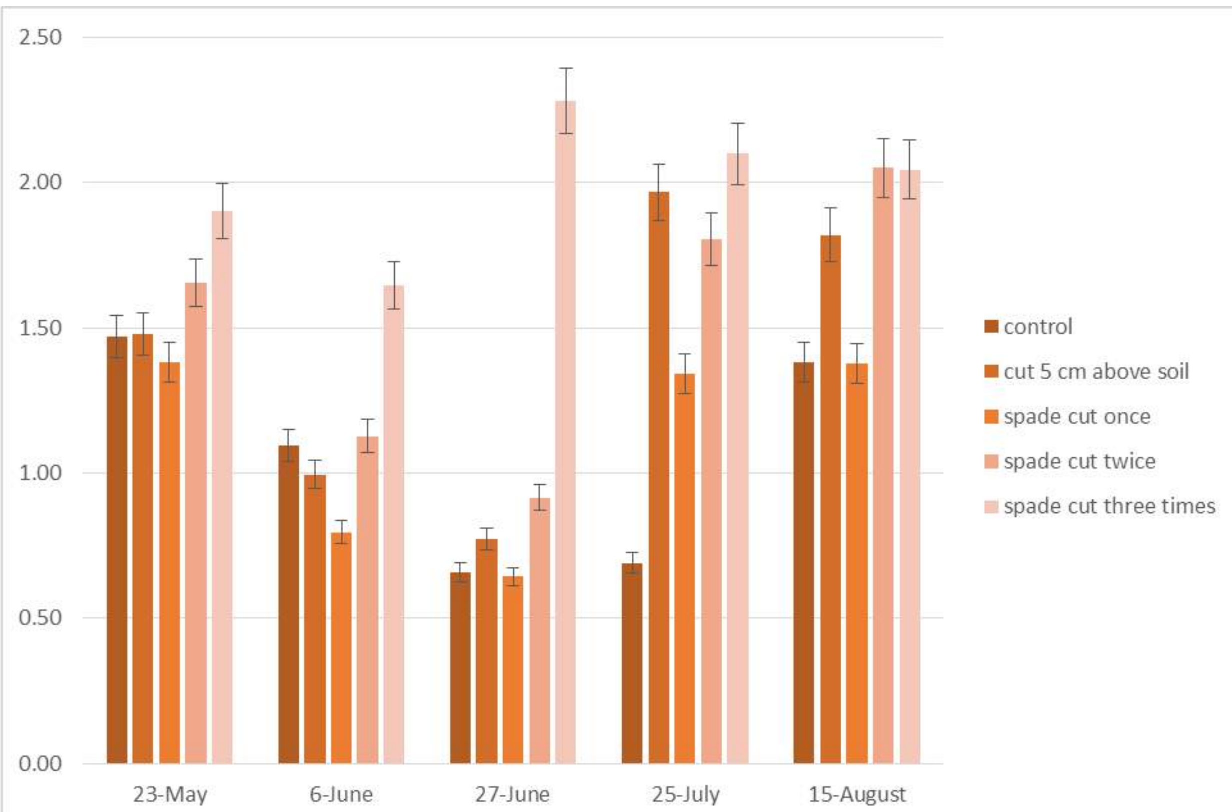
Section 5 - 5 cm below soil, three times – Total Number in test plots A, B, C, D

	Plant Species	May 23	June 6	June 27	July 25	Aug 15
1	Burdock	4	2	2	4	4
2	Dandelion	3				1
3	Catnip	10	17	15	11	12
4	Dame's Rocket	50	37	24	12	24
5	Motherwort	16	10	8	7	19
6	Common Vetch	20	10	5	5	2
7	Wintercress	10	5	5	2	2
8	Wild Parsnip	7	7	7	5	6
9	Spiny Plumeless Thistle	1	1	1	1	1
10	Sweet Clover					
11	Butter and Eggs					
12	Garlic Mustard	4			10	
13	Canada Thistle	27	16	10	5	4
14	Bull Thistle	1	2	2	3	3
15	Queen Anne's Lace					
16	Aster	14	7	7	10	19
17	Teasel					
18	Curly Dock	4	5	2	2	2
19	DSV				3	
20	Mullein	6	5	5	5	4
21	Poplar Sprout					
22	Grasses					
23	Bitter Nightshade					
24	"stick to your socks"					
25	Barren Strawberry					
26	Grape Vine seedling					
27	Yellow Wood Sorrel					
28	Cinquefoil				5	
29	Raspberry Seedlings					
30	Evening Primrose	1	1			
31	Daisy Fleabane		2			
32	Canada Goldenrod	129	73	35	84	85
33	Manitoba Maple				4	1
34	Phragmites	191	238	3	71	26
	Number of species	**18**	**17**	**15**	**19**	**17**

Table 1. Summary of Shannon Index Values for the Humberwood Dry Site, Summer 2017

Plot	23-May	6-June	27-June	25-July	15-August
control	1.47	1.09	0.66	0.69	1.38
cut 5 cm above soil	1.48	0.99	0.77	1.97	1.82
spade cut once	1.38	0.80	0.64	1.34	1.38
spade cut twice	1.65	1.13	0.92	1.80	2.05
spade cut three times	1.90	1.65	2.28	2.10	2.04

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



Phragmites Measurement Data
Wet Patch May 24, 2017

Test Section 1 - Control

Plot	A	B	C	D
Density (stalks/m^2)	58	70	90	65
Average Height (cm)	72.5	66.4	91.7	102.1
Average Diameter (cm)	0..60	0.46	0.64	0.67

Test Section 2 – Secateur cut 5cm above soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	77	57	100	71
Average Height (cm)	86.4	83.8	80.6	103.8
Average Diameter (cm)	0.54	0.43	0.45	0.52

Test Section 3 - Spade cut 5cm below soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	61	87	17	47
Average Height (cm)	80.5	76.5	53.0	82.8
Average Diameter (cm)	0.61	0.54	0.46	0.64

Test Section 4 - Spade cut 5cm below soil surface in July & August

Plot	A	B	C	D
Density (stalks/m^2)	43	44	92	51
Average Height (cm)	75.7	69.3	78.4	86.7
Average Diameter (cm)	0.60	0.55	0.50	0.62

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

Plot	A	B	C	D
Density (stalks/m^2)	19	53	137	113
Average Height (cm)	87.3	76.2	70.1	86.1
Average Diameter (cm)	0.67	0.57	0.52	0.70

Wet Patch June 7, 2017

Test Section 1 - Control

Plot	A	B	C	D
Density (stalks/m^2)	63	64	100	64
Average Height (cm)	129.9	120.4	161.4	166.7
Average Diameter (cm)	0.62	0.54	0.61	0.66

Test Section 2 – Secateur cut 5cm above soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	85	75	102	78
Average Height (cm)	132.2	129.6	123.0	147.1
Average Diameter (cm)	0.53	0.54	0.55	0.60

Test Section 3 - Spade cut 5cm below soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	91	124	36	51
Average Height (cm)	101.6	116.9	80.7	132.5
Average Diameter (cm)	0.43	0.53	0.42	0.59

Test Section 4 - Spade cut 5cm below soil surface in July & August

Plot	A	B	C	D
Density (stalks/m^2)	97	67	132	87
Average Height (cm)	102.6	104.5	102.9	46.6
Average Diameter (cm)	0.57	0.53	0.49	0.56

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

Plot	A	B	C	D
Density (stalks/m^2)	29	135	142	116
Average Height (cm)	111.8	96.2	128.1	122.4
Average Diameter (cm)	0.56	0.52	0.50	0.69

Wet Patch June 28, 2017

Test Section 1 - Control

Plot	A	B	C	D
Density (stalks/m^2)	63	87	105	64
Average Height (cm)	185.0	167.9	220.4	235.6
Average Diameter (cm)	0.57	0.54	0.64	0.76

Test Section 2 - Secateur cut 5cm above soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	75	64	101	74
Average Height (cm)	182.1	179.3	198.6	210.9
Average Diameter (cm)	0.62	0.58	0.55	0.60

Test Section 3 - Spade cut 5cm below soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	70	110	49	147
Average Height (cm)	172.8	171.9	113.4	178.9
Average Diameter (cm)	0.60	0.55	0.48	0.58

Test Section 4 - Spade cut 5cm below soil surface in July & August

Plot	A	B	C	D
Density (stalks/m^2)	49	52	83	55
Average Height (cm)	183.2	152.0	163.4	171.7
Average Diameter (cm)	0.70	0.56	0.57	0.60

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

Plot	A	B	C	D
Density (stalks/m^2)	3	6	0	0
Average Height (cm)	63.2	74.8	NA	NA
Average Diameter (cm)	0.33	0.53	NA	NA

Wet Patch July 26, 2017

Test Section 1 - Control

Plot	A	B	C	D
Density(stalks/m^2)	60	88	98	65
Average Height (cm)	222.3	196.8	245.3	267.6
Average Diameter (cm)	0.59	0.54	0.68	0.73

Test Section 2 - Secateur cut 5cm above soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	0	3	0	0
Average Height (cm)	NA	39.8	NA	NA
Average Diameter (cm)	NA	0.47	NA	NA

Test Section 3 - Spade cut 5cm below soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	8	35	12	4
Average Height (cm)	12.1	15.4	24.6	9.25
Average Diameter (cm)	0.35	0.37	0.39	0.23

Test Section 4 - Spade cut 5cm below soil surface in July & August

Plot	A	B	C	D
Density (stalks/m^2)	7	6	25	4
Average Height (cm)	22.5	24.0	12.0	11.3
Average Diameter (cm)	0.31	0.35	0.26	0.25

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

Plot	A	B	C	D
Density (stalks/m^2)	9	10	23	3
Average Height (cm)	72.0	55.1	24.7	31.5
Average Diameter (cm)	0.41	0.41	0.32	0.37

Wet Patch August 16, 2017

Test Section 1 - Control

Plot	A	B	C	D
Density (stalks/m^2)	69	67	94	63
Average Height (cm)	224.3	198.4	252.6	265.9
Average (cm)	0.56	0.51	0.60	0.64

Test Section 2 - Secateur cut 5cm above soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	2	3	0	0
Average Height (cm)	51.0	98.0	NA	NA
Average Diameter (cm)	0.30	0.50	NA	NA

Test Section 3 - Spade cut 5cm below soil surface in July

Plot	A	B	C	D
Density (stalks/m^2)	18	53	21	6
Average Height (cm)	75.6	73.0	80.8	39.6
Average Diameter (cm)	0.45	0.42	0.45	0.35

Test Section 4 - Spade cut 5cm below soil surface in July & August

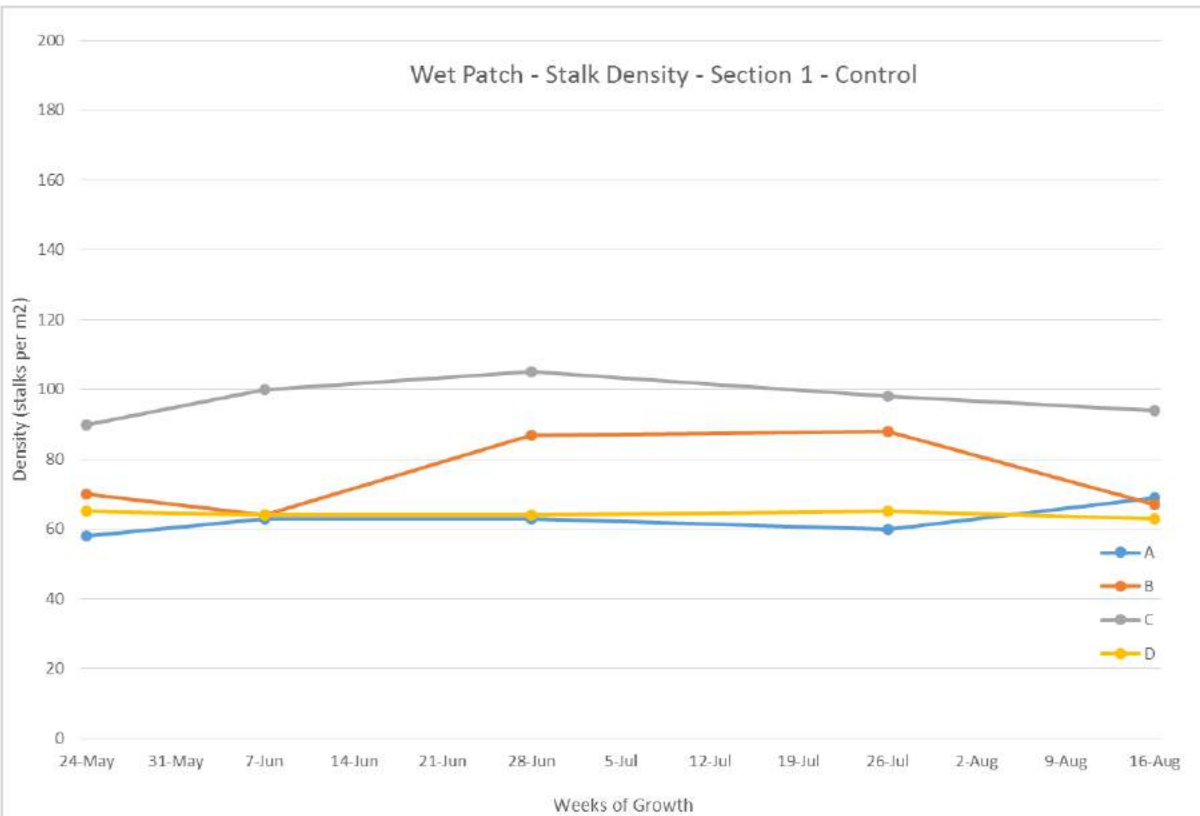
Plot	A	B	C	D
Density (stalks/m^2)	14	16	18	8
Average Height (cm)	51.6	50.9	39.0	53.4
Average Diameter (cm)	0.41	0.39	0.38	0.41

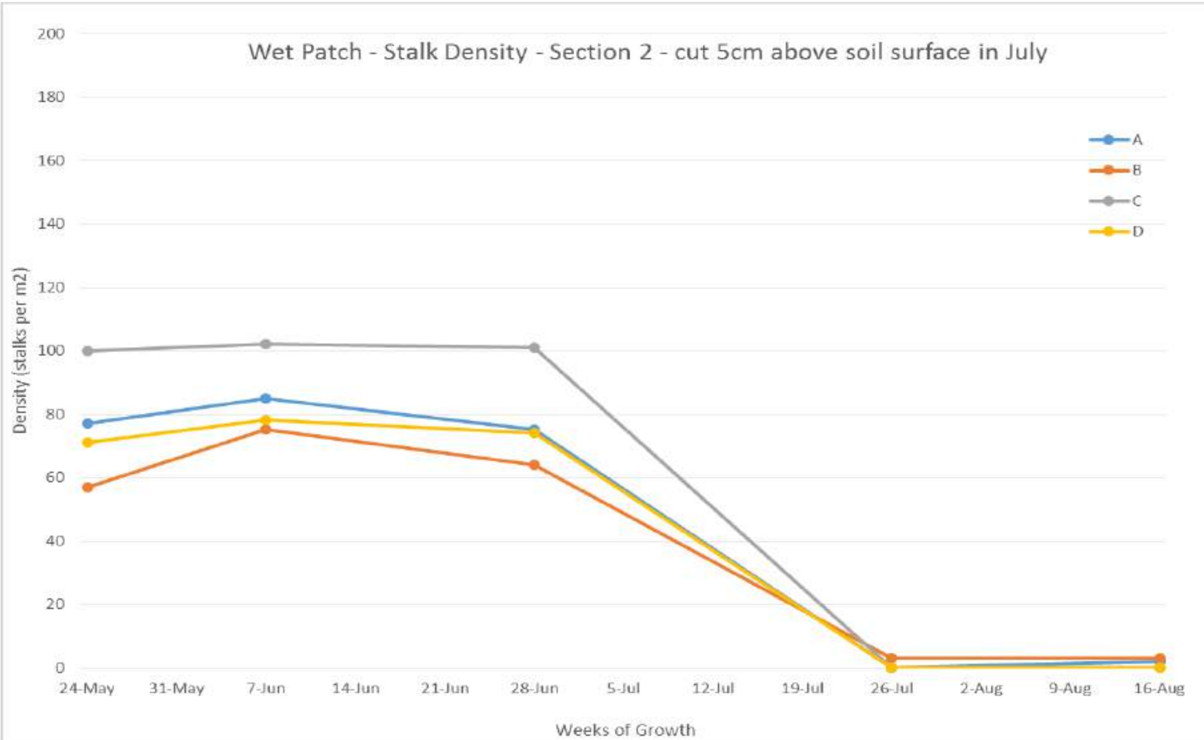
Test Section 5 - Spade cut 5cm below soil surface in June, July & August

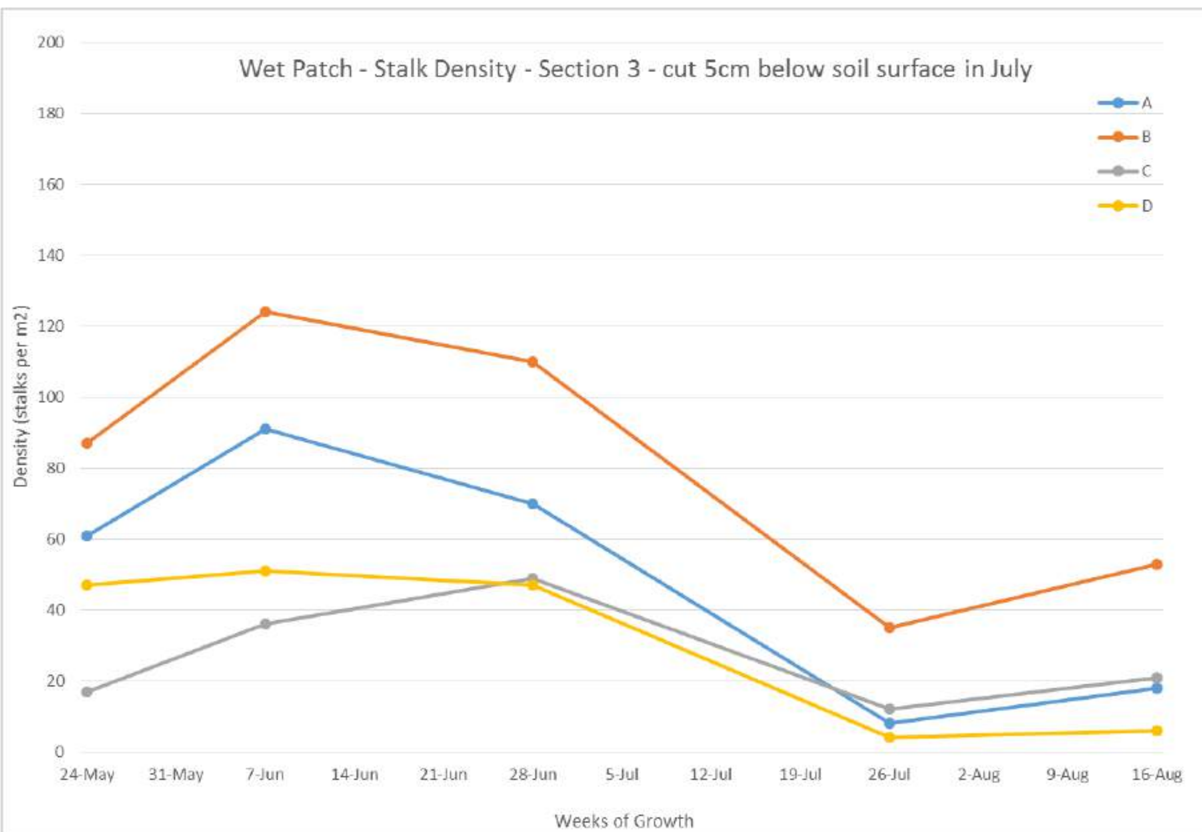
Plot	A	B	C	D
Density (stalks/m^2)	11	19	12	0
Average Height (cm)	33.1	42.9	27.3	NA
Average Diameter (cm)	0.16	0.30	0.33	NA

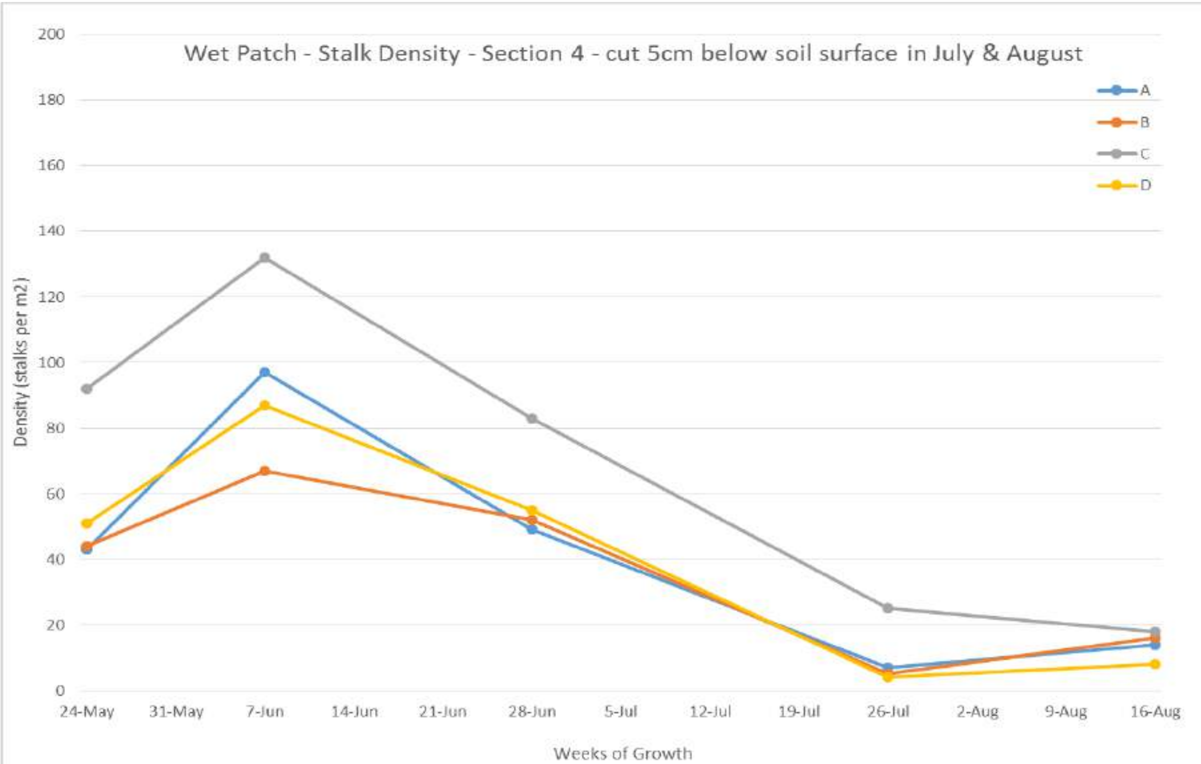
Graphic Representation of Measurement Data for Wet Patch

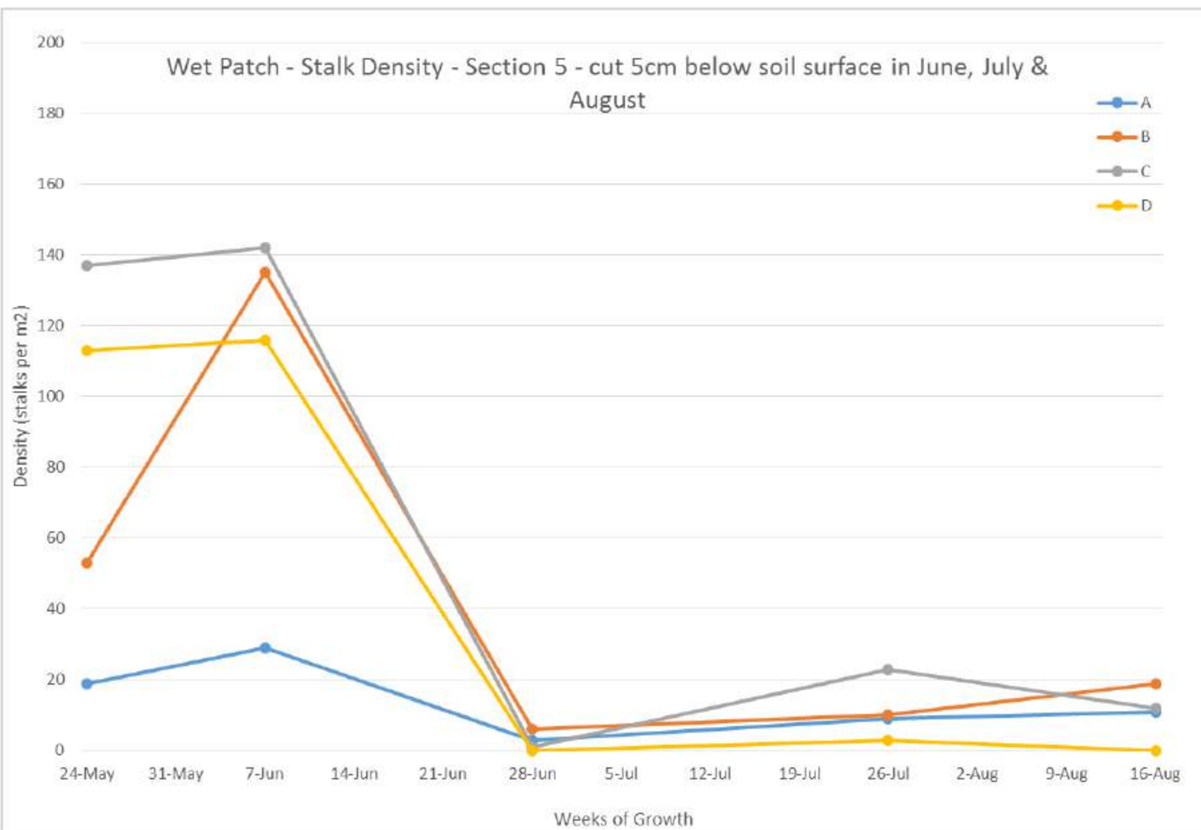
Wet Patch Stalk Density



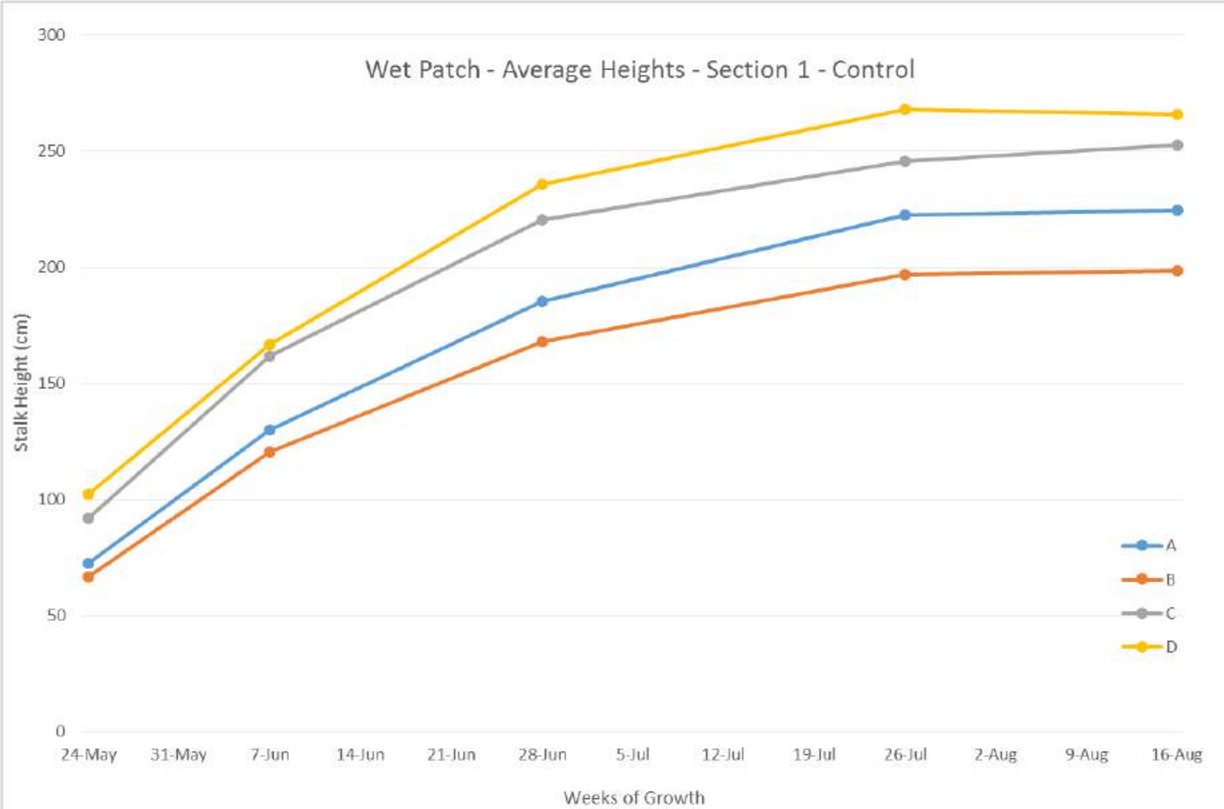

Wet Patch - Stalk Density - Section 2 - cut 5cm above soil surface in July
Density (stalks per m2)
Weeks of Growth
A
B
C
D
0
20
40
60
80
100
120
140
160
180
200
24-May
31-May
7-Jun
14-Jun
21-Jun
28-Jun
5-Jul
12-Jul
19-Jul
26-Jul
2-Aug
9-Aug
16-Aug

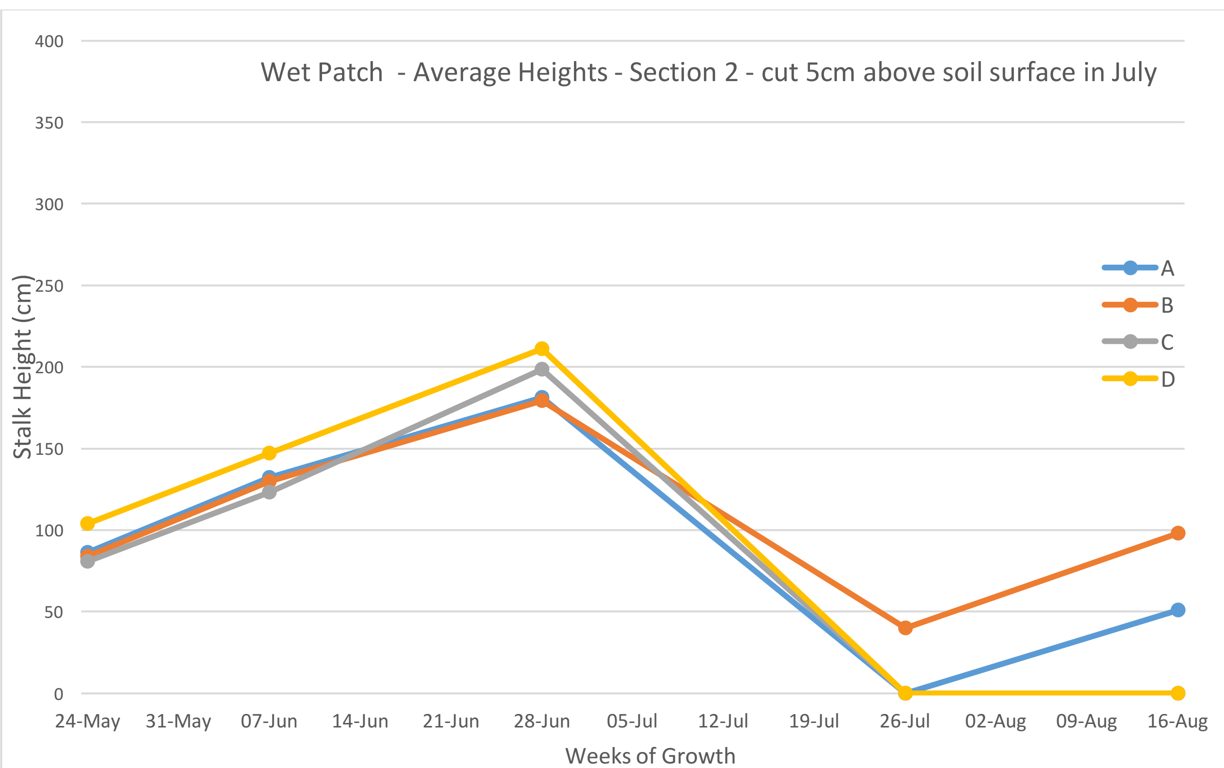

Wet Patch - Stalk Density - Section 3 - cut 5cm below soil surface in July
Density (stalks per m2)
Weeks of Growth
A
B
C
D
0
20
40
60
80
100
120
140
160
180
200
24-May
31-May
7-Jun
14-Jun
21-Jun
28-Jun
5-Jul
12-Jul
19-Jul
26-Jul
2-Aug
9-Aug
16-Aug

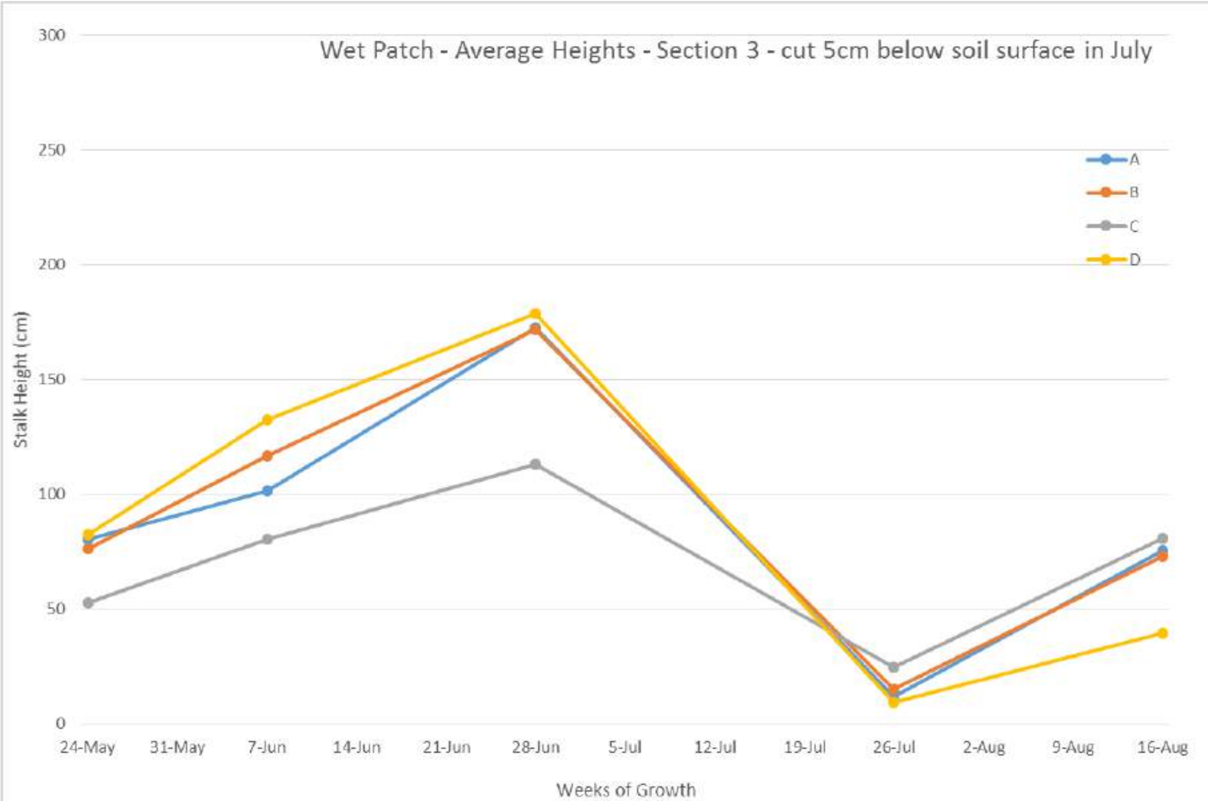

Wet Patch - Stalk Density - Section 4 - cut 5cm below soil surface in July & August
A
B
C
D
Density (stalks per m2)
200
180
160
140
120
100
80
60
40
20
0
24-May
31-May
7-Jun
14-Jun
21-Jun
28-Jun
5-Jul
12-Jul
19-Jul
26-Jul
2-Aug
9-Aug
16-Aug
Weeks of Growth

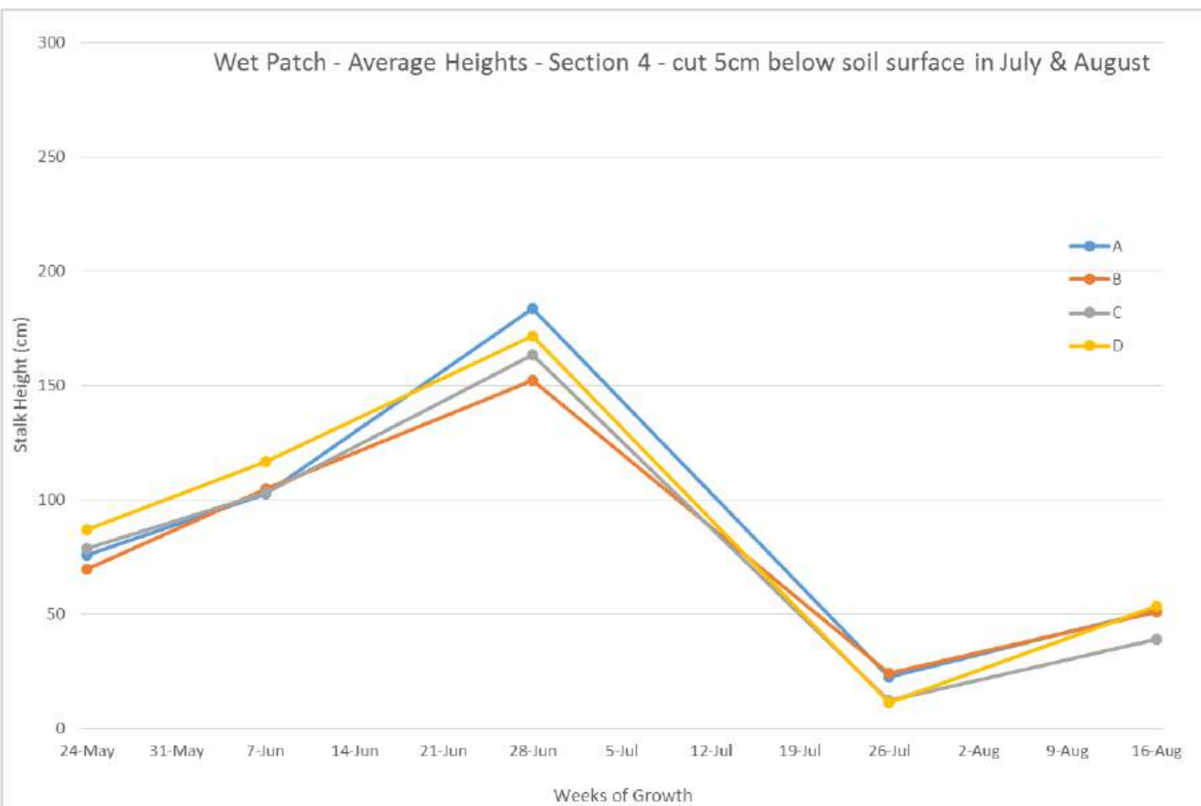

Wet Patch - Stalk Density - Section 5 - cut 5cm below soil surface in June, July & August
A
B
C
D
Density (stalks per m2)
200
180
160
140
120
100
80
60
40
20
0
24-May
31-May
7-Jun
14-Jun
21-Jun
28-Jun
5-Jul
12-Jul
19-Jul
26-Jul
2-Aug
9-Aug
16-Aug
Weeks of Growth

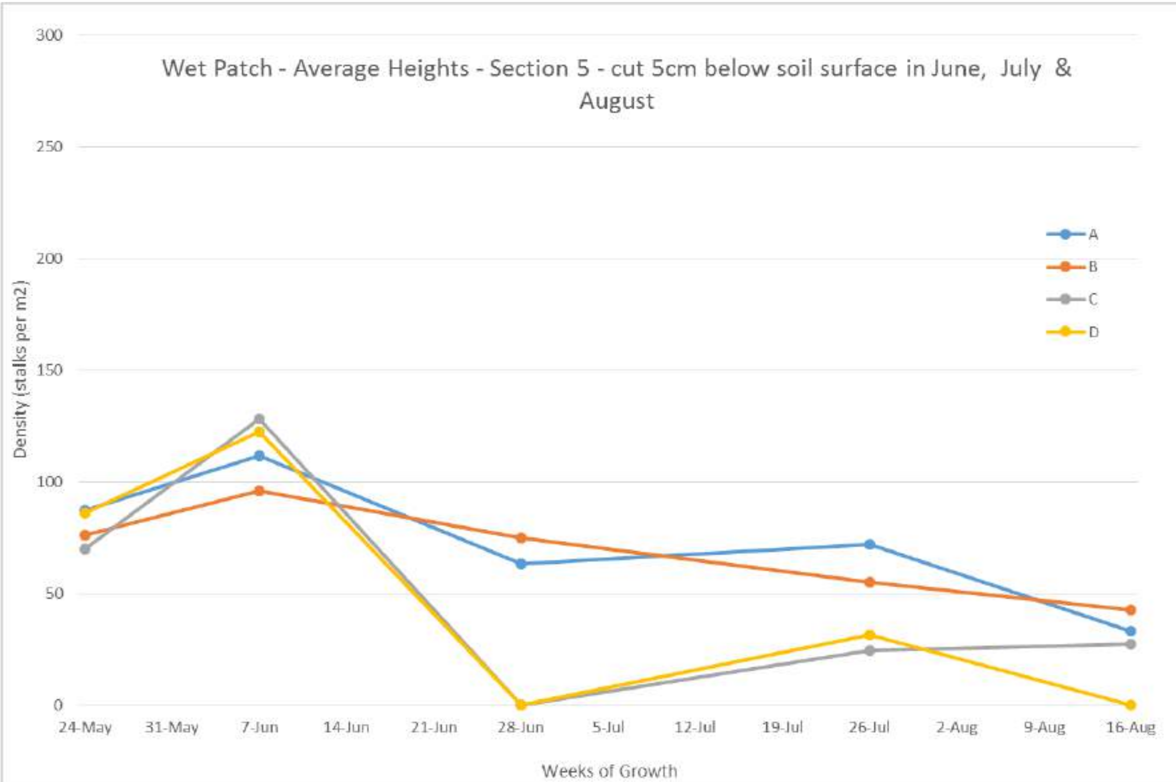
Wet Patch Stalk Heights



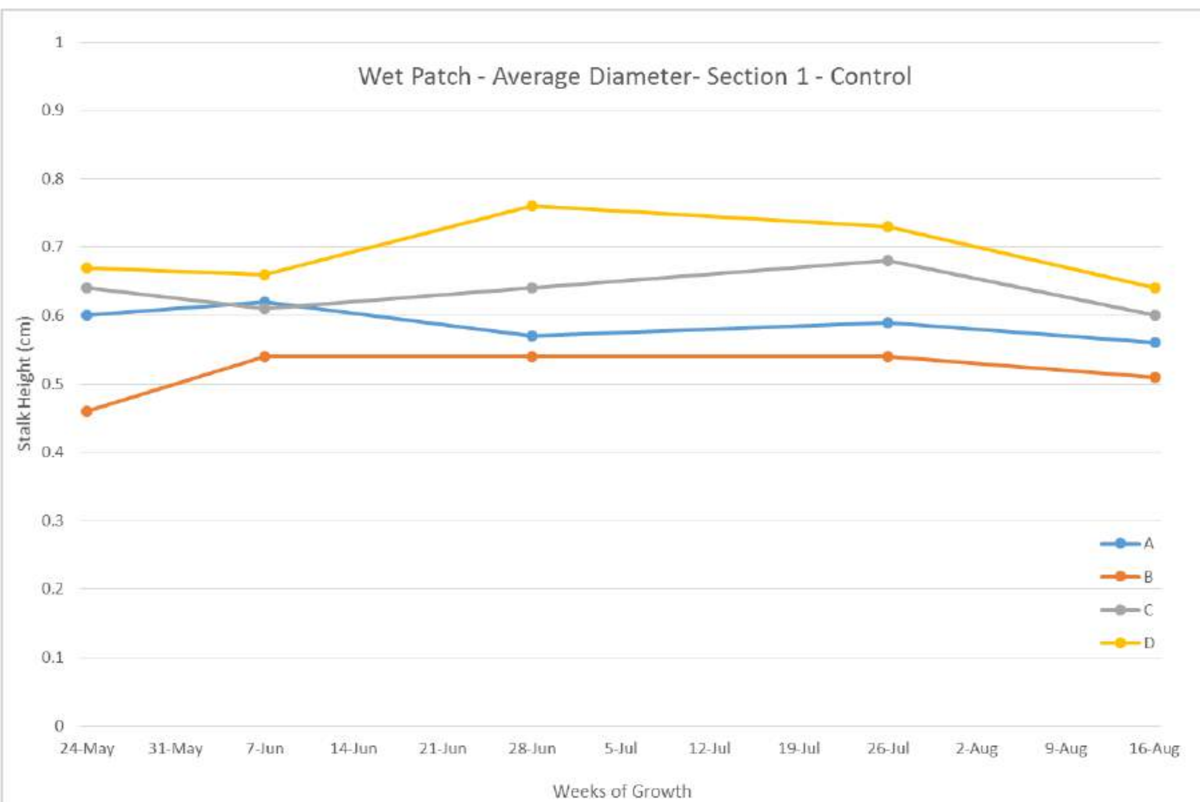


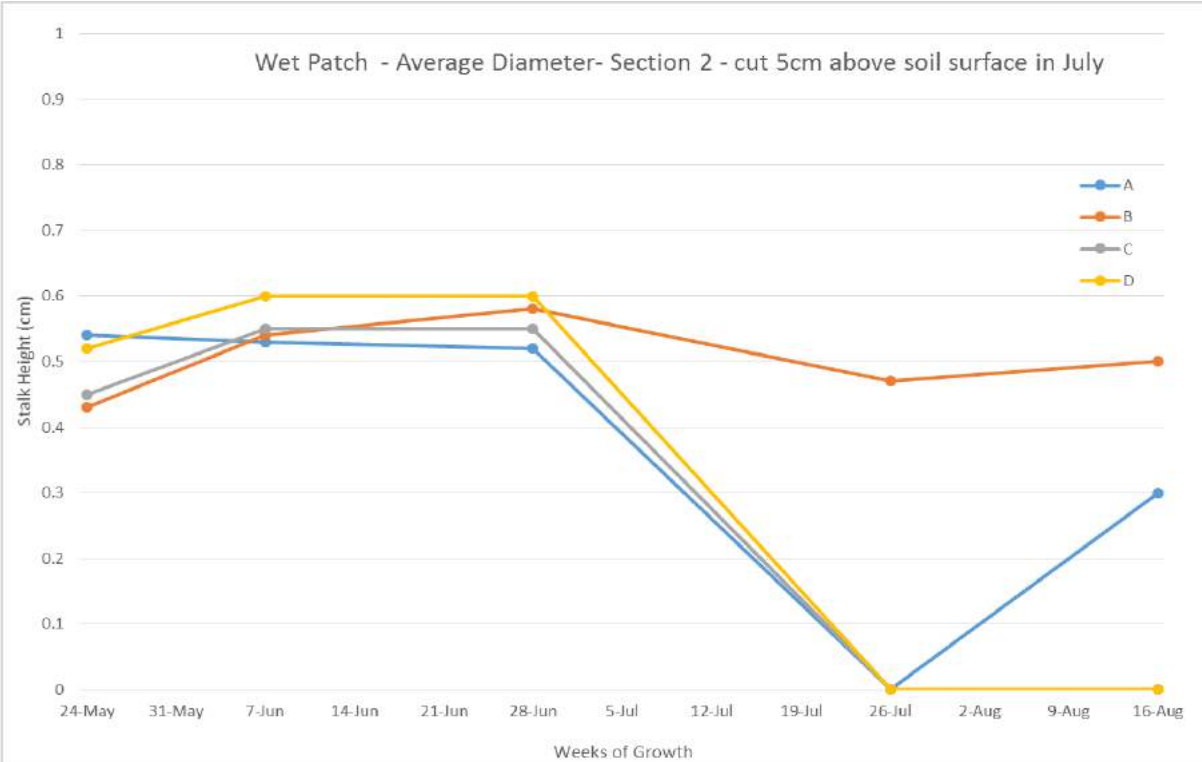

Wet Patch - Average Heights - Section 3 - cut 5cm below soil surface in July
Stalk Height (cm)
300
250
200
150
100
50
0
24-May
31-May
7-Jun
14-Jun
21-Jun
28-Jun
5-Jul
12-Jul
19-Jul
26-Jul
2-Aug
9-Aug
16-Aug
Weeks of Growth
A
B
C
D

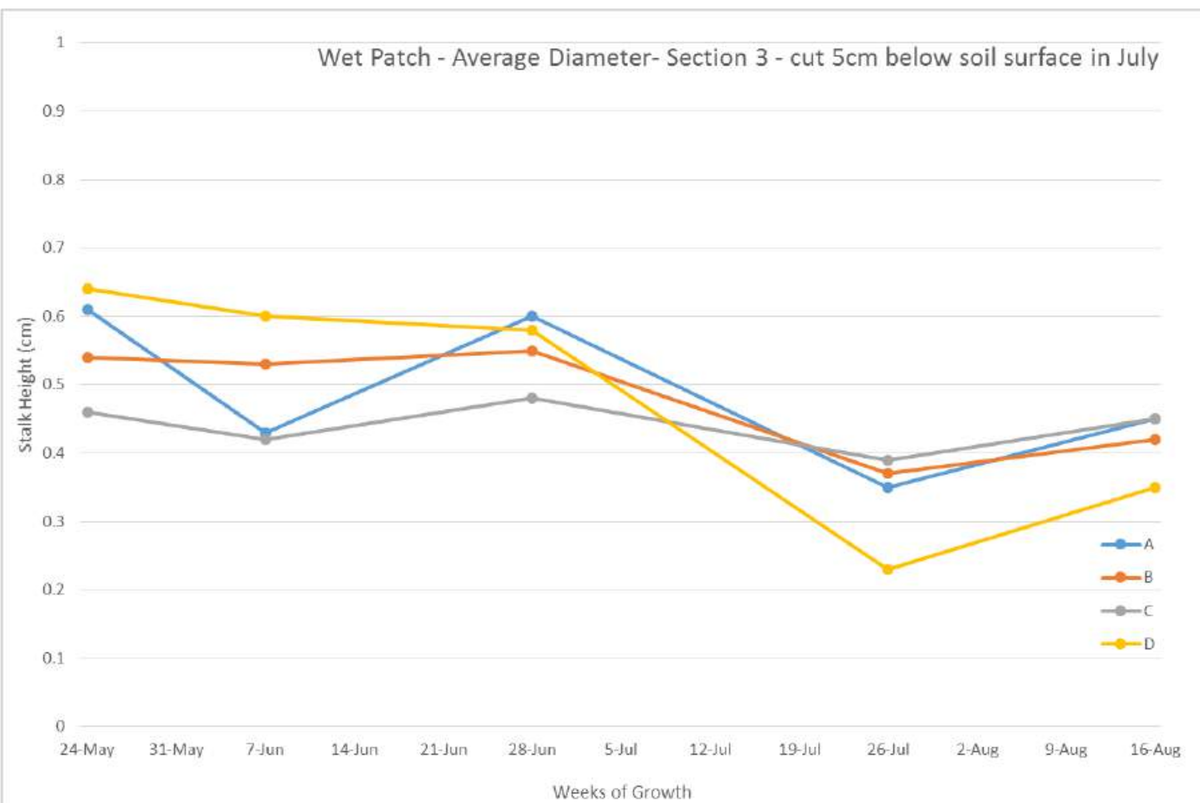

Wet Patch - Average Heights - Section 4 - cut 5cm below soil surface in July & August
Stalk Height (cm)
300
250
200
150
100
50
0
24-May
31-May
7-Jun
14-Jun
21-Jun
28-Jun
5-Jul
12-Jul
19-Jul
26-Jul
2-Aug
9-Aug
16-Aug
Weeks of Growth
A
B
C
D

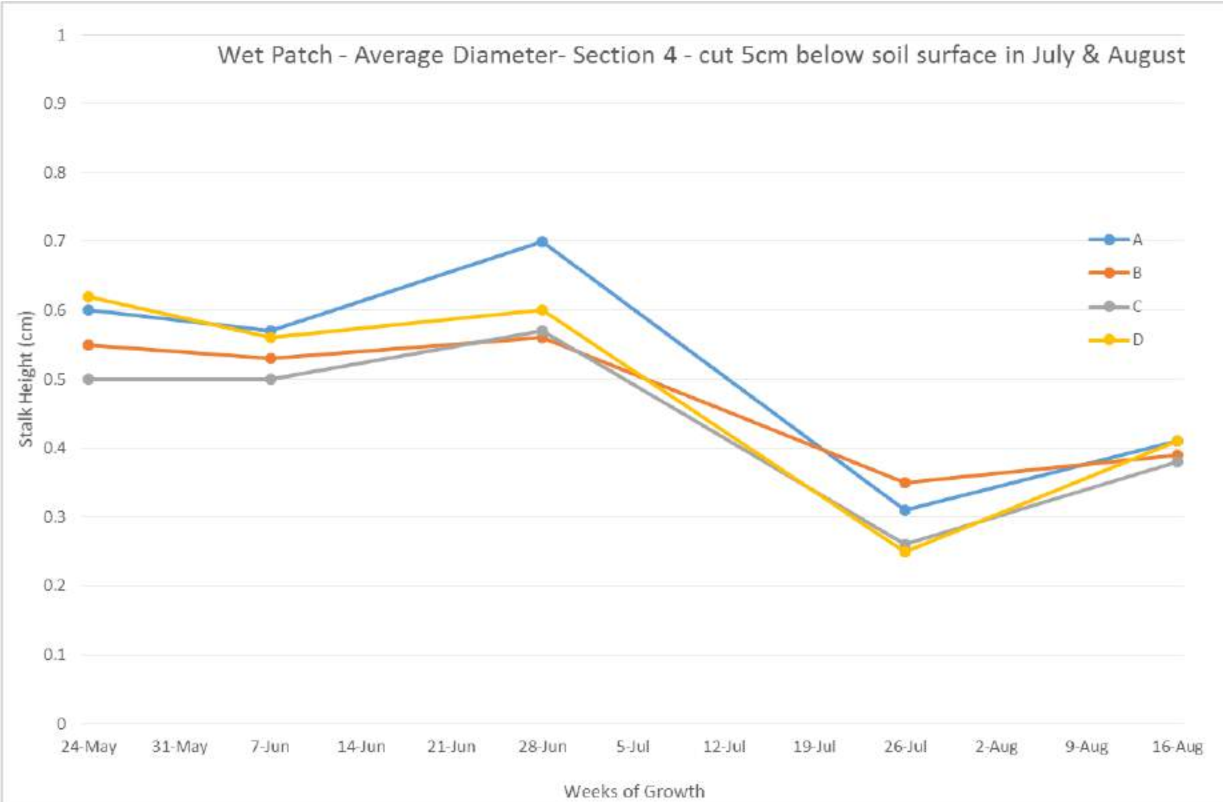


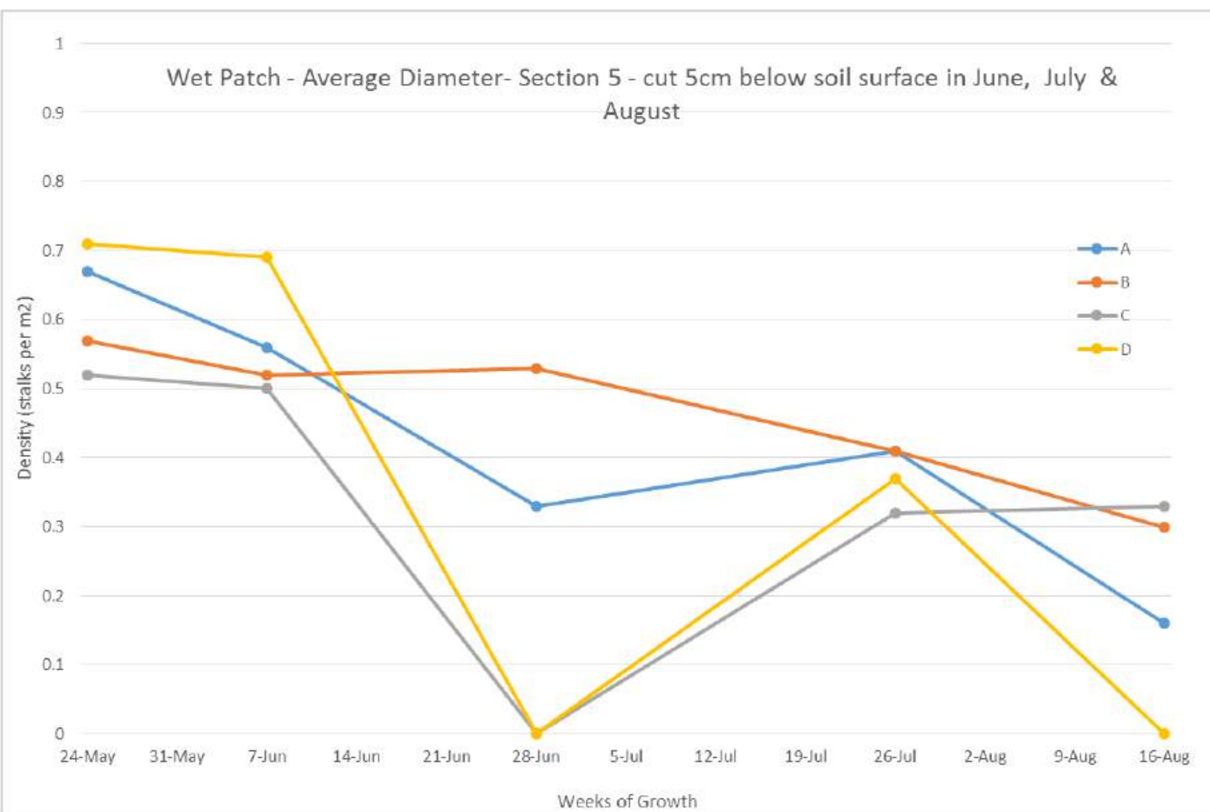
Wet Patch Stalk Diameters




Wet Patch - Average Diameter- Section 2 - cut 5cm above soil surface in July
Stalk Height (cm)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
A
B
C
D
24-May
31-May
7-Jun
14-Jun
21-Jun
28-Jun
5-Jul
12-Jul
19-Jul
26-Jul
2-Aug
9-Aug
16-Aug
Weeks of Growth


Wet Patch - Average Diameter- Section 3 - cut 5cm below soil surface in July
Stalk Height (cm)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
A
B
C
D
24-May
31-May
7-Jun
14-Jun
21-Jun
28-Jun
5-Jul
12-Jul
19-Jul
26-Jul
2-Aug
9-Aug
16-Aug
Weeks of Growth


Wet Patch - Average Diameter- Section 4 - cut 5cm below soil surface in July & August
Stalk Height (cm)
Weeks of Growth
A
B
C
D
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
24-May
31-May
7-Jun
14-Jun
21-Jun
28-Jun
5-Jul
12-Jul
19-Jul
26-Jul
2-Aug
9-Aug
16-Aug


Wet Patch - Average Diameter- Section 5 - cut 5cm below soil surface in June, July & August
Density (stalks per m2)
Weeks of Growth
A
B
C
D
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
24-May
31-May
7-Jun
14-Jun
21-Jun
28-Jun
5-Jul
12-Jul
19-Jul
26-Jul
2-Aug
9-Aug
16-Aug

Wet Patch Plant Species Data

Section 1 – Control – Total number in test plots A, B, C, D

	Plant Species	May 24	June 7	June 28	July 26	Aug 16
1	Cattail	31	28	28	30	31
2	Common Vetch	6		5	4	2
3	Loosestrife	45	81	26	78	75
4	Canada Thistle	4	1	4	3	3
5	Sweet Clover			1	2	
6	Queen Anne's Lace	1	1	1	3	2
7	Common Plantain					
8	Curly Dock					
9	Sow Thistle		5	9	13	12
10	Grasses					6
11	Elecampane					
12	Aster	55	41	66	59	56
13	Dandelion				4	
14	Wild Parsnip			2	3	3
15	Black Medic					
16	Witch Grass					
17	Ragweed					2
18	Hairy Willow Herb					1
19	Bog Willow Herb					
20	Monarda					
21	Torrey's Bulrush					
22	Canada Goldenrod	3	4		6	1
23	Horsetail					
24	Sedge					
25	Rush	15	29	20	20	20
26	Beach Goldenrod					
27	Wetland Wild Mint					8
28	Phragmites	283	291	319	311	293
	Number of species	**9**	**9**	**11**	**13**	**14**

Wet Patch Plant Species Data

Section 2 – 5cm above soil, once – Total number in test plots A, B, C, D

	Plant Species	May 24	June 7	June 28	July 26	Aug 16
1	Cattail	30	29	29	35	41
2	Common Vetch			1	1	3
3	Loosestrife	31	41	17	54	148
4	Canada Thistle					
5	Sweet Clover	15	13	14	16	9
6	Queen Anne's Lace		2	4	7	8
7	Common Plantain					
8	Curly Dock		2			
9	Sow Thistle		4	13	21	18
10	Grasses		1	3	13	9
11	Elecampane					
12	Aster	50	40	25	70	60
13	Dandelion					1
14	Wild Parsnip				2	
15	Black Medic					
16	Witch Grass					
17	Ragweed					
18	Hairy Willow Herb					
19	Bog Willow Herb					
20	Monarda			10		
21	Torrey's Bulrush					
22	Canada Goldenrod	4	3	3	8	4
23	Horsetail					
24	Sedge	1	1	17		
25	Rush	15	35		19	
26	Beach Goldenrod					1
27	Wetland Wild Mint				6	8
28	Phragmites	305	340	314	3	5
	Number of species	**8**	**12**	**13**	**13**	**14**

Wet Patch Plant Species Data

Section 3 – 5cm below soil, once – Total number in test plots A, B, C, D

	Plant Species	May 24	June 7	June 28	July 26	Aug 16
1	Cattail	16	16	18	25	24
2	Common Vetch					
3	Loosestrife	47	64	16	76	101
4	Canada Thistle	4	4	3	2	5
5	Sweet Clover	26	22	31	15	10
6	Queen Anne's Lace	7	7	9	10	12
7	Common Plantain	2	2	2	2	5
8	Curly Dock	13	21	13	10	14
9	Sow Thistle	9	12	6	21	22
10	Grasses	6	8	8	20	15
11	Elecampane	6				
12	Aster	41	49	57	68	64
13	Dandelion	2	1	1	1	16
14	Wild Parsnip	1	1	3	2	2
15	Black Medic		1	4	4	
16	Witch Grass					
17	Ragweed				2	2
18	Hairy Willow Herb				1	1
19	Bog Willow Herb					
20	Monarda					
21	Torrey's Bulrush					
22	Canada Goldenrod	3	9	6	14	11
23	Horsetail					
24	Sedge			4		
25	Rush				3	17
26	Beach Goldenrod					
27	Wetland Wild Mint					
28	Phragmites	212	302	276	59	98
	Number of species	**15**	**15**	**13**	**18**	**17**

Wet Patch Plant Species Data

Section 4 – 5cm below soil, twice – Total number in test plots A, B, C, D

	Plant Species	May 24	June 7	June 28	July 26	Aug 16
1	Cattail	8	6	6	7	17
2	Common Vetch			2	1	1
3	Loosestrife	58	54	20	59	83
4	Canada Thistle					
5	Sweet Clover	14	27	15	14	11
6	Queen Anne's Lace	8	6	5	25	12
7	Common Plantain					
8	Curly Dock				1	2
9	Sow Thistle	10	14	17	28	24
10	Grasses	19	39	6	40	35
11	Elecampane	1	1	1	1	1
12	Aster	45	134	88	193	138
13	Dandelion	1				
14	Wild Parsnip	1		1	3	2
15	Black Medic				1	
16	Witch Grass				1	
17	Ragweed					
18	Hairy Willow Herb					
19	Bog Willow Herb			2	1	
20	Monarda					
21	Torrey's Bulrush			4	3	8
22	Canada Goldenrod	4	1	3	2	14
23	Horsetail	2				
24	Sedge	3	2	4		
25	Rush				2	24
26	Beach Goldenrod					
27	Wetland Wild Mint					
28	Phragmites	230	383	239	42	56
	Number of species	**14**	**11**	**15**	**18**	**15**

Wet Patch Plant Species Data

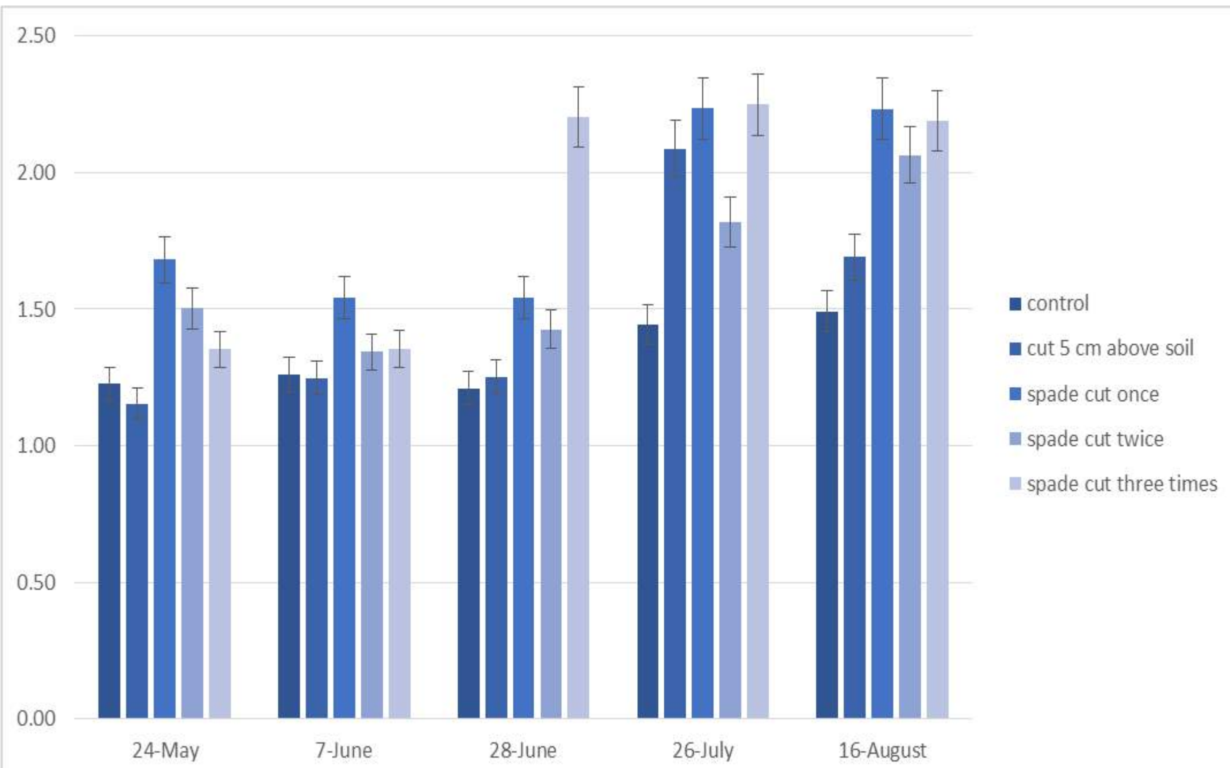
Section 5 - 5cm below soil, three times – Total number in test plots A, B, C, D

	Plant Species	May 24	June 7	June 28	July 26	Aug 16
1	Cattail	19	6	19	37	63
2	Common Vetch				2	2
3	Loosestrife	21	35	26	66	81
4	Canada Thistle					
5	Sweet Clover	16	26	21	20	17
6	Queen Anne's Lace		3	4	30	27
7	Common Plantain	5				
8	Curly Dock	6	7	9	9	11
9	Sow Thistle	43	43	31	51	23
10	Grasses	18	39	17	11	28
11	Elecampane					
12	Aster	32	41	35	63	52
13	Dandelion	1	1			
14	Wild Parsnip		1	1	2	1
15	Black Medic		3	1	1	2
16	Witch Grass					
17	Ragweed					
18	Hairy Willow Herb					
19	Bog Willow Herb					
20	Monarda					
21	Torrey's Bulrush					
22	Canada Goldenrod		19	12	27	17
23	Horsetail	10				
24	Sedge					
25	Rush				5	
26	Beach Goldenrod					
27	Wetland Wild Mint					
28	Phragmites	322	422	10	45	42
	Number of species	**11**	**13**	**12**	**14**	**12**

Table 2. Summary of Shannon Index Values for the Humberwood Wet Site, Summer 2017

Plot	24-May	7-June	28-June	26-July	16-August
control	1.23	1.26	1.21	1.44	1.49
cut 5 cm above soil	1.15	1.25	1.25	2.09	1.69
spade cut once	1.68	1.54	1.54	2.24	2.23
spade cut twice	1.50	1.34	1.43	1.82	2.06
spade cut three times	1.35	1.36	2.21	2.25	2.19

Figure 2. Shannon Index Values for the Humberwood Wet 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.

Dry Patch:

Control - The stalk densities in Section 1, the Control section remained consistently high throughout the growing season. They were actually slightly lower than last year's initial densities but remained consistent throughout the growing season. This may be due to the slight disturbance (unavoidable) caused by removing the standing stalks at the beginning of the season or entering the test section (walking within the section) in order to perform the measurements during the testing season. Test plot D, closest to the poplar tree, had the lowest stalk density in this section. This may be a result of the competition from the nearby large Poplar tree (at the end of this season, one of the rhizome core samples taken revealed a Phragmites rhizome growing through a woody Poplar root).

Phragmites rhizome growing through woody Poplar root

***Section 2* – *stalks cut 5 cm above the surface of the soil- July, 2017*.** The initial stalk densities were slightly higher in this section than last year. The stalks in this section were not removed using the spade technique but were cut off above the soil surface without disturbing the rhizomes below. The stalk density remained consistent until the removal in July. The final densities were substantially lower at the end of the season as compared to the end of last season. It appears that this method of removing the stalks has an effect on the long term growth of Phragmites over two seasons.

***Section 3* – *spade cut once- July, 2017*.** The initial stalk densities from last year were relatively close to the numbers obtained this year. The stalk density was reduced by about half after the spade removal in July and then experienced a slight increase in August but remained below the initial numbers in May of this year. The final densities were comparable with last year's final results. In this case the end of the second year appears to be similar to the result in the end of the first year. One spade removal for two consecutive seasons may not be enough to substantially control Phragmites in the short term.

Section 4 – ***Spade cut twice- July and August, 2017***. The initial stalks densities from this year are less than the densities from last year. The stalk densities remained consistent until the July spade removal. The densities dropped substantially and then remained low. The final densities were lower than the final densities at the end of the previous season. This may indicate that two consecutive seasons with two removals in July and August is effective in approaching control of Phragmites.

Section 5 – ***Spade cut three times- June, July and August, 2017***. The initial stalk densities in this test section were substantially lower than those seen last year. After the June spade removal, the stalk densities were dramatically reduced and remained very low throughout the rest of the season. The final stalk densities, as compared to last year, were about the same. This may indicate that repeated spade removals for multiple seasons will be most effective in Phragmites control in the long term.

Wet Patch:

Control - The stalk densities in Section 1, the Control section remained consistently high throughout the growing season. They were actually slightly lower than last year's initial densities but remained consistent throughout this growing season. This may be a result of deer traffic through the section (the deer were using the site as a travelway to the wetland prior to our setup in May 2017) or due to the slight disturbance (unavoidable) caused by removing the standing stalks at the beginning of the season or by entering the test section (walking within the section) in order to perform the measurements during the testing season. The two test plots that were most affected by the deer traffic were cordoned off in May to prevent further disturbance during our research. The deer continued to walk through the site until the Phragmites were taller (mid-summer) but they remained on the trail that was created through the middle of the site and did not interfere with the growth in the test plots.

Deer travelway through Wet Patch

Deer tracks in mud

***Section 2* – *stalks cut 5 cm above the surface of the soil- July, 2017*.** The initial densities were a little lower than the densities measured the previous year but consistent with Control densities measured this season, 2017. After the July cut, the densities were drastically reduced and remained low until the end of the season. This is similar to the results obtained last year. This cutting method appears to affect the long term growth.
***Section 3* – *spade cut once- July, 2017*.** Two of the test plots compared similarly with last year's results. Two of the plots had far fewer stalks (1/3 to ½ the number of stalks) present at the beginning of the season compared to last year. We observed several of the new growth stalks in these plots to be damaged by the presence of a stem borer which may account for the reduced initial density in these plots. At the end of the season, after the July spade removal, the results were comparable to last year's results. One spade removal for two consecutive seasons may not be enough to substantially control Phragmites in the short term.

stems with evidence of borer activity

stem borer larva

***Section 4* – *Spade cut twice- July and August, 2017*.** Initially, the stalks densities in this plot were somewhat fewer than those of the previous season. After the July spade removal, the density was substantially reduced and remained low after the August spade removal. Spade removal twice in two consecutive seasons appears to be effective in Phragmites control.
***Section 5* – *Spade cut three times- June, July and August, 2017*.** This section shows quite a variation in initial density in May 2017 but all plots experience a drastic drop in density after the June spade removal and remains low after the July and August removals. The final densities are similar to those measured at the end of August last year. Repeated spade removal over two seasons appears to be an effective Phragmites control.

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.

Dry Patch:
Control – This summer was much cooler and wetter than the previous summer. These growing conditions would be expected to favour the growth of Phragmites. Growth throughout the season resulted in stalks heights of approximately 2 metres by late June and remained at this height until the end of the growing season. Many of the stalks were flowering by August. The influence of the shade and competition by the Poplar may have affected flowering in this section. Phragmites in the surrounding undisturbed areas on the outside of the test site, farther from the Poplar, had many flowers.
Section 2 – ***stalks cut 5 cm above the surface of the soil- July, 2017***. The heights of the stalks in this section followed a similar growth curve to the Control until the end of June. After cutting in July, the regrowth attained similar heights by August to the initial growth measured in May and no stalks flowered.
Section 3 – ***spade cut once- July, 2017***. The heights of the stalks in this section followed a similar growth curve to the Control until the end of June. After spade removal in July, the regrowth attained similar heights by August to the initial growth measured in May and no stalks flowered.
Section 4 – ***Spade cut twice- July and August, 2017***. The heights of the stalks in this section followed a similar growth curve to the Control until the end of June. After spade removals in July and August, the regrowth remained lower than the growth measured in May and no stalks flowered. Repeated removals keep stalk height reduced, thereby reducing the shading effect of the Phragmites stalks on the other plant species present.
Section 5 - ***Spade cut three times- June, July and August, 2017***. The heights of the stalks in this section followed a similar growth curve to the Control until the beginning of June. After spade removals in June, July and August, the regrowth consistently remained lower than the growth measured in May and no stalks flowered. Repeated removals keep stalk height reduced, thereby reducing the shading effect of the Phragmites stalks on the other plant species present.

Wet Patch:
Control – This section shows a steady height growth curve until July, at which time the growth leveled off. The heights at the end of the season range between 2m and 3m. The wet growing season resulted in stalk heights that were taller than the previous dry season measurements. This would be expected due to the wet conditions that occurred this summer. Most stalks were flowering by the end of August.
Section 2 – ***stalks cut 5 cm above the surface of the soil- July, 2017***. The initial growth curve followed the height growth curve of the Control plots until the end of June. After cutting in July, the very sparse regrowth attained similar heights by August to the initial growth measured in May and no stalks flowered.
Section 3 – ***spade cut once- July, 2017***. The heights of the stalks in this section followed a similar height growth curve to the Control until the end of June. After spade removal in July, the regrowth attained similar heights by August to the initial growth measured in May and no stalks flowered.
Section 4 – ***Spade cut twice- July and August, 2017.*** The initial height growth curve followed the growth curve of the Control plots until the end of June. After spade removal in July, the height was drastically reduced and stayed low after the spade cut in August. The heights remained lower than the heights measured in May. This may indicate

reduction of the rhizome reserves. No stalks flowered in August.
Section 5 – ***Spade cut three times- June, July and August, 2017***. The stalks in this section began growing as the other sections had being similar to the Control section, however, after the June spade cut, the stalk heights were reduced and remained slightly lower than the May measurements after the June, July and August removals. This may indicate reduction of the rhizome reserves. No stalks flowered in August.

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.

Dry Patch:
Control – The stalk diameters remained consistent throughout the season. The measurements ranged between 0.4 cm and 0.7 cm.
Section 2 – ***stalks cut 5 cm above the surface of the soil- July, 2017.*** The stalk diameters were initially consistent between 0.4 cm and 0.5 cm on average. After the July cut, the diameters dropped to an average of between 0.1 cm and 0.3 cm. The regrowth measures a thinner diameter than the initial growth.
Section 3 – ***spade cut once- July, 2017.*** **I**nitially, the diameters ranged between 0.5 cm and 0.6 cm until the spade removal in July. The regrowth diameters measured in the range of 0.2 cm and 0.4 cm, thinner than the initial growth.
Section 4 – ***Spade cut twice- July and August, 2017***. Prior to the spade removal in July, the diameters ranged between 0.3 cm and 0.5 cm. After the removals in July and August, the diameters ranged between 0.1 cm and 0.3 cm. Two removals over two seasons appears to affect the initial and final diameter of the stalks.
Section 5 - ***Spade cut three times- June, July and August, 2017.*** Prior to the spade removal in June, the diameters ranged between 0.4 cm and 0.6 cm. After the removals in June, July and August, the diameters ranged between 0.1 cm and 0.3 cm. Three removals over two seasons appears to affect the initial and final diameter of the stalks.

Wet Patch:
Control - The stalk diameters remained in the range between 0.5 cm and 0.8 cm throughout the test season (2017).
Section 2 – ***stalks cut 5 cm above the surface of the soil- July, 2017.*** The stalk diameter remained between 0.4 cm and 0.6 cm, however, for the final measurements in August, there were only 5 stalks to measure. It was a very small sample.
Section 3 – ***spade cut once- July, 2017.*** The stalk diameter remains between 0.5 cm and 0.7 cm from May to the end of June. After the July spade removal, the stalk diameters of the regrowth ranged between 0.2 cm and 0.5 cm. Spade removal appears to affect stalk diameter.
Section 4 – ***Spade cut twice- July and August, 2017***. The stalk diameter remains between 0.5 cm and 0.7 cm from May to the end of June. After the July and August spade removals, the stalk diameters of the regrowth range between 0.2 cm and 0.4 cm. Spade removal appears to affect stalk diameter.

Section 5 – ***Spade cut three times- June, July and August, 2017***. Prior to the June spade removal, the stalk diameters range between 0.5 cm and 0.7 cm. After the spade removals, the diameters range between 0.1 cm and 0.5 cm. Spade removal appears to affect stalk diameter.

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

Dry Patch (Density of stalks/m^2)

Control	Test Plot A	Test Plot B	Test Plot C	Test Plot D
June 8, 2016	209	156	96	44
June 6, 2017	155	88	75	90

Section 2	Test Plot A	Test Plot B	Test Plot C	Test Plot D
June 8, 2016	102	87	67	55
June 6, 2017	106	104	88	66

Section 3	Test Plot A	Test Plot B	Test Plot C	Test Plot D
June 8, 2016	85	150	130	121
June 6, 2017	133	111	118	98

Section 4	Test Plot A	Test Plot B	Test Plot C	Test Plot D
June 8, 2016	236	117	133	217
June 6, 2017	151	87	95	150

Section 5	Test Plot A	Test Plot B	Test Plot C	Test Plot D
June 8, 2016	127	201	151	111
June 6, 2017	56	91	54	37

Wet Patch (Density of stalks/m^2)

Control	Test Plot A	Test Plot B	Test Plot C	Test Plot D
June 7, 2016	70	101	159	120
June 7, 2017	63	64	100	64

Section 2	Test Plot A	Test Plot B	Test Plot C	Test Plot D
June 7, 2016	131	112	133	87
June 7, 2017	85	75	102	78

Section 3	Test Plot A	Test Plot B	Test Plot C	Test Plot D
June 7, 2016	106	160	91	108
June 7, 2017	91	124	36	51

Section 4	Test Plot A	Test Plot B	Test Plot C	Test Plot D
June 7, 2016	137	100	185	120
June 7, 2017	97	67	132	87

Section 5	Test Plot A	Test Plot B	Test Plot C	Test Plot D
June 7, 2016	93	99	199	145
June 7, 2017	29	135	142	116

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

Dry Patch (Density of stalks/m^2)

Control	Test Plot A	Test Plot B	Test Plot C	Test Plot D
August 17, 2016	199	154	103	54
August 15, 2017	70	67	60	39

Section 2	Test Plot A	Test Plot B	Test Plot C	Test Plot D
August 17, 2016	106	116	81	69
August 15, 2017	29	56	42	11

Section 3	Test Plot A	Test Plot B	Test Plot C	Test Plot D
August 17, 2016	84	85	72	71
August 15, 2017	79	35	78	69

Section 4	Test Plot A	Test Plot B	Test Plot C	Test Plot D
August 17, 2016	57	31	51	80
August 15, 2017	30	22	20	22

Section 5	Test Plot A	Test Plot B	Test Plot C	Test Plot D
August 17, 2016	9	10	4	8
August 15, 2017	7	9	4	6

Wet Patch (Density of stalks/m^2)

Control	Test Plot A	Test Plot B	Test Plot C	Test Plot D
August 16, 2016	85	122	146	199
August 16, 2017	69	67	94	63

Section 2	Test Plot A	Test Plot B	Test Plot C	Test Plot D
August 16, 2016	4	15	20	7
August 16, 2017	2	3	0	0

Section 3	Test Plot A	Test Plot B	Test Plot C	Test Plot D
August 16, 2016	14	24	21	10
August 16, 2017	18	53	21	6

Section 4	Test Plot A	Test Plot B	Test Plot C	Test Plot D
August 16, 2016	7	9	21	6
August 16, 2017	14	16	18	8

Section 5	Test Plot A	Test Plot B	Test Plot C	Test Plot D
August 16, 2016	4	10	11	10
August 16, 2017	11	19	12	0

Note: A visit to the sites on September 29, 2017 was conducted to observe the growth on the sites.
At the Dry Patch, there were no Phragmites stalks in the test sections in flower. The growth of the other plant species was very tall and dense, making it difficult to see the Phragmites stalks.

Dry Patch, Section 5, September 29, 2017

In the Wet Patch, there were 4 stalks with flowers within the 4 test sections. The flowers, however, were very small and sparse compared to the flowers on the stalks within the control section. The stalks with the flowers in the test sections were not as tall as the stalks in the control section.

Flowerheads in Control section (Sept 29)

Flowerhead in Section 3 (Sept 29)

Plant Biodiversity

The Humberwood Test Sites are located on the Humber River Floodplain in the North end of Etobicoke, Ontario. It is an urban-affected site, adjacent to a school and community centre, and is accessible by public trails. Diversity counts were collected five times from May through August, 2017.

As an urban site with frequent disturbance by human activity, we would expect that a healthy community for this site would include a mixture of native and introduced plants that have become naturalized (introduced plants that have been integrated into an ecosystem). For the recovery of this site, we expect that additional management of other invasive species will be necessary, but that the naturalized species will remain.

Dry Site:
Plant Species observed at the Humberwood Dry Site, Summer 2017.

Native Plant Species	Introduced- Naturalized	Introduced - Significant Invasive
		Phragmites australis subsp. *australis*
Barren Strawberry	Aster	Canada Thistle
Canada Goldenrod	Bitter Nightshade	Dog-Strangling Vine
Cinquefoil	Bull Thistle	Garlic Mustard
Daisy Fleabane	Burdock	Sweet Clover
Enchanter's Nightshade	Butter and Eggs	Wild Parsnip
Evening Primrose	Catnip	
Grape Vine	Common Vetch	
Manitoba Maple	Curly Dock	
Raspberry Seedlings	Dame’s Rocket	
Yellow Wood Sorrel	Dandelion	
Grasses	Motherwort	
	Mullein	
	Poplar	
	Queen Anne’s Lace	
	Spiny Plumeless Thistle	
	Teasel	
	Wintercress	
	Grasses	

Of the 34 species observed at the dry site over the course of the summer, 10 were identified as native species, and the remaining 24 were identified as introduced. Several plants observed could not be identified as being native or introduced. These included the small grasses, and poplar. The large Poplar Tree beside the research site was planted several years prior to this study. It is assumed that the small poplar shoots appearing in the research site are suckers from the roots of the parent tree. In addition to Invasive Phragmites, several other invasive species of significant concern were observed, including Garlic Mustard, Dog-strangling Vine, Wild Parsnip, Canada Thistle and White Sweet Clover. Overall, the composition of the community on this site is typical of a disturbed, urban meadow. Many of the naturalized plants serve as important sources of food and shelter for wildlife, and should be accepted in long-term recovery plans.

Spiny Plumeless Thistle with Monarch Butterfly feeding on flowers (Dry Patch)

Control – The control plot showed low diversity overall, with a minimum index value of 0.66 occurring at the end of June. This highest diversity occurred in May (H'=1.43), perhaps because of the abundance of Garlic Mustard and Dame's Rocket that occurred early in the season. Both species belong to the Brassicaceae family, which is known to be resistant to the allelopathic effects of Invasive Phragmites (Rudrappa *et* al.2007). They are also early bloomers, so their presence in the test site diminished naturally over the course of the summer. The diversity of the control section also increased somewhat in July and August. This increase may be an artifact of the formula used: the total number of individual plants present in July (348), August (352), including Phragmites stalks, was less than half the number present in May (729). As a result, relative abundance each plant species appears greater, although the total number of individuals is much lower. Overall, the diversity of the Control Plot was higher than expected. This may have been due to the competitive effect of a mature popular tree adjacent to the control plot. The removal of dead stalks and thatch at the beginning of the growing season may have also promoted greater diversity on the Control Section. The removal of the Phragmites stalks in the adjacent test sections would have allowed more light to penetrate the Control section, which may have enhanced the conditions for other plant species to grow in the Control section.

Section 2- stalks cut 5 cm above the surface of the soil- July, 2017. At the start of the season, the diversity of this section was relatively low, and very similar to the diversity observed in the control section. This suggests that the cutting of this section done in the previous year had little to no effect on the survival of the underground tissues. However, following the removal by cutting done in July, the diversity of the section increased significantly. This finding is in line with Hazelton *et al*.'s 2014 study, which found that the removal of stalks by cutting allowed for some recovery of diversity through the opening up of the canopy. The number of other species observed, 16, remained constant through August. However, the rebounding of the Invasive Phragmites stalks, from a low of 78 to 138 in August, suggests the recovery will be short-lived without further intervention.

Section 3- spade cut once- July, 2017. Overall, this section showed the lowest community diversity of all of the sections for the entire length of the season. The diversity of this section decreased from May (H'=1.38) through the end of June (H'=0.64). Following the spade cut in July, diversity for this section increased modestly. However, there was very little increase in the community diversity between July and August, (H'=1.34 to H'= 1.38). At the end of the recording period, the community diversity for this section was found to be identical to the value found for the control section, suggesting that performing a one-time spade cutting on the stalks of a stand has little to no effect in improving biodiversity.

Section 4- Spade cut twice- July and August, 2017. The community diversity in this section was consistently higher than the diversity found in the Control section. Although this section decreased in diversity over the first half of the summer, it recovered substantially following the first spading period in July, and continued to increase in diversity throughout the latter half of the summer. The final diversity value (H'=2.05) was on par with the diversity value found for Section 5 in August (H'=2.04), suggesting that spade-cutting Phragmites twice over the course of the growing season had a similar positive impact as spade-cutting three times, within the growing season.

Section 5- Spade cut three times- June, July and August, 2017. Diversity values for this section were consistently the highest throughout the season. Most notably, the diversity observed on this section was significantly higher (H'=1.90) than that of the Control (H'=1.47) at the start of the growing season suggesting that the spade-cutting of the previous year did in fact reduce the productivity of the Invasive Phragmites on this section. The diversity value for Section 5 in May was also higher than that of Section 4 (H'=1.65) suggesting that spade-cutting three times over the course of the previous season was more effective than spade-cutting only two times, in reducing the survival and productivity of the Invasive Phragmites and improving biodiversity.

Wet Site

Table 3. Plant Species observed at the Humberwood Wet Site, Summer 2017.

Native Plant Species	Introduced	Introduced - Significant Invasive
Beach Goldenrod	Aster	*Phragmites australis* subsp. *australis*
Bog Willow Herb	Black Medic	Sweet Clover
Canada Goldenrod	Canada Thistle	Canada Thistle
Horsetail	Common Plantain	Hairy Willow Herb
Monarda	Common Vetch	Loosestrife
Rush	Curly Dock	Wild Parsnip
Sedge	Dandelion	
Torrey’s Bulrush	Elecampane	
Wetland Wild Mint	Queen Anne’s Lace	
	Ragweed	

	Sow Thistle Witch Grass Grasses Cattail	

28 species were observed on this site, of which 9 were native and 19 were introduced. Of the introduced species, 6 are considered invasive species of significant concern. The Loosestrife plants (also an invasive species) at this site were seriously affected at the beginning of the season by the Black Margined Beetle (*Galerucella clamariensis*). By the end of June, many of the plants were completed eaten by the beetle. This species made a recovery by the end of August when it appeared that the beetle was not present. Many young plants appeared at that time.


Loosestrife with Black Margined Beetle


Foliage damage due to Beetle activity

This mix of native and naturalized species is typical of Southern Ontario urban wetlands, or water meadows. The test site is adjacent to a stormwater catchment system, and the water table for the area fluctuates significantly throughout the season, and from year-to-year. As a result, we may expect the community composition to vary depending on the availability of water. As with the Humberwood Dry Site, naturalized species in the Wet Site are important contributors to this system.

Control- Although the diversity of this section was consistently the lowest of all the sections on the site, over the course of the summer, it does increase in diversity from a low of H'=1.22 in May to a high of H'=1.49 In August. This unexpected increase in diversity is also seen in Section 2, and may be the result of Invasive Phragmites having a reduced competitive advantage when it co-occurs with Invasive Cattail (Chun and Choi 2009). This may also result from the increased sunlight available as a result of removals of Phragmites stalks from adjacent test sections.

Section 2- stalks cut 5cm above soil- July 2017. The diversity of this section was consistently low, with values in May (H'=1.15) and June (H'=1.25, 1.25), being very similar to those found for the Control section (H'=1.22, 1.26 and 1.21 for May 24, June 7 and June 28, respectively) over the same period of time. It does show a significant increase in diversity immediately following the cutting of the Invasive Phragmites stalks in July (H'=2.09). This recovery is short-lived however, as by August, the diversity of the

section had decreased significantly (H'= 1.70).
Section 3- spade-cut once- July, 2017. This section consistently had the highest diversity of the site overall. This may be due to the location of the section. As it lies in the centre of the test site, it was the most insulated from the Invasive Phragmites stand surrounding the test site. This likely means that the Invasive Phragmites found in this plot had the least connection to the surrounding stand, and was therefore receiving little additional resources. Otherwise, the diversity for this section followed the same trend as was seen in Section 3 on the dry site. The diversity decreased from the start of the summer, but rebounded following the spade-cut event in July. Diversity in July (H'=2.24) and August (H=2.23) remained more-or-less unchanged.
Section 4- spade-cut twice – July and August 2017. This section had unexpectedly low diversity throughout the growing season. Within the section, two of the replicates were notably unproductive, possibly due to some animal disturbance at the start of the season. Despite this, the diversity trend for this section across the summer was very similar to that observed in Section 4 of the dry site. Diversity for this section was also significantly higher than that of the Control section at the start of the summer (H'=1.50 and H'=1.22 for Plots 4 and Control, respectively). This suggests that spade-cutting Phragmites twice over the course of the previous summer had a negative effect on the competitive effect of Invasive Phragmites.
Section 5- spade-cut three times- June, July and August, 2017. The diversity for this section, while being consistently higher than that of the Control section was still lower than anticipated. This may be due to the fact that this Plot lies adjacent to an untouched stand of Invasive Phragmites. Any connected underground tissues between the section and this stand would allow the section to receive additional resources (Mal and Narine 2004).

Fire Ants and Phragmites
On several occasions, while working on the two sites, either collecting data or spade removing Phragmites stalks, fire ants appeared and began defensive behaviour (climbing under clothing and stinging). This behaviour has been observed at other locations where Phragmites is present. Protective measures were taken to try to avoid this occurrence being repeated. (see Appendix A for more information about Fire Ants)

Conclusions
With regards to community diversity and recovery, spade-cutting appears to be an effective method of controlling Invasive Phragmites. On both test sites, spade-cutting was shown to improve community diversity and reduce Phragmites stalk densities when compared against the Control Plots. Also, spade-cutting was shown to be more effective than hand-cutting the Phragmites stalks above the surface of the soil in improving community diversity. This suggests that spade-cutting is significantly impacting the viability and productivity of the rhizomes, as hypothesized. Generally, spade-cutting three times over the 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. Improved plant species diversity supports animal diversity.

Some of the animals present on the Research Sites:


Ladybug larva

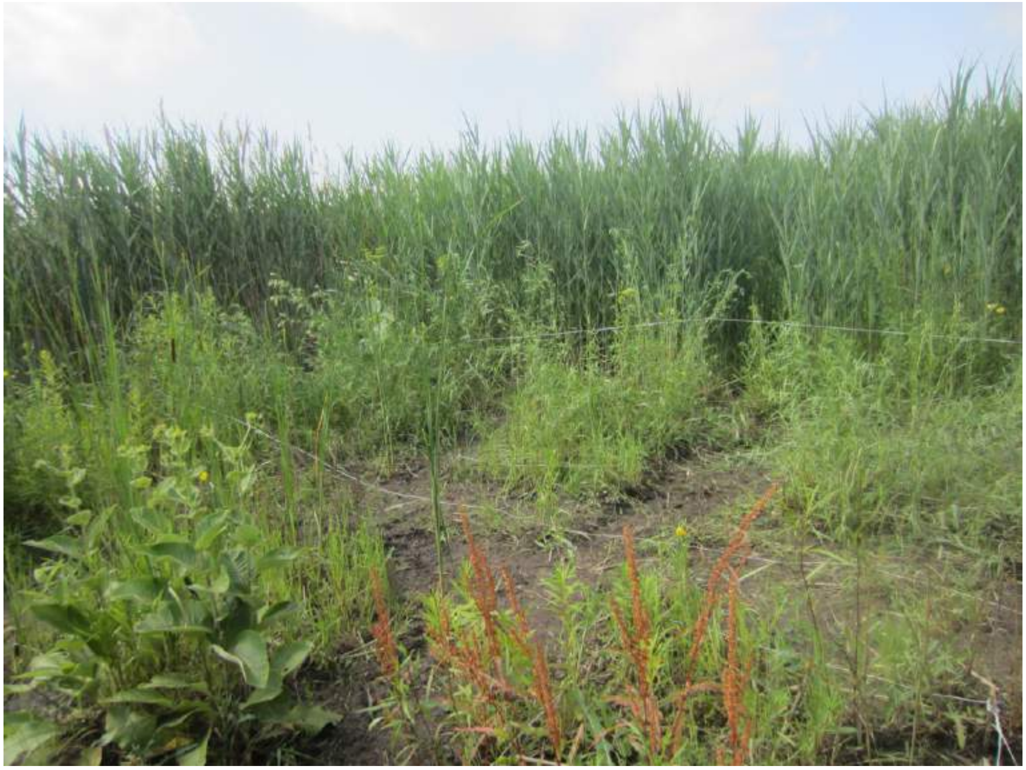

Ladybug pupa


Chimney Crayfish hole (Wet Patch)


Argiope aurantia spider on web

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 of the site. When treating an area using the spading technique, it is important to remove all the stalks to prevent any photosynthesis within the stand. The effects seen in this study are very encouraging even with this as a consideration.


Tall Phragmites stalks surrounding the test site

Spade removal of Phragmites stalks reduces 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 its 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 is 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. The more frequently the stalks are removed in a season, the greater the effect on the regrowth. It also appears that repeated removal for two consecutive seasons also weakens the initial spring growth in the second season (reduced diameters and densities in Section 5 where the stalks were spade removed 3 times last season). This section also showed the most dramatic reduction in stalk density at the end of the second season in both the Dry and Wet Patches.
Cutting the stalks 5 cm above the soil (Section 2) also resulted in substantially reduced stalk densities this season. This may make a case for mowing Phragmites as a control measure, although mowing would also affect the other plant species by keeping them cropped and unable to produce seeds. This effect has been observed along the mown paths through the Arboretum. The Phragmites grows on either side of these paths with

very little growth appearing on the path. The other plant species present in these paths are primarily grasses and, in some very low wet areas, some short rushes. It appears that these plants can withstand the constant cropping of growth and the foot traffic along the paths better than the Phragmites although the plant community diversity is limited.

Plant Biodiversity

We anticipated that the control of Invasive Phragmites through the spading technique would allow the native and naturalized plant community to recover. This season was the second season for this technique to be applied. Many of the other plant species at the sites are biennial or perennial. These plants first appeared last summer and persisted at the sites for a second season. They were able to thrive, flower and set seed during this second summer. Many of these plants became quite tall and dense. This made it challenging to navigate through the sections and to locate the boundaries of the test plots, particularly in the Dry Patch. There was a great deal of competition for space.


Dense growth of other plant species in Dry Patch

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, we chose to use the Shannon Index, 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 B (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 sections that were 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 may have made it possible for new seedlings to develop initially. 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. Biennials, in their second year, died after producing seed. 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. (Hand-cutting the Phragmites stalks is also a selective removal technique).

In all of the test 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.

The recommendation for establishing Phragmites control and improving biodiversity, based on this study, would be to spade remove all Phragmites stalks from an established patch at least 3 times a growing season, beginning in June and repeating in July and August for repeated years until the number of stalks in the initial and final densities has reached a manageable number which is practical to be removed without much time and effort. We would recommend a sustainable final density of less than 5 stalks/m^2. It is recognized that until a better method of control is discovered, annual maintenance to remove the few stalks that will likely appear each season will be required.

<u>Next Steps</u>

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 two sites. From previous experience of spade removal of Phragmites on residential properties, it is predicted that it would take 3 to 7 years to reach a sustainable control of Phragmites using the spading technique.

Also, while working this fall with the City of Toronto, Parks, Recreation and Forestry stewardship groups (a partner in this project), 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. 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. 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.


October 2017 – Milne Hollow


October 2017 – Wymbolwood Beach

It would be very interesting to test the effects of spading this late in the season on the initial density of the spring growth in the following season. This would require a new test plot that could be established in the fall. The plot would need to be staked out and data collected on the established growth in fall. The stalks could be spade removed in the test section and left undisturbed in the control section. The regrowth in the spring for the test and control sections could then be measured and compared the following season.

Another area, where research is needed, is to investigate the possible connection between Phragmites and Fire Ants. Both organisms are non-native and both prefer moist soil conditions. Fire Ants build nests deep into the ground and Phragmites rhizomes grow deep into the ground. The researchers have observed the presence of Fire Ants in conjunction with Phragmites infestations on several occasions. It would be interesting to know if there is a connection between Phragmites and Fire Ant Colonies and the exact nature of the connection if it exists.

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NOTE: All photos in this report were taken by Lynn Short

Appendix A

European Fire Ants – *Myrmica rubra*

Originally a common and widespread species exclusive to Europe, European Fire Ants (*M. rubra)* have now been introduced to North America. It is speculated they have arrived through intercontinental human activities such as travel and trade. *M. rubra* is yellowish-brown in color and looks very similar to other ant species. A key feature that sets them apart is the double-balled skinny waist between the thorax and abdomen. *Myrmica rubra* are divided into 3 castes: the first being the Queen who is responsible for laying eggs (identifiable by their wings, and can grow 5-8mm in length), the second being males, who reproduce with the Queen, then die shortly afterward (also identifiable by their wings, and grow 5-7mm in length), and the third being worker ants who are responsible for nest building, scouting out food sources, defending the Queen and her eggs, and raising young larvae (grow from 3-5.5mm in length). The worker ants are daughter ants who do not reproduce or have wings. The Queen loses her wings once the colony is established.

M. rubra thrive in damp habitats and soils with a high water table, but are very seldom found in true bogs. The densest populations occur on heavy clay soils where they will build their nests in the soil or under flat rocks. Their nests are usually found in places that ensure consistent high humidity for the colony. In Eastern Europe it is considered to be a forest species where there is very moist soil. They prefer to nest under moss or in rotten wood. In areas bordering rivers and lakes, the most common micro-habitat for European Fire Ants ranges from areas of open grass below 20cm in height to areas of tall grass and reeds over 2 meters tall.

Fire Ant populations are polygynous, meaning there can be many queens per colony. They are also polydomous meaning that each colony can have multiple nests in close proximity. This results in high density nests which can cause breakaway queens and workers to form satellite colonies.

Infestations in North America appear to be a product of human-aided dispersal by movement of infested soil, mulch or potted plants. *M. rubra* nests are particularly cryptic for the most part because they do not construct mounds of soil at the entrance to the nest. Instead, they burrow into the ground, resulting in great difficulty detecting the nest and increasing the chances of people and pets inadvertently disrupting their home. Once the nest is disturbed, the workers will climb on the intruder and sting repeatedly. The burning sensation that results from the sting gives rise to the common name, “Fire Ant”.

Fire ants are omnivores and their diets can include plants, microscopic organisms, invertebrates and vertebrates. Worker ants however cannot feed on solid food particles so they prefer liquid nutrition. To find food, worker ants disperse randomly, and once contact is made with a food source they return to the colony, leaving a pheromone trail. Multiple worker ants then follow the trail back to the food source in order to forage and protect it.

Fire ants have strong mandibles and venomous stingers. They can sting multiple times while injecting a venom that can paralyze and kill animals larger than them. If the prey is too large, they can dismantle it into transportable sizes. They are known to prey on ticks and weevils. They also feed on the honeydew produced by sucking insects like aphids, whiteflies, scales, and mealybugs. Fire ants often tend to the insects that produce the honeydew and provide them with protection from parasites and predators. They eliminate disease by removing unhealthy individuals from the population, allowing the honeydew producing insects to grow and multiply. This is a harvesting strategy to increase the yield of the honeydew. Fire ants also feed on germinating seeds and are known to tunnel into young plant stalks and tubers. Additionally, they can cause tree girdling by removing bark at the base.

Myrmica rubra's* possible connection with *Phragmites australis:

A connection between these invasive insects and the invasive plant *Phragmites australis* has been speculated to be present. This is due to the frequency of fire ant populations being observed in *Phragmites* stands by the researchers on this project. One factor may be due to the presence of aphids on the foliage of the Phragmites which attracts them to the area. It may also be that the rhizome structure underground provides stability for the tunnels within their nests in the moist sandy soil. More research would be needed to establish this connection.

Aphids on Phragmites Leaf

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(Appendix A prepared by Keiran Wade)

Appendix B

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:
$H' = -\sum(p_i \ln p_i)$
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.

(Appendix B prepared by Jana Freeman)