Monitoring of *Phragmites australis* expansion and recruitment within the Black Swamp and lower Tookayerta Region

FINAL REPORT
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1. Synopsis

*Phragmites australis (*hereafter referred to as *Phragmites)* is arguably one of the most cosmopolitan (Clevering *et al.* 2001; Den Hartog *et al.* 1989; Lambertini *et al.* 2012c; Sun *et al.* 2007; Uddin *et al.* 2012; Uddin *et al.* 2014) and invasive (Kueffer *et al.* 2013; Pyšek *et al.* 2013) species worldwide and is found in every continent except Antarctica (Kobbing *et al.* 2013; Lambertini *et al.* 2012b). *Phragmites* is the subject of many research projects, and is a useful model to better understand when and how a species becomes invasive, because of its ability to establish, survive, expand and modify the environment within which it persists (Meyerson *et al.* 2016).

The native range of *Phragmites* occurs in eastern and central Australia from Cape York to Tasmania (Atlas of Living Australia 2016). *Phragmites* has undergone a redistribution on account of anthropogenic influences (Roberts 2000a), with contraction tending to be more common in northern Australia compared with expansion in South Australia (Packer unpublished data). One of the expanding populations that are of particular conservation concern is within the Fleurieu Peninsula Swamps (hereafter referred to as Fleurieu Swamps) in the Mount Lofty Ranges, South Australia. These wetlands are recognised and protected as an endangered ecological community under the Commonwealths *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

The locally named Black Swamp is a Fleurieu Swamp ecological community that occurs within the lower Tookayerta and lower Finniss catchments. This entire Black Swamp is within the boundary of the Coorong, Lower Lakes and Murray Mouth (CLLMM) region. Landholders and the Fleurieu Swamp Recovery Team have observed a significant and ongoing expansion of *Phragmites* since 2003. This expansion corresponds with a time when conservationists were urging landholders to remove the grazing pressure from their swamps. Grazing is known to limit reed height and density while stock are present ((Bart and Hartman 2000; Haslam 1972; Spence 1964; Vulink *et al.* 2000), and to increase these when the grazing pressure is removed (Ranwell 1961). In the Fleurireu Swamps, historic grazing and its recent removal appears to have resulted in the expansion of *Phragmites* monospecific stands.

This project was designed to address the *Phragmites* expansion within the Black Swamp and lower Tookayerta system by identifying the environmental, biological and anthropogenic drivers that influenced *Phragmites* establishment and persistence.

Findings from this project demonstrate that *Phragmites* has indeed expanded within the Black Swamp system, particularly in areas where grazing has been removed. The research project concluded that the monospecific stands of *Phragmites* were correlated with reduced floristic richness in the study system, and that other parts of the Tookayerta are also vulnerable to *Phragmites* expansion and dominance. The dense and tall *Phragmites* populations occurred on sites with lower water table and deeper litter accumulation compared with mixed vegetation communities. In contrast, the wetter areas of this swamp system tended to support shorter *Phragmites* and the vegetation community was more floristically diverse. This study also suggested that cutting and flooding can negatively impact *Phragmites* and can be considered a management tool if the seasonal and environmental conditions are suitable.

The findings from this study provide critical restoration considerations for the Black Swamp region and surrounding landscape. Revegetation with tube stock planting is unlikely to be successful if it occurs in proximity (e.g. <50 m) to existing robust *Phragmites* stands. *Phragmites* has the potential to reduce water and nutrient availability beyond the aboveground edge of the stand and to crowd out revegetated areas as stem density increases. The expansion of *Phragmites* also has biodiversity conservation implications for threatened species, such as the endangered Mount Lofty Ranges Southern Emu-wren, that require structurally complex habitats.

2. Project overview

2.1 Background

Phragmites australis is arguably one of the most cosmopolitan and invasive species worldwide (Sun *et al.* 2007; Uddin *et al.* 2012; Uddin *et al.* 2014) and found in every continent except Antarctica (Kobbing *et al.* 2013). Typically, *Phragmites* grows in wetlands and margins within freshwater conditions but it will also tolerate slightly brackish (Meyerson *et al.* 2000)(Croft 2004; Gotch 2013; Jessop *et al.* 2006; Kobbing *et al.* 2013) to strongly saline conditions where it can persist (but not flower) amidst mangroves (Packer unpublished data).

This plant is one of the most widely researched plant species because of its perceived benefits and/or threats to ecosystem health and services (Mozdzer *et al.* 2013). *Phragmites* is a clonal grass species that can grow to four metres in height (Hanganu *et al.* 1999) and produce dense monospecific stands that results in a homogenous floristic assemblage (Hudon *et al.* 2005). As such, much of the contemporary research on *Phragmites* investigates expansion and progression dynamics (An *et al.* 2012; Chambers *et al.* 1999b). Previous studies were more focussed on dieback trends and health of vegetation stands as a result of massive contraction of Phragmites vegetation communities in Europe (Güsewell and Klötzli 2000; Güsewell *et al.* 2000).

Within Australia, *Phragmites* has undergone a re-distribution on account of anthropogenic changes such as regulated hydrology and eutrophication. There is reduced *Phragmites* populations in some areas and yet evidence of significant *Phragmites* expansion in other regions such as parts of South-eastern Australia (Roberts 2000).

Phragmites is found in many habitats in South Australia, from arid mound springs to the lower lakes of the River Murray floodplains. Within the Mount Lofty Ranges, *Phragmites* is common within wetland vegetation communities, riparian systems and associated edges. The critically endangered Fleurieu Swamps sit within the Southern Mount Lofty Ranges landscape and consist of mixed shrub, sedge, reed and fern vegetation assemblages (Fig.1). *Phragmites* is found in varying abundances within the Fleurieu Swamps, with greater densities more likely within the Eastern lowland Fleurieu Swamps.

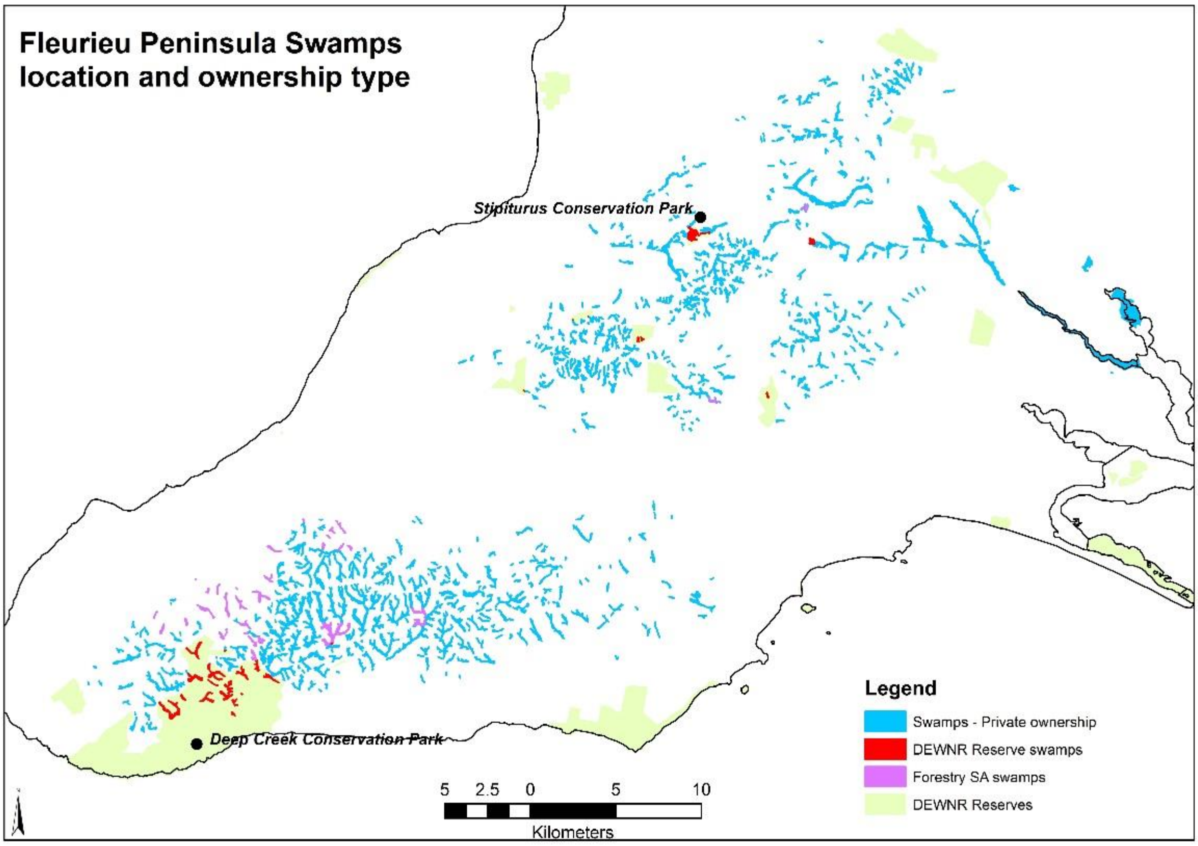

Figure 1: The distribution of the Fleurieu Peninsula Swamps. Source: The Fleurieu Peninsula Swamps Draft Recovery Plan 2014.

The Fleurieu Swamps are a mosaic of different structural formations that merge into one another depending on soil, hydrology and terrain (Duffield and Hill 2002; Duffield, Milne *et al.* 2000; Smith 2005; TSSC 2003). The vegetation formations are typically dense, consisting of shrub, sedge, reed and fern habitats of variable densities and configurations. These vegetation groups occur independently or in association with one another. A diversity of swamp vegetation groups are considered an indicator of a healthy and dynamic swamp (Duffield and Hill 2002). Soil type and associated hydrology contributes to the plant species composition, density and structure within the Fleurieu Swamps (Croft 1999; Duffield and Hill 2002; Duffield, Milne *et al.* 2000; Harding 2005).

The locally named Black Swamp is a Fleurieu Swamp ecological community, that occurs within the within the lower Tookayerta and lower Finniss catchments. Within the Black Swamp system, a densely vegetated *Phragmites* assemblage has been recorded within parcels that were no longer grazed or actively slashed (Croft 2004). Conversely, other areas within the Black Swamp system that have been actively managed with grazing or slashing had reduced densities of *Phragmites* and increased cover of sedges such as *Baumea* species (Croft 2004). Croft (2004) suggests that the increased abundances of *Phragmites* within Black Swamp could also be partly attributed to recent siltation of the swamp caused by anthropogenic modification of the landscape.

2.2 Project objectives and planning

2.2.1 Scope

This project investigated the distribution and abundance of *Phragmites* within the Black Swamp, lower Tookayerta region. The focus of the project was to identify the physical conditions and management history that determined and supported monospecific stands of *Phragmites* within Black Swamp and to predict the potential impacts this could have on floristic diversity. The core investigations were delivered as part of a University of Adelaide honours research project, supported by a convened Steering Group.

2.2.2 Project conception

The Conservation Council of SA (CCSA) Fleurieu Swamp Recovery Program identified the incremental expansion of *Phragmites* within the lower Tookayerta swamp system in 2012. The dominance of *Phragmites* was a concern to the Recovery Program as it appeared to be compromising the floristic diversity and structural complexity of this catchment. This trend appeared to be happening after considerable conservation efforts to remove grazing from the swamps during the 1990's. There was further concern that the continued expansion of *Phragmites* within this wetland community was influencing vegetation community shifts that no longer provided optimum habitat for the endangered Mount Lofty Ranges Southern Emu-wren (MLRSEW).

Within the Black Swamp area, two ecological burns were undertaken during winter 2013 on unallocated crown land within the lower portion of this catchment. The purpose of the burn was to assess the operational and logistical capacity of implementing burns (for biodiversity outcomes) within *Phragmites* vegetation communities. Observational assessments after the burn indicated a distinct proliferation of *Phragmites* within a short-time frame (within a year). A *Phragmites* project that focussed on expansion trends within Black Swamp was developed by CCSA in partnership with Department of Environment, Water and Natural Resources (DEWNR).

Evidence based research concludes that *Phragmites* has the capacity to expand and dominate large areas (An *et al.* 2012; Chambers *et al.* 1999b; Roberts 2000b). In some instances, *Phragmites* can convert entire vegetation assemblages into *Phragmites* monospecific stands.

The expansion of *Phragmites* within the Black Swamp lower Tookayerta catchment was a concern for several reasons. These included:

1. This species is often associated with the Fleurieu Swamps and an increase in its range and abundance could impact on the integrity of swamps (an endangered ecological community).
2. Considerable investment in restoration within the Black Swamp and Tookayerta region has occurred within the last 10 years (by both the CLLMM Vegetation Program and the Goolwa to Wellington Local Action Plan (GWLAP)). These on-ground actions could be compromised if *Phragmites* outcompetes tube-stock plantings.

3. The Fleurieu Swamp Recovery Project staff indicated that *Phragmites* was becoming increasingly dominant within the Black Swamp system. The 2013 ecological burns within this area was aimed to improve the quality of MLRSEW habitat, however there has been prolific *Phragmites* re-establishment as a consequence of the burn.
4. Traditional restoration for Fleurieu Swamp conservation has been to reduce impacts from domestic stock by fencing the vegetation. Although such strategies may initiate natural regeneration of swamp flora, it could also provide openings within which the opportunistic *Phragmites* will quickly colonise.

2.2.3 Objectives

As documented within the initial CCSA project proposal, there were three objectives related to *Phragmites* that needed to be addressed. These were:

1. What threat does the proliferation of *Phragmites* pose to restoration and revegetation efforts within the CLLMM region?
2. What is the potential of *Phragmites* to become an ecological threat to the integrity and diversity of the Black Swamp and lower Tookayerta system?
3. If *Phragmites* is considered to be a threat, what are effective management strategies for controlling invasion and spread of *Phragmites*?

2.2.4 Project management

Conservation Council of SA was the service delivery agent and facilitated information exchange between the CLLMM Vegetation Program, the Fleurieu Swamp Recovery Program, the University of Adelaide and other stakeholders. As part of this project, a steering group was convened that met regularly to discuss the honours research project and provide technical support. The steering group represented DEWNR, CCSA and the University of Adelaide. A project timeline was constructed during the creation phase and revised during progress evaluation stages (Table 1).

Research data collected as part of the honours project has been managed within a Microsoft Access database. This is a multi-relationship database that was specifically designed and utilised for this project. A copy of the dataset and two Endnote libraries have been made available to DEWNR.

Table 1: The project timeline and associated tasks that were undertaken.

MAJOR TASK	2014		2015												2016					
	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
Conservation SA Interim literature review and project plan Deadline: 31st October 2014	■																			
Feedback from interim report	■																			
Approval of phase 2 Deadline: 15th November 2014	■																			
Revise and refine literature review and project plan based on feedback Deadline: 19th December 2014		■																		
Continued liaison with University of Adelaide on honours project			■	■																
Seek honours student to undertake research				■	■															
Establish project steering group Meet with honours student and supervisor/s				■	■															
Commence preparatory work for honours project					■	■	■													
Honours student commences project							■													
Honours literature review								■	■	■	■	■								
Site reconnaissance to select study sites										■	■									
Study experimental design revised and data collection methods trialled												■	■							
Vegetation field data collection														■	■	■				
Collection soil/water/rhizome samples														■	■	■				
Pond experiments														■	■	■				
Data entry															■	■				
Analysis and write up of honours thesis																	■	■	■	
Preliminary honours research results																			■	
Discussion about honours research results																			■	
Final report Deadline: 31st May 2016																				■
Honours thesis submitted Deadline: 31st May 2016																				■

3. Background literature

3.1 Distribution

3.1.1 Worldwide distribution

Phragmites australis (common Reed) is a cosmopolitan species that occurs worldwide (Kobbing *et al.* 2013; Lambertini *et al.* 2012b). The range that this species naturally occurred is unclear however it is considered native to Africa, Europe, North America and some parts of Asia (Government 2014a).). The highly invasive *Phragmites* that were cryptically introduced into North America on several occasions all belong to the same Eurasian haplotype M (Lambertini *et al.* 2012b; Saltonstall 2002a) . In many instances, this introduced haplotype has outcompeted and replaced the native *Phragmites* within North America.

3.1.2 Local distribution

Phragmites is distributed throughout Australia within various climatic zones (Hocking 1989; Uddin *et al.* 2012). *Phragmites* dominated wetland communities are particularly common in south-eastern Australia (Morris *et al.* 2008).

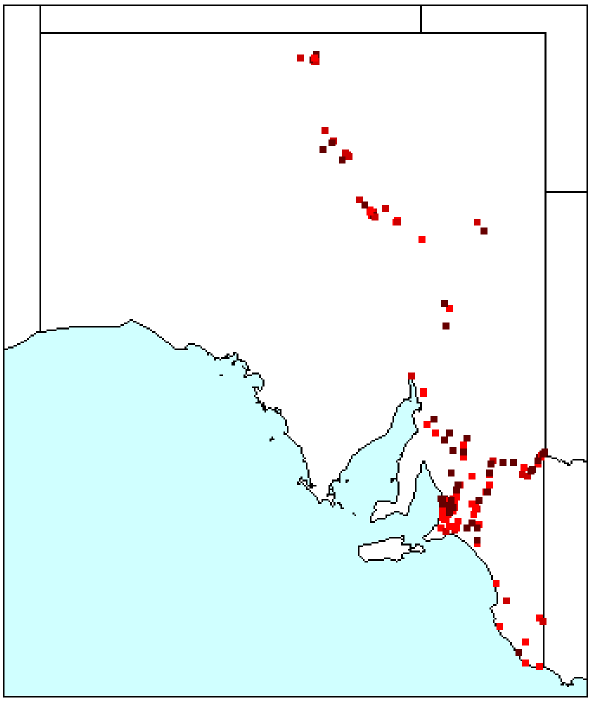

Figure 2: The distribution of *Phragmites australis* within South Australia. Source: Electronic flora database http://www.flora.sa.gov.au/cgi-bin/specimens_map_gd.cgi?genus=*Phragmites*&species=australis&infraname=&region=SA

Phragmites is commonly distributed within and around waterways within the Mount Lofty Ranges and Lower Lakes region of the Murray-Darling Basin (South Australia) (Fig. 2). The shoreline zone of the Lower Lakes was identified as being mostly dominated by *Phragmites* (and *Typha* species) with significant abundances at all sampling times (Nicol *et al.* 2013). The occurrence of *Phragmites* was recorded at all elevations with greater frequencies within lower-lying areas (Nicol *et al.* 2013). These greater abundances of *Phragmites* within the Lower Lakes region occurred in association with reduced floristic diversity (Nicol *et al.* 2013).

Within the Black Swamp system (Lower Tookayerta), densely vegetated *Phragmites* assemblages have been recorded within wetland areas that were no longer grazed or actively slashed (Croft 2004). Conversely, areas within this swamp system that have been actively managed with grazing or slashing had reduced densities of *Phragmites* and increased cover of sedges such as *Baumea* species (Croft 2004). This trend has also been observed in the Great Artesian Basin wetlands where *Phragmites* is mostly absent within heavily grazed areas (by domestic stock) but dense in zones that are void of such grazing pressures (Gotch 2013).

3.2 Biology of *Phragmites australis*

Phragmites australis belongs to the Gramineae family (Citation: Trin. ex Steudel, Nom. bot. edn 2, 2:324 (1841)). This grass species has a C3 photosynthetic pathway. The grasses are large tufted perennials with narrow lanceolate leaves that protrude from the culms (Jessop *et al.* 2006). The culms (stems) can reach heights of up to 4-metres and the flowering period within South Australia is recognised as December to August (Jessop *et al.* 2006). Although the belowground organs persist for several years, the shoots only survive for one year (Roberts 2013).

There are several dozen genetic lineages of *Phragmites* in the Northern Hemisphere that include native and non-native lineages (Mozdzer *et al.* 2013; Blossey 2014) with some groups often co-existing within the same areas (Saltonstall 2002). There is concern that hybridisation between the lineages is possible and could be a major threat to protecting the genetic integrity of the native species of localised areas (Lambertini *et al.* 2012; Mozdzer *et al.* 2013).

The introduced genotypes have a range of environmental tolerances and thrive in nitrogen rich areas that allows rapid establishment and expansion (Hudon *et al.* 2005). The Eurasian *Phragmites* (considered the more invasive species) is more efficient with allocation of oxygen to vital organs, thus giving the species the ability to establish and mobilise ecological niches (Chambers *et al.* 1999; Lambertini *et al.* 2012). The Eurasian *Phragmites* genotypes also have physiological and morphological advantages as they produce more individuals per unit area and are faster growing and taller (Mozdzer and Zieman 2010; Mozdzer *et al.* 2013). Under stressful conditions, the exotic *Phragmites* lineage effectively utilises vital attributes to persist (Mozdzer *et al.* 2013). This suggests that this genotype is actually advantaged by disturbance, a characteristic demonstrated by successful invasive species.

3.3 Establishment

3.3.1 Reproduction

Phragmites is a woody perennial clonal grass that can reproduce vegetatively (as rhizomes, or using stolons) or sexually via seedling recruitment. The primary re-establishment of *Phragmites* is by rhizomatous growth and less frequently, through seedling recruitment (Uddin *et al.* 2012).

A germination study by Nicol *et al.* (2010) found that despite *Phragmites* being present at various sites, seedlings were not detected (Nicol and Ward 2010). This suggested that there are issues with the viability of *Phragmites* seeds and/or the conditions required for germination were not available.

The small and light seeds of *Phragmites* would be easily distributed by both wind, water and possibly via faunal dispersal (Gotch 2013). In Australia, it is generally accepted that seedling germination of *Phragmites* is limited as the seeds require particular environmental conditions (Greenwood and MacFarlane 2006; Gotch 2013). The results from the germination trial conducted by Nicol and Ward (2010) concluded that sexual reproduction of *Phragmites* is unlikely. In contrast a study on the Eurasian *Phragmites* lineage demonstrated that invasion was mostly accounted for by seedling recruitment (Belzile *et al.* 2010).

Although individuals of *Phragmites* will die at the end of the growing season, the below ground structures (rhizomes) are perennial and facilitates ongoing persistence and expansion (Kobbing *et al.* 2013).

3.3.2 Expansion capacity

There has been considerable interest in this species worldwide because of its invasiveness and the potential of native and non-native genotypes to hybridise, particularly within the northern hemisphere (Blossey 2014). The annual spread of *Phragmites* rhizomes and aerial stolons are prolific (Hudon *et al.* 2005; Kobbing *et al.* 2013) with the capacity of up to 200 stems per metre^2 (Hudon *et al.* 2005). The ability of *Phragmites* to spatially expand is variable (Hudon *et al.* 2005). Mal and Narine (2004) documented lateral expansion within existing colonies can be up to 10 metres within a year.

Vegetation propagules of *Phragmites* accounted for 88% of horizontal expansion within a Canadian wetland and resulted in the occupied area increasing to 32.6 hectares (from <1 hectare) within a 23-year period (Hudon *et al.* 2005). Within a United States of America marshland there is empirical information that has quantified the ability of *Phragmites* to increase in range up to 1.5m year $^{-1}$ (Crain *et al.* 2004). Within the South Australian section of the Great Artesian Springs wetlands, the shoot biomass values of *Phragmites* within the Great Artesian Springs wetland (South Australia) were in excess of 10kg/ m^2 (Davies *et al.* 2010).

The magnitude of lateral expansion in any one year period is likely determined by hydrological conditions of the previous season (Hudon *et al* 2005). There was a significant relationship between the growth and expansion of *Phragmites* and water levels for preceding years (Hudon *et al* 2005).

A study by Kuhl and Zemlin (2000) suggested that the success of *Phragmites* growth (shoot density and size) and flowering varied between terrestrial and aquatic areas (Kuhl and Zemlin 2000). The different responses of *Phragmites* clones depending on water inundation was also noted by Rolletschek et al (2000) and Klotzli and Zust (1973) (Klotzi and Zust 1973; Rolletschek *et al.* 2000). This suggests that management of *Phragmites* expansion should be specific to the hydrology of each site.

3.4 Environmental thresholds

3.4.1 Tolerances

As *Phragmites* has a C3 photosynthetic pathway, its range is likely to increase worldwide in response to projected climate change. A laboratory experiment suggested that *Phragmites* will respond favourably to elevated CO_2 as there were increases in biomass in response to elevated carbon levels (Mozdzer and Megonigal 2012). This response was explained by increased physiology and morphological plasticity (Mozdzer and Megonigal 2012).

Phragmites is able to persist when exposed to desiccation and/or reduced water levels (Nicol and Ward 2010). Within a swamp wetland in New South Wales, *Phragmites* was able to re-establish as soon as water was returned to the system after an extended drought period. This occurred after 5 years of senescence and demonstrated the persistence and vigour of *Phragmites* rhizomes (Roberts 2013).

There is evidence to suggest that *Phragmites* can adapt to highly saline conditions by modifying the diffusion of solutes within its leaf cell structures (Lissner and Schierup 1997). This is consistent with distributional observations of *Phragmites* within the Great Artesian Basin occurring in both freshwater and brackish environment (Gotch 2013).

Phragmites is also able to establish and survive within an environmental setting with varied hydrological regimes. Dense masses of *Phragmites* in the South-east of South Australia are expected to occur in areas that have fluctuating water levels (Deegan *et al.* 2007). Similarly, *Phragmites* was associated with various flow conditions within the Great Artesian Basin (Gotch 2013).

Phragmites is an opportunistic coloniser and is able to respond favourably to ecological disturbance. For example, an ecological restoration program that disturbed the soil substrate resulted in *Phragmites* colonising 80% of the total area (Welch *et al.* 2006). Similarly, anthropogenic driven environmental changes can result in expansion of *Phragmites* (Moore 1973).

3.4.2 Sensitivities

Although water levels may not impact on the persistence of *Phragmites*, it might determine overall plant foliage. There are records of reduced *Phragmites* biomass within areas that are no longer permanently inundated (Resleigh and Foster 2012).

Despite *Phragmites* being able to persist within wetlands with different water availability, there is sufficient evidence that growth can be hindered if the depth of saturation exceeds 0.5 metres (Denis 2011). Established *Phragmites* stands are unlikely to persist beyond three years if they are subjected to water depth greater than 1 metre (Denis 2011). The foliage cover of *Phragmites* is also reduced when subjected to more than 100 days of consecutive flooding within a year (Denis 2011, Hudon *et al.* 2005).

It is possible that *Phragmites* is sensitive to magnesium and potassium levels (Sun *et al.* 2007). The growth of *Phragmites* was negatively impacted within a New Jersey (North America) wetland that had increased magnesium and potassium (Sun *et al.* 2007).

Although there is evidence to suggest that *Phragmites* will colonise highly saline areas, the ongoing persistence of the population is questionable (Hocking 1989; Marks *et al.* 1994). Blossey (2014) suggested that flooding *Phragmites* stands with full strength saltwater could result in mortality of existing individuals.

3.5 Impacts from Phragmites australis

3.5.1 Impacts on biogeochemical processes

Phragmites can influence and modify biogeochemical cycles within wetland systems (Windham and Ehrenfield 2003; Modzer et al 2013). Gallic acid, that interferes with protein structures of other plant species, can be released from the rhizomes of *Phragmites* (Mozdzer *et al.* 2013). The release of biochemicals (via allelopathic processes) that influences germination and growth of other species is a characteristic typical of highly invasive species (Callaway *et al.* 2002; Crain *et al.* 2004). The results from Uddin et al (2012) demonstrated that *Phragmites* has allelopathic potential as the leaves and rhizomes produce phytotoxic chemicals that could interfere with germination and physiological pathways of other plant species.

Phragmites is effective at taking in nutrients that could otherwise be available to other flora (Kiviat 2013; Kotze 2013; Nikolić *et al.* 2014). This efficient utilisation of nutrients and ability to quickly invade an area means that *Phragmites* can aggressively invade and permanently dominate a wetland community.

3.5.2 Physical modifications

The slow decomposition and substantial biomass accumulation of *Phragmites* can create an aggregated surface layer (Hudon et al 2005; Denis 2011). This accumulation of litter and debris modifies the topography at a fine scale by elevating the soil profile (Denis 2011). This process may result in drying out of areas and impacting on species that require saturation for germination and/or persistence.

The culms and leaves from *Phragmites* contain silica that produces stiff plant foliage (Kiviat 2013). This material may not readily break-down thus preventing recruitment of other plant species as vital resources such as sunlight and air are unavailable. Such an environment could exclusively favour enduring sprouters such as *Phragmites*.

3.5.3 Impacts on biodiversity

There is extensive empirical evidence that abundant *Phragmites* is associated with areas of reduced floristic richness within New England wetlands (Keller 2000; Hazelton *et al.* 2014). However the relationship between *Phragmites* and reduced plant diversity is not always straightforward. Invasion and spread of *Phragmites* may not result in reduced diversity if other plants are competitive and capable of persisting (Keller 2000). The amount of water and timing of inundation is also likely to influence a *Phragmites*-reduced plant richness relationship (Keller 2000).

There has been considerable research on *Phragmites* population increases within the Great Artesian Basin wetlands with results suggesting that there is a strong relationship between reduced floristic richness as *Phragmites* dominated monostands increase (Fensham *et al.* 2004; Davies *et al.* 2010; Gotch 2013)).

The dense monospecific *Phragmites* stands are often described as poor quality habitat (Roman *et al.* 1984; Sun *et al.* 2007) or with the potential to impact on ecological processes that will then cause habitat deterioration for some fauna groups (Hudon *et al.* 2005; Kodric-Brown *et al.* 2007).

Phragmites biomass accumulation and clogging has been documented as reducing oxygen levels and preventing the distribution of larval and juvenile fish (Hudon *et al.* 2005; Kodric-Brown *et al.* 2007). Another study found that dense *Phragmites* populations did not impact on tadpole, juvenile and adult frogs (Anuran family) (Mazerolle *et al.* 2014).

Insect diversity has been documented as less diverse in systems dominated by *Phragmites* (Denis 2011). In contrast, there are several papers that highlight the biological importance of *Phragmites* for invertebrates. The litter that is derived from *Phragmites* could be an important component of the invertebrate food chain and support fungi species as noted by Gulis *et al*. 2006 (Gulis *et al.* 2006). Removing the dead material of *Phragmites* could impact on invertebrate species (a food source for birds) that utilise the detritus. Discrete cutting of a *Phragmites* dominated Slovakian wetland actually increased community heterogeneity and consequently the numbers of arthropods (Trnka *et al.* 2014). This provided suitable habitat for a diverse range of passerines (Trnka *et al.* 2014).

Dense *Phragmites* stands can provide nest material and nesting opportunities for bird species (Kane 2001; Kiviat 2013). Some fauna species may have a preference for dense *Phragmites* areas, particularly avian species that require the stand specific structures for breeding and nesting.

At a regional scale, *Phragmites* vegetation stands within the Black Swamp and Tookayerta area are considered critical habitat for avian species of conservation significance including the Australasian Bittern, Great Crested Grebe and various Crakes (Croft 2004). The endangered MLRSEW occurs within these Lower Tookayerta swamps and wetlands (Pickett 2016). Over time, the distribution of the MLRSEW within Black Swamp has decreased with sub-populations trending towards a restriction to the lower reaches such as Finniss Park. The MLRSEW Recovery Team has discussed if these changes are being primarily influenced by increases of *Phragmites* density or if there are other drivers such as predation and/or limited food resources.

4. *Phragmites australis* research

The research component of this project was undertaken by the University of Adelaide as part of an honours study with assistance from CCSA and DEWNR. As part of the compulsory core requirements of the honours project, a literature review and project proposal was submitted (Attachment A). The information contained within this chapter and subsequent chapters is derived from the honours project (Attachment B).

The title of the honours project is "Expansion and dominance of *Phragmites australis* (common reed) and its implications for the critically endangered Fleurieu Peninsula Swamps, South Australia". To satisfy the original objectives of this project, the honours project nested three specific objectives underneath an overarching aim to "understand the effect of *Phragmites* within the Black Swamp and Tookayerta System and determine the reasons for its expansion in the region". An additional fourth objective was also developed to support the findings from the other research objectives. These objectives were:

1. Assess the rate and extent of *Phragmites* expansion in the Black Swamp and Tookayerta System;
2. Determine correlations between abundance of *Phragmites,* environmental factors and plant diversity;
3. Determine if cutting below mean water level is an effective management tool to supress the monospecific expansion of *Phragmites; and*
4. Identify the different abundances of *Phragmites* and if this was related to historical and/or current land management.

4.1 Hypotheses

To support the specific research objectives, five specific research questions were addressed as part of this honours project. These are tabled below (Table 2) as they relate to the overall objectives.

Table 2: Research questions that were developed as part of the Honours study

Research objective	Research questions
Assess the rate and extent of *Phragmites* expansion in the Black Swamp and Tookayerta System.	1. Has *Phragmites* expanded spatially within the Black Swamp and Tookayerta system?
Determine correlations between abundance of *Phragmites,* environmental factors and plant diversity.	2. Is *Phragmites abundance* within the Black Swamp and Tookayerta system correlated with specific environmental factors? 3. Is there an association between *Phragmites* density and floristic diversity within the Black Swamp and Tookayerta system?
Determine if cutting below mean water level is an effective management tool to supress the monospecific expansion of *Phragmites.*	4. Does cutting of *Phragmites* below mean water level suppress monospecific expansion?
Identify the different abundances of *Phragmites* and if this was related to historical and/or current land management.	5. Is there an association between *Phragmites* density and distribution and historical grazing by domestic livestock?

4.2 Study site

The broad study site was the Black Swamp wetlands that form part of the lower Tookayerta system. This area is approximately 80km south of Adelaide, South Australia and sits within the Coorong, Lower Lakes and Murray Mouth region within the SA Murray Darling Basin NRM region (Fig.3.).

The Black Swamp wetlands comprises nine different land titles and the vegetation is a mix of *Phragmites*, *Typha domingensis*, *Carex* species, *Baumea* species and *Leptospermum* species. This swamp system is recognised as a Fleurieu Peninsula Swamp, a critically endangered ecological community listed under the EPBC Act (1999).

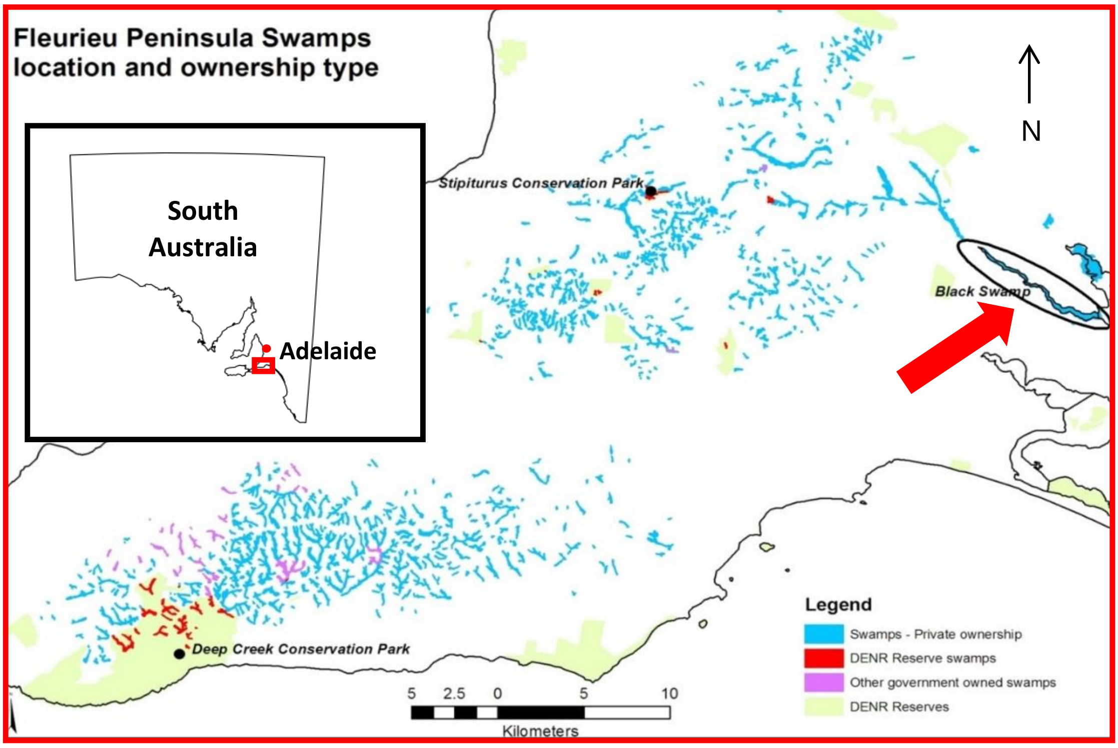

Figure 3: Map of Fleurieu Peninsula swamps and the specific Black Swamp study site

Two study sites within Black Swamp were chosen for field assessments. Each of the sites represented different cattle grazing management histories and varied densities of *Phragmites* and vegetation assemblages. Both of these sites are privately owned and to protect the privacy of the landholders are referred to as Site 1 and Site 2 (Table 3; Fig.4.). MLRSEW have been observed within the swamps on these properties but not since 1996 (Site 1; Fig.4.) and 2012 (Site 2; Fig.4.).

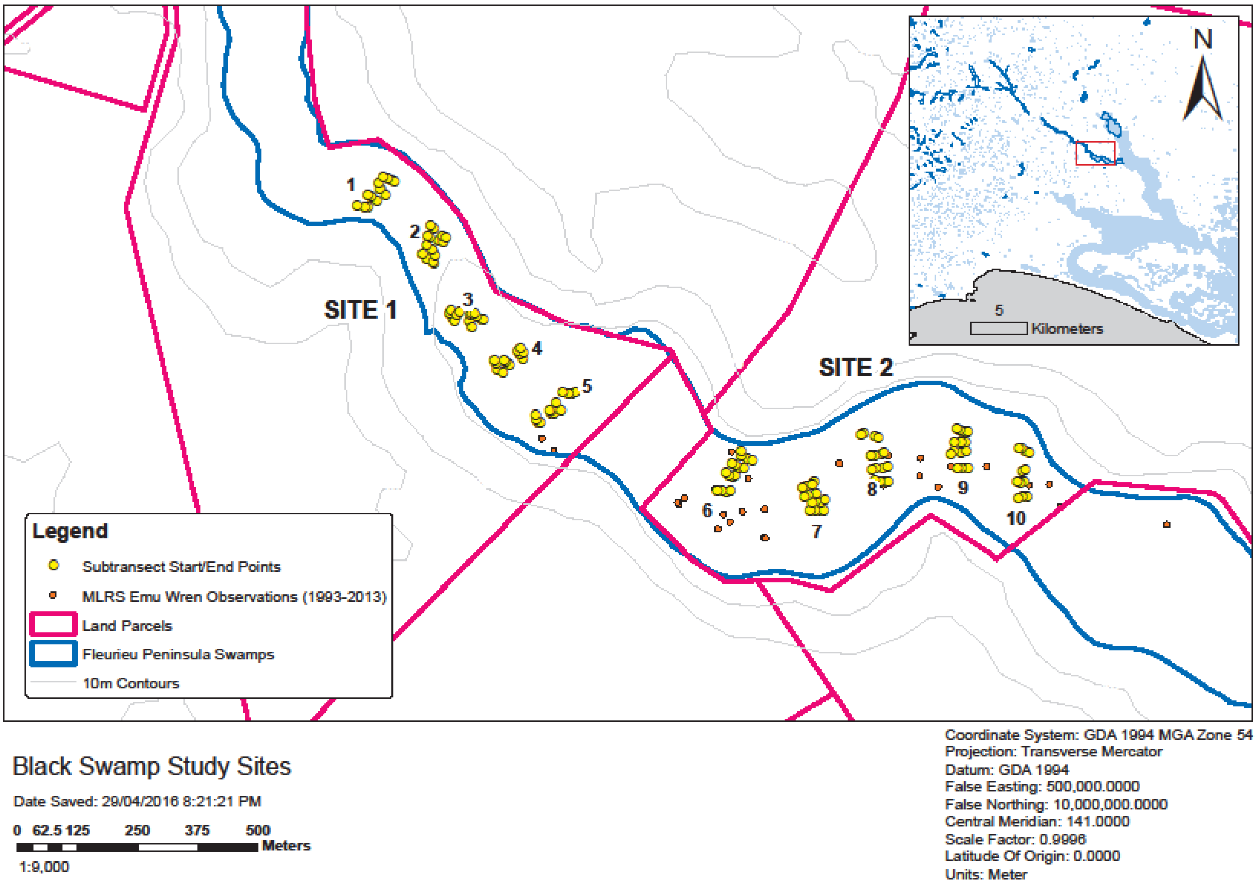

Figure 4: Map showing comparison sites and placement of survey transects (numbered) and sub-transects (yellow markers).

Table 3: Information on the properties that constituted study sites.

Site	Vegetation Type	Last Grazed	Land Management History
1	*Phragmites* dominant (dominant monospecific *Phragmites* stand)	1996	Site grazed prior to 1996 (previously a dairy farm). Swamp was used as dairy paddock and heavily grazed. Since 1996 the swamp has not been grazed or slashed.
2	Mixed (*Phragmites* present in patches, not dominant)	2002	Grazed with cattle long-term prior to 2002. Grazing completely ceased in 2002.

5. Methodology

This research required a combination of field-based data collection and pond experiments (Attachment B). Field assessments utilised a nested transect based design to collect vegetation data while the pond experiments investigated the response of *Phragmites* rhizomes under varied flooding periods.

5.1 Field-based research

5.1.1 Experimental design

The field work assessments collected information on floristic richness, *Phragmites* vertical foliage density, height and number of stems and environmental factors such as litter depth, surface water soil analyses (samples analysed).

At each site, five transects were located using stratification. The transects were placed perpendicular to the drainage channel to account for topographical and hydrological variability (Fig.5.). The start of each transect was located at least 20 metres from the swamp edge to limit edge effects (Fig.5.).

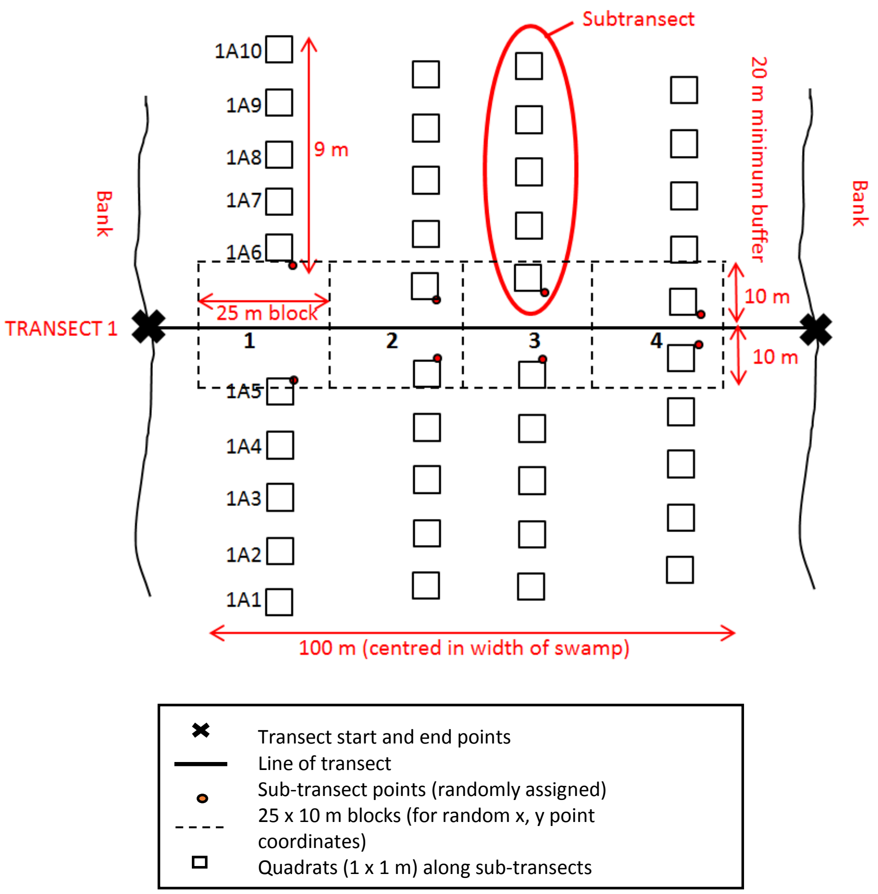

Figure 5: Experimental design of transect, sub-transect and quadrat placement within the study sites

Each transect supported four sub-transects that were 10 metres in length. The sub-transects were located from a single point that was determined using randomly generated x/y coordinates. There were ten 1 m^2 quadrats systematically placed along the sub-transect (five either side of the transect line) with spaces between each quadrat to reduce surveying impacts. This produced 40 quadrats per transect (200 samples per site). The vegetation survey was undertaken within the quadrats (Table 4) and collected information on:

a) Species richness - any species that had biomass within the quadrat;
b) Vertical profile of foliage cover – this is recorded using the vertical pole intercept method. Using a graduated pole (marked at every 10 cm), the number of vertical foliage hits of all species is recorded and if it was live or dead matter. This method has been developed specifically for vegetation within the Fleurieu Swamps and has been amended as part of this research;
c) The depth and composition of the litter at the location of the pole (centre of the quadrat);
d) The density of *Phragmites* – recorded as the number of stems;
e) The height of the tallest *Phragmites* stem; and
f) Water depth: the depth of standing water or depth to reach water (depth to saturation) was recorded.

Additional sampling was also undertaken that included:

a) Soil sampling: samples were collected from 15-30 cm deep (at each corner of the quadrat) and combined into one larger sub-transect sample. The soil was collected with a 50 mm soil auger. Soil surface material and plant litter was excluded. Each sample was weighed to 500 g and sent to APAL Agricultural Laboratories for analyses. The following information was provided:
    - pH (Water),
    - pH (CaCl),
    - electrical conductivity (EC),
    - organic carbon,
    - nitrate NO_3,
    - ammonium NH_4,
    - PBI (+Colwell P),
    - sulphur (KCL),
    - Colwell potassium (K),
    - Colwell phosphorus (P).

Table 4: Summary of the number of transect, sub-transects and quadrats that were established as part of this study.

Site	Transects	Sub-transects		Quadrats	
		Number	Assessment	Number	Assessment
Phragmites dominant (Site 1)	5	20 (8 per transect)	-Soil sample (combined from 5 x quadrats) (500 g)	200 (5 per sub-transect)	-Species richness -Vertical foliage cover -Litter depth -Number of *Phragmites* stems -Height of tallest *Phragmites* stem -Soil sampled -Water depth
Mixed (Site 2)	5	20 (8 per transect)	-Soil sample (combined from 5 x quadrats) (500 g)	200 (5 per sub-transect)	-Species richness -Vertical foliage cover -Litter depth -Number of *Phragmites* stems -Height of tallest *Phragmites* stem -Soil sampled -Water depth

5.1.2 Data management and analyses

Data collected from field assessments has been stored and managed within a Microsoft Access database.

Exploratory data analysis was conducted at both scales to check for outliers, and collinearity within the response and explanatory variables using Pearson correlation coefficients (<0.60) and variance inflation factors (Zuur *et al.* 2007). All analyses were conducted in R version 3.3.0 (R Core Team 2015). Linear and generalized linear models (GLMs) were generated using the package lme4 version 1.1-9 (Bates *et al.* 2015). Post-hoc differences between categorical treatments were assessed using Tukey's Honestly Significant Difference (HSD) tests in the multcomp package version 1.4-1 (Torsten *et al.* 2015).

Floristic Species richness (S) and Shannon diversity (H') were used as the main response variables, and *Phragmites* stem density, litter depth, soil nutrients, soil characteristics and water conditions were used as the covariates (Table 5). Species richness (S) was calculated from species presence in a quadrat, and Shannon Index (H') and Pielou's Evenness (J) were calculated from pole touches. These measures were used to quantify the species distribution in each quadrat (n=400) and each sub-transect (n=80) and were used as response variables to *Phragmites* (such as stem density and height). The indexes were calculated as follows:

Shannon Index (H'), based on 'percentage composition by species' (Peet 1975)

$$H' = -\sum Pi \ \ln Pi$$

and Pielou's Evenness (J) (Peet 1975)

$$J = \frac{H'}{\ln(S)}$$

Analyses were conducted using R Studio software (3.3.0). A mixed modelling approach was used to investigate the influence of environmental variables on the native vegetation community (Table 5). The means of each variable were compared for each of the two main sites. Means and 95% confidence intervals of the variables in each site were compared. The significant response and explanatory variables were then selected for use in the models.

Table 5: Description of environmental variables surveyed across five quadrats for each sub-transect and compared across two sites. Sub-transect: 5 x 1 m^2, n= 40 per site, n= 80 total.

Response Variables	**Details**
Mean Species Richness (S)	Mean number of species in 5 x 1 m^2 quadrats
Shannon Diversity Index (H')	Calculated by proportion of species in 5 x 1 m^2 quadrats
Pielou's Evenness (J)	Calculated from Shannon's diversity (H') and mean species richness (S)
Explanatory Environmental Variables	**Details**
Mean Litter Depth	Mean depth above soil level (cm) in 5 x 1m^2 quadrats
Mean Water Depth	Mean level above (+) or below (-) soil level (cm) in 5 x 1m^2 quadrats
Mean Phragmites Touches	Mean number of pole touches in 5 x 1m^2 quadrats
Mean Tallest Phragmites Height	Mean height (cm) of tallest Phragmites in 5 x 1m^2 quadrats
Mean Phragmites Stem Density	Mean density of Phragmites stems in 5 x 1m^2 quadrats
Soil pH	Soil CaCl pH, measured from soil samples. 5 x samples combined for each sub-transect.
Soil N:P	Ratio of Nitrate (NO_3) to Colwell Phosphorus (P) (mg/kg), measured from soils samples. 5 x samples combined for each sub-transect.
Soil EC	Electrical conductivity (1:5) as a measure of salinity (dS/m), measured from soils samples. 5 x samples combined for each sub-transect.
Soil N	Nitrate (NO_3) (mg/kg) measured from soil samples. 5 x samples combined for each sub-transect.
Soil P	Colwell Phosphorous (P) (mg/kg) measured from soil samples. 5 x samples combined for each sub-transect.

5.2 Pond experiments

Pond experiments were undertaken at the University of Adelaide with the aim of assessing cut and flooding techniques (flooding delays) on the biomass allocation of *Phragmites.* This was to investigate the potential of such treatments to control *Phragmites*. It was expected that this study would provide insights into the environmental tolerances and sensitivities of *Phragmites* populations within Black Swamp. This required the extraction of *Phragmites* rhizomes from the study site. Accordingly, approval was sought and given from Native Vegetation Council under Regulation 5 (1) (zi) Clearance for preserving, enhancing biological diversity.

5.2.1 Experimental design

Pre-experiment preparation

Prior to rhizome collection, 60 pots of 30 cm diameter (13 litre capacity) were pre-treated to anoxic conditions to mimic wetland soils (Aldridge and Ganf 2003). Pots were lined with 90% block-out shade cloth and filled with approximately 11 kg of sandy-loam soil, mixed with 42 g of Osmocote® (NPKS 13 : 2 : 4 : 6) and 135 g of fine sawdust. Pots were submerged in outdoor ponds for 132 days prior to planting (Fig.6.). On inundation, each pot was capped with a 2 cm layer of clay to simulate the natural redox potential of anoxic soil (reducing oxygen diffusion) and to reduce the growth of algae (White *et al.* 2007). Redox was measured weekly for ten weeks in a random subsample of pots (10 per week) at 5 cm below the clay layer with a Vernier ORP probe and a Vernier LabQuest II connected science system.

One hundred and thirty *Phragmites* ramets were initially collected during active growing season (October 2015) and sorted into the rhizomes, culms and roots. The rhizomes were cut back to three nodes and transferred to the University (culms and roots discarded). These rhizomes were collected within Site 1 and planted in pots (as described above). An individual rhizome was planted into one 30 cm diameter pot with pre-prepared soil (N=120 pots). Each rhizome was planted to 20 cm depth and saturated for eight weeks.

The rhizomes failed to establish while submerged and subsequently twelve rhizomes per week were extracted for the following four weeks (Roberts 2016; Attachment B). These were then placed in water in shallow trays within the glasshouse facilities at the University of Adelaide to assess viability of the rhizomes. From a total of 48 rhizomes extracted, viability was only observed in rhizomes inundated for a total of 8 weeks. Rhizomes inundated for 9, 10 and 11 weeks showed no signs of viability.

The same collection design (above) was repeated with new rhizomes collected on November 27th 2015 from the *Phragmites* dominated swamp (Site 1; within a 50 m radius). One hundred and forty seven *Phragmites* rhizomes with shoots were chosen, cut back to three nodes (Fig.7.) and the cut ends sealed with wax to reduce tissue damage (White *et al.* 2007).

Establishing the experiment

Instead of establishing the samples within the ponds, the samples were grown in high light and nutrient rich conditions in shallow trays lined with sandy loam in the Adelaide University Benham Glasshouse facilities (approximately 25 degrees C). The samples were established for 101 days and were permanently inundated during this time. After establishment, 46 suitable ramets were selected (Fig.7.), washed and the sprouted shoots cut to 20 cm above the root/rhizome level. The ramets were weighed and the number of stems counted, then randomly allocated to pot numbers and planted in a controlled outdoor pond in saturated soil (surface water approximately 5 cm above soil surface) at The University of Adelaide (Fig.7.).

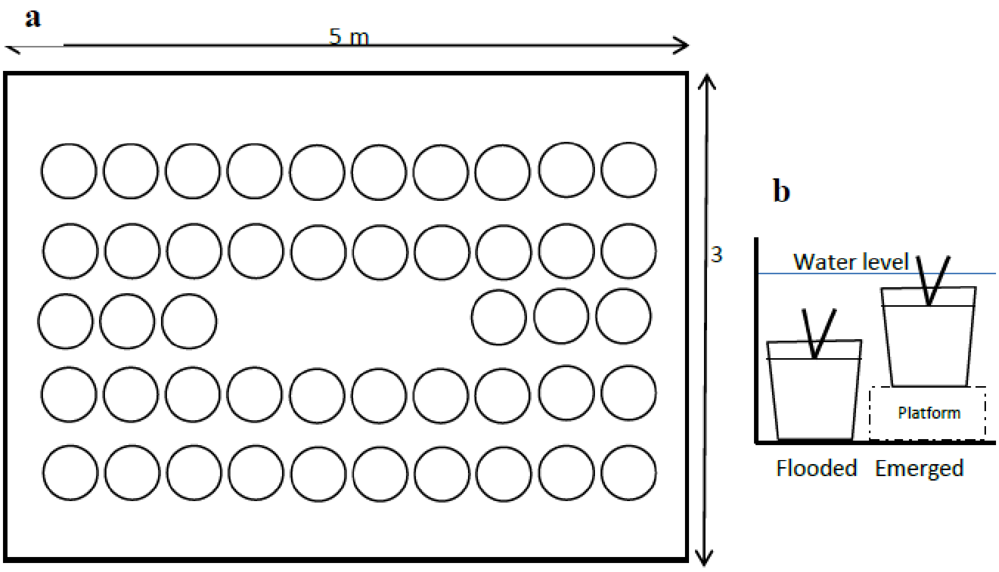

Figure 6: a: A birds-eye view of the common garden experiment in outdoor pond. b: Side view example (not to scale) of flooded and emerged samples inside pond.

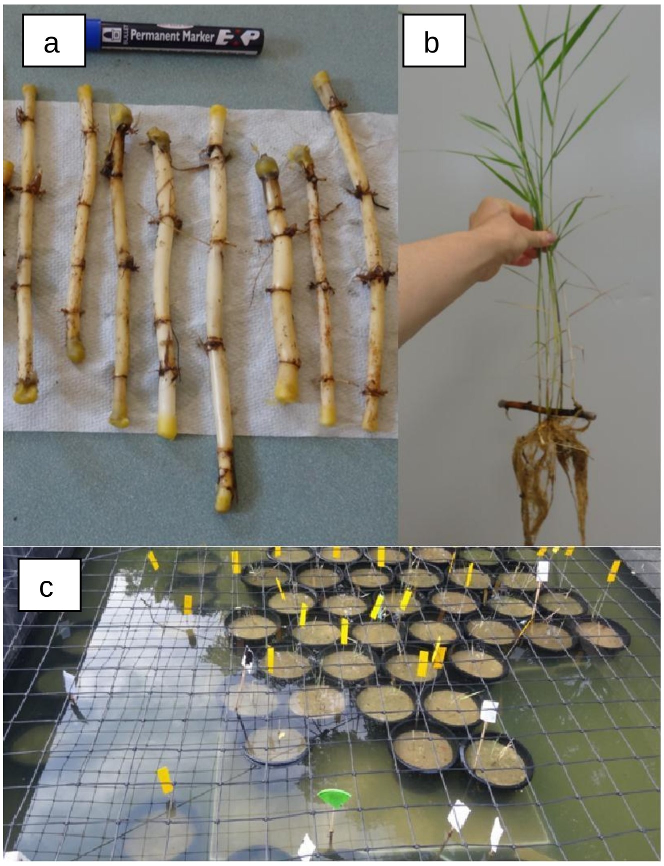

Figure 7: a. Collected rhizomes cut to three nodes with waxed ends; b. *Phragmites* ramet after establishment in greenhouse; c. flooded and emerged treatments in outdoor ponds at Adelaide University.

Treatment application

Each of the 46 samples were randomly allocated to a flood delay between 1 and 14 days. Each sample was inundated at least 20 cm below the surface for 14 full days, beginning from the allocated flood day, then elevated (on day 15 of flooding) and allowed to establish for 7 days (Table 6) and then exhumed for processing and assessment. Emergent plants were elevated on 30 cm platforms with cut culms protruding from the water surface (Fig.7.). Six samples remained emergent for the duration of the experiment (35 days) as control group.

Table 6: Example of flooding regime showing only first 10 samples and first 19 days of the experiment. C denotes the control treatment example.

= Flooded (F) = Emerged (E)

Pot #	Flood Day	7/03/16	8/03/16	9/03/16	10/03/16	11/03/16	12/03/16	13/03/16	14/03/16	15/03/16	16/03/16	17/03/16	18/03/16	19/03/16	20/03/16	21/03/16	22/03/16	23/03/16	24/03/16	25/03/16
78	C	E																		
98	0	F															E			
94	0	F															E			
63	0	F															E			
71	1	E	F															E		
102	2	E		F															E	
92	2	E		F															E	
95	2	E		F															E	
91	2	E		F															E	
101	3	E			F															E
110	3	E			F															E

On completion of the flooding cycle, each sample was exhumed, washed and weighed. Each ramet was separated into units (shoot, root and rhizome) and the following variables were recorded:

- Wet weight of each unit;
- Height of new shoots (measured from root to tip);
- Number of new shoots; and
- Dry weight of each unit.

To obtain dry weight, labelled units were dried at 60 ˚C for 48 hours, then for a further 24 hours to check mass was constant (Hellings and Gallagher 1992).

5.2.2 Data analyses

Analyses were conducted using R Studio software (3.3.0). A linear regression was inappropriate due to anomalies in the data, so flooding intervals were grouped into four treatments based on the flood delay after cutting (0-2 days, 3-7 days, 8-14 days and the control). Response variables (Table 7) were obtained from measurements and were compared to determine significance between the three flood delay groups and the unflooded control group. Mean estimates and 95% confidence intervals of response variables were compared between these groups and plotted to determine linear trends.

Table 7: A tabled list of the designated response variables assigned as part of the pond experiments

Response Variable	**Description**
Weight difference	Post-treatment total wet weight of ramet/pre-treatment total wet weight of ramet (g)
Above Ground Biomass	Post treatment dry weight of stems (g)
Below Ground Biomass	Post treatment combined dry weight of roots + rhizomes (g)
Root Biomass	Post treatment dry weight of roots (g)
Maximum Shoot Height	Maximum height of post-treatment shoots in cm, measured from the first root (or from rhizome if no roots present) (cm)
Maximum Shoot Height (outlier removed)	Maximum height of post-treatment shoots measured from first root (or from rhizome if no roots present). Outlier removed.
Number of New Shoots	Count of new shoots post-treatment
Proportion of Roots	Dry weight of roots / total initial wet weight
Proportion of Shoots	Dry weight of shoots / total initial wet weight

5.3 Aerial photography analyses

Aerial photography analysis was used to assess the rate of *Phragmites* expansion within the study site. The information collected by field surveys assisted in validating *Phragmites* patch location, density and height. Summer true colour aerial photographs of the study area (1949, 2001, 2003/2005 (mosaic of images), 2010 and 2014) were provided by The Department of Environment, Water and Natural Resources. Shape files of the region were also provided by the Conservation Council of SA.

True colour three band (RGB) aerial images (1 m pixel resolution) were analysed with ArcGIS (10.3.1) software and the *Phragmites* patch was identified in imagery using colour, texture and ground truth data/observations. Summer images were selected to capture *Phragmites* in active growth stage (Haslam 2010). The 2003/2005 and the 2014 images were chosen for initial aerial image comparison of *Phragmites* stand area, the former to coincide with the removal of grazing from the mixed site and the latter being the most recent available imagery. The 1949 imagery (panchromatic) was not appropriate for analysis.

Supervised (maximum likelihood) classification was performed in ArcMap (10.3.1) on the 2003/2005 and 2014 images. Three classes were chosen for the classification (*Phragmites* dominant, mixed (herbaceous/sedge) and sedge/*Baumea* mixed. The training data band plots were examined during the classification to determine band separations of three different classes. Training data points for supervised classification were based on field surveys, field GPS data and reported habitat zones (Birds for Biodiversity 2004). Ground truth data was collected during field surveys and used to qualitatively analyse the spread of dominant *Phragmites*.

Unsupervised (ISO cluster) classification was also trialled for the 2003/2005 and 2014 images in ArcMap (10.3.1) software. The accuracy was assessed visually using ground truth data collected during field surveys (field GPS points and field observations).

Band separation was not sufficient between mixed vegetation and the dominant *Phragmites* feature classes for both the 2003/5 and 2014 images due to similarity of pixel values, and thus inappropriate for statistical comparison. Change detection analysis (including change detection mapping) of the region of interest (ROI), (Black Swamp) therefore wasn't undertaken. Other imagery was subsequently excluded from analysis. A qualitative assessment was therefore undertaken on the 2003/2005 and 2014 images to evaluate the extent and location of *Phragmites* stands within Black Swamp (see section 6.3). Adobe Illustrator (Version CS5) was used to display the *Phragmites* stands on aerial imagery for assessment of expansion trends.

6. Results

This section provides the results from the honours research study that were available at the time of writing this final report. Information has been extracted from the honours thesis (currently under examination; Roberts 2016). The examined and peer reviewed version of the honours thesis will be provided as an addendum to this report.

6.1 Field based work

Plant species in each main site were assigned to a plant functional group according to Casanova (Table 8). In the *Phragmites* dominant site (Site 1; Table 8), 13 different species were recorded from five functional groups. Five of these species were absent from the mixed site. In contrast, there were forty-six plants species, constituting seven water plant functional groups recorded within the mixed site (Site 2; Table 8). Within Site 2, there were 12 introduced species and 38 species which were absent from the *Phragmites* dominant site.

The majority of plant species from both sites belong to the amphibious fluctuation tolerators (Afte) group (Table 8). Species from the terrestrial dry (Tdry) and amphibious fluctuation responders plastic (Afrp) functional groups were absent from the *Phragmites* dominated site. Key species differed between groups; *Leptospermum sp.* was present in the *Phragmites* dominated site and introduced species (mainly grasses) were present only in the mixed site. Regionally rare and uncommon species were present in both sites; one in the *Phragmites* dominated site (*Lycopus australis (R)*), and six in the mixed site (*Austrostipa meulleri (R), Baumea gunnii (R), Lycopus australis (R), Viminaria juncea (R), Eleocharis gracilis (U) and Villarsia umbricola* var. *umbricola (U)).*

There was a reduced understory complex within the *Phragmites* dominated site when compared to the other site. The mixed swamp complex (Site 2) had a variety of ground layer plant species such as *Eleocharis* species, *Gratiola peruviana*, *Hydrocotyle* species, *Centella cordifolia, Villarsia umbricola* var. *umbricola* and *Isolepis inundata.* The characteristic swamp shrub, *Viminaria juncea* was only recorded within this non-dominated *Phragmites* mixed swamp (Site 2).

Table 8: Species presence in each site, including functional groups (FG) and regional conservation status. THB = Unallocated; Afte = Amphibious fluctuation tolerators emergent; Tdamp = Terrestrial Damp species; Afrp = Amphibious fluctuation responders plastic; SE = submerged but requires emergent tissue; Aftw = Amphibious fluctuation tolerators woody; R = rare; U = uncommon; * = introduced species.

Species Name	Common Name	FG	Site 1	Site 2	Regional Status
Agrostis sp.	Blown-grass/Bent Grass	THB	-	X	
*****Aira*** sp.	Hair Grass	THB	-	X	
Austrostipa muelleri	Tangled Spear Grass	THB	-	X	R
Baumea sp.	Twig-rush	Afte	X	-	
Baumea arthrophylla	Swamp Twig-rush	Afte	X	X	
Baumea articulata	Jointed Twig-rush	Afte	X	X	
Baumea gunnii	Slender Twig-rush	Afte	-	X	R
Baumea laxa	Lax Twig-rush	Afte	X	X	
Blechnum minus	Soft Water-fern	Afte	X	-	
Carex appressa	Tall Sedge	Afte	-	X	
Carex sp.	Sedge	Afte	-	X	
Centella cordifolia	Native Centella	Afte	-	X	
Calystegia sepium ssp. ***roseata***	Large Bindweed	Afte	-	X	
Distichlis distichophylla	Emu Grass	Tdamp	-	X	
Eleocharis acuta	Common Spike-rush	Afte	-	X	
Eleocharis gracilis	Slender Spike-rush	THB	-	X	U
Eleocharis sp.	Spike-rush	THB	-	X	
Epilobium pallidiflorum	Showy Willow-herb	Tdamp	X	X	
****Festuca arundinacea***	Tall Meadow Fescue	Tdamp	-	X	
Glyceria australis	Australian Sweet-grass	Afte	-	X	
Gratiola peruviana	Austral Brooklime	Tdamp	-	X	
Hydrocotyle sp.	Pennywort	THB	-	X	
****Holcus lanatus***	Yorkshire Fog	Tdamp	-	X	
Hydrocotyle pterocarpa		THB	-	X	
****Hypochaeris radicata***	Rough Cat's Ear	Tdry	-	X	
Isachne globosa	Swamp Millet	Afte	X	X	
Isolepis inundata	Swamp Club-rush	THB	-	X	
Juncus pallidus	Pale Rush	Afte	-	X	
Juncus sp.	Rush	THB	-	X	
Juncus sarophorus	Rush	Tdamp	-	X	
Leptospermum sp.	Tea Tree	THB	X	-	
Leptospermum continentale x ***lanigerum***	Tea Tree	Aftw	X	-	
Leptospermum lanigerum	Silky Tea Tree	Aftw	X	-	
Lobelia anceps	Angled Lobelia	Afte	-	X	
*****Lotus*** sp.	Lotus	THB	-	X	
****Lotus uliginosus***	Greater Bird's-foot Trefoil	Tdry	-	X	
Lycopus australis	Australian Gipsywort	Afte	X	X	R
****Paspalum distichum***	Water Couch	Afte	-	X	
****Paspalum dilatatum***	Paspalum	Tdamp	-	X	
Persicaria decipiens	Slender Knotweed	Afrp	-	X	
*****Phalarais arundinacea*** var. ***arundinacea***	Reed Canary Grass	THB	-	X	
*****Phalaris*** sp.	Canary Grass	THB	-	X	
****Phalaris minor***	Lesser Canary Grass	Afte	-	X	
Phragmites australis	Common Reed	SE	X	X	
****Sonchus oleraceus***	Common Sow-thistle	Tdry	-	X	
Triglochin procerum	Water-ribbons	SE	X	X	
Typha domingensis	Narrow-leaf Bullrush	SE	-	X	
Triglochin striata	Streaked Arrowgrass	Tdamp	-	X	
Viminaria juncea	Native Broom	Aftw	-	X	R
Villarsia umbricola var. ***umbricola***	Lax Marsh-flower	Afrp	-	X	U
Unidentified herbaceous plant	N/A	THB	-	X	

The co-occurrence of species with *Phragmites* was also explored and quantified by site (Table 9). Clear differences by site are evident, with 31 species co-occurring in quadrats with *Phragmites* in the mixed site (Site 2), compared with only 12 co-occurring with *Phragmites* in the *Phragmites* dominant site (Site 1). The percentages of quadrats the co-occurring species were present in was generally low in the mixed site. The species that co-occurred with *Phragmites* in the most quadrats were *Baumea arthrophylla* in the *Phragmites* dominant site (co-occurring in 75.5% of quadrats) and *Triglochin procerum* in the mixed site (co-occurring in 23.5% of quadrats).

Table 9: List of species co-occurring in quadrats with *Phragmites,* and the percentage of quadrats that vegetation species were recorded within.

Co-occurrence with *Phragmites*	***Phragmites* Dominant**		**Mixed Site**	
Species name	**# quadrats**	**%**	**# quadrats**	**%**
Baumea articulata	86	43	12	6
Blechnum minus	12	6		
Baumea arthrophylla	151	75.5	7	3.5
Austrostipa muelleri			5	2.5
Distichlis distichophylla			2	1
Baumea sp.	3	1.5		
Baumea laxa	1	0.5	10	5
Carex sp.			1	0.5
Carex apressa			11	5.5
Eleocharis gracilis			9	4.5
Centella cordifolia			5	2.5
Calystegia sepium ssp. *roseata*			31	15.5
Epilobium pallidiflorum	3	1.5	5	2.5
Eleocharis acuta			2	1
Eleocharis sp.			1	0.5
**Festuca arundinacea*			2	1
Gratiola peruviana			5	2.5
**Holcus lantanus*			2	1
**Hypochaeris radicata*			3	1.5
Isolepis inundata			5	2.5
Isachne globosa	49	24.5	3	1.5
Juncus pallidus			1	0.5
Juncus sp.			5	2.5
**Lotus* sp.	10	5		
Juncus sarophorus			16	8
Leptospermum continentale x lanigerum	5	2.5		
Triglochin striata			2	1
Leptospermum lanigerum	65	32.5		
Lobelia anceps			1	0.5
**Paspalum distichum*			3	1.5
**Lotus uliginosus*			1	0.5
Persicaria decipiens			5	2.5
Lycopus australis	102	51	14	7
Triglochin procerum	1	0.5	47	23.5
**Phalaris* sp.			52	26
**Phalaris arundinacea* var. *arundinacea*			17	8.5
Villarsia umbricola var. *umbricola*			4	2
Total species richness in *Phragmites* quadrats	**12**		**31**	

Mean estimates of environmental variables were compared between sites (Table 10). There were significant differences between sites for two of the three response variables (Shannon's diversity (H') and mean species richness (S)). Pielou's evenness was similar between sites. The means of all tested biotic explanatory variables (mean *Phragmites* pole touches, mean *Phragmites* stem density, mean tallest *Phragmites* height) and selected abiotic explanatory variables (mean litter depth, soil pH, soil N:P and soil salinity (EC)) were significantly different between sites.

Table 10: 95% Confidence intervals and estimated means for response and explanatory variables. Tukey's honest significant difference (HSD) test for multiple comparisons of means. Bolded p values are significant for a 95% confidence interval (<0.05).

	***Phragmites* Dominant site**		**Mixed Site**		**Tukey Scores**	
Response Variable	**mean**	**95% CI**	**mean**	**95% CI**	**z value**	**p value**
Shannon's Diversity (H')	0.85	(0.79, 1.04)	1.14	(0.96, 1.20)	3.39	**<0.001**
Pielou's Evenness (J)	0.71	(0.65, 0.77)	0.71	(0.65, 0.78)	0.13	0.90
Mean Species Richness (S)	3.51	(3.07, 3.94)	4.60	(4.16, 5.03)	3.44	**<0.001**
Explanatory Variable						
Mean Litter Depth (cm)	56.27	(47.88, 64.66)	21.23	(12.85, 29.62)	-5.79	**<0.001**
Mean Water Depth (cm)	-11.86	(-15.28, -8.43)	5.44	(2.01, 8.86)	6.99	**<0.001**
Mean Phragmites Touches	19.13	(16.34, 21.92)	6.21	(3.42, 9.00)	-6.41	**<0.001**
Mean Tallest Phragmites	332.11	(297.41, 366.82)	115.49	(80.49, 149.89)	8.66	**<0.001**
Mean Phragmites Stem	86.35	(70.30, 102.40)	37.98	(21.93, 54.02)	-3.55	**<0.001**
Soil pH (CaCal)	5.89	(5.77, 6.01)	4.95	(4.83, 5.07)	-10.63	**<0.001**
Soil N:P (mg/kg)	0.18	(0.08, 0.28)	0.03	(-0.07, 0.13)	-2.11	**0.035**
Soil EC 1:5 (dS/m)	1.18	(1.06, 1.30)	0.92	(0.80, 1.05)	-2.848	**0.004**
Soil N (NO_3) (mg/kg)	6.05	(2.58, 9.52)	0.70	(-2.78, 4.17)	-2.136	**0.033**
Soil P (mg/kg)	43.95	(38.89, 48.01)	25.30	(21.24, 29.36)	-6.368	**<0.001**

There was greater *Phragmites* density (density/m^2) within areas that were drier, often without surface water (Site 1). There was a trend of reduced *Phragmites* density within transects that had an inundated substrate (Fig.8.).

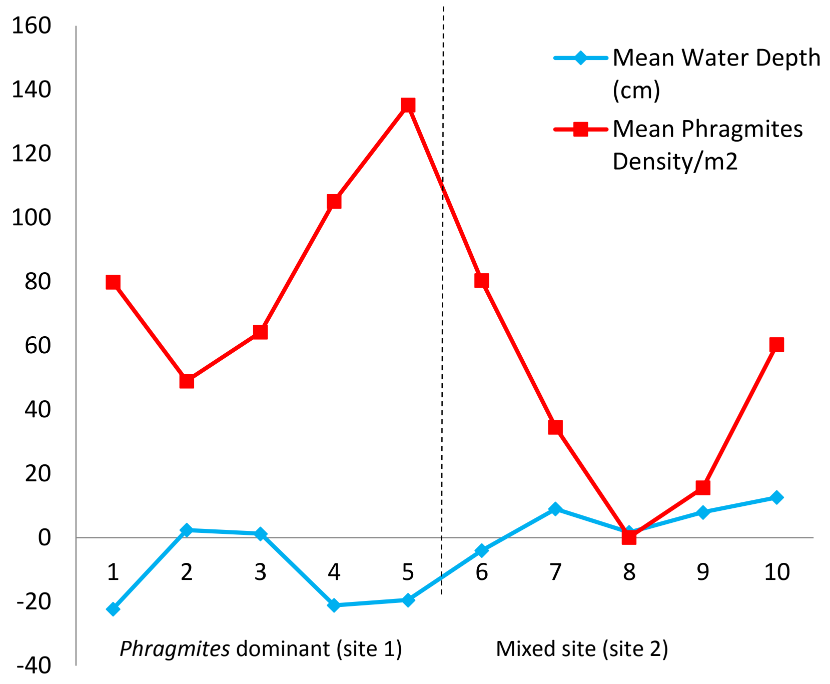

Figure 8: The mean density per metre of *Phragmites* (red line) plotted against the mean water depth (cm) for each sub-transect sample across both sites. Transects are plotted on the x-axis (1-5=site 1 and 6-10=site 2) and the values (cm) on the y-axis. A negative water depth indicates the depth to saturation below soil surface (0= the soil surface).

6.2 Pond experiments

There was 40.82% viability of *Phragmites* grown in the glasshouse; only 60 out of the 147 rhizomes developed into viable ramets.

The mean of the maximum shoot height response variable was statistically significant (95% confidence interval) in the control treatment (no flooding) when compared to all treatment groups (Table 11). The mean of the maximum shoot height was 65.70 cm in the controls compared with 33.55 cm (0-2 days), 33.58 cm (3-7 days) and 39.7 cm (8-14 days) for the other flood delay treatments.

The mean estimates of all other response variables were compared between flood delay treatments with no statistically significant differences. All response variables were greatest in the control samples, albeit statistically insignificant. The lowest weight (g) of below ground biomass, above ground biomass and root biomass was found in response to the 3-7 day flood delay response, with similar values recorded in the 0-2 day and 8-14 day flood delay treatments.

Table 11: 95% Confidence intervals and estimated means for response variables against flooding delay intervals. Significance tested by Tukey's honest significant difference (HSD) tests for multiple comparisons of means. Bolded mean is significant for a 95% confidence interval (p value <0.05).

	Flood delay 0-2 days		**Flood delay 3-7 days**		**Flood delay 8-14 days**		**Control (not flooded)**	
Response Variable	mean	95% CI	mean	95% CI	mean	95% CI	mean	95% CI
Weight difference (g)	-10.11	(-15.37, -4.86)	-6.61	(-10.21, -3.01)	-6.07	(-9.90, -2.23)	-2.92	(-8.98, 3.15)
Above Ground Biomass (g)	0.68	(0.38, 0.99)	0.46	(0.26, 0.68)	0.60	(0.37, 0.82)	0.95	(0.59, 1.30)
Below Ground Biomass (g)	3.41	(2.04, 4.79)	2.85	(1.91, 3.79)	3.40	(2.40, 4.40)	3.42	(1.83, 5.00)
Root Biomass (g)	0.98	(0.27, 1.68)	0.48	(0.00, 0.96)	0.69	(0.18, 1.20)	1.19	(0.38, 2.00)
Maximum Shoot Height (cm)	33.55	(20.18, 46.92)	33.58	(24.41, 42.75)	39.70	(29.94, 49.46)	55.75	(40.31, 71.19)
Maximum Shoot Height (outlier removed)	33.55	(21.37, 45.73)	33.58	(25.22, 41.93)	39.70	(30.81, 48.59)	**65.70**	(50.30, 81.10)
Number of New Shoots	2.00	(0.81, 3.19)	2.06	(1.24, 2.88)	2.80	(1.93, 3.67)	3.83	(2.46, 5.21)
Proportion of Roots (g)	0.17	(0.08, 0.25)	0.13	(0.07, 0.18)	0.15	(0.09, 0.21)	0.27	(0.17, 0.36)
Proportion of Shoots (g)	0.15	(0.09, 0.21)	0.09	(0.05, 0.13)	0.11	(0.07, 0.15)	0.15	(0.08, 0.21)

The estimated means and 95% confidence intervals were plotted to examine the relationship between each response variable and the flood group treatments. There were no statistically significant differences (Fig.9.).

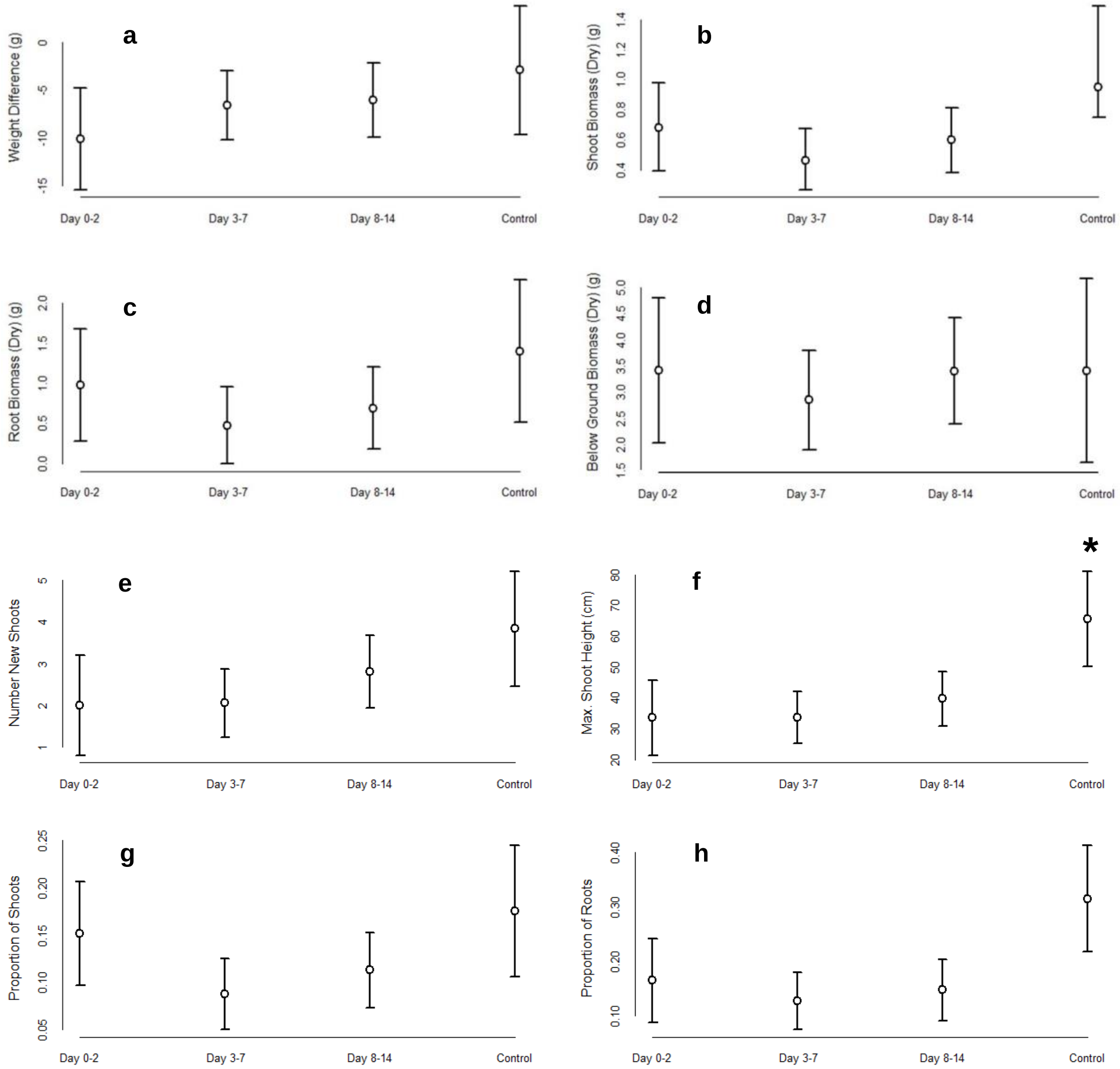

Figure 9: Mean estimates with 95% confidence intervals. '*' denotes statistical significance (p value <0.05). a: Weight difference, b: shoot biomass, c: root biomass, d: below ground biomass, e: number of new shoots, f: maximum shoot height, g: proportion of shoots, h: proportion of roots.

6.3 Aerial imagery assessment

Dominant *Phragmites* patches were visually identified and displayed on a map for comparison between 2003/2005 and 2014 (Fig.10.). The dominant *Phragmites* front has spread south east (approximately 73 metres x 14 metres) within the 9-11 year period into the mixed site (Site 2). Another six separate *Phragmites* patches have formed within the mixed site (Fig.10.).

The *Phragmites* stands in 2014 included expansions from the existing *Phragmites* stand in the western property as well as isolated patches (that is, not connected to existing *Phragmites* areas). The recent *Phragmites* invasions occurred within the interior section of the swamp as well as on the edges (Fig.10.).

The density of the *Phragmites* surveyed in patch A (Fig.10.) along transect 6 is 106 stems/m^2 (mean tallest height 348 cm), 69 stems/m^2 at patch B (mean tallest height 192 cm), 124 stems/m² at patch C (mean tallest height 188cm), 121 stems/m² at patch D (mean tallest height 334 cm) and 2 stems/m² at patch E (mean tallest height 27 cm).

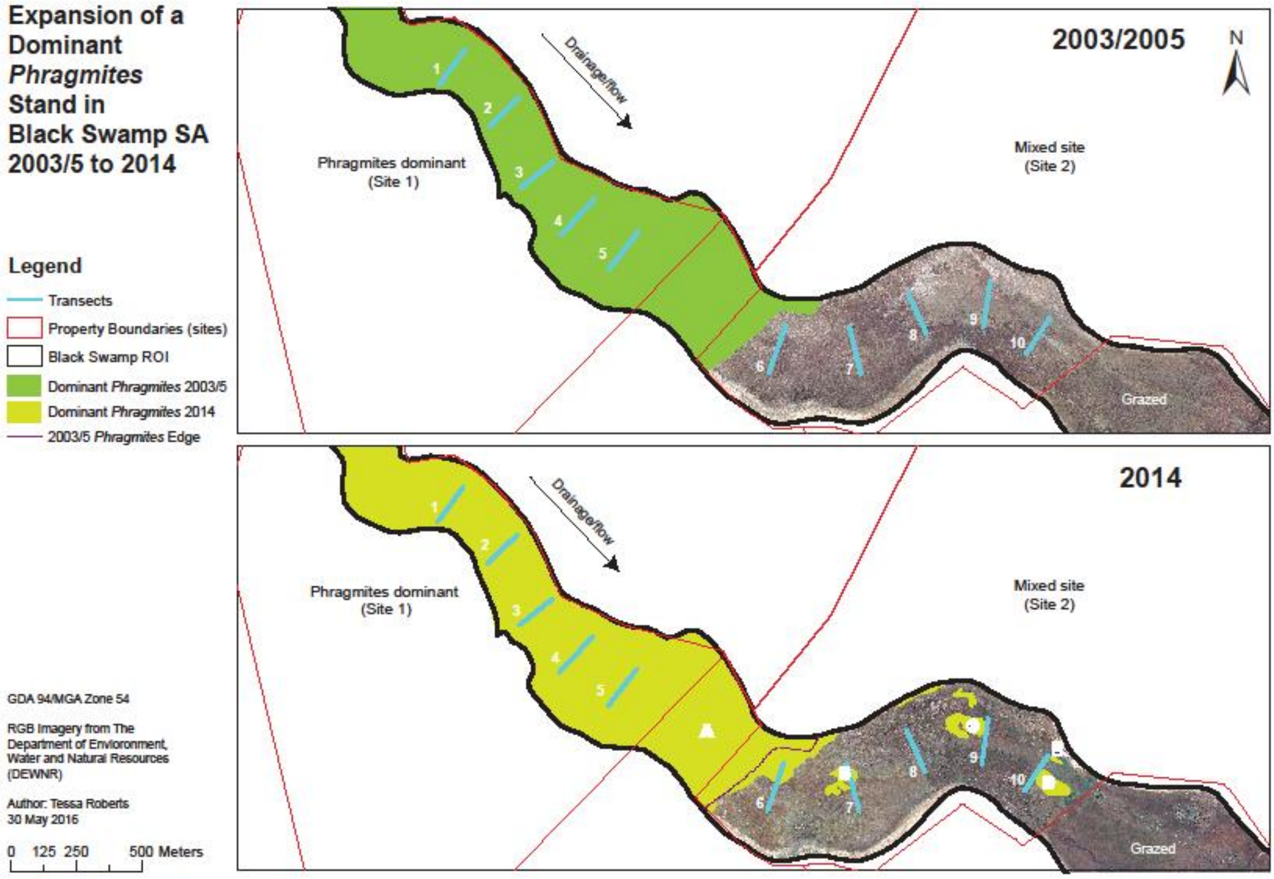

Figure 10: Expansion of *Phragmites* from the *Phragmites* dominant site to the mixed site. Map based on aerial imagery (2003/5 and 2014 imagery), and field surveys/GPS points and observations (observations Feb/Mar 2016). Green/yellow-green sections are *Phragmites* dominant areas. *Phragmites* patches in 2014 are labelled A-E and transects are labelled 1-10.

7. Discussion

Phragmites expansion

There was a notable expansion of *Phragmites* within the Black Swamp system. The new areas of *Phragmites* stands are likely a mix of expanded areas (connected to previous *Phragmites* patches) and new invasions (isolated from existing *Phragmites* patches). The newly recruited *Phragmites* patches comprised individuals of different heights. This could suggest that the populated stands represent mixed age-classes. The expanded areas were likely recruited from underground rhizomes whereas the new isolated and sparse patches probably resulted from floating plant material, or less likely seed germination.

It is also possible that the new *Phragmites* stands recorded in Site 2 (Fig.10.) were established from rhizomes that had been persistent, but dormant, within the swamp. The previous grazing regime might have controlled ongoing sprouting of the rhizomes as new shoots could have been consumed or trampled by stock and then vigorous sprouting could have occurred once cattle were removed.

Correlation between environmental factors and *Phragmites*

The abundance of *Phragmites* was strongly correlated to several environmental factors such as deeper litter accumulation and reduced water depth. These factors are interrelated as a drier area is expected to accumulate plant matter (litter) at a rate greater than it can decompose. The stiff culms and leaves of Phragmites do not readily break down therefore plant material is likely to remain in-situ for prolong periods (Kiviat 2013). This supports other empirical research that concludes *Phragmites* acts as an ecosystem engineer, altering microclimate and topography that only it can optimise (Hudon et al 2005; Denis 2011).

It is likely that the significantly denser and taller stands of *Phragmites* (mean density of 86 stems per square metre and mean tallest height of 332 mm) in the *Phragmites* dominant site are influencing water depth. *Phragmites* is known to have a high rate of evapotranspiration (Haslam 2010). The water depth in the *Phragmites* dominated site is below the surface (-11.86 mean depth) and significantly lower than in the mixed site where the density of *Phragmites* is significantly lower (40 stems per square metre). The disparity between the sites is unexpected as it is all part of the same swamp system (thus hydrologically connected).

Phragmites is known to tolerate and optimise nutrient rich environments and to adapt to nutrient deficiencies (Hocking 1989). Both of the study sites had anthropogenic influences such as domestic grazing that could have modified soil nutrients within the Black Swamp system. Intense grazing regimes (in terms of stock and frequency) can result in excess nutrient loads, creating an environment that will facilitate the productive establishment and persistence of *Phragmites*, this then generates a feedback effect. *Phragmites* is also known to alter nutrient cycles (Hocking 1989) and the significantly higher Phosphorous in the *Phragmites* dominated site (44 mg/kg compared 25 mg/kg in the mixed site) may support this. The build-up of litter can also alter physical and chemical properties of the soil (Facelli and Picket 1991).

Association between *Phragmites* density and floristic diversity

This study concluded that there was a notable absence of weed species within the *Phragmites* dominated site whereas twelve introduced species were recorded within the mixed site (26% of all plant species present). A dense *Phragmites* area will limit the space available for opportunistic weed species to germinate and persist. This trend of dominant species forming dense monospecific stands and excluding weed species has been observed in other Fleurieu Swamp systems. In long undisturbed Fleurieu Swamps located upstream from Black Swamp (within the upper Tookayerta catchment Nangkita), the vegetation assemblage was mostly dominated by a single species (*Leptospermum continentale)* and was absent of introduced plants species (Duffield 2015).

There was a strong association between reduced floristic diversity and *Phragmites* foliage density. This relationship has been observed and documented in other Fleurieu Peninsula Swamps (Duffield 2012; Duffield 2015). A study within the Nangkita swamps (upstream from this study site) investigated if there was a relationship between plant diversity and productivity (in terms of above ground biomass). The study concluded that the environmental variables (particularly substrate saturation and soil type) influenced the overall biomass of key swamp plants, and this then predicted plant community richness (Duffield 2012; Duffield 2015). From these studies it can be inferred that other Fleurieu Swamps that are densely foliated with one or two key long-lived plant species will likely have reduced floristic richness (Duffield 2015).

Response of *Phragmites* to cutting and flooding treatments

In the pond experiment, the shoot height and therefore the growth of *Phragmites* ramets was influenced by flooding in the cut/flood trial. However the actual timing of the flood delay did not have a statistically significant effect, which could be due to the variability of the data, the limited sample size and/or the limited duration of the experiment. The wider literature supports this finding that flooding alone will impact on above ground and below ground *Phragmites* foliage (Denis 2011, Hudon *et al.* 2005). Other trials in the northern hemisphere have determined that cutting (Greet and Rees 2015) and cutting then flooding of stems in late summer can be effective, and that flooding cut stems for four weeks with saline water may kill the plants (Russell and Kraaij 2008). The EC values in the Black Swamp soils were quite high (mean of 1.18 dS/m in the *Phragmites* dominant site), so this may enhance the success of future cut/flood trials in Black Swamp.

Association between *Phragmites* expansion and removal of grazing pressures

Results from the qualitative spatial imagery assessments as part of this study suggest that *Phragmites* expansion did occur during a time when grazing pressure was removed from the swamp. This study could not conclusively determine if there was a direct cause and effect relationship between grazing pressure and *Phragmites* density in Black Swamp. Limited availability and quality of long term spatial imagery meant that no assessment was done on *Phragmites* during a time when the swamps were being continually grazed (thus making comparisons difficult). However, examples elsewhere demonstrate that the permanent removal of grazing pressure (by domestic stock) provide opportunities for quick invaders to colonise an area. Introducing or maintaining appropriate grazing regimes within the Strathbogie Ranges is considered an appropriate tool for preventing the encroachment of *Phragmites* (Coates *et al.* 2010). An experimental trial of grazing within the Lower Lakes, South Australia suggested that removal of grazing increased the biomass of *Phragmites* (Resleigh and Foster 2012).

Phragmites expansion and threats to restoration and biodiversity in Black Swamp

Since the 1990's there has been substantial regional and landholder restoration investment within Black Swamp, to enhance the ecological community and optimise habitat for threatened and swamp dependant species. The expansion of *Phragmites* poses a significant threat to these ecological assets as this aggressive increase in occupancy has transitioned the vegetation community into a *Phragmites* monospecific stand. These dominant monospecific stands represent a vegetation community that is structurally and floristically uniform.

The long-term effectiveness of restoration (particularly traditional tube-stock plantings) within Black Swamp could be compromised by the expansion of *Phragmites*. Selecting appropriate target sites is critical as proximity to robust and dense *Phragmites* should be avoided, or, allocation of resources must be set aside to regularly control any *Phragmites* encroachment into the revegetated site. Results from this study indicated that *Baumea arthophylla* and *B.articulata* were still able to persist within areas that were densely populated with *Phragmites*. Selecting vigorous and fast growing swamp plants will optimise revegetation success within Black Swamp. Alternatively experimental restoration methods, such as ecologically-based disturbance, could be considered. These are discussed later in section 8.2.2. These potential management strategies have been derived from existing empirical knowledge and findings from this honours study.

8. Management implications

8.1 Key findings

8.1.1 Expansion of *Phragmites*

- *Phragmites* reedland vegetation communities within the Black Swamp system have expanded since 2003.
- The ongoing expansion comprised the extension of pre-existing *Phragmites* monospecific stands and the establishment of new (isolated) patches. The new *Phragmites* patches are a conservation concern as it suggests that *Phragmites* has the potential to successfully invade isolated and disconnected habitats. This new establishment could have been germination (dispersed by wind, water or fauna), clonal via dispersed fragments or a result of previously dormant in-situ rhizomes. Further investigation is critical.
- It appears likely that the initial *Phragmites* expansion boom was a result of removal of grazing. Without grazing pressures, *Phragmites* has the ability to aggressively establish within an area. Once the area was populated with dense stands of *Phragmites*, the physical environment could have been modified as the accumulation of leaf litter produced drier mounds that also excluded germination and persistence of water dependant swamp plants.
- From the spatial analyses undertaken, it would appear that *Phragmites* expansion will continue to be both extensions from existing stands (likely vegetative) and also via invasion of previously unoccupied areas (likely seedling recruitment or sprouting from dispersed plant fragments). This has significant implications for landscape restoration. While managing existing *Phragmites* populations (e.g. slashing edges) within discrete areas might be successful at the individual property scale, it may not address *Phragmites* issues within an entire swamp system.

8.1.2 Impact of *Phragmites* on the vegetation community

- A suite of interacting biotic and abiotic factors (such as water depth), with endogenous and exogenous drivers, have influenced the floristic diversity and structure of the swamp vegetation assemblages within Black Swamp.
- The *Phragmites* dominated area was strongly correlated with drier areas of the Black Swamp system. This is a relevant finding as it suggests that *Phragmites* will persist and possibly increase its range in response to hydrological stress (Roberts 2000). Prolonged drought periods or reallocation of environmental water resources to land uses such as irrigation might result in increased range of *Phragmites*.
- Swamp areas with greater abundances of *Phragmites* will probably have reduced species richness. The ability of *Phragmites* to modify the physical environment and create micro-niche conditions that only it can persist in, is another possible explanation. These causes are most likely not operating independently and the

interactive effect of several processes could have initiated and supported the *Phragmites* expansion.
- During field collection, an observation was made that grazed swamp areas were absent in *Phragmites*, *Phalaris* species and *Paspalum dilatatum.* All of these species are opportunistic grass species.

8.1.3 Impact of *Phragmites* on ecosystem functioning

- The environmental processes of litter accumulation, plant matter breakdown, soil chemical exchange is likely driven by hydrological factors, and possibly even anthropogenic influences (although this could not be specifically addressed by this study). *Phragmites* will also engineer the physical environment altering nutrient cycles and affecting water table depth by high evapotranspiration in dense stands (Haslam 2010).
- The growth and persistence of *Phragmites* could be influenced with hydrological manipulations (as indicated by the pond experiments), particularly where this is combined with cutting.

8.2 Management and control options

8.2.1 Lessons learnt elsewhere

There has been considerable investment in trialling the best methods for controlling *Phragmites* within Europe and the United States (Keller 2000; Saltonstall 2002). Management options have included slashing, burning, cutting and herbicide application (Keller 2000; Saltonstall 2002; Sun *et al.* 2007). Typically the effectiveness of these treatments were short-term and only smaller areas can be treated (Sun *et al.* 2007). More recently, the use of bio-agents such as invertebrates has been investigated (Keller 2000; Sun *et al.* 2007; Hazelton *et al.* 2014).

The timing of management burns aimed to reduce *Phragmites* is critical. A study by Cowie *et al.* (1992) suggested that burning *Phragmites* within marshland habitats resulted in shorter but greater density of the stems. Burning *Phragmites* assemblages at the end of their growing season is likely the most effective time for exclusively removing above-ground mass (Güsewell 2003). However, removing *Phragmites* living shoots during their growing phase will encourage the development of rhizomatous buds (Roberts 2013). Removing the above ground foliage of *Phragmites* during summer or early autumn is documented as the most efficient time as the nutrient contents of their shoots are greatest, thus inflicting physiological stress (Hellings and Gallagher 1992; Güsewell 2003).

Conversely, burning during a time when the underground organs are active could stimulate *Phragmites* expansion as vegetative shooting will be prolific (Sun *et al.* 2007). Burning *Phragmites* within the dormancy period (end of winter) in the Great Artesian Basin was demonstrated as inappropriate with the best time to burn during the peak growing season

(Davies *et al.* 2010). This is because the horizontal rhizomes are developing towards the end of the growing season and before the onset of winter (Hudon *et al.* 2005).

An experimental trial that flooded *Phragmites* and then followed up with a prescribed burn found that *Phragmites* height and density was reduced (Sun *et al.* 2007). An assessment by Rolletschek *et al.* (2000) demonstrated that removal of old *Phragmites* culms could deprive oxygen to individuals if this occurred in flooded environments. This hypoxia effect however did not occur within the dry areas.

A mowing experiment within a Swedish fen wetland investigated the response of *Phragmites* to mowing during different seasons and at different regimes (Güsewell *et al.* 2000). The objective of this study was to control *Phragmites* and enhance populations of native species. The study concluded that although there were short-term fluctuations of *Phragmites* shoots, the impacts in the long-term were negligible and environmental drivers are more influential in determining *Phragmites* stands (Güsewell *et al.* 2000).

Chemical control has also been suggested with options of spot spraying with glyphosate during late summer/early autumn combined with burning (Government 2014b). Controlling *Phragmites* with herbicides can cause negative impacts on other flora species (Güsewell 2003) and should be reluctantly considered after a comprehensive risk assessment has been undertaken.

Permanent removal of grazing pressure (by domestic stock) provides opportunities for quick invaders to colonise an area. Introducing or maintaining appropriate grazing regimes within the Strathbogie Ranges is considered an appropriate tool for preventing the encroachment of *Phragmites* (Coates *et al.* 2010). An experimental trial of grazing within the Lower Lakes, South Australia suggested that removal of grazing increased the biomass of *Phragmites* (Resleigh and Foster 2012).

8.2.2 *Phragmites* management considerations for the Black Swamp system

Results from this research can be juxtaposed with evidence from empirical *Phragmites* management trials and scientific literature to develop local management considerations.

A *Phragmites* control burn would only be effective if it was seasonally appropriate and occurred at a time that would impose maximum physiological stress. Within the Black Swamp system, this would result in a hot burn and undertaking such a management burn during the season specified is dangerous. The ability to control the spread of a hot burn during South Australia's summer season is questionable. An early autumn burn could be equally as perilous as Southern autumns are demonstrating trends of delayed rains, and the preceding summer months could result in a high fuel load. Implementing a *Phragmites* management burn during summer is therefore not recommended for Black Swamp.

Results from the honours research supports documented management treatments of combining defoliation (to ground level) with complete flooding (for set periods of time). Utilisation of this method could be challenging within some sites, particularly the drier sites (such as Site 1). If this type of control is to be implemented, the site would need increased water availability to flood out the exposed culms immediately after the burn or slash is applied. This would potentially require construction of infrastructure (to retain water within the site) and should only be implemented if there was certainty that the swamps downstream would not be negatively affected.

The management of *Phragmites* by either burning or slashing while also protecting and enhancing populations of native species poses a conservation challenge within some systems. Repeat slashing of *Phragmites*, if undertaken regularly, could control the amount of *Phragmites* above ground biomass and limit expansion via seedling recruitment and suckering. However, if this was a broad-scale clearance, it would also remove the biomass of other co-existing plant species that were present. This could limit the persistence of these other swamp plants if it occurred during critical flowering (or fruit development) life-stages as it would reduce seedbank replenishment. Any proposed burn or slash should take into consideration the other floristic components of the system, particularly threatened or declining flora populations.

Any suggested management should be underpinned by the environmental setting. Results from the honours research project found that environmental factors occurred in association with reduced or greater *Phragmites* densities. Smart priority setting and decision making will determine the success of long-term *Phragmites* control. It might be ineffective to direct resources towards controlling an extensive patch that comprises robust clonal *Phragmites* monostands within a dry environment. A more strategic approach might be to manage the edges of the population and aim to prevent further expansion. Alternatively, a wise conservation investment might be focussing on new isolated invasions.

Combining herbicide control with defoliation of *Phragmites* culms must be cautiously undertaken with consideration of spray drift, off-target damage, residual life span and impacts on native flora and fauna species. Herbicide application should be avoided within wetter areas, but could possibly be used within the drier portions of the swamp (if the above considerations were not considered a threat). The exclusive use of herbicides may not be sufficient to control *Phragmites*, however coupling its application with defoliation efforts (slashing or grazing) could result in reduced *Phragmites* biomass.

Managing *Phragmites* within the Black Swamp system should be considered within a systems based framework with specific property management plans developed to satisfy landscape conservation objectives. The environmental and biodiversity assets (and associated threats) for the entire Black Swamp system would be identified and prescriptions for site specific on-ground management would contribute to the overall biodiversity conservation objectives for the system.

Between 2003 and 2013, the most common conservation practice associated with Fleurieu Swamps was removal of disturbances such as grazing. Although this management practice is advantageous within heavily grazed and degraded swamps, the permanent exclusion of grazing pressure could eventually result in a vegetation assemblages that are dominated by competitive species such as *Phragmites*. This increase of *Phragmites* after the removal of grazing was a key finding of the honours research project (Roberts 2016).

On-ground habitat protection strategies have typically urged landholders to maximise fencing buffers around swamps (between 5-10 metres). The purpose of maximising swamp buffers has been to reduce edge effects and potentially expedite landscape connectivity opportunities. This strategy might also have advantages in offering openings for the swamp edges to expand, however in some locations, it may also provide ecological gaps that are rapidly occupied (and then dominated) by *Phragmites*.

When appraising the wider *Phragmites* literature and the results from this study, there are specific *Phragmites* management considerations for the Black Swamp and lower Tookayerta swamps. These considerations may also be relevant for other Fleurieu Peninsula Swamps. These have been tabled (Table 12).

Table 12: Summary of potential *Phragmites* control methods

Potential method	**Description**	**Considerations for Black Swamp area**
Slashing (mowing) Slashing (mowing) and burn	Removal of stands by either mowing or slashing. Removal of stands with slashing and then following up with a burn when/if re-sprouting occurs	A critical limitation of this perturbation is that it cannot be undertaken during winter and spring. This is likely to be time consuming and probably only feasible around the periphery of dense stands. For this purpose alone, it could be effective if it was regular. Many grasses are actually favoured by slashing and if slashing is undertaken at the wrong time of the year, it could encourage prolific rhizomatous recovery of *Phragmites* or spread of other invasive grasses such as *Paspalum* and *Phalaris* species.
Herbicide application Herbicide application and burn	Spot spraying patches with an effective herbicide. After treatment of *Phragmites*, removal of the dead biomass might allow recruitment and persistence of other flora species	Using chemicals in waterways is undesirable as it could negatively impact on the wetland and its biota. Unless the herbicide application is strategic and undertaken at a careful patch scale, off-target damage (to other areas) is a major concern. Follow up use of herbicides after slashing (at the right time of the year) might be appropriate within a drier section of the *Phragmites* stands.

Potential method	Description	Considerations for Black Swamp area
Biological control	Introducing soil pathogens that drill into the shoots of *Phragmites*	Investigation into use of biological agents for controlling and causing mortality of *Phragmites* populations is only recent with further research required. This work has been done in the northern hemisphere and results may not be relevant to southern climates/conditions. In Black Swamp, observations were made by the honours student (Roberts 2016) that grubs would burrow into stems and kill the top portions (within the drier Site 1). The effect was not significant but this process could possibly impact on *Phragmites* productivity.
Burning Burning and flooding	Burning stands to remove biomass and density of canes at the right season. Flooding of cane stubbles after burning will deprive underground organs of oxygen. This is not always possible in natural systems and may require considerable infrastructure.	Avoid burning during winter dormancy period when below ground material is developing. Burning during this season only encourages the establishment and encroachment of *Phragmites* as observed within one swamp that was burnt during winter 2013. Optimal burning during *Phragmites* active growing season in late summer poses a high risk to the entire Black Swamp system. Such a hot burn has the potential to get out of control and catastrophically impact non-target areas, (both the swamp and surrounding landscape).
Flooding	Flooding *Phragmites* for extended periods (particularly during periods when below ground organs are vulnerable).	This is also likely to impact on other plant species that do not tolerate inundation. Such management is also likely to require manipulation and/or construction of infrastructure. However, this is probably the most effective way of reducing the persistence of *Phragmites* within the Black Swamp system, and more widely, the Fleurieu Swamps. Flooding if coupled with removal of biomass (e.g. via slashing) is predicted to control *Phragmites*.
Alternative: Addressing prevention rather than cure	A potential way of managing *Phragmites* is to focus on preventing the expansion and dominance of populations.	This approach has not been trialled. Such a method might require manipulating the area to favour other species. For the Black Swamp system, temporary control of *Phragmites* (over a period of 3 years) to reduce its expansion concurrent with intense planting efforts of larger sedges and shrubs (such as *Baumea arthrophylla*, *Baumea rubiginosa* and *Leptoserpmum* species) may be beneficial.

8.3 Recommendations

There needs to be a committed and consolidated effort of identifying *Phragmites* “hot spots”, such as new invasions (patches) that are isolated from pre-existing *Phragmites* stands. This could be done via spatial analyses using high resolution satellite imagery.

Recent revegetation and restoration projects within the Black Swamp and lower Tookayerta swamps should be regularly monitored to identify any new P*hragmites* patches. These emerging *Phragmites* populations should be mapped, and ideally controlled. If the *Phragmites* is left uncontrolled, it has the capacity to dominate the area and either crowd out plantings or outcompete for vital resources (such as water, light and nutrients) that may impact on the viability of revegetated seedlings.

It is critical that when considering restoration sites, the proximity to *Phragmites* populations is evaluated as part of the decision making process. Traditional revegetation techniques of tube-stock plantings, without any supplementary work, will struggle to compete with *Phragmites* in the long-term. Re-establishment of swamp plants within the Black Swamp system will need to be coupled with control of *Phragmites*, both prior to planting efforts and after revegetation has occurred.

The identification of the new *Phragmites* areas (within Site 2) presents an opportunity to trial effective control and management. A possible experimental trial within new *Phragmites* patches and old-growth *Phragmites* could investigate community response to a) repeat slashing (summer and early autumn for 2 years) b) defoliation and inundation c) defoliation and herbicide application (dry sites only) d) grazing that trialled various configurations of timing, intensity and duration. An additional component of the trial could be including the core part of the swamp and the edge areas. These trials should be undertaken within an adaptive management framework of implementing, testing, evaluating and modifying management techniques as required.

Summer satellite imagery at ≤1 m resolution with a greater range of bands (i.e. containing near infra-red wavelengths) should be used for better classification of imagery utilising a range of bands including the near infra-red (NIR) to better class actively growing *Phragmites*. The normalised difference vegetation index (NDVI) may be useful in mapping the extent of dense stands of *Phragmites* but this method would need to be trialled first to assess its effectiveness.

Repeating the pond experiments with longer flooding periods (and greater samples) could produce different and more reliable results.

Further investigations are required to conclusively identify if *Phragmites* expansion within Black Swamp and other lower Tookayerta swamps was a primary driver for the decline of

MLRSEW sub-populations (from the 1990’s). A recent MRLSEW sub-population explosion to the north of the Finniss Park provides an opportunity to monitor MLRSEW (and other avian diversity) response to habitat succession (and if *Phragmite*s invades this area now that grazing has been removed).

9. Evaluation of project

9.1 Challenges

This project was based in a region with properties that are exclusively privately owned. This requires careful planning and organisation for property access. Fortunately, all landholders were enthusiastic about the project and allowed full access to their properties.

One of the biggest challenges was achieving the honours research within a limited time. Data had to be collected by end of February 2016, entered and analysed by April 2016 with a draft thesis due by the end of May 2016. These were all critical and uncompromising deadlines.

Integrating academic objectives and on-ground significance is a universal challenge. The honours student consistently strived to keep the scope of the honours project relevant to conservation management while also ensuring sufficient scientific rigour of the research.

The *Phragmites* dominated vegetation community is difficult to survey. Survey efforts could be biased and disturbance can be caused from surveyor trampling. This was addressed by trialling and modifying the data collection method to allow for buffers between quadrats. There were also WHS issues that needed to be considered when working within this type of vegetation community. This was addressed by following the University of Adelaide safety and field work protocols, having an assistant and all times and first aid training.

An honours research project has a limited 12-month candidature and seasonal data collection replication is restricted. To comprehensively address *Phragmites* expansion within this swamp system, at least 2 years (with minimum of two seasons) of data collection is required. The project would have also benefited from additional sites, but this was not possible within the confines of a short term honours project.

Seed was collected to undertake *Phragmites* germination trials however the magnitude of the field work (see section 5.1) and the need to repeat the pond experiments (see section 5.2) exhausted all available time as part of the honours project. However there is readily available literature that mostly concurs that viability of *Phragmites* seeds is limited, and that germination requires very specific environmental conditions. Establishment of *Phragmites* is expected to rely on vegetative reproduction.

9.2 Additional work that added value to the project

There have been achievements beyond the specific milestones that augment the strength of the project. Such accomplishments include:

- The honours student submitted an abstract to the ESA 2015 conference and presented a poster that acknowledged CCSA and DEWNR (Attachment C).

- One of the co-supervisors, Jasmin Packer, has extensive reedlands research experience in the northern hemisphere and accordingly is becoming a local expert on *Phragmites*. Jasmin has recently co-authored a manuscript for submission to The Journal of Ecology titled "Biological Flora of the British Isles: *Phragmites australis*".
- This project has contributed to the conception and development of an ARC Linkage Grant proposal that focussed on *Phragmites australis*, with the Fleurieu Swamps being one of the core study sites.
- Landholders within the Black swamp area have first-hand observations of the competitive ability of *Phragmites* to dominate their swamps. This project has addressed concerns that they have expressed for many years and acknowledges their role as custodians and land-managers.

9.3 Future directions

As this project addressed the potential threat that *Phragmites* poses to the landscape, a postdoctoral research project has been developed that will expand on the work undertaken as part of this project. This initiation of this post-doctoral research project was concurrent with the honours project as it became clear that expansion and invasion dynamics of *Phragmites* cannot be thoroughly investigated within a short-time frame (such as an honours project).

As part of the Fleurieu Swamp Trial project, slashing trials of *Phragmites* monospecific stands is planned for early autumn 2017. The purpose of this trial is to evaluate and quantify the human resources required to effectively slash this type of vegetation community and the monitoring effort that is required. This work will be undertaken by Natural Resources South Australian Murray-Darling Basin a part of the Ranges to River Project. The Fleurieu Swamp Recovery Project will also be involved in this work. This work is a critical step to an even larger objective of trialling the control of *Phragmites* (e.g. via slashing and then flooding) as it will allow the operational costings (time and effort per $10m^2$ of Phragmites) to be determined.

The Fleurieu Swamp Recovery Project is investigating opportunities for monitoring other properties within this Black Swamp system, with a particular focus on swamps that are recovering after the removal of disturbances such as grazing. The aim of this monitoring is to understand habitat succession dynamics within this swamp system and how it relates to presence and absence of the endangered Mount Lofty Ranges Southern Emu-wren.

The Natural Resources South Australian Murray-Darling Basin is initiating conversations about hydrological manipulation opportunities within Fleurieu Swamps. This discussion and the water allocation planning processes are a start to investigating if intervention can result in an increase (quantity and time) of water resources within Black Swamp.

10. Conclusion

Phragmites australis is a cosmopolitan grass species that is of international interest because of its extensive range, adaptive capacity, environmental tolerances and invasive attributes. Despite evidence that *Phragmites* has ecological and biological functions within a vegetation community, it appears that its expansive potential within a natural wetland is an environmental and management concern.

A review of literature on *Phragmites* concluded that an absence of long-term data sets made it difficult to predict the long-term trajectory of a vegetation community after *Phragmites* management (Hazelton *et al.* 2014). This study is no exception to this as its duration was only one-year. However, findings from the honours project did demonstrate the differences within Fleurieu Swamp reedland vegetation systems, the ability of Phragmites to expand and invade new areas, and the complex interaction between environmental processes, biological features and land management practices.

Within the Black Swamp system, it is unclear if *Phragmites* has simply responded to exogenous and/or endogenous changes, or if it has itself caused such modifications that permits further expansion and safe-guards its persistence. When natural processes such as disturbance and water regimes are altered, expansion of monospecific stands may occur, which can be detrimental for other concomitant species. These mechanisms of expansion are not well understood and further research is necessary to gain a greater understanding of these mechanisms to inform more efficient management practises.

Most *Phragmites* management strategies focus on removal either by burning, mowing or slashing yet the persistence and vigour of below-ground organs ensures that this species will quickly re-establish. Regardless of the removal treatment, it must occur at a time when the rhizomes and below-ground buds are negatively affected. The optimum time for this is the late summer active growing period but water allocation is needed to permanently drown the underground parts and reduce sprouting. This presents a management challenge with potentially conflicting conservation objectives. This season of burning required to effectively control *Phragmites* is likely to produce a hotter burn with greater threats posed to nearby vegetation communities, property, wildlife and personal safety. Slashing at this time of the year is limited as the region would probably be subjected to high fire danger season constrictions that prohibit the use of machinery.

The Black Swamp system is an endangered ecological community that has changed over the last decade. Conservation efforts to improve the condition of the vegetation within this area has focussed on removing grazing pressures, which has probably resulted in increased *Phragmites*, reduced floristic diversity and modification of the physical environment (particularly available surface water and litter depth). Ongoing expansion of *Phragmites* within Black Swamp is likely to further impact on vegetation structural complexities, plant richness and quality habitat for dependent fauna species such as the endangered Mount Lofty

Ranges Southern Emu-wren. Conservation and restoration blueprints for Black Swamp and the surrounding landscape must carefully consider the current extent, ecological role, competitive exclusion and potential expansion of *Phragmites* and the likely risk this poses to biodiversity conservation.

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