Mt Lofty Ranges
Southern Emu-wren &
Fleurieu Peninsula Swamps
Recovery Program

Conservation Council SA

Milestone 2: Interim Report

Part A: The literature review

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

Black swamp: Image taken by Alys Stevens 2006

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1. BACKGROUND

The expansion of *Phragmites australis* (here-after referred to as *Phragmites*) is of concern for several reasons.

a) This species is often associated with the Fleurieu Peninsula (FP) Swamps and an increase in its range and abundance could impact on the integrity of the FP Swamps (an endangered ecological community).
b) Considerable investment in restoration within the Black Swamp and Tookayerta region has occurred within the last 10 years (by both CLLMM and the GWLAP). These on-ground actions could be compromised as *Phragmites* can outcompete other plant species.
c) The FPS Recovery Project staff has indicated that *Phragmites* is becoming increasingly dominant within the Black Swamp system. The 2013 ecological burns within this area was aimed to improve the quality of emu-wren habitat, however there has been prolific *Phragmites* re-establishment as a consequence.
d) A traditional restoration method for FP Swamps conservation has been to reduce impacts from domestic stock by fencing the vegetation. Although such strategies may initiate natural regeneration of flora, it could also provide openings within which the opportunistic *Phragmites* will quickly colonise.

1.1 Purpose and outline of the literature review

This literature review is part of a contractual agreement between the Conservation Council of South Australia and South Australian Government (Vegetation Program, River Murray Operations and Major Projects Branch). This interim literature review partially fulfils Milestone 2 under this agreement. The other component of Milestone 2 is a project proposal and plan (“Part B: The Research Plan”). This is a preliminary proposal and provides a framework that will be reviewed and improved as part of the honours core component work (https://sciences.adelaide.edu.au/future-students/honours/ees/2015-eels-hons-projects-30sept14.pdf).

The final literature review and project plan is due on the 19th December (Milestone 3 as per contract). The next phase of the project is continuation of honours project development, managing the honours project, field work, potential monitoring of a control burn and synthesis of results from honours project into a management-based document (refer to initial proposal and contract agreement).

The scientific literature available on *Phragmites* is incredibly extensive. The most detailed empirical studies have occurred in North America and Europe and the transferability of this information to a regional level must be treated with caution. The literature review was a desktop study that used several search engines to identify and access journal papers and technical reports. Over 115 articles were reviewed with 96 imported into the bibliographic software program EndNote X7. All of these papers have been attached as an annotated bibliography.

The purpose of undertaking this literature review was to:

a) Critically examine the international empirical information on *Phragmites.*
b) Further develop an understanding on potential *Phragmites* issues within the Black Swamp system, Tookayerta.
c) Provide a baseline review that can be utilised by the honours student, thus expediting progress and ensuring timely delivery of project milestones.

An additional literature review will be undertaken as a compulsory core component of the honours research project (2015).

1.2 Summary

Phragmites 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* will grow within damp areas and the margins of open water bodies. Although *Phragmites* is expected to occur within freshwater conditions, it will also tolerate slightly brackish conditions (Croft 2004; Jessop *et al.* 2006; Gotch 2013; Kobbing *et al.* 2013).

Phragmites 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, capable of growing several metres in height. It can produce dense monospecific stands that results in a homogenous floristic assemblage (Hudon *et al.* 2005). Earlier research on *Phragmites* was focussed on population dieback trends and health of the vegetation stands, while recent literature is investigating the expansion and progression dynamics (Güsewell and Klötzli 2000; Güsewell *et al.* 2000). This shifted research focus is because *Phragmites* invasion into natural wetland assemblages is of international concern.

Natural systems will undergo changes in response to environmental conditions and biological drivers. In addition to naturally occurring trajectories, vegetation communities will be influenced and manipulated by anthropogenic causes (Keller 2000). The land-use history of a wetland vegetation community can influence soil and water quality and quantity, thus determining the plant groups that are present.

2. A SUMMARY ON *PHRAGMITES*

2.1 Taxonomy and biology

Phragmites australis (Common Reed) 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 5-metres and the flowering period is recognised as December to August (Jessop *et al.* 2006). Although the belowground organs live 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). Genetic testing has confirmed that there are many haplotypes of *Phragmites* that often co-exist 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 genotypes also have physiological and morphological advantages as they produce more ramets per unit area, 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.

Phragmites in Australia is described as octoploid (that is, eight complete sets of chromosomes) although genetic testing from samples taken along the Murrumbidgee River detected decaploid material (Roberts 2000). In comparison, the North American and European *Phragmites* has four sets of complete chromosomes (tetraploid)

A review of the native and introduced *Phragmites* genetic lineages identified that results from field study's, microcosm experiments, natural factors and ecophysiology failed to be integrated and synthesised (Mozdzer *et al.* 2013).

This literature review did not find information on variable *Phragmites* lineages within Southern Australia, or evidence of one or more regional genotypes.

2.2 Distribution

2.2.1 Worldwide distribution

Phragmites is a cosmopolitan species that occurs worldwide. 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 introduced species recorded in North America belong to the same haplotype (Sun *et al.* 2007). In many instances, this genotype has outcompeted and replaced the native *Phragmites* species within the northern hemisphere.

As *Phragmites* is a C3 grass, its range is likely to be increased worldwide under projected climate change scenarios. A laboratory experiment suggested that *Phragmites* will respond favourably to elevated C02 as biomass increased simultaneous with increased carbon levels (Mozdzer and Megonigal 2012).

2.2.2 Australian and regional (SA) 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) – Fig.1.

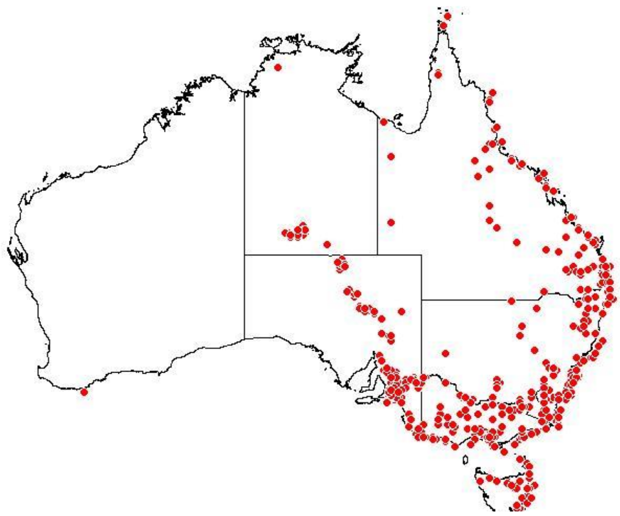

Figure 1: Australia wide distribution of *Phragmites australis*. Source: Australia's Virtual Herbarium

It is assumed that *Phragmites* has undergone a re-distribution on account on anthropogenic changes as there is evidence of reduced populations in some areas and yet substantial expansion in other parts of South-eastern Australia (Roberts 2000).

The shores-line zone of the Lower Lakes (South Australia, Murray Darling Basin) 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 and exposure to wave action (Nicol *et al.* 2013).

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.

Similarly, the wetlands of the Great Artesian Basin have an obvious absence of *Phragmites* within heavily grazed areas and considerable densities in zones that are void of grazing pressure (Gotch 2013).

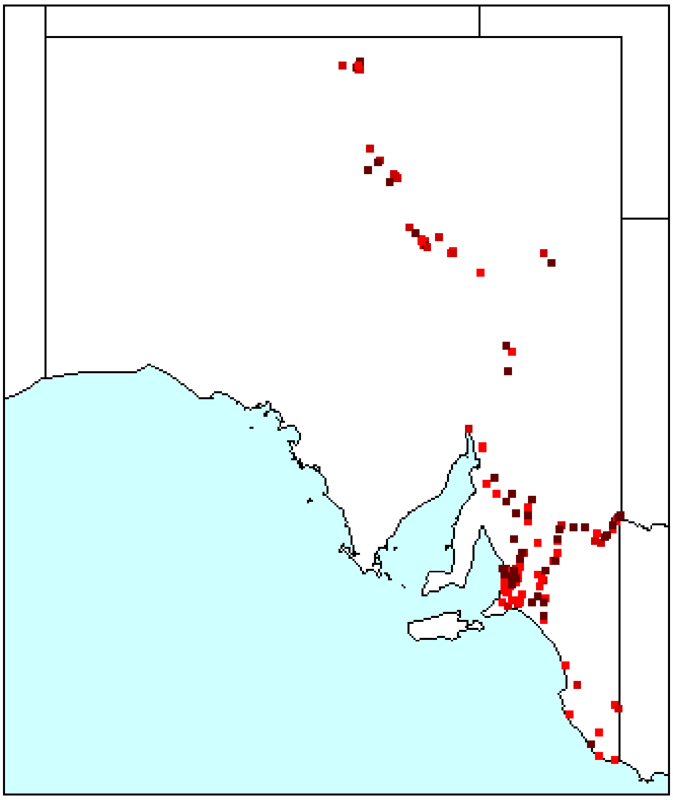

Figure 2: The distribution of *Phragmites australis* within South Australia. Source: Electronic flora database http://www.flora.sa.gov.au/cgi-bin/specimens_map_gd.cgi?genus=*Phragmites*&species=australis&infraname=&region=SA

3. REPRODUCTION STRATEGIES

3.1 Recruitment and regeneration

Phragmites is a woody perennial clonal grass that can reproduce vegetatively (rhizomes, or using stolons) or sexually via seedling recruitment. Although individuals of *Phragmites* will die at the end of the growing season, the below ground structures (rhizomes) are perennial (Kobbing *et al.* 2013).

The annual spread of *Phragmites* rhizomes and aerial stolons are very prolific (Hudon *et al.* 2005; Kobbing *et al.* 2013) with the capacity of up to 200 stems per metre² (Hudon *et al.* 2005). The ability of *Phragmites* to spatially expand is variable, with lateral spreads of up to 10 metres documented (Hudon *et al.* 2005).

Phragmites mostly re-establishes via rhizomatous growth and less frequently, through seedling recruitment (Uddin *et al.* 2012). A germination study by Nicol et al (2010) found that despite Phragmites presence at various sites, it was not detected (Nicol and Ward 2010). This suggests that there are issues with viability of Phragmites seeds and/or the conditions required for germination were not available.

Vegetation propagules of *Phragmites* accounted for 88% of horizontal expansion within a Canadian wetland. This resulted in the occupied area increasing to 32.6 hectares (from < 1 hectare) within a 23-year period (Hudon *et al.* 2005). It is likely that in other areas, *Phragmites* also re-establishes via asexual methods. The shoot biomass values of *Phragmites* within the Great Artesian Springs wetland were in excess of 10kg/ m² (Davies *et al.* 2010), this amount of material would facilitate expansive invasion.

The *Phragmites* seeds are tiny and light and thus expected to be distributed easily by both wind, water and possibly via faunal dispersal (Gotch 2013). Although it has previously been accepted that the seeds of *Phragmites* requires particular environmental conditions for germination and ongoing establishment, a study on the Eurasian *Phragmites* lineage demonstrated that invasion was mostly accounted for by seedling recruitment (Belzile *et al.* 2010). However in Australia, it is generally accepted that Phragmites germination success by seed is limited (Greenwood and MacFarlane 2006; Gotch 2013). The results from the germination trial conducted by Nicol and Ward (2010) also suggest sexual reproduction of *Phragmites* is unlikely.

The survival of *Phragmites* by re-establishment (rhizomatous growth) or recruitment (seedlings) can vary according to physical conditions. Individuals that are rhizome-based are likely to be less sensitive to salinity than juvenile plants that were produced by seeds (Lissner and Schierup 1997)

3.2 Expansion ability and invasiveness

There has been considerable interest in this species worldwide because of its invasiveness and the potential of native and non-native haplotypes to hybridise, particularly within the northern hemisphere (Blossey 2014).

The colonisation and expansion of *Phragmites* across North America is threatening the integrity and composition of wetland plant assemblages (Chambers *et al.* 1999; Kobbing *et al.* 2013; Blossey 2014). The species is highly productive in terms of the amount of above-ground biomass produced (and subsequent area it occupies) with as much as 30t/ha/year produced (Kobbing *et al.* 2013).

Phragmites typically occurs as dense stands in areas that are associated with reduced floristic diversity (Denis 2011). It is assumed that there is a negative relationship between abundant *Phragmites* assemblages, vegetation richness and structural complexities. Research suggests that a dense canopy of woody shrubs has the potential to limit establishment and expansion of *Phragmites* (Albert et al 2013). Such a pattern could be a result of competition for natural resources such as light and space. It is therefore prudent to carefully consider (and stage) the removal of woody weed species that occur within *Phragmites* wetlands (and surrounds). Large-scale removal of woody weed species could provide opportunities for *Phragmites* to colonise.

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 correlation between the growth and expansion of *Phragmites* and water levels for preceding years (Hudon *et al* 2005).

Empirical information has documented the ability of *Phragmites* to increase in range up to 1.5m year $^{-1}$ in a United States marshland (Crain *et al.* 2004). Phragmites has been demonstrated as expanding in range within a Canadian wetland, simultaneous with raised surfaces (Hudon *et al.* 2005).

4. ENVIRONMENTAL TOLERANCES OR SENSITIVITES

Phragmites is able to tolerate and persist during periods of desiccation caused by reduced water levels (Nicol and Ward 2010). An extended drought in a swamp wetland in New South Wales, Australia resulted in senescence of *Phragmites* populations. However, return of water into the system (after 5 years of senescence) resulted in *Phragmites* growth and re-establishment thus demonstrating the persistence of the rhizomes despite the drought conditions (Roberts 2013)

There is evidence to suggest that *Phragmites* can adapt to high 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* occurring in both freshwater and brackish environments. *Phragmites* was present within a range of conductivities and pH levels within the Great Artesian Basin (Gotch 2013). This implies that within this region it has also adapted to a range of conditions. Research has indicated a tolerance of hydric stress and increased salinity, particularly by the Eurasian genotypes (Denis 2011).

Phragmites is expected to occur in dense masses within the South-east of South Australia that have environmental conditions of fluctuating water levels (Deegan *et al.* 2007). Similarly, *Phragmites* was associated with various flow conditions within the Great Artesian Basin (Gotch 2013). 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 were no longer permanently inundated (Resleigh and Foster 2012).

The depth of water saturation (>0.5m) can limit the growth of *Phragmites* (Denis 2011). Established stands are unlikely to persist beyond 3 years with water depth >1 metre (Denis 2011).The cover of *Phragmites* is also reduced when subjected to >100 days of flooding within a year (Denis 2011, Hudon *et al.* 2005).

It is possible that *Phragmites australis* 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). Various *Phragmites* genotypes had a preference for ammonium compounds when compared to other wetland plants (Modzer et al 2013). There is a range of nutrients that are not accessed by other wetland plants but *Phragmites* will utilise (Modzer et al 2013). This means that the anthropogenic increase of nutrient loading has benefited *Phragmites* in terms of cover and abundance (Modzer et al 2013).

Some research has found that brackish wetland areas will support vigorous growth of *Phragmites* (Marks *et al.* 1994; Chambers *et al.* 2003; Sun *et al.* 2007). There is evidence to suggest that *Phragmites* will colonise areas with high salinity (as high as 40) however persistence of the population/s is questionable (Hocking 1989; Marks *et al.* 1994). In fact, Blossey (2014) suggested that flooding *Phragmites* stands with full strength saltwater will permanently control populations.

Laboratory based experiments that subjected *Phragmites* to increased salinity and elevated carbon dioxide levels resulted in increased physiology and morphological plasticity (Mozdzer and Megonigal 2012).

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 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 options might need to be specifically tailored to the hydrologically of each site.

5. ECOSYSTEM CHANGES CAUSED BY *PHRAGMITES*

5.1 Environmental changes

5.1.1 Biogeochemical changes

Colonisation by *Phragmites* can alter the biogeochemical cycles within wetland systems (Windham and Ehrenfield 2003; Modzer et al 2013). The rhizomes of *Phragmites can* release gallic acid (Mozdzer *et al.* 2013). Gallic acid can interfere with the protein structures of other plant species, thus curbing their persistence, longevity and vigour.

An experimental study by Uddin et al (2012) concluded that *Phragmites* dominated wetlands could impact on other species by inhibiting germination potential (Uddin *et al.* 2012). 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). When coupled with *Phragmites* ability to quickly invade an area (section 3.2), this means that this species can very quickly and permanently dominate a wetland community.

5.1.2 Physical modifications

Phragmites can modify the environment by changing the micro topography via soil elevation (Denis 2011). The slow decomposition of *Phragmites* coupled with substantial biomass accumulation creates an aggregated surface layer that can cause drying out at this level (Hudon et al 2005; Denis 2011). This in turn will impact on other species, particularly those with saturation requirements. Germinant persistence is also unlikely in an area that has dense old growth *Phragmites* litter as vital resources such as sunlight and air are largely unavailable.

The culms and leaves from *Phragmites* contain silica that produces the stiff plant material (Kiviat 2013). This foliage may not readily break-down. Modification of the micro-topography (from build-up of undecomposed organic material), will make it difficult for new species to recruit individuals. Such an environment favours enduring spouters such as *Phragmites*.

5.2 Ecological changes

5.2.1 Biodiversity impacts

There has been considerable research on *Phragmites* population increases within the Great Artesian Basin wetlands. The results from such studies indicated that there is a strong relationship between increased *Phragmites* dominated vegetation stands and less plant diversity (Fensham *et al.* 2004). The dense *Phragmites* thickets that establish within spring ecosystems of the Great Artesian Basin have been identified as a threat to several endangered plant species (Davies *et al.* 2010; Gotch 2013)

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).

An investigation of the interaction and competition between *Phragmites* and *Melaleuca ericifolia* found that the *Phragmites* reduced the growth of native plants such as *M.ericifolia*, although persistence continued (Morris 2008).

5.2.2 Fauna

The relationship between extensive stands of *Phragmites* and abundances of fauna species varies. The dense stands of *Phragmites* are often described as poor quality habitat (CT *et al.* 1984; Sun *et al.* 2007).

A study that correlated the numbers of tadpole, juvenile and adult frogs (Anuran family) concluded that there was no impact on the anuran abundances within areas densely populated with *Phragmites* (Mazerolle *et al.* 2014). However, biomass accumulation and clogging from *Phragmites* 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). 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*. Dense *Phragmites* stands can provide nest material and nesting opportunities for bird species (Kane 2001; Kiviat 2013). 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)

Some fauna species may have a preference for dense *Phragmites* areas, particularly avian species that require the stands for breeding and nesting. 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).

Stands of *Phragmites* within the Black Swamp and Tookayerta area are considered critical habitat for several avian species of conservation significance including the Australasian Bittern, Great Crested Grebe and various Crakes (Croft 2004)

6. ECOLOGICAL BENEFITS OF *PHRAGMITES*

Despite the invasiveness and potential of *Phragmites* to become an environmental weed, there are several ecological benefits of this species.

Phragmites can be beneficial within a vegetation community as it provides ecosystem services (Assessment 2005). Water passing through a *Phragmites* wetland can be purified as nutrients and heavy metals are sequestered (Kiviat 2013; Kobbing *et al.* 2013). This purification can occur with the roots of *Phragmites* removing nitrogen and phosphorus as it passes through the wetland (Köbbing *et al.* ; Kobbing *et al.* 2013).

There is also the potential of *Phragmites* to capture atmospheric carbon and store this in-situ at various spatial scales. Maintaining *Phragmites* dominated wetlands will facilitate on-going carbon capture and ensure that it is not released into the atmosphere (Kiviat 2013)

Phragmites also has physical functional benefits as it can stabilise soils thus reducing impacts from erosion. This species is often deliberately introduced into erosion susceptible landscapes to stabilise and accumulate surfaces (Mozdzer *et al.* 2013) or used as a filtering plant within wetland wastewater treatments (Brisson and Chazarenc 2009).

7. RESPONSE OF *PHRAGMITES* TO DISTURBANCE

Modification of management practices (such as reduced grazing and/or mowing) can provide opportunities for *Phragmites* to dominate the vegetation community, often at the expense of other species (Güsewell 2003).

The exclusion of disturbance will likely result in quick invasion and colonisation of large wetland areas. 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 is considered an opportunistic coloniser and able to respond favourably to ecological disturbance. For example, an ecological restoration program that disturbed substrates resulted in 80% of the area being colonised by *Phragmites* (Welch *et al.* 2006). Similarly, anthropogenic driven environmental changes can result in expansion of *Phragmites* (Moore 1973).

8. MANAGEMENT AND POTENTIAL CONTROL OPTIONS

A review of literature on *Phragmites* asserted 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 same review also highlighted the absence of investigations that aimed to control *Phragmites* at a landscape scale as most on-ground efforts were limited to small discrete patches. Keller (2000) also concluded that long-term research was needed to investigate and understand invasion, spread and persistence of *Phragmites*.

It cannot be assumed that removing *Phragmites* will trigger the desirable shifts needed to maintain or initiate a trajectory into a more desirable and diverse vegetation assemblage. Unless the ecological and physiological drivers that make this species so competitive are addressed, removal could initiate greater abundances and frequencies of *Phragmites*.

There has been considerable intellectual and financial 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 are 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).

A study by Cowie et al (1992) suggested that burning *Phragmites* within marshland habitats resulted in shorter but more of the canes; this resulted in allocation of environmental resources that supported other plant species

The timing of such burns is critical. A burn at the end of the *Phragmites* growing season is likely the most effective time for undertaking a control burn that has the primary objective of simply removing above-ground mass. However, removal of living shoots during the growing phase will encourage the growth of rhizomatous growth buds (Roberts 2013). Removal of *Phragmites* above ground biomass during summer or early autumn is documented as the most efficient time as the nutrient contents of *Phragmites* shoots are maximal (Hellings and Gallagher 1992; Güsewell 2003).

In contrast, burning during a time when underground organs are active could stimulate *Phragmites* expansion as vegetative shooting will increase (Sun *et al.* 2007). Firing up of *Phragmites* within the during the dormancy period (end of winter) in the Great Artesian Basin is considered 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).

There is sufficient empirical information that asserts the coupling of inundation (for particular periods of time) and burning (during the right season) could control *Phragmites.* 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 conservation challenge within some systems is the management of *Phragmites* by either burning or slashing while also protecting and enhancing populations of native species. Continued slashing during the flowering life-stage could possibly control in-situ *Phragmites* populations and limit potential spread. However such a management action during inappropriate times has been shown to sometimes increase the abundance of *Phragmites* (Güsewell 2003).

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 and combining with burning (Government 2014b).

However this might be limited to drier areas as glyphosate is not recommended in or near waterways. Herbicide application cannot always be applied within wetlands of high conservation significance. Controlling *Phragmites* with herbicides can cause negative impacts on other native vegetation species (Güsewell 2003).

In North America, the potential of soil pathogens to impact and thus control *Phragmites* extent has been investigated. Use of the shoot-boring moth insect, *Archanara geminipunctata,* to control *Phragmites* has been considered as a potential biological agent (Blossey 2014). Results from Gusewells (2003) mowing experiment within a Swiss Fen suggested that using such a biological control will be more effective if coupled with mowing (Güsewell 2003). However, potential hybridisation between native and non-native genotypes (section 2.1) might impact on the effectiveness of biological control.

An alternative conservation strategy and management of *Phragmites* is to focus on the prevention rather than a cure. Keller (2000) highlighted the need to better understand what on-ground efforts can prevent *Phragmites* establishment and expansion.

9. SUMMARY STATEMENT

Phragmites 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 concern.

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 encourages further expansion and safe-guards its persistence.

Most *Phragmites* management strategies focus on removal either by burning, mowing or slashing. However, 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. This presents a conservation conundrum. This season of burning is likely to produce a hotter burn with greater threats posed to nearby vegetation communities, property, wildlife and personal safety.

10. REFERENCES

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Phragmites australis (common reed) has expanded in many wetland habitats. Its ability to exclude other plant species has led to both control and eradication programs. This study examined two control methods—herbicide application or a herbicide-burning combination—for their efficacy and ability to restore plant biodiversity in non-tidal wetlands. Two Phragmites-dominated sites received the herbicide glyphosate. One of these sites was burned following herbicide application. Plant and soil macroinvertebrate abundance and diversity were evaluated pre-treatment and every year for four years post-treatment using belt transects. The growth of Phragmites propagules—seeds, rhizomes, and rooted shoots—was examined in the greenhouse and under bare, burned, or vegetated soil conditions. Both control programs greatly reduced Phragmites abundance and increased plant biodiversity. Plant re-growth was quicker on the herbicide-burn site, with presumably a more rapid return to wetland function. Re-growth at both sites depended upon a pre-existing, diverse soil seed bank. There were no directed changes in soil macroinvertebrate abundance or diversity and they appeared unaffected by changes in the plant community. Phragmites seeds survived only on bare soils, while buried rhizomes survived under all soil conditions. This suggests natural seeding of disturbed soils and inadvertent human planting of rhizomes as likely avenues for Phragmites colonization. Herbicide control, with or without burning, can reduce Phragmites abundance and increase plant biodiversity temporarily. These changes do not necessarily lead to a more diverse animal community. Moreover, unless Phragmites is eradicated and further human disturbance is prohibited, it will likely eventually re-establish dominance.

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Belzile, F., et al. (2010). "Seeds contribute strongly to the spread of the invasive genotype of the common reed (Phragmites australis)." Biological Invasions **12**(7): 2243-2250.

The introduced subspecies of the common reed (Phragmites australis (Cav.) Trin. ex Steud. subsp. australis; Poaceae) is considered one of the most invasive plants in North American wetlands. Given its relatively low seed set and its tremendous capacity to spread via stolons or rhizomes, it has generally been thought that the spread of vegetative diaspores was responsible for the establishment of new populations. To test this hypothesis, we sampled a single plant from each of 345 visually-distinct common reed stands located along the shores of Lake St. François (southern Quebec, Canada). With a set of six nuclear microsatellite markers, we distinguished 134 different genotypes. The number of individuals sharing the same genotype ranged from one to 16, and averaged 2.1. Most genotypes were encountered only once. We examined the spatial distribution of the most frequent genotypes and found little evidence of clusters along the lakeshore. These data contradict the hypothesis that a common reed invasion is initiated by the introduction of vegetative diaspores from a few clones. Rather, they clearly support the alternative hypothesis that seeds were the primary diaspores responsible for the establishment of common reed populations.

Blanch, S. J., et al. (2000). "Water regimes and littoral plants in four weir pools of the River Murray, Australia." Regulated Rivers: Research & Management **16**(5): 445-456.

The composition and distribution of littoral vegetation in four weir pools of the lower Murray were surveyed in summer 1994. Between-weir gradients in the amplitude of water level fluctuations were reflected in the typical distributions of plants, with a 4–6 m elevational range in upper-pool sites, where levels fluctuate most, and a 1–1.5 m band in the lower-pool sites, where levels are more stable. Forty-one of 48 species occurred across much of the longitudinal×elevational site matrix within this cone-shaped distribution, indicating considerable tolerance to flooding and exposure; this was especially apparent for Phragmites australis, Cyperus spp. and Centipeda spp. The 41 species were represented in seven of nine water-regime groups identified by cluster analysis. The remainder, found within ±1 m of the water surface in lower-pool reaches, were aquatic macrophytes such as Vallisneria americana and Typha spp. and amphibious 'mudmats' such as Glossostigma elatinoides. Water regimes at given sites were measured by the number of days in 2 years flooded to any depth (>0 cm), or to 0–30 cm, and by days exposed by >100 cm. Inter-pool differences in the median number of days flooded to >0 cm and 0–30 cm were 3–30% and <8%, respectively, for all species except Typha spp. but an order of magnitude for the number of days exposed by >100 cm. However, eight of 14 common or representative species analysed showed significant inter-pool differences in the number of days flooded to >0 cm, indicating that sufficient variation exists to necessitate considerable intra-pool replication to allow for the detection of statistical differences in a multi-pool experiment. The practice of maintaining stable weir pool levels limits vegetation processes, e.g. germination, recruitment, decomposition. An increase in the amplitude of river level fluctuations during low flows, from the current 10–20 cm range to 20–50 cm, would reinstate water regimes suitable to the majority of species surveyed. Copyright © 2000 John Wiley & Sons, Ltd.

Blossey, B. (2014). Identification, development and release of insect biocontrol agents for the management of *Phragmites australis*. Ithaca, New York, Department of Natural Resources, Cornell University.

Introduced Phragmites australis is rapidly spreading in North America, threatening wetland plant communities and endemic native genotypes (Phragmites australis americanus). Lack of successful long-term control resulted in initiation of biological control research. In the past, the program targeting introduced Phragmites has focused on several promising potential biological control agents with large impacts on P. australis. The purpose of this report is to: (1) identify potential agents for in-depth study; (2) outline and report initial testing procedures and results of host-specificity studies of identified agents; (3) assess possibilities to develop laboratory/greenhouse mass-rearing procedures; (4) outline approaches for long-term monitoring at pre-release sites; and (5) assess the extent of hybridization between native and introduced genotypes. All selected insect species are stem miners that overwinter as eggs, with larvae feeding in spring and early summer. Host specificity testing is being conducted in a Rhode Island quarantine facility and at the Center for Agricultural Bioscience International (CABI) in Switzerland. In addition, investigations continue on the impact of Phragmites populations on native fauna and flora as well as the economic and ecological effects of Phragmites invasion. Hybridization between native and introduced genotypes appears to be restricted to a single hybridization event in central New York State.

Borruso, L., et al. (2014). "Rhizosphere effect and salinity competing to shape microbial communities in Phragmites australis (Cav.) Trin. ex-Steud." FEMS Microbiology Letters: n/a-n/a.

Rhizobacterial communities associated with Phragmites australis (Cav.) Trin. ex in a hypersaline pond close to Wuliangsuhai lake (Inner Mongolia – China) were investigated and compared with the microbial communities in bulk sediments of the same pond. Microbiological analyses have been done by Automated Ribosomal Intergenic Spacer Analysis (ARISA) and partial 16S rRNA gene 454 pyrosequencing. Although community richness was higher in the rhizosphere samples than in bulk sediments, the salinity seemed to be the major factor in shaping the microbial communities structure. Halanaerobiales was the most abundant taxon found in all the different samples and Desulfosalsimonas was observed to be more present in the rhizosphere rather than in bulk sediment. This article is protected by copyright. All rights reserved.

Brisson, J. and F. Chazarenc (2009). "Maximising pollutant removal in constructed wetlands: should we pay more attention to macrophyte species selection?" Science of the Total Environment **407**: 3923-3930.

While the positive role of macrophytes on removal efficiency in constructed wetlands has been well established, possible differences in performance between plants species of comparable life forms and sizes are much harder to demonstrate. We reviewed 35 experimental studies published in peer-reviewed journals and proceedings on the effect of macrophyte species selection on pollutant removal in SSFCW. The studies cover a wide range of macrophyte species, experimental approaches (from well-replicated microcosm experiments to comparison between full full-size constructed wetlands), climatic conditions (from tropical to cold-temperate) and types of effluent (domestic, industrial, etc.). Frequent methodological limitations in these studies compel caution in the interpretation of their results. Yet, the fact that the majority found some (occasionally large) differences in efficiency between plant species for one or more type of pollutant suggests that macrophyte species selection does matter. However, there is little generalization to be made that could help guide species selection for SSFCW, except for the exact conditions in which the experiments were done. For example, the same pair of species that was tested in different studies occasionally gave opposite results in terms of which one performs best. Also, most studies provided few insights on the mechanisms or plant properties that could explain the observed differences in plant species efficiency. Finally, we discuss other relevant research questions and approaches that could help better guide macrophyte species selection for CW.

Callaway, R. M., et al. (2002). "Positive interactions among alpine plants increase with stress." Nature **417**(6891): 844-848.

Plants can have positive effects on each other1. For example, the accumulation of nutrients, provision of shade, amelioration of disturbance, or protection from herbivores by some species can enhance the performance of

neighbouring species. Thus the notion that the distributions and abundances of plant species are independent of other species may be inadequate as a theoretical underpinning for understanding species coexistence and diversity2. But there have been no large-scale experiments designed to examine the generality of positive interactions in plant communities and their importance relative to competition. Here we show that the biomass, growth and reproduction of alpine plant species are higher when other plants are nearby. In an experiment conducted in subalpine and alpine plant communities with 115 species in 11 different mountain ranges, we find that competition generally, but not exclusively, dominates interactions at lower elevations where conditions are less physically stressful. In contrast, at high elevations where abiotic stress is high the interactions among plants are predominantly positive. Furthermore, across all high and low sites positive interactions are more important at sites with low temperatures in the early summer, but competition prevails at warmer sites.

Chambers, R. M., et al. (1999). "Expansion of Phragmites australis into tidal wetlands of North America." Aquatic Botany **64**(3–4): 261-273.

Phragmites expansion into tidal wetlands of North America is most extensive along the northern and middle Atlantic coasts, but over 80% of the US coastal wetland area occurs along the Gulf of Mexico and southern Atlantic coasts and may be susceptible to ongoing expansion. Rapid spread of Phragmites has been documented in freshwater (<0.5 ppt), oligohaline (0.5–5 ppt) and mesohaline (5–18 ppt) tidal wetlands. The advance of Phragmites into tidal wetlands of North America may have been facilitated by widespread coastal changes since European settlement, including disturbance of hydrologic cycles and nutrient regimes; the presence of Phragmites has become a signature of tidal wetland alteration. Although ploidy levels from 2n = 36 to 72 have been documented for Phragmites throughout the continent, no genetics research to date has tested whether recent introduction of aggressive clones could account for Phragmites expansion. A fundamental concern regarding Phragmites expansion, particularly into tidal freshwater wetlands, is the observed reduction in biodiversity as many native species of plants are replaced by a more cosmopolitan species. Commensurate with a shift in habitat type is a reduction in insect, avian and other animal assemblages. Ecosystem services, including support of higher trophic levels, enhancement of water quality and sediment stabilization, however, are not diminished when a tidal wetland becomes dominated by Phragmites, provided that tidal flooding is retained.

Chambers, R. M., et al. (2003). "Phragmites australis invasion and expansion in tidal wetlands: Interactions among salinity, sulfide, and hydrology." Estuaries **26**(2): 398-406.

Through their physiological effects on ion, oxygen, and carbon balance, respectively, salinity, sulfide, and prolonged flooding combine to constrain the invasion and spread ofPhragmites in tidal wetlands. Initial sites of vigorous invasion by seed germination and growth from rhizome fragments appear limited to sections of marsh where salinity is <10‰, sulfide concentrations are less than 0.1 mM, and flooding frequency is less than 10%. In polyhaline tidal wetlands the invasion sites include the upland fringe and some high marsh creek banks. The zones of potential invasion tend to be larger in marshes occupying lower-salinity portions of estuaries and in marshes that have been altered hydrologically. Owing to clonal integration and a positive feedback loop of growth-induced modification of edaphic soil conditions, however, a greater total area of wetland is susceptible toPhragmites expansion away from sites of establishment. Mature clones have been reported growing in different marshes with salinity up to 45‰, sulfide concentration up to 1.75 mM, and flooding frequency up to 100%. ForPhragmites establishment and expansion in tidal marshes, windows of opportunity open with microtopographic enhancement of subsurface drainage patterns, marsh-wide depression of flooding and salinity regimes, and variation in sea level driven by global warming and lunar nodal cycles. To avoidPhragmites monocultures, tidal wetland creation, restoration, and management must be considered within the context of these different scales of plant-environment interaction.

Clevering, O. A. and J. Lissner (1999). "Taxonomy, chromosome numbers, clonal diversity and population dynamics of Phragmites australis." Aquatic Botany **64**(3–4): 185-208.

Phragmites australis (Cav.) Trin. ex Steud. (common reed) is one of the most widespread plant species in the world. The species has a high phenotypic variation in morphology and life-history traits. This high phenotypic variation can be related to variance in chromosome numbers, clonal diversity, plasticity of clones or a combination of these. An overview of our present, still limited, knowledge concerning the amounts, causes and maintenance of genetic diversity in P. australis is given. In P. australis a large range in euploid number has been found (between 3x–12x, except for 5x and 9x, with x = 12). In Europe tetraploids are dominant, whereas octoploids predominate in Asia. Aneuploids also occur regularly in P. australis, and differences in chromosome numbers have been observed even within clones. Clonal diversity in P. australis has been studied using allozyme polymorphisms and molecular markers. Both mono- and polyclonal stands are known to exist. A surprisingly high number of clones has been found in European stands. Environmental and genetic factors, which may account for

this high clonal diversity, are discussed. In most studies on the occurrence of ecotypes in P. australis no distinction has been made between plastic and genetic variation. But evidence exists that responses to climate, hydrology and salt have a genetic basis. Until now no attempts have been made to determine which genes or gene complexes are responsible for these different responses.

Coates, F., et al. (2010). The floristic values of wetlands in the Highlands and Strathbogie Ranges. Victoria, Australia, Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment.

Crain, C. M., et al. (2004). "PHYSICAL AND BIOTIC DRIVERS OF PLANT DISTRIBUTION ACROSS ESTUARINE SALINITY GRADIENTS." Ecology **85**(9): 2539-2549.

Although it has long been recognized that marsh plant community composition shifts across estuarine salinity gradients, the mechanisms responsible for this species zonation have never been experimentally examined. In southern New England marshes of the United States, we investigated the relative importance of physical and biotic factors in generating estuarine species distribution patterns. Greenhouse studies revealed that all of the common plants in this system grow better in fresh water than in full-strength salt water. To test the hypothesis that the spatial segregation of these plants is driven by differential tolerance to salt stress and plant competition, we performed transplant experiments with 10 common plants in the system. When freshwater marsh plants were transplanted to salt marshes, they did poorly and generally died with or without neighbors present. In contrast, when saltmarsh plants were transplanted to freshwater marshes, they thrived in the absence of neighbors, growing better than they did in salt marshes, but when neighbors were present, they were strongly suppressed. These results suggest that the spatial segregation of plants across estuarine salinity gradients is driven by competitively superior freshwater marsh plants displacing salt-tolerant plants to physically harsh saltmarsh habitats, whereas freshwater marsh plants are limited from living in salt marshes by physical factors (e.g., high salinities). These results contribute to our understanding of the organization and assembly of tidal marsh plant communities and have important implications for understanding how marsh plant communities will respond to human modification of estuarine hydrology and climate change.

Croft, S. (2004). Black Swamp habitat description. Adelaide, South Australia, Birds for Biodiversity, Conservation Council of SA.

CT, R., et al. (1984). "Salt marsh vegetation change in response to tidal restriction." Environmental Management **8**: 141-150.

Vegetation change in response to restriction of the normal tidal prism of six Connecticut salt marshes is documented. Tidal flow at the study sites was restricted with tide gates and associated causeways and dikes for purposes of flood protection, mosquito control, and/or salt hay farming. One study site has been under a regime of reduced tidal flow since colonial times, while the duration of restriction at the other sites ranges from less than ten years to several decades. The data indicate that with tidal restriction there is a substantial reduction in soil water salinity, lowering of the water table level, as well as a relative drop in the marsh surface elevation. These factors are considered to favor the establishment and spread ofPhragmites australis (common reed grass) and other less salt-tolerant species, with an attendant loss ofSpartina-dominated marsh. Based on detailed vegetation mapping of the study sites, a generalized scheme is presented to describe the sequence of vegetation change from typicalSpartina- toPhragmites-dominated marshes. The restoration of thesePhragmites systems is feasible following the reintroduction of tidal flow. At several sites dominated byPhragmites, tidal flow was reintroduced after two decades of continuous restriction, resulting in a marked reduction inPhragmites height and the reestablishment of typical salt marsh vegetation along creekbanks. It is suggested that large-scale restoration efforts be initiated in order that these degraded systems once again assume their roles within the salt marsh-estuarine ecosystem.

Davies, R. J. P., et al. (2010). "Competitive effects of Phragmites australis on the endangered artesian spring endemic Eriocaulon carsonii." Aquatic Botany **92**(4): 245-249.

We investigated the relative importance of above- and below-ground competition by reeds (Phragmites australis (Cav.) Trin. ex Steud) on the growth rate of Eriocaulon carsonii F.Muell. subsp. carsonii, an endangered plant threatened by reeds on artesian springs in Australia. Soil-filled buckets containing E. carsonii were frequently watered to simulate artesian spring conditions and subject to three treatments: (1) no Phragmites (control), (2) Phragmites (ABG), and (3) Phragmites with shoots tied back (BG). After thirteen months, Phragmites mean below-ground biomasses had increased to c. 3 kg m−2 and mean above-ground biomasses to c. 1 kg m−2. After the same period, mean root biomass of E. carsonii plants was significantly lower in buckets subject to both Phragmites treatments compared with control plants, as was E. carsonii foliage area. Comparison of the two Phragmites treatments indicated that below-ground competition was the primary cause of this reduced growth in E. carsonii. The vulnerability of E. carsonii to competitive exclusion by P. australis is in part due to the highly synchronized phenologies of the two species.

Deegan, B. M., et al. (2007). "The influence of water level fluctuations on the growth of four emergent macrophyte species." Aquatic Botany **86**(4): 309-315.

The influence of the amplitude of cyclic water level fluctuations on the growth of four species of emergent macrophyte (Cyperus vaginatus, Phragmites australis, Triglochin procerum and Typha domingensis) was studied in a controlled, pond-based experiment. The amplitudes of water level fluctuations were static, ±15, ±30 and ±45 cm, each cycling over a forty-day period. In all treatments the water level fluctuated around an initial water depth of 60 cm. Within each amplitude treatment, plants were grown at three elevations with the sediment surface at 20, 40 or 60 cm. Only T. domingensis and P. australis showed a significant response to amplitude. Biomass of T. domingensis was similar in the static, ±15 and ±30 cm amplitude treatments but dropped by ca. 52% when grown in amplitudes of ±45 cm. In contrast, the largest biomass for P. australis occurred in the ±30 cm amplitude treatment suggesting this species prefers moderately fluctuating water levels. The response of P. australis to amplitude was contingent upon elevation with plants growing in the ±45 cm amplitude, low elevation treatment having particularly low biomasses. C. vaginatus biomass increased with increasing elevation but did not respond to amplitude while T. procerum did not respond to either amplitude or elevation likely due to the ability of the species to photosynthesise under water. The relative growth rate and the average emergent surface area were logarithmically related in C. vaginatus suggesting flooding of the photosynthetic canopy was limiting the ability of this species to acquire atmospheric carbon. No clear relationship was found for T. domingensis or P. australis indicating that a factor other than access to atmospheric carbon was restricting the growth of these species.

Engloner, A. I. (2009). "Structure, growth dynamics and biomass of reed (Phragmites australis) – A review." Flora - Morphology, Distribution, Functional Ecology of Plants **204**(5): 331-346.

This paper reviews about 190 publications related to the anatomy, morphology and growth of aboveground and belowground parts of common reed (Phragmites australis). In addition to the general description of plant structure, observations on germination, growth dynamics, biomass, effects of habitat conditions such as temperature, salinity, nutrient supply and water depth are evaluated. The impact of animal, fungal and algal attacks, and human intervention (burning and harvesting) on reed growth, and the potential genetic determinacy behind the response of reed to environmental changes are also discussed.

Fensham, R. J., et al. (2004). "Vegetation patterns in permanent spring wetlands in arid Australia." Australian Journal of Botany **52**(6): 719-728.

A transect-based quadrat survey was conducted within 11 spring wetlands fed by permanent groundwater flows from the Great Artesian Basin at Elizabeth Springs in western Queensland. Flow patterns within individual wetlands change with sedimentation associated with mound building, siltation of abandoned drains and changes in aquifer pressure associated with artificial extraction from bores. The pattern of floristic groups for the wetland quadrats was poorly related to soil texture, water pH, slope and topographic position. Patterns were most clearly related to wetland age as determined from aerial photography, with a clear successional sequence from mono-specific stands of Cyperus laevigatus on newly formed wetland areas to more diverse wetland assemblages. However, evidence from other Great Artesian Basin springs suggests that succession can also result in reduced species richness where the palatable tall reed Phragmites australis develops mono-specific stands.

Gotch, T. (2013). Allocating water and maintaining springs in the Great Artesian Basin. Ground-water Ecosystems of the Western Great Artesian Basian. T. Gotch. Canberra, Australia, National Water Comission.

This publication is part of a series of works commissioned by the National Water Commission under its Raising National Water Standards Program and its major partners: the Flinders University of South Australia, the South Australian Government, the South Australian Arid Lands Natural Resources Management Board, The University of Adelaide, the Northern Territory Government and the Commonwealth Scientific and Industrial Research Organisation, as part of the Allocating Water and Maintaining Springs in the Great Artesian Basin (AWMSGAB) project.

Government, Q. (2014). "Weeds of Australia." Fact Sheet Index: *Phragmites australis*.

Government, W. A. (2014). "FloraBase the Western Australia Flora." from https://florabase.dpaw.wa.gov.au/browse/profile/555.

Gratton, C. and R. F. Denno (2005). "Restoration of Arthropod Assemblages in a Spartina Salt Marsh following Removal of the Invasive Plant Phragmites australis." Restoration Ecology **13**(2): 358-372.

Invasive plants are one of the most serious threats to native species assemblages and have been responsible for the degradation of natural habitats worldwide. As a result, removal of invasive species and reestablishment of natural vegetation have been attempted in order to restore biodiversity and ecosystem function. This study examined how native arthropod assemblages, an abundant and functionally important group of organisms in many ecosystems, are affected by the incursion of the invasive wetland plant Phragmites australis and if the restoration of the native vegetation in brackish Spartina alterniflora marshes results in the reestablishment of the arthropod community. The invasion of Phragmites into a coastal Spartina marsh in southern New Jersey seriously altered arthropod assemblages and trophic structure by changing the abundance of trophic groups (detritivores, herbivores, carnivores) and their taxonomic composition. Herbivore assemblages shifted from the dominance of external free-living specialists (e.g., planthoppers) in Spartina to concealed feeders in Phragmites (stem-feeding cecidomyiids). Moreover, free-living arthropods in Phragmites became dominated by detritivores such as Collembola and chironomids. The dominant marsh spiders, web-building linyphiids, were significantly reduced in Phragmites habitats, likely caused by differences in the physical environment of the invaded habitats (e.g., lower stem densities). Thus, trophic structure of arthropod assemblages in Phragmites, as seen in the large shifts in feeding guilds, was significantly different from that in Spartina. Removal of Phragmites with the herbicide glyphosate resulted in the rapid return of Spartina (≤5 yrs). Moreover, return of the dominant vegetation was accompanied by the recovery of most original habitat characteristics (e.g., live and dead plant biomass, water flow rate). The arthropod assemblage associated with Spartina also quickly returned to its preinvasion state and was not distinguishable from that in uninvaded Spartina reference sites. This study provides evidence that the reestablishment of native vegetation in areas previously altered by an invasive plant can result in the rapid recovery of the native arthropod assemblage associated with the restored habitat.

Guo, W.-Y., et al. (2013). "Invasion of Old World Phragmites australis in the New World: precipitation and temperature patterns combined with human influences redesign the invasive niche." Global Change Biology **19**(11): 3406-3422.

After its introduction into North America, Euro-Asian Phragmites australis became an aggressive invasive wetland grass along the Atlantic coast of North America. Its distribution range has since expanded to the middle, south and southwest of North America, where invasive P. australis has replaced millions of hectares of native plants in inland and tidal wetlands. Another P. australis invasion from the Mediterranean region is simultaneously occurring in the Gulf region of the United States and some countries in South America. Here, we analysed the occurrence records of the two Old World invasive lineages of P. australis (Haplotype M and Med) in both their native and introduced ranges using environmental niche models (ENMs) to assess (i) whether a niche shift accompanied the invasions in the New World; (ii) the role of biologically relevant climatic variables and human influence in the process of invasion; and (iii) the current potential distribution of these two lineages. We detected local niche shifts along the East Coast of North America and the Gulf Coast of the United States for Haplotype M and around the Mississippi Delta and Florida of the United States for Med. The new niche of the introduced Haplotype M accounts for temperature fluctuations and increased precipitation. The introduced Med lineage has enlarged its original subtropical niche to the tropics-subtropics, invading regions with a high annual mean temperature (> ca. 10 °C) and high precipitation in the driest period. Human influence is an important factor for both niches. We suggest that an increase in precipitation in the 20th century, global warming and human-made habitats have shaped the invasive niches of the two lineages in the New World. However, as the invasions are ongoing and human and natural disturbances occur concomitantly, the future distribution ranges of the two lineages may diverge from the potential distribution ranges detected in this study.

Güsewell, S. (2003). "Management of Phragmites australis in Swiss fen meadows by mowing in early summer." Wetlands Ecology and Management **11**(6): 433-445.

Mowing experiments were carried out from1995 to 2001 in Swiss fen meadows toinvestigate whether the abundance of Phragmites australis is reduced by mowingin early summer in addition to mowing inautumn. Experimental plots of 100 m2were established in three fen meadows thatare mown every year in September; treatedplots received an additional cut in lateJune either every year or every two years.Until 1997, the additional cut had noeffect on the above-ground biomass of Phragmites (monitored every year in lateJune). As from 1998, the biomass of Phragmites was 25–30% lower in the plotswith annual June cut than in the controlplots. However, the pooled biomass of allother plant species decreased similarly, sothat the degree of dominance of Phragmites was not reduced. An additionalJune cut every two years had no effect onthe biomass of Phragmites. In June2001, the shoots of Phragmites weresmaller in annually June-cut plots than incontrol plots, but allometric relationshipsbetween shoot length and diameter, shootgrowth from June to August, and nitrogenand phosphorus concentrations of shoots didnot differ between June-cut and controlplots. The additional June cut increasedthe total export of N with the hay by 18%,and that of P by 50% in 2001. Theseadditional nutrient exports were smallerthan those found in the first years of theexperiment and not larger for Phragmites than for the remainder of thevegetation. Together, the results suggestthat a depletion of below-ground storescaused Phragmites to decrease afterseveral years of additional mowing in June.Eighty further permanent quadrats in fenmeadows with normal management (mownannually in September) were surveyed in1995–96 and in 2001. The above-groundbiomass of Phragmites increasedduring this time in 49 out of 80 plots,with a mean relative difference of +35.5%.Thus, even if additional mowing in earlysummer only slightly reduced theperformance of Phragmites compared toplots mown only in September, thistreatment might help to prevent the speciesfrom spreading under the current conditionsin Swiss fen meadows

Güsewell, S. and F. Klötzli (2000). "Assessment of aquatic and terrestrial reed (Phragmites australis) stands." Wetlands Ecology and Management **8**(6): 367-373.

A survey of recent publications shows that research on Phragmites australishas oftenapplied character because of the considerableecological and economic significance of the species.The main applications are water treatment, agriculture(food production or weed control) and natureconservation. In Europe, most research on natural reedstands has been motivated by reed die-back and effortstowards protection or restoration. Reed progressionand reed control have been the main concerns in otherparts of the world, and reed progression has alsoreceived increasing attention in Europe. While reeddie-back generally affects aquatic stands, progressioncan occur at both terrestrial and aquatic sites, andit can be desired (e.g. lake shore restoration)or unwanted (e.g. in species-rich fens ormarshes). Therefore, reed stands need to be assessedindividually to decide on management aims andappropriate methods. The varying status of Phragmites australisformed the background of the`European Reed Conference' held in Zürich/Switzerlandin October 1998. The seven contributions published inthis special issue are introduced with particularreference to differences between aquatic andterrestrial reed stands and to approaches used in theirassessment

Güsewell, S., et al. (2000). "Dynamics of common reed (Phragmites australisTrin.) in Swiss fens with different management." Wetlands Ecology and Management **8**(6): 375-389.

Dynamics of common reed (Phragmites australisTrin.) in Central Europe have so far mostly beeninvestigated in connection with studies on reed`die-back' along lake shores. However, there hasrecently been increasing concern about reed expansionat terrestrial sites, such as fens and wet grasslands.In this paper we report on the results of fourseparate studies which monitored reed dynamics inSwiss fens with various mowing regimes over a periodof 4 to 15 years. The first study compared unmownplots with plots mown in winter in a triennialrotation; the second one included unmown plots, plotsmown in summer, and plots mown in winter; the thirdone compared plots mown in June and September withplots only mown in September; the fourth studyinvestigated only plots mown in September. Shootnumber and shoot size were recorded in permanentquadrats. In all studies the performance of P.australisfluctuated without trend or tended todecrease during the period investigated. Thedecreasing tendency concerned shoot size rather thanshoot number, and within a given study it was strongerfor plots with initially taller shoots. The variousmowing regimes did hardly influence these changes.Mowing in winter every three years reduced shoot sizein the year after mowing, but not on the long term.Mowing every year in late summer reduced the shootsize compared with unmown plots on the short term, butthis effect almost disappeared on the long term, aftermowing had become biennial. Mowing in June (inaddition to in September) caused no noticeableeffects. We conclude that other factors (e.g. weatherconditions, competition, or population processes) aremore important than management in determining theabundance of P. australisin the fen communitiesinvestigated here, although long-term effects ofmowing in summer still need more investigation. As apractical consequence it is suggested that at siteswhich are not strongly dominated by P.australis, as most of those investigated here,reducing the performance of this species should notconstitute a major target of nature conservationmanagement, nor can its dynamics be used as anindicator for management success before underlyingcauses are better understood

Hazelton, E. L. G., et al. (2014). "Phragmites australis Management in the United States: 40 years of methods and outcomes." AoB Plants.

Studies on invasive plant management are often short in duration, are limited in the methods tested, and lack an adequate description of plant communities that replace the invader following removal. Here we present a comprehensive review of management studies on a single species, in an effort to elucidate future directions for research in invasive plant management. We reviewed the literature on Phragmites management in North America in an effort to synthesize our understanding of management efforts, identify gaps in knowledge and improve efficacy of management. Additionally, we assessed recent ecological findings concerning Phragmites mechanisms of invasion and integrate these findings into our recommendations for more effective management. Our overall goal is to examine whether or not current management approaches can be improved and whether they promote reestablishment of native plant communities. We found: (1) little information on community-level recovery of vegetation following removal of Phragmites; and (2) most management approaches focus on the removal of Phragmites from individual stands or groups of stands over a relatively small area. With a few exceptions, recovery studies did not monitor vegetation for substantial durations, thus limiting adequate evaluation of the recovery trajectory. We also found that none of the recovery studies were conducted in a landscape context, even though it is now well documented that land-use patterns on adjacent habitats influence the structure and function of wetlands, including the expansion of Phragmites. We suggest that Phragmites management needs to shift to watershed scale efforts in coastal regions, or larger management units inland. In addition, management efforts should focus on restoring native plant communities, rather than simply eradicating Phragmites stands. Wetlands and watersheds should be prioritized to identify ecosystems that would benefit most from Phragmites management and those where the negative impact of management would be minimal.

Hellings, S. and J. Gallagher (1992). "The effects of salinity and flooding in *Phragmites australis*." Journal Applied Ecology **29**: 41-49.

The need to control common reed Phragmites australis in the tidal marshes of Delaware and other mid-Atlantic US states became a priority of coastal zone managers due to a dramatic expansion in the area occupied by this robust grass. Mowing and burning has been attempted as a means of control but has usually resulted in little or no success. Herbicide control may be effective but may not be compatible with other marsh management objectives. This study examined the effects of water salinity, flooding and cutting on P.australis growth in an outdoor experimental trial

Hines, J., et al. (2014). "Genotypic trait variation modifies effects of climate warming and nitrogen deposition on litter mass loss and microbial respiration." Global Change Biology: n/a-n/a.

Intraspecific variation in genotypically determined traits can influence ecosystem processes. Therefore, the impact of climate change on ecosystems may depend, in part, on the distribution of plant genotypes. Here we experimentally assess effects of climate warming and excess nitrogen supply on litter decomposition using 12 genotypes of a cosmopolitan foundation species collected across a 2100-km latitudinal gradient and grown in a common garden. Genotypically determined litter chemistry traits varied substantially within and among geographic regions, which strongly affected decomposition and the magnitude of warming effects, as warming accelerated litter mass loss of high-nutrient, but not low-nutrient genotypes. Although increased nitrogen supply alone had no effect on decomposition, it strongly accelerated litter mass loss of all genotypes when combined with warming. Rates of microbial respiration associated with the leaf litter showed nearly identical responses as litter mass loss. These results highlight the importance of interactive effects of environmental factors and suggest that loss or gain of genetic variation associated with key phenotypic traits can buffer, or exacerbate, the impact of global change on ecosystem process rates in the future. This article is protected by copyright. All rights reserved.

Hocking, P. J. (1989). "Seasonal dynamics of production, and nutrient accumulation and cycling by <I>Phragmites asutralis</I> (Cav.) Trin. <I>ex</I> Stuedel in a nutrient-enriched swamp in Inland Australia. I. Whole Plants." Marine and Freshwater Research **40**(5): 421-444.

<P>A study was made of the seasonal changes in dry matter production and patterns of nutrient accumulation by <I>Phragmites australis</I> in a nutrient-enriched swamp in inland Australia. The density of live shoots was highest (224 m⁻²) in October, but the peak standing crop of live shoots (9890 g m⁻²) occurred in early May. Peak below-ground biomass (21 058 g m⁻²) occurred in early August. Rhizome biomass constituted 75% of the below-ground biomass, and showed a distinct seasonal pattern. Net annual above-ground primary production (NAAP), estimated by the maximum-minimum method, was 9513 g m⁻². Correction for shoot mortality and leaf shedding before, and production after, the maximum standing crop was attained increased NAAP to 12 898 g m⁻². Whole plant production estimated by the maximum-minimum method was 9960 g m⁻², and the corrected estimate was 14 945 g m⁻². A model of dry-matter production indicated that translocation of carbohydrate from rhizomes could

have provided 33% of the dry matter of shoots. About 23% of the dry matter of shoots was redistributed to below-ground organs during senescence. </P><P>Concentrations of N, P, K, S, Cl and Cu declined, but concentrations of Ca, Mg, Na, Fe and Mn increased as shoots aged. Concentrations of N, P and Zn in rhizomes reached maxima in winter, and decreased in spring. Rhizomes usually contained the greatest quantity of a nutrient in the whole plant, and roots usually had less than 25% of the total plant content. There were seasonal fluctuations in the quantities of N, P, K, Zn and Cu in rhizomes. Nutrient accumulation by live shoots was underestimated by 22-55% using the maximum-minimum method. Nutrient budgets showed considerable internal cycling of N, P, K, S and Cu from rhizomes to developing shoots in spring, and from senescing shoots to rhizomes during autumn and winter.</P>

Hudon, C., et al. (2005). "Hydrological factors controlling the spread of the common reed (*Phragmites australis*) in the St. Lawrence River (Quebec, Canada)." Ecoscience **12**: 347-357.

The spread of Phragmites australis between 1980 and 2002 was documented from seven series of aerial photographs and remote sensing images covering the Grandes Battures Tailhandier (Boucherville Islands, St. Lawrence River, Québec, Canada). Over the 23-y period, the colonized surface rose exponentially from 0.86 to 32.6 ha, corresponding to an 18% annual increase. This increase resulted mostly from vegetative growth, although the establishment of new colonies ? most likely resulting from seed germination ? allowed longer-range dispersion. Hydrological factors, especially the water level and duration of flooding over the growth season (July 1 to October 31) of the previous year, favoured the spread of colonies. Gains were highest the year following low water-level conditions and in a southerly direction, whereas they were reduced when plants grew at more than 1.5 m above mean water level or when they were flooded for more than 100 d during the previous growing season. The rate of surface colonization observed at Boucherville Islands was compared to that recorded at four other fluvial sites. Between Cornwall and Trois-Rivières, the noticeable increase in the number of colonized sites since 1980 suggests that low water levels in 1995, 1999, and 2001 favoured the establishment of colonies of P. australis along the shores of the St. Lawrence River.

Huguenot, D., et al. (2014). "Remediation of sediment and water contaminated by copper in small-scaled constructed wetlands: effect of bioaugmentation and phytoextraction." Environmental Science and Pollution Research: 1-12.

The use of plants and microorganisms to mitigate sediment contaminated by copper was studied in microcosms that mimic the functioning of a stormwater basin (SWB) connected to vineyard watershed. The impact of phytoremediation and bioaugmentation with siderophore-producing bacteria on the fate of Cu was studied in two contrasted (batch vs. semi-continuous) hydraulic regimes. The fate of copper was characterised following its discharge at the outlet of the microcosms, its pore water concentration in the sediment, the assessment of its bioaccessible fraction in the rhizosphere and the measurement of its content in plant tissues. Physico-chemical (pH, redox potential) and biological parameters (total heterotrophic bacteria) were also monitored. As expected, the results showed a clear impact of the hydraulic regime on the redox potential and thus on the pore water concentration of Cu. Copper in pore water was also dependent on the frequency of Cu-polluted water discharges. Repeated bioaugmentation increased the total heterotrophic microflora as well as the Cu bioaccessibility in the rhizosphere and increased the amount of Cu extracted by Phragmites australis by a factor of ~2. Sugar beet pulp, used as a filter to avoid copper flushing, retained 20 % of outcoming Cu and led to an overall retention of Cu higher than 94 % when arranged at the outlet of microcosms. Bioaugmentation clearly improved the phytoextraction rate of Cu in a small-scaled SWB designed to mimic the functioning of a full-size SWB connected to vineyard watershed

Jayawardana, J. M. C. K., et al. (2006). "Macroinvertebrate communities in willow (Salix spp.) and reed beds (Phragmites australis) in central Victorian streams in Australia." Marine and Freshwater Research **57**(4): 429-439.

Exotic willows (Salix spp.) are widespread riparian tree species of rivers in temperate Australia and New Zealand. Despite being considered as a weed of national significance, little is known about the habitat value of willows and the impact on aquatic biota of vegetation change following willow management programmes. Macroinvertebrate fauna in root habitats of willows and Phragmites australis habitats were examined in three central Victorian rivers to understand the effect of such littoral habitat changes on macroinvertebrates. Data were analysed using Partially Nested Factorial ANOVA with season, river and habitat as main effects. Habitat structure had a significant effect ($P < 0.05$) on macroinvertebrate community assemblage. However, effect of habitat was not consistent among seasons. The greatest community differences among habitats were observed during winter and least separation during autumn. Taxa responsible for community differences among habitats were also identified. Species richness and abundance did not show consistent variation among habitats over different rivers or seasons. This study provided some indication of the macroinvertebrate community changes that would take place in situations where riparian vegetation changes takes place from willows to P. australis.

Jessop, J., et al. (2006). Grasses of South Australia: an illustrated guide to the native and naturalised species. Adelaide, Australia, Wakefield Press.

Keller, B. M. (2000). "Plant diversity in Lythrum, Phragmites, and Typhamarshes, Massachusetts, U.S.A." Wetlands Ecology and Management **8**(6): 391-401.

Concern about colonization of marshesby plant species such as Phragmites australisand Lythrum salicariahas highlighted the needfor management strategies. However, there is a lack ofinformation in the literature on which to base thesedecisions. This study compares the alpha diversity ofmarshes to assess the impact of invasion by Phragmitesand Lythrum. Species occurrence andstem density were measured in marshes dominated by Phragmites, Lythrum, Typhaspp., or otherherbaceous perennials in the Charles River watershedin eastern Massachusetts, USA, and species richness,Shannon's H′, Simpson's reciprocal (1/D), and Pielou'sJ were compared among six community types. The threediversity indices had significantly higher values forTypha-Lythrummarshes than for any of the othermarsh types (Tukey test, $p< 0.05$), with mean values(± s.d.) of H′ = 2.00 ± 0.74, 1/D = 3.51± 1.68 and J = 0.69 ± 0.1. Marshes dominatedby Phragmiteshad the lowest diversity, with H′= 0 and D = 1, i.e. they were monospecific. Typhadominated marshes had the second lowest values,with H′ = 0.17 ± 0.05, 1/D = 1.05 ± 0.01, andJ = 0.11 ± 0.03. These results support the ideathat a reduction in diversity can be expected inmarshes colonized by Phragmites. However, thehigh diversity found in the Typha-Lythrummarshes contradicts the expectation of lower diversityafter invasion by Lythrum. This information mayalter marsh management decisions

Kimball, M. E., et al. (2010). "Evaluation of Long-Term Response of Intertidal Creek Nekton to Phragmites australis (Common Reed) Removal in Oligohaline Delaware Bay Salt Marshes." Restoration Ecology **18**(5): 772-779.

In the oligohaline Alloway Creek watershed of the upper Delaware Bay, invasive Phragmites australis (Common reed; hereafter Phragmites) has been removed in an attempt to restore tidal marshes to pre-invasion form and function. In order to determine the effects of Phragmites on nekton use of intertidal creeks and to evaluate the success of this restoration, intertidal creek nekton assemblages were sampled with weirs from May to November for 7 years (1999-2005) in three marsh types: natural Spartina alterniflora (Smooth cordgrass; hereafter Spartina), sites treated for Phragmites removal (hereafter referred to as Treated), and invasive Phragmites marshes. Replicate intertidal creek collections in all three marsh types consisted primarily of resident nekton and were dominated by a relatively low number of ubiquitous intertidal species. The Treated marsh nekton assemblage was distinguished by greater abundances of most nekton, especially Fundulus heteroclitus (Mummichog). Phragmites had little impact on nekton use of intertidal creeks over this period as evidenced by similar nekton assemblages in the Spartina and Phragmites marshes for most years. Long-term assemblage-level analyses and nekton abundances indicated that the Treated marsh provided enhanced conditions for intertidal creek nekton. The response of intertidal creek nekton suggests that the stage of the restoration may influence the results of comparisons between the marsh types and should be considered when evaluating marsh restorations.

Kiviat, E. (2013). "Ecosystem services of Phragmites in North America with emphasis on habitat functions." AoB Plants **5**.

Phragmites australis (common reed) is widespread in North America, with native and non-native haplotypes. Many ecologists and wetland managers have considered P. australis a weed with little value to the native biota or human society. I document important ecosystem services of Phragmites including support for many common and rare species of plants and animals. This paper is based on an extensive review of the ecology and natural history literature, discussions with field workers, and observations in 13 US states and one Canadian province during the past 40 years. Phragmites sequesters nutrients, heavy metals and carbon, builds and stabilizes soils, and creates self-maintaining vegetation in urban and industrial areas where many plants do not thrive. These non-habitat ecosystem services are proportional to biomass and productivity. Phragmites was widely used by Native Americans for many purposes; the most important current direct use is for the treatment of wastes. Most of the knowledge of non-habitat ecosystem services is based on studies of P. australis haplotype M (an Old World haplotype). Phragmites also has habitat functions for many organisms. These functions depend on the characteristics of the landscape, habitat, Phragmites stand, species using Phragmites and life history element. The functions that Phragmites provides for many species are optimal at lower levels of Phragmites biomass and extent of stands. Old World Phragmites, contrary to many published statements, as well as North American native Phragmites, provide valuable ecosystem services including products for human use and habitat functions for other organisms. Phragmites stands may need management (e.g. thinning, fragmentation, containment or removal) to create or maintain suitable habitat for desired species of animals and plants.

Klotzi, F. and S. Zust (1973). "Conservation of reed-beds in Switzerland." Hydrobiology **20**: 229-235.

Kobbing, J., et al. (2013). "The utilisation of reed (Phragmites australis): a review." International Mire Conservation Group and International Peat Society **13**: 1-14.

Reed (Phragmites) is a wetland plant genus that has been utilised by man since ancient times. It is a tall, thin,highly productive grass (Poaceae) with an above-ground biomass of up to 30 t ha-1y-1. Due to its world-widedominance, it is often cheap and readily available as a raw material. Reed has been used for centuries as a fodder plant in summer, and the stems have traditionally been harvested in winter as a raw material for crafts and for construction materials including roofing. It became popular for pulp and paper production in the middle of the twentieth century and, in recent years, has been used in sewage water treatment and as a source of renewable energy that is unlikely to compete with food production. This article explores the global extent of reedbeds and potential yields; and catalogues historical uses of reed, forgotten applications and new opportunities for its utilisation. Quality requirements,products and related stand management (such as harvesting time) are also reviewed.

Köbbing, J. F., et al. "Economic evaluation of common reed potential for energy production: A case study in Wuliangsuhai Lake (Inner Mongolia, China)." Biomass and Bioenergy(0).

Wuliangsuhai Lake is one of the largest wetlands in Inner Mongolia, China, half covered by large and highly productive Common Reed (Phragmites australis) stands. However, benefits from current utilization practices do not cover the costs of harvesting. Against this background, Wuliangsuhai Lake is taken as a case study for the assessment of the potential use of reed biomass for energy production. Taking into account, both the present and the potential reed availability, four scenarios are considered, i.e. (1) a decentralized application in household stoves, (2) a centralized reed supplied combined heat and power gasification, (3) a direct combustion plant and (4) a co-firing in existing coal plants. Two field campaigns have been conducted firstly collect information about the current situation of the reed and coal market and secondly to measure reed above-ground biomass. The suitability of reed for thermochemical conversion processes has been evaluated by means of chemical-physical, calorimetric, and thermal analyses of the samples. The potential energy production is valued regarding the profitability on the current Chinese energy market. Possible subsidies for reed as a renewable resource are taken into account. The evaluation has shown that reed has the potential to act as an energy feedstock. In relation to the considered study site, reed energy use can be profitable on the household level, in CHP combustion plants and in co-combustion. Gasification CHP plants are not economic feasible under current conditions. The results show that reed can be a sustainable alternative to highly health and environment damaging coal.

Kotze, D. C. (2013). "The effects of fire on wetland structure and functioning." African Journal of Aquatic Science **38**(3): 237-247.

Fire is an extensively used wetland management tool in both tropical and temperate areas, but its effects on wetlands are not well understood. The purpose of this paper is to review the effects of fire on wetland hydrology, biogeochemical cycling and vegetation composition, including primary effects that take place during the fire such as combustion of plant material, loss of volatile substances to the atmosphere and deposition of ash on the soil surface, and secondary effects such as alteration of soil pH as a result of ash deposition, exposure of the soil surface to solar radiation, and increased availability of nutrients. Several of the secondary effects are most dramatic immediately after a fire, but become progressively modulated by newly stimulated vegetation growth. The findings suggest that the effects of fire depend upon a wetland's characteristics, including its climatic and hydrological context, as well as upon interactions with other disturbances such as grazing. Thus, similar fire regimes may have dramatically different outcomes. Where knowledge gaps were identified, some general predictions are offered, drawing from comparable ecosystems such as mesic grasslands. These predictions provide potential hypotheses for further research.

Kuhl, H. and R. Zemlin (2000). "Increasing the efficiency of reed plantations on stressed lake and river shores by using special clones of Phragmites australis." Wetlands Ecology and Management **8**: 415-426.

In an investigation aimed at comparing the variationin growth and expansion of different reed clones, 10reed clones were planted in spring of 1995 on sixexperimental fields on the River Dahme and the RiverHavel in Berlin. Their sites of origin differed innutrient supply, substrate quality and shoreexposition. The main aim of this large-scaleexperiment was to search for reed clones that would beable to colonize lake shores rapidly and to expandinto deeper water. Two years after planting thedeveloping reed stands differed significantly inmorphology and stand structure, both among clones andamong sites. This indicates that the development ofreed stands depended on the environment as well as onthe genotype. The differences in development impliedthat some of the clones would be more suited thanothers for restoration purposes, so that successfulrestoration of a degraded river or lake shores mightdepend on the selection of the best suited clones.The nitrogen contents in the aboveground biomass oftwo clones differing in nitrogen dynamics at theiroriginal sites (described as `assimilation' and`translocation' types in the literature) did notdiffer in this experiment, even though the two clonesdid differ in some morphological traits. These resultsmight be influenced by the fact that stands were stilldeveloping and that possibly clones had reached adifferent degree of maturity. Nevertheless, theysuggest that nitrogen content depends more on siteconditions, with only little genetically determineddifference, and that morphological variation isdetermined by factors other than variation in nitrogenuptake.

Lambertini, C., et al. (2012). "Tracing the origin of Gulf Coast Phragmites (Poaceae): a story of long-distance dispersal and hybridization." American Journal of Botany **99**: 538-551.

Long-distance dispersal can affect speciation processes in two opposing ways. Dispersal can promote geographic isolation or it can bring together geographically distant and distantly related genotypes, thus counteracting local differentiation. We used the Gulf Coast of North America (GC), a “hot spot” of reed diversity and evolutionary dynamics, as a model system to study the diversification processes within the invasive, cosmopolitan, polyploid grass Phragmites

League, M., et al. (2007). "Predicting the Effectiveness of Phragmites Control Measures using a Rhizome Growth Potential Bioassay." Wetlands Ecology and Management **15**(1): 27-41.

In the last century, Phragmites australis (common reed) has expanded from a minor component of the mid-Atlantic tidal wetlands to a dominant species in many locations. Expansion of Phragmites results in decreased plant diversity and alterations to the tidal characteristics of the marsh, resulting in decreased wetland value. Management efforts have used a variety of strategies in an attempt to control its expansion. We tested a greenhouse bioassay that provided insight into the rhizome vitality of six herbicide-treated sites in the Alloway Creek Watershed, NJ well in advance of the growing season. At three sites, rhizomes were exhumed and classified by depth (0–25 cm and 25–75 cm) and appearance (color and firmness). Concurrently, the same protocol was followed, but conducted on an areal basis at three additional sites. Material was grown in sand under greenhouse conditions void of nutrient supplements for 70 days, after which shoots were removed and the rhizomes replanted for 30 days. Effectiveness of control strategies was quantified by examining rhizome color, vitality, and shoot densities in the field. Color was indicative of quality of rhizome reserves. Less than 0.2% of the firm, brown rhizomes produced shoots upon initial planting and none produced shoots upon replanting, whereas 50.9% of white rhizomes produced shoots on initial planting. Rhizome vitality was quantified by examining shoot emergence and the morphology of the shoots. Coupling rhizome vitality with observed field densities resulted in a predictive capability, and shoot density and biomass predictions were compared to field measurements in July 2001. We tested and accurately predicted the relative shoot densities and shoot biomass of the three sites for which we collected rhizome material on an areal basis. The result is a rapid, valuable, and cost-effective monitoring tool that can quickly quantify the effects of past control methods and predict future growth potential.

Li, X., et al. (2014). "The impact of the change in vegetation structure on the ecological functions of salt marshes: the example of the Yangtze estuary." Regional Environmental Change **14**(2): 623-632.

Salt marshes worldwide are faced with threats from rising sea levels and coastal development. We measured changes in salt marsh vegetation structure using remote sensing and its consequences for carbon sequestration, wave attenuation, and sediment trapping ability using remotely sensed imaging, field measurement data, and the published literature data pertaining to the Yangtze Estuary, a rapidly urbanizing area in Eastern China. From 1980 to 2010, the total area of vegetated salt marsh decreased by 17 %, but the vegetation structure changed more dramatically, with the ratio of Phragmites/Spartina/Scirpus changing from 24:0:76, to 77:0:23, 44:13:43, and 33:39:28 in 1980, 1990, 2000, and 2010, respectively. Carbon sequestration increased slightly from 1980 to 2010, with the dramatic shifts in plant species composition. The total length of seawall inadequately protected by salt marsh vegetation increased from 44 km in 1980 to 300 km in 2010. Sediment accretion increased (from 8 to 14 million m3/year) due to the spread of Spartina, which to some extent compensated the loss of total vegetated area in the salt marsh. Changes in the delivery of functions were not linearly related to the change in the area of vegetated salt marsh, but more from the combined effect of changing vegetation structure, sediment input, and land reclamation. Under threat of sea-level rise, protection and maintenance of vegetation structure outside the seawall are of great importance for the safe economic development inside the seawall.

Lissner, J. and H.-H. Schierup (1997). "Effects of salinity on the growth of Phragmites australis." Aquatic Botany **55**(4): 247-260.

The field salinity tolerance of Phragmites australis was evaluated by investigating 27 natural reed habitats along the eastern and western coasts of Jutland, Denmark. Die-back took place in the lower fringe of stands, before the onset of flowering, at sites where soil water salinities were higher than 15‰ within the rooting depth. In greenhouse experiments, juvenile plants produced from seeds and rhizome-grown plants, grown over a range of salinity levels, displayed different levels of salt tolerance. Both types of plants showed low mortality at salinity levels of 15‰ and lower. A total of 75% of the rhizome-grown plants survived 22.5‰ salinity in the rooting medium, whereas only 12% of the juvenile plants survived this salinity level. All plants grown at salinity levels of 35‰ and 50‰ died. Relative growth rates of juvenile plants were negatively correlated with salinity levels. Relative growth rates of rhizome-grown plants on a wet weight basis showed an optimum at 5‰ salinity. However, rates based on leaf number and shoot height were unaffected by salinities from 0–5‰, but decreased at higher salinities. Phragmites australis adapted to saline conditions by adjusting the level of osmotically active solutes in its leaves. In the salinity range allowing survival (0–22.5‰) osmolality in leaves of rhizome-grown plants was approximately 200 mmol kg^{-1} higher than medium osmolality. In leaves of juvenile plants, osmotic pressure and chlorinity increased exponentially at salinity levels above 10‰ in the rooting medium, indicating a lower capability of osmoregulation. However, water stress could also be responsible for the lower resistance to salinity of these juvenile plants, as was suggested by a wilted appearance of leaves exposed to high salinities. Leaf longevity was not affected by different salinity treatments. Phragmites australis did not use leaf abscission to excrete toxic salts during the growth season.

Ma, B., et al. (2013). "Shifts in diversity and community structure of endophytic bacteria and archaea across root, stem and leaf tissues in the common reed, Phragmites australis, along a salinity gradient in a marine tidal wetland of northern China." Antonie van Leeuwenhoek **104**(5): 759-768.

The effects of salt stress on endophytic prokaryotic communities in plants are largely unknown, and the distribution patterns of bacterial and archaeal endophytes in different tissues of a plant species are rarely compared. We investigated the endophytic bacterial and archaeal communities in roots, stems and leaves of the common reed, Phragmites australis, collected from three tidal zones along a salinity gradient, using terminal restriction fragment (T-RF) length polymorphism analysis of the 16S rRNA genes. The results showed that the bacterial diversity in the roots was significantly higher than that in the leaves, whereas similar archaeal diversity was revealed for either plant tissues or tidal zones. Network analysis revealed that T-RFs were grouped largely by tissue, and the major groups were generally linked by a few common T-RFs. Unique T-RFs in roots were mainly present in plants growing in the supratidal zone, but unique T-RFs in stems and leaves were mainly present in those from the middle and high tidal zones. Non-metric multidimensional scaling ordination and analysis of similarity revealed that bacterial communities were significantly different among tissues ($P < 0.05$), but similar among tidal zones ($P = 0.49$). However, the archaeal communities differed among tidal zones ($P < 0.05$), but were similar among tissues ($P = 0.89$). This study indicates that: (1) the endophytic archaeal communities are influenced more significantly than the endophytic bacterial communities by soil salinity, and (2) the differential distribution patterns of bacterial and archaeal endophytes in plant tissues along a salinity gradient imply that these two groups play different roles in coastal hydrophytes.

Marchand, L., et al. (2014). "Trace element transfer from soil to leaves of macrophytes along the Jalle d'Eysines River, France and their potential use as contamination biomonitors." Ecological Indicators **46**(0): 425-437.

Biomonitoring complements the physico-chemical analysis of environmental matrices, accounting for the subtle biological changes in organisms affected by exogenous chemicals. Here, the relationships between the concentrations of trace elements (TE) in the soil, soil-pore water and leaves of seven rooted macrophytes (Ranunculus acris L., Phragmites australis (Cav.) Trin. Ex Steud., Carex riparia Ehrh., Lythrum salicaria L., Iris pseudacorus L., Juncus effusus L., and Phalaris arundinacea L.) were investigated along an urban river – the Jalle d'Eysines River, France – with increasing TE contamination in riverbank soils, from its source to its confluence with the Garonne River. Copper, Zn, Cd, Cr, Pb, Ni, Mo and As were considered. Macrophytes were sampled in June 2011, at the peak of the growing season. For five species, a canonical correspondence analysis (CCA) was used to assess correlations between foliar TE concentrations and total TE concentrations in the soil. Along the Jalle d'Eysines River, P. australis and P. arundinacea are relevant biomonitors for soil Mo contamination. P. australis and C. riparia biomonitor soil Cd contamination, while R. acris is a relevant biomonitor of soil Ni contamination. Copper and Mo concentrations in the soil-pore water are monitored by, respectively P. arundinacea and P. australis.

Marks, M., et al. (1994). "*Phragmites australis*: threats, management and monitoring." Natural Areas Journal **14**(4): 285-294.

The threat posed by Phragmites australis as it spreads to the detriment of other species typical of the community are described in detail including the global range of P. australis, its natural habitat and its biology/ecology. The recovery potential of areas invaded by P. australis and the management programmes associated with this are reviewed. Monitoring requirements and procedures are detailed in relation to effective management programmes which include biological control, burning, the use of plastic mulch, disking, chemical control, cutting, grazing, dredging and draining or the manipulation of the water table and salinity.

Martin, L. and B. Blossey (2013). "The Runaway Weed: Costs and Failures of Phragmites australis Management in the USA." Estuaries and Coasts **36**(3): 626-632.

While public funding of invasive species management has increased substantially in the past decade, there have been few cross-institutional assessments of management programs. We assessed management of Phragmites australis, a problematic invader of coastal habitats, through a cross-institutional economic survey of 285 land managers from US public and private conservation organizations. We found that from 2005 to 2009, these organizations spent >$4.6 million per year on P. australis management, and that 94 % used herbicide to treat a total area of ~80,000 ha. Despite these high expenditures, few organizations accomplished their management objectives. There was no relationship between resources invested in management and management success, and those organizations that endorsed a particular objective were no more likely to achieve it. Our results question the efficacy of current P. australis management strategies and call for future monitoring of biological management outcomes.

Martina, J. P., et al. (2014). "Organic matter stocks increase with degree of invasion in temperate inland wetlands." Plant and Soil: 1-17.

Both soil and ecosystem C stocks increased due to the presence of invasive species, as did aboveground biomass C and N stocks. Additionally, there were significant differences in C and N mineralization in soil collected from monocultures of each invasive species (Phalaris > Typha > Phragmites) linked to the quality of their litter (C/N ratios).

Mazerolle, M., et al. (2014). "Common reed (Phragmites australis) invasion and amphibian distribution in freshwater wetlands." Wetlands Ecology and Management **22**(3): 325-340.

Invasive plants can substantially modify wetland structure and animal distribution patterns. In eastern North America, a Eurasian haplotype of the common reed (Phragmites australis, haplotype M) is invading wetlands. We studied the invasion of common reed in freshwater wetlands of an urbanized landscape and its effects on the distribution of amphibians at different life stages. Specifically, we hypothesized that the probability of reed invasion would be greatest in wetlands near anthropic disturbances. We predicted that the probability of desiccation at sampling stations increases with reed cover. Furthermore, we expected that wetlands invaded by common reed would have lower amphibian abundances, apparent survival, and rates of recruitment. We conducted trapping surveys to compare anuran assemblages of tadpoles, juveniles, and adults in 50 wetlands during two field seasons. The probability of reed invasion in wetlands increased with the cover of heavily-managed areas within 1,000 m and the distance to the nearest forest, but decreased with the length of roads within 1,000 m. The probability of station desiccation increased with reed cover. We found no evidence of a negative effect of reed presence on anuran population parameters, at any life stage. Landscape variables, such as the percent cover of forest or heavily-managed areas within a given radius from each wetland, influenced the abundance or the apparent survival of juvenile frogs and the abundance of ranid tadpoles. Our results show that amphibian patterns depend more strongly on the structure of the landscape surrounding wetlands than on exotic reed invasion in wetlands.

McCormick, M., et al. (2010). "Extent and Reproductive Mechanisms of Phragmites australis Spread in Brackish Wetlands in Chesapeake Bay, Maryland (USA)." Wetlands **30**(1): 67-74.

The number of patches of non-native Phragmites australis in brackish tidal wetlands in the Rhode River subestuary increased from 5 in 1971–72 to 212 in 2007, and the area covered by the patches increased more than 25 times during the same time interval. Genetic analysis of the patches showed that the expansion has primarily been from seed, and genetic similarities between patches indicate that most cross-pollination occurs within a distance of 50 m. Comparison of patches in different parts of the subestuary indicate that the expansion of Phragmites australis has occurred at the scale of the entire subestuary and not the scale of subsections of the subestuary dominated by differing upland land-uses

Moore, D. (1973). Changes in the aquatic vascular plant flora of East Harbor State park, Ottawa, Ohio since 1895. Colombus, Ohio, Ohio State University. **Master Science Thesis**.

Morris, K., et al. (2008). "Floristic shifts in wetlands: the effects of environmental variables on the interaction between Phragmites australis (Common Reed) and Melaleuca ericifolia (Swamp Paperbark)." Marine and Freshwater Research **59**(3): 187-204.

Over the past 40–50 years, the woody shrub Melaleuca ericifolia has progressively invaded large areas of Phragmites australis in Dowd Morass, a Ramsar-listed, brackish wetland in south-eastern Australia. To understand the processes underlying this shift we grew Phragmites and Melaleuca alone and together under contrasting sediment organic-matter loadings and salinities. To examine if the capacity of Phragmites to aerate the sediment influenced plant interactions, we also dissipated convective gas flow in some Phragmites plants by perforating their stems. Although Phragmites suppressed the growth of Melaleuca under all conditions, Melaleuca persisted. We did not find Phragmites ramets to be more sensitive to salinity than Melaleuca seedlings. Surprisingly Phragmites did not increase sediment redox and was more sensitive to increased organic-matter loading than Melaleuca. These results do not support the notion that colonisation by Melaleuca was facilitated by a decline in Phragmites at higher salinities or through aeration of the sediments by Phragmites. Seedlings of Melaleuca, however, were easily blown over by wind and it is likely that Phragmites stands shelter Melaleuca during establishment. Although our short-term experiment did not show that Melaleuca was a better competitor, differences in seasonal growth patterns may contribute to a shift in competitive abilities over a longer time scale.

Mozdzer, T. and J. Megonigal (2012). "Jack-and-Master trait responses to elevated CO2 and N: a comparison of native and introduced *Phragmites australis* " PLOS One(7).

Global change is predicted to promote plant invasions world-wide, reducing biodiversity and ecosystem function. Phenotypic plasticity may influence the ability of introduced plant species to invade and dominate extant communities. However, interpreting differences in plasticity can be confounded by phylogenetic differences in morphology and physiology. Here we present a novel case investigating the role of fitness trait values and phenotypic plasticity to global change factors between conspecific lineages of Phragmites australis. We hypothesized that due to observed differences in the competitive success of North American-native and Eurasian-introduced P. australis genotypes, Eurasian-introduced P. australis would exhibit greater fitness in response to global change factors. Plasticity and plant performance to ambient and predicted levels of carbon dioxide and nitrogen pollution were investigated to understand how invasion pressure may change in North America under a realistic global change scenario. We found that the introduced Eurasian genotype expressed greater mean trait values in nearly every ecophysiological trait measured – aboveground and belowground – to elevated CO2 and nitrogen, outperforming the native North American conspecific by a factor of two to three under every global change scenario. This response is consistent with “jack and master” phenotypic plasticity. We suggest that differences in plant nitrogen productivity, specific leaf area, belowground biomass allocation, and inherently higher relative growth rate are the plant traits that may enhance invasion of Eurasian Phragmites in North America. Given the high degree of genotypic variability within this species, and our limited number of genotypes, our results must be interpreted cautiously. Our study is the first to demonstrate the potential importance of jack-and-master phenotypic plasticity in plant invasions when facing imminent global change conditions. We suggest that jack-and-master invasive genotypes and/or species similar to introduced P. australis will have an increased ecological fitness, facilitating their invasion in both stressful and resource rich environments.

Mozdzer, T. and J. P. Megonigal (2013). "Increased Methane Emissions by an Introduced Phragmites australis Lineage under Global Change." Wetlands **33**(4): 609-615.

North American wetlands have been invaded by an introduced lineage of the common reed, Phragmites australis. Native lineages occur in North America, but many populations have been extirpated by the introduced conspecific lineage. Little is known about how subtle changes in plant lineage may affect methane (CH4) emissions. Native and introduced Phragmites were grown under current and predicted future levels of atmospheric CO2 and nitrogen(N) pollution in order to understand how CH4 emissions may vary between conspecific lineages. We found introduced Phragmites emitted more CH4 than native Phragmites, and that CH4 emissions increased significantly in both with CO2+N treatment. There was no significant difference in CH4

production potentials, but CH4 oxidation potentials were higher in soils from the introduced lineage. Intraspecific plant responses to resource availability changed CH4 emissions, with plant density, root mass, and leaf area being significantly positively correlated with higher emissions. The absence of CO2-only or N-only effects highlights a limitation on the generalization that CH4 emissions are proportional to plant productivity. Our data suggest that intraspecific changes in plant community composition have important implications for greenhouse emissions. Furthermore, global change-enhanced invasion by introduced Phragmites may increase CH4 emissions unless these factors cause a compensatory increase in carbon sequestration

Mozdzer, T. J., et al. (2013). "Physiological ecology and functional traits of North American native and Eurasian introduced Phragmites australis lineages." AoB Plants **5**.

Physiological ecology and plant functional traits are often used to explain plant invasion. To gain a better understanding of how traits influence invasion, studies usually compare the invasive plant to a native congener, but there are few conspecific examples in the literature. In North America, the presence of native and introduced genetic lineages of the common reed, Phragmites australis, presents a unique example to evaluate how traits influence plant invasion. We reviewed the literature on functional traits of P. australis lineages in North America, specifically contrasting lineages present on the Atlantic Coast. We focused on differences in physiology between the lineage introduced from Eurasia and the lineage native to North America, specifically seeking to identify the causes underlying the recent expansion of the introduced lineage. Our goals were to better understand which traits may confer invasiveness, provide predictions of how these lineages may respond to interspecific competition or imminent global change, and provide guidance for future research. We reviewed published studies and articles in press, and conducted personal communications with appropriate researchers and managers to develop a comparative dataset. We compared the native and introduced lineages and focused on plant physiological ecology and functional traits. Under both stressful and favourable conditions, our review showed that introduced P. australis consistently exhibited greater ramet density, height and biomass, higher and more plastic relative growth rate, nitrogen productivity and specific leaf area, higher mass specific nitrogen uptake rates, as well as greater phenotypic plasticity compared with the native lineage. We suggest that ecophysiological and other plant functional traits elucidate potential mechanisms for the introduced lineage's invasiveness under current and predicted global change conditions. However, our review identified a disconnect between field surveys, experiments, natural competition and plant ecophysiology that must be addressed in future field studies. Given the likelihood of hybridization between lineages, a better understanding of plant traits in native, non-native and hybrid lineages is needed to manage current invasions and to predict the outcome of interactions among novel genotypes. Comparative physiology and other plant functional traits may provide additional tools to predict the trajectory of current and potential future invasions.

Mozdzer, T. J. and J. C. Zieman (2010). "Ecophysiological differences between genetic lineages facilitate the invasion of non-native Phragmites australis in North American Atlantic coast wetlands." Journal of Ecology **98**(2): 451-458.

1. Over the last century, native Phragmites australis lineages have been almost completely replaced along the North American Atlantic coast by an aggressive lineage originating from Eurasia. Understanding the mechanisms that facilitate biological invasions is critical to better understand what makes an invasive species successful. 2. Our objective was to determine what makes the introduced lineage so successful in the study area by specifically investigating if morphological and ecophysiological differences exist between native and introduced genetic lineages of P. australis. We hypothesized a priori that due to phenotypic differences and differences in plant nitrogen (N) content between lineages, the introduced lineage would have a greater photosynthetic potential. 3. In situ ecophysiological and morphological data were collected for 2 years in a mid-Atlantic tidal marsh and in a glasshouse experiment. We measured photosynthetic parameters (Amax, water use efficiency, stomatal conductance) using infrared gas analysis, in conjunction with ecophysiological and morphological parameters [specific leaf area (SLA), leaf area, chlorophyll content, N content]. 4. Introduced P. australis maintained 51% greater rates of photosynthesis and up to 100% greater rates of stomatal conductance which are magnified by its 38–83% greater photosynthetic canopy compared to the native type. The introduced lineage also had a significantly greater SLA and N content. Glasshouse-grown plants and naturally occurring populations demonstrated similar trends in ecophysiological characteristics, verifying the heritability of these differences. These ecophysiological differences, when combined with an extended growing season, provide the mechanism to explain the success of introduced P. australis in North America. 5. Our findings suggest the native type is a low-nutrient specialist, with a more efficient photosynthetic mechanisms and lower N demand, whereas the introduced type requires nearly four times more N than the native type to be an effective competitor. 6. Synthesis. Our study is the first to combine field and laboratory data to explain a biological invasion attributed to ecophysiological differences between genetic lineages. Our data corroborates earlier work suggesting anthropogenic modification of wetland environments has provided the state change necessary for the success of

introduced P. australis. Finally, our results suggest that genotypic differences within species merit further investigations, especially when related to biological invasions.

Nicol, J., et al. (2013). Resilience and resistance of aquatic plant communities downstream of Lock 1 in the Murray River. Adelaide, Australia, Goyder Institute for Water Research. **13/5**.

Nicol, J. and R. Ward (2010). Seed bank assessment of Goolwa Channel, Lower Finniss River and Lower Currency Creek, South Australia. Adelaide, South Australia, South Australian Research and Development Institute (Aquatic Sciences).

Nikolić, L., et al. (2014). "Nutrient removal by Phragmites australis (Cav.) Trin. ex Steud. In the constructed wetland system." Contemporary Problems of Ecology **7**(4): 449-454.

Significant results are achieved with the use of semiaquatic vegetation for purification of municipal wastewater as well as other types of waste waters. The first constructed system for purification of municipal wastewater was made at the end of 1970s years in the United Kingdom, with semiaquatic plants playing the role of phytoremediation plants. In Serbia, municipal waste water purification based on constructed wetland system method was applied for the first time in the village of Glo an near Novi Sad and it was put in operation in 2004. The recipient of purified municipal wastewater has been the Danube River. Biological factors in this anthropogenic ecosystem are emergent plants, with dominance of the common reed. This emergent plant with its roles in phytofiltration and phytoaccumulation positively influences the quality of waters finally discharged into the Danube. The paper presents the results of nutrients (N, P, K), organic matter and total ash contents in dry matter of dominant plant species Phragmites australis (Cav.) Trin. ex Steud. in Glo an constructed wetland system in the period from 2004 to 2007.

Palta, M., et al. (2014). "“Hotspots” and “Hot Moments” of Denitrification in Urban Brownfield Wetlands." Ecosystems: 1-17.

Resleigh, J. and P. Foster (2012). Reporting the results of the Lower Lakes grazing trials 2005-2011. Adelaide, South Australia, Rural Solutions, South Australia

Roberts, J. (2000). "Changes inPhragmites australis in south-eastern Australia: A habitat assessment." Folia Geobotanica **35**(4): 353-362.

The status of common reed (Phragmites australis) in south-eastern Australia was assessed by considering its physical habitat.Phragmites habitats were categorized into three types — wetland, riverine and estuarine and all three showed negative change (loss, degradation) since European settlement. However, there were also instances of positive (new, re-establishment) changes. Integrating these negative and positive changes at the catchment scale for the Murrumbidgee River, suggests a re-distribution ofPhragmites is occurring, and this may be true for other rivers managed for irrigation. Agriculture appears to be the principal cause ofPhragmites australis losses in eastern Australia. There is no evidence to date of reed decline in Australia like that in parts of Europe, nor of expansion as in the coastal wetlands of the United States of America. The habitat approach used here was qualitative but this was necessary due to the lack of historical data onPhragmites and to the limited number of case studies. However, quantitative studies are needed, in order to understand how river health and aquatic biodiversity are being affected.

Rolletschek, H., et al. (2000). "Physiological consequences of mowing and burning of Phragmites australis stands for rhizome ventilation and amino acid metabolism." Wetlands Ecology and Management **8**: 427-437.

Mowing and burning of Phragmitesaustralis-stands have been recommended in the recentliterature as management tools for both protection andcontrol, and both favourable and detrimental effectsof these treatments were actually observed. This studyaims to clarify this apparent contradiction using anew physiological approach. Reed stands in thebiosphere reserves of Trebon (Czech Republic) and theDanube Delta (Romania) were investigated usingparameters of convective ventilation and amino acidpatterns. Flooded mown reed and unflooded burned reedwas compared to unmanaged control stands withcomparable hydrology and trophic level. Managementtook place in winter. The elimination of old culmsthrough mowing resulted in a lower ventilationefficiency due to a high counterpressure of rhizomes.The corresponding gas flow rates were reduced to 38%of the value in control stands, indicating a stronglyimpaired oxygen supply to basal and below-ground plantparts after mowing. Concomitantly, significantlyincreased levels of alanine and gamma-aminobutyricacid in basal culm internodes of shoots were measuredas signs of a metabolic shift due to hypoxic stress.Conversely, shoot loss by burning (without flooding)did not diminish ventilation efficiency and gas flowrate, i.e. oxygen supply to buried organs wasunaffected. Correspondingly, the level ofhypoxia-indicating amino acids (alanine,gamma-aminobutyric acid) did not indicate more severeoxygen deficiency in basal and below-ground plantparts of burned reed. It is concluded that the impactof mowing and burning on P. australisstronglydepends on the water level and on whether or notflooding occurs after the treatment. The mechanismresponsible for detrimental effects is probablyimpaired convective ventilation followed by hypoxia inbasal plant parts. This aspect should be taken intoaccount when mowing or burning in winter are used asmanagement tools for wetlands.

Russell, I. and T. Kraaij (2008). "Effects of cutting Phragmites australis along an inundation gradient, with implications for managing reed encroachment in a South African estuarine lake system." Wetlands Ecology and Management **16**(5): 383-393.

Substantive encroachment of Phragmites australis (common reed) occurred since the 1970s in the Wilderness estuarine lakes, a National Park and Ramsar site. Cutting of reeds in late summer as a means of controlling reed encroachment was investigated under three different inundation regimes, termed ‘wet zone’ (permanently inundated), ‘moist zone’ (infrequently inundated) and ‘dry zone’ (rarely inundated). The effects of a single annual cut were furthermore compared to those of two successive annual cuts. Without cutting, wet zones had thinner and shorter, but more abundant reeds than drier zones. Cutting in dry and moist zones resulted after one year in more, but shorter and thinner reeds, whereas in wet zones reeds were almost eliminated. After two years, reeds in wet zones had not recovered from the first annual cut. In moist and dry zones, a second annual cut did not result in amplified detrimental effects on reeds. Throughout the experiment, moisture zone was the factor with the largest effect, cutting had the second largest impact, and inter-annual variation was relatively unimportant. We have demonstrated that cutting alone has minimal long-term effect on above-ground reed biomass, whereas reed growth and survivorship can be strongly suppressed through cutting in late-summer in conjunction with inundation with moderately saline water (5.0–7.5 g kg−1). Cut reeds must remain completely inundated for at least a four-week period, or else emerging shoots should be re-cut below the water level. Cut material should be removed from the treatment site. Whenever possible, cutting and inundation should be undertaken to coincide with periods when salinity levels of surface waters are higher. It is foreseen that reed management in the Wilderness Lakes would have positive effects on other biota by countering progression towards single species domination of wetland plant communities and reinstating exposed sandbanks which are extensively utilised by resident and migratory waterbirds

Saltonstall, K. (2002). Cryptic invasion by non-native genotypes of the common reed, *Phragmites australis* into North America. Proceedings of the National Academy of Sciences of the United States of America.

Silliman, B. R., et al. (2014). "Livestock as a potential biological control agent for an invasive wetland plant." PeerJ **2**: e567.

Invasive species threaten biodiversity and incur costs exceeding billions of US$. Eradication efforts, however, are nearly always unsuccessful. Throughout much of North America, land managers have used expensive, and ultimately ineffective, techniques to combat invasive Phragmites australis in marshes. Here, we reveal that Phragmites may potentially be controlled by employing an affordable measure from its native European range: livestock grazing. Experimental field tests demonstrate that rotational goat grazing (where goats have no choice but to graze Phragmites) can reduce Phragmites cover from 100 to 20% and that cows and horses also readily consume this plant. These results, combined with the fact that Europeans have suppressed Phragmites through seasonal livestock grazing for 6,000 years, suggest Phragmites management can shift to include more economical and effective top-down control strategies. More generally, these findings support an emerging paradigm shift in conservation from high-cost eradication to economically sustainable control of dominant invasive species

Sun, H., et al. (2007). "Response of Phragmites to environmental parameters associated with treatments." Wetlands Ecology and Management **15**(1): 63-79.

This multi-year study evaluated the response of invasive Phragmites australis to changes in pore water geochemistry associated with tidal enhancement, alone or in combination with other prescribed management regimes used by the US Fish and Wildlife Service. A pilot study was conducted prior to the treatment experiment that showed a negative correlation between the growth of Phragmites and cation concentrations in a transitional vegetation zone. In the targeted 535-acre brackish-water impoundment (East Pool) where Phragmites dominated, the soil water chemistry was changed by introducing tidal salt water through water control structures in June of 1999. Soil profiles, pH, salinity and cation concentration data in addition to Phragmites height and density data were collected both before and after the treatments were imposed, where possible. It was generally observed that a soil water salinity above ~28 would be needed to maintain the reduction of Phragmites and to support its replacement by salt marsh species. In the tidal water manipulated experimental macroplots, the soil water salinity changed from 7.1 to 32 on average between 1999 and 2001. The reduction of the average height of Phragmites ranged from 25% to 84% for different treatment combinations, while untreated sites exhibited a slight increases in height. The reduction in average live density ranged from 51% to 87% for different treatment combinations. The greatest reduction of Phragmites density and height resulted when tidal enhancement was followed by a prescribed burn in the winter. Also, significant negative correlations were observed between Phragmites height and the main cations associated with tidal salt water including Mg^{2+}, Na^+ and K^+ and to a lesser extent Ca^{2+}. pH did not change drastically with the introduction of tidal water over the period of 1999–2001 and did not appear to play a significant role in changing the growth of Phragmites. A reduction of soil adhesiveness associated with the decay of Phragmites roots was observed after a two month period in 2001 when plants were submerged in standing water. This points to the need to maintain tidal exchange to promote a gradual transition from a Phragmites-dominated system to a Spartina-dominated system. Towards the end of the growing season in 2001, Spartina patens and Distichlis spicata had begun to ramify into the center of the island patches.

Taddeo, S. and S. De Blois (2012). "Coexistence of introduced and native common reed (*Phragmites australis*) in freshwater wetlands." Ecoscience **19**: 99-105.

Invasive species are especially problematic when introduced into ecosystems with native congeners. The extent to which niches overlap in space determines whether the introduced species threatens the native one or the native species can escape competition or the effect of control. We compared the spatial distribution in relation to landscape and land-use/land-cover variables of introduced and native Phragmites australis (common reed) in a landscape of protected freshwater wetlands in Quebec, Canada. Results showed that the wetlands still serve as refuges for native P. australis. At this stage of invasion, native and introduced P. australis occupy distinct spatial niches, the more abundant native type in low marsh and areas of lesser human impacts, the introduced one closer to roads and drier land covers. For now, native P. australis largely escapes competition, and the lack of spatial overlap could reduce opportunities for hybridization. Our study also suggests that invasion foci could still be controlled without endangering the native type. Whether the heterogeneous wetland conditions and the different spatial niches will be sufficient to allow long-term coexistence of native and introduced P. australis remains to be seen, but the situation needs to be closely monitored, especially in wetlands protected for biodiversity conservation.

Teal, J. M. and S. Peterson (2005). "The interaction Between Science and Policy in the Control of Phragmites in Oligohaline Marshes of Delaware Bay." Restoration Ecology **13**(1): 223-227.

Public Service Enterprise Group of New Jersey (PSEG) restored Delaware Bay marshes to enhance fish production as part of a mitigation negotiated in the company's New Jersey Pollutant Discharge Elimination System permit. Restoration meant control of an introduced type of the common reed, Phragmites, which had displaced Spartina alterniflora and S. patens. Phragmites dominance altered the function and structure of the brackish marshes and reduced habitat value by raising and flattening marsh surface and covering smaller tidal creeks. A common control technique is to use an herbicide—glyphosate. Public concern about herbicide use led to public meetings where the concerns were discussed and data provided. The scientific information regarding the herbicide did not satisfy the public. PSEG and New Jersey regulators agreed to test other methods for reed control and limit the amount of herbicide used. Experiments with methods of Phragmites control indicate that herbicide application over three or more growing seasons, concentrating in an area until control was complete, is the most effective control method.

Thompson, D. J. and J. M. Shay (1985). "The effects of fire on Phragmites australis in the Delta Marsh, Manitoba." Canadian Journal of Botany **63**(10): 1864-1869.

A dense stand of Phragmites australis (Cav.) Trin. ex Steudel in the Delta Marsh was divided into a grid of 20 experimental plots. Three different burn treatments (August 1979, October 1979, and May 1980) were each applied to four plots, with the remaining plots as controls. Shoot biomass was greater after spring and fall burns in comparison with the controls but less on summer-burned plots. Total shoot density was higher after all burning treatments in comparison with the controls. Flowering shoot density was lower after summer and fall burns in comparison with the controls but higher following spring burns. All burn treatments resulted in lower mean shoot weight than on controls primarily as a result of greater densities of shorter, thinner vegetative shoots. Belowground standing crop was higher by mid-September of 1980 on spring- and fall-burned plots but not on those burned in the summer. The seasonal minimum total nonstructural carbohydrate contents of rhizomes were reduced after summer and spring burns in comparison with the controls

Thompson, D. J. and J. M. Shay (1989). "First-year response of a Phragmites marsh community to seasonal burning." Canadian Journal of Botany **67**(5): 1448-1455.

The effect of seasonal burning was determined on a stand of Phragmites australis with an understory of Teucrium occidentale, Urtica dioica, and three less abundant species. Each portion of the stand was subjected to one of three burn treatments: August 1979, October 1979, or May 1980. By August 1980, the summer-burned community had decreased in dominance and increased in species diversity, richness, and evenness. In contrast, these community characteristics were unaltered on the spring and fall burns. Understory species showed three different responses to season of burn: (1) Atriplex patula and Sonchus arvensis were absent on unburned plots; their aboveground biomass increased on summer burns owing to seedling establishment but did not increase on spring burns. (2) Cirsium arvense and Lycopus asper were fairly frequent on unburned plots but had low aboveground biomass; their aboveground biomass increased on summer burns owing to both vegetative spread and seedling establishment but did not change on spring burns. (3) Mentha arvensis, T. occidentale, and U. dioica had both high frequencies and biomass on unburned plots; their biomass was reduced on summer burns but increased on spring burns. Species with responses 1 and 2 increased in biomass to a lesser extent on fall burns, whereas those with response 3 declined in biomass on fall burns

Trnka, A., et al. (2014). "Management of reedbeds: mosaic reed cutting does not affect prey abundance and nest predation rate of reed passerine birds." Wetlands Ecology and Management **22**(3): 227-234.

Reed passerine birds are strict habitat specialists inhabiting reedbed habitats. In Europe, many of these species are threatened due to loss and degradation of natural reedbeds. Another important factor that can negatively affect the abundance of reed passerines is commercial reed harvesting. Previous studies have shown negative impacts of large-scale winter reed cutting on passerine breeding assemblages and arthropod communities. The effect of reed cutting on a small scale, however, has not been studied experimentally to date. The aim of this study was to investigate whether and how small-scale, mosaic reed cutting influences prey abundance and nest predation rate of reed passerines. In June, after the reed had reached maturity, we conducted nest predation experiments with artificial nests and arthropod sampling using pan traps in cut reed patches, adjacent uncut reed patches and unmanaged reedbed. We found no differences in the risk of egg predation between three types of reedbeds. In contrast, the abundance of arthropods in cut and adjacent uncut reed patches was significantly higher than that in unmanaged reedbed. We assume this was caused by habitat heterogeneity, small size of cut patches and their rapid recolonization by arthropods from adjacent uncut patches. Our results suggest that in contrast to large-scale reed cutting, small-scale, mosaic reed cutting has no negative effect on nest survival and food abundance of reed passerine birds. However, given that we performed all experiments in June, i.e., when the reed was mature, our findings cannot be generalized to whole breeding period of all reed passerine birds. Therefore, temporal variation in nest predation rate and arthropod abundance in managed and unmanaged reedbeds during the entire breeding season should be examined in future studies.

Uddin, M. N., et al. (2012). "Phytotoxic evaluation of Phragmites australis: an investigation of aqueous extracts of different organs." Marine and Freshwater Research **63**(9): 777-787.

Phragmites australis is one of the most widespread and invasive plants on earth. Allelopathic interference has been considered as a possible way associated with its invasiveness in wetlands. A series of ecologically realistic experiments was conducted to explore allelochemical phytotoxicity of Phragmites. Germination bioassays using aqueous extracts of different organs (leaf, stem, root and rhizome) of Phragmites were tested with model seeds (Lactuca sativa and Raphanus sativus) and associated plant species (Juncus pallidus and Rumex conglomeratus). These studies showed that leaf and rhizome extracts exhibited strong inhibition on germination, biometric and physiological parameters (all $P \leq 0.001$). Dose–response studies confirmed LC_{50} (4.68% and 11.25%) of Lactuca for leaf and rhizome extracts respectively. Root growth of Juncus and Rumex was inhibited by 75% and 30%, respectively, in leaf leachate-incorporated soil. Chlorophyll content and maximum quantum yield (F_v/F_m) were significantly reduced with leaf and rhizome leachates. The stability and quantity of water-soluble phenolics in anaerobic versus aerobic condition may influence phytotoxic effects to other species. Phragmites organs can be ranked in order of allelopathic potentiality as follows: leaf > rhizome > root > stem. The present study highlighted the potential impacts of allelochemicals on plant recruitment in wetlands invaded by Phragmites.

Uddin, M. N., et al. (2014). "Is phytotoxicity of Phragmites australis residue influenced by decomposition condition, time and density?" Marine and Freshwater Research **65**(6): 505-516.

Phragmites australis is an invasive wetland plant and allelopathy appears to contribute to its invasiveness. We studied dynamics of physicochemical characteristics and phytotoxicity through residue decomposition of Phragmites with and without soil under different conditions and density over time. Physicochemical variables (water-soluble phenolics, dissolved organic carbon, specific ultraviolet absorbance, pH, electrical conductivity, osmotic potential and some anions, namely PO_4^{3-}, Cl^-, NO_2^-, NO_3^- and SO_4^{2-}) of extracts were more consistent and showed normal range in aerobic rather than anaerobic conditions. 'Residue alone' and 'residue with soil' extracts exhibited significant inhibition on germination and growth of Poa labillardierei and Lactuca sativa initially but reduced over time in aerobic conditions whereas the inhibition increased sharply and remained almost stable in anaerobic conditions ($P \leq 0.001$). Regression analyses showed that water-soluble phenolics were a significant predictor of the inhibitory effects on germination and growth of tested species compared with other variables in the extracts. Long-term decomposed residues exhibited significant effects on germination and growth of Melaleuca ericifolia ($P \leq 0.01$) depending on residue density in soil. The results demonstrated that decomposition condition and soil incorporation coupled with residue density may play a crucial role over time in dynamics of physicochemical variables and associated phytotoxicity. The study contributes to understanding of the ecological consequences of phytotoxins in residue decomposition, partially explaining the invasion process of Phragmites in wetlands and thereby improving wetland management.

Valkama, E., et al. (2008). "The impact of reed management on wildlife: A meta-analytical review of European studies." Biological Conservation **141**(2): 364-374.

We reviewed European studies on the effect of reed management (harvesting, burning, mowing and grazing) on reedbed wildlife, and in addition, on the performance of re-growing reed (Phragmites australis). Our database consisted of 21 studies conducted on 10 plant species, 17 taxonomic groups of invertebrates and 11 bird species, and published between 1982 and 2006. We found that reed management modifies the structure of re-growing reed stands: reed stems were shorter and denser in managed sites than in unmanaged sites. However, harvesting does not have an impact on aboveground biomass. Plant species richness increased by 90% in managed stands in fresh water marshes, but not in saline water marshes. Overall, reed management had a significant negative impact on invertebrate community, but the duration of management was an important factor determining the magnitude of the effect. Short-term management (1–2 years) had no effect on invertebrates, whereas management for longer period significantly reduced invertebrate abundance. Reed harvesting and burning reduced abundance of passerine birds by about 60%. This was probably associated with food limitation as the numbers of butterflies, beetles and some spiders were reduced. Therefore, the optimal reed management regime to preserve number of birds and invertebrates in reedbeds could be a rotation of short-term management (1–2 years). However, the optimal interval between management applications should be established in future studies.

van der Putten, W. H. (1997). "Die-back of Phragmites australis in European wetlands: an overview of the European Research Programme on Reed Die-back and Progression (1993–1994)." Aquatic Botany **59**(3–4): 263-275.

Reed (Phragmites australis (Cav.) Trin. ex Steudel) is one of the dominant plant species in European land-water ecotones. During the past decades reed belts have died back, especially in central and eastern Europe. The aim of the European Research Programme on Reed Die-back and Progression (EUREED), was to examine how increasing eutrophication, changed water table management, temperature, reduced genetic variation and their interactions may contribute to reed die-back. Eutrophication appeared to be a key factor, but the effects on P. australis were indirect, via the accumulation and decay of litter and allogenous organic matter, rather than acting directly via disturbed carbohydrate cycling or reduced porosity of the aerenchymous plant tissue. The formation of toxic byproducts of decomposing litter in anoxic environment, such as acetic acid, may reduce reed vigour. Sulphide may act as a principal toxin especially at brackish sites, such as Lake Fert, Hungary. There were large differences in genetic variability. However, populations from eutrophic sites did not grow faster and were not more plastic than populations from oligotrophic sites. Variation within populations could be large as compared to variation between populations when exposed to nitrogen, liquid manure and litter. DNA-fingerprinting showed differences between land and water reeds. This may be due to a differential selective force during establishment, e.g., when the water table recovers after a drawdown. Selection by water table during establishment could affect the susceptibility of clones in the mature stage for indirect effects of eutrophication. It was concluded that in stagnant water bodies the present water table management enforces the effects of eutrophication on the reed die-back. In addition, local disturbances, such as the mechanical mowing of reeds may enhance reed die-back.

Weis, J. and P. Weis (2003). "Is the invasion of the common reed, Phragmites australis, into tidal marshes of the eastern US an ecological disaster?".

Welch, B., et al. (2006). "Dominant environmental factors in wetland plant communities invaded by Phragmites australis in East Harbor, Ohio, USA." Wetlands Ecology and Management **14**(6): 511-525.

Elevation, standing crop, disturbance and soil fertility often emerge from studies of freshwater plant communities as the dominant environmental factors determining both species richness and species composition. Few studies in North America have investigated the relationship between these factors and species abundance (standing crop) and species composition in the context of invasion by Phragmites australis. This study explores the influence of key abiotic and biotic variables on species abundance and composition across three Lake Erie wetlands differing in hydrology and Phragmites abundance in East Harbor, Ohio, USA. Standing crop for 92 species was related to standard sediment analyses, wave exposure, distance to shoreline, elevation, light interference, species density, and Phragmites standing crop in each of 95 1 × 1 m quadrats by using canonical correspondence analysis (CCA). Elevation (Axis I) and Phragmites standing crop-soil fertility (Axis II) explained 35.7 and 26.2%, respectively, of the variation in the species–environment relationships. Wave exposure was not a primary component of the first four canonical axes. Axis I was instrumental in describing species composition, separating wet meadow species from marsh species. Axis II was inversely related to species density for both wet meadow and marsh species. These findings generally support prevailing models describing the distribution of wetland plants along environmental gradients. Two discrepancies were noted, however: (1) species density was highest in the most sheltered sites and (2) wave exposure was directly associated with Phragmites standing crop-soil fertility gradient. The structural integrity of Phragmites stems, topographic heterogeneity and differential responses to anthropogenic disturbance may contribute to departure from prevailing multivariate models. This information has direct implications for local and regional wetland managers.

White, S. D., et al. (2007). "The influence of water level fluctuations on the potential for convective flow in the emergent macrophytes Typha domingensis and Phragmites australis." Aquatic Botany **86**(4): 369-376.

This paper examines the influence of the amplitude of water level fluctuations and elevation on the gas space anatomy and potential for convective flow in the emergent macrophytes Typha domingensis Pers. and Phragmites australis (Cav.) Trin. ex Steud. Plants were grown under a range of amplitudes of cyclic water level fluctuations: static, ±15, ±30 and ±45 cm. The water level of each treatment fluctuated around an initial and average depth of 60 cm. Within each amplitude treatment, plants were grown at three elevations: sediment surface 20, 40 and 60 cm above the base of the pond. The gas space anatomy of T. domingensis showed a range of modifications in response to experimental treatments. Lacunal cross-sectional area of the leaves increased with decreasing elevation as a product of changes in both fractional porosity and total cross-sectional area. Lacunal cross-sectional area of leaves was maintained across the gradient in amplitude through changes in fractional porosity despite decreasing total cross-sectional area. As a result of these adaptations in gas space anatomy, specific resistance in T. domingensis decreased with decreasing elevation but was unaffected by amplitude. In contrast, no unequivocal anatomical modifications were detected in P. australis and the specific resistance was constant across treatments. Estimates of the total resistance to convection in the above-ground parts of the plant suggests the adaptations in the gas space anatomy by T. domingensis largely compensated for increases in the pathlength of convection due to decreasing elevation. Total resistance increased significantly with increasing amplitude. P. australis had a low specific resistance which minimised the effect of increasing amplitude on total resistance but, lacking the ability to adapt gas space anatomy, the total resistance was strongly affected by elevation. The differential impact of elevation and amplitude suggests the two species have contrasting aptitudes for aeration across gradients in elevation and amplitude. T. domingensis is better suited to tolerate a range of static water depths whereas P. australis is better suited to fluctuating water levels especially when growing at high elevations.

Zhang, X., et al. (2014). "Litter mass loss and nutrient dynamics of four emergent macrophytes during aerial decomposition in freshwater marshes of the Sanjiang plain, Northeast China." Plant and Soil: 1-9.

Following one year of aerial decomposition, the leaf and culm mass losses were 19.3–45.1 % and 14.3–23.1 %, respectively. Litter mass loss was closely related to microbial respiration rates and initial ratios of C:N and C:P. The fact that litter N concentrations increased during aerial decomposition resulted in net N immobilization. After one year of decay, however, there was a net release of P from the standing litter in all cases, but the temporal pattern of P concentrations varied between the decomposing litter of the four different species. Our results provide evidence that the decomposition of standing litter from emergent macrophytes contributes markedly to overall litter decay, and thus is a key component of C and nutrient cycles in temperate wetlands.