

Common Reed *Phragmites australis*: Control and Effects Upon Bio diversity in Freshwater Nontidal Wetlands

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Abstract

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.

Key words: *Phragmites australis*, control, biodiversity, wetlands.

Introduction

Phragmites australis (Cav.) Trin. ex Steud (common reed) is a tall (1.5–4.0 m), coarse perennial grass found primarily in brackish and freshwater wetlands, growing at or above mean high water. Along the Atlantic coast of the United States it is common in moist uplands and wet areas of the dune systems of coast barrier islands (Gleason & Cronquist 1963; Fernald 1970; Brown & Brown 1984). It has a worldwide distribution (Tucker 1990) and is endemic to North America (Niering & Warren 1977). *P. australis* (henceforth *Phragmites*) appears to be rapidly increasing in abundance in many areas of the United States (Hauber et al. 1991; Marks et al. 1994; Fell et al. 1998).

Phragmites seeds profusely and spreads vegetatively by a vigorous system of rhizomes and stolons, forming dense stands of monotypic communities (Best et al. 1981; Hara et al. 1993; Marks et al. 1994). Seeds are dispersed by wind during the winter months, but may also be carried by birds such as *Agelaius phoeniceus* (red-winged blackbirds) (Haslam 1969). *Phragmites* colonies in the northeastern United States have been reported to produce mostly non-viable seeds (Tucker 1990), although inflorescences exposed to overwintering conditions can produce abundant viable seeds (M. S. Ailstock, unpublished data). Colonies expand peripherally by lateral rhizome growth, typically subterranean. The upright, aerial stems serve mainly for photosynthesis and seed formation. These aerial stems are derived from rhizome buds which are probably formed during the previous year's growth. At the end of each growing season all the aerial stems die and are replaced in the following year by the growth of pre-existing rhizome buds (Haslam 1969).

The large size, high reproductive potential, and rapid growth rate of *Phragmites* has led to differences of opinion held by biologists and resource managers with respect to the plant's ecological value and potential usefulness for environmental enhancement (Bibby & Lunn 1982; Eleuterius & Gill 1983; Kruczynski 1983; Anderson & Ohmart 1985).

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Phragmites can be considered a wetland management problem due to its ability to survive anthropogenic changes and rapidly colonize and dominate disturbed soils. In this capacity it is capable of invading adjacent areas and crowding out other wetland plant species, reducing the overall plant diversity of the affected system (Weisser & Parsons 1981; Szczepanska & Szczepanski 1982; Galinato & van der Valk 1986; Marks et al. 1994). By forming monocultures, *Phragmites* may supplant other species considered to be more important as food or cover for wildlife. However, it can be an important soil stabilizer and may have application as a nutrient sink for treating wastewater prior to release (Bonham 1983; Kamio 1985; Gersberg et al. 1986; Brix 1987; House et al. 1994). These potential uses have led to development of propagation and field establishment protocols (Eleuterius 1974; Stout 1977).

Given the high invasive potential of *Phragmites*, programs for control and utilization are largely incompatible (Haslam 1971; Nir 1976; Kasasian 1977; Best et al. 1981; Smith & Kadlec 1983, Haberl & Perfier 1989; Staubitz et al. 1989). This incompatibility has led to three divergent policies of *Phragmites* management: eradication, control, and tolerance under certain circumstances such as in areas with low water quality (Eleuterius 1974; Stout 1977; Brix 1987). A number of methods for controlling this plant have been suggested or attempted. These include biological control through insect introduction (Tscharntke 1989), hydrologic control through flooding (Hellings & Gallagher 1992), chemical control with non-specific herbicides (Cross & Fleming 1989), and mechanical control by cutting or burning (Lee 1990; Cowie et al. 1992).

Specific studies quantifying patterns of change in *Phragmites* populations in North America are rare. However, reports from the United States (Hauber et al. 1991; Chambers et al. 1999), South Africa (Weisser & Parsons 1981), and anecdotal evidence from numerous wetlands managers along the Atlantic Coast and the Chesapeake Bay watershed suggest that populations are rapidly increasing in many areas. These increases appear to correlate well with human population growth in those areas. It is, therefore, important to understand the patterns and processes of *Phragmites* growth and how human wetland manipulation may accelerate colonization.

In 1987, preliminary observations of *Phragmites* growth in Maryland were made by aerial reconnaissance of areas identified as "problem" sites by the Maryland Department of Natural Resources. Based upon these observations the authors concluded that (1) practices which cause soil disturbance promote colonization; (2) *Phragmites* in undisturbed areas often appears as circular colonies, suggesting vegetative spread from a single propagule; (3) dense monotypic stands are more commonly found in isolated pockets or along stream

borders; and (4) this varied distribution poses problems for implementing some methods of control.

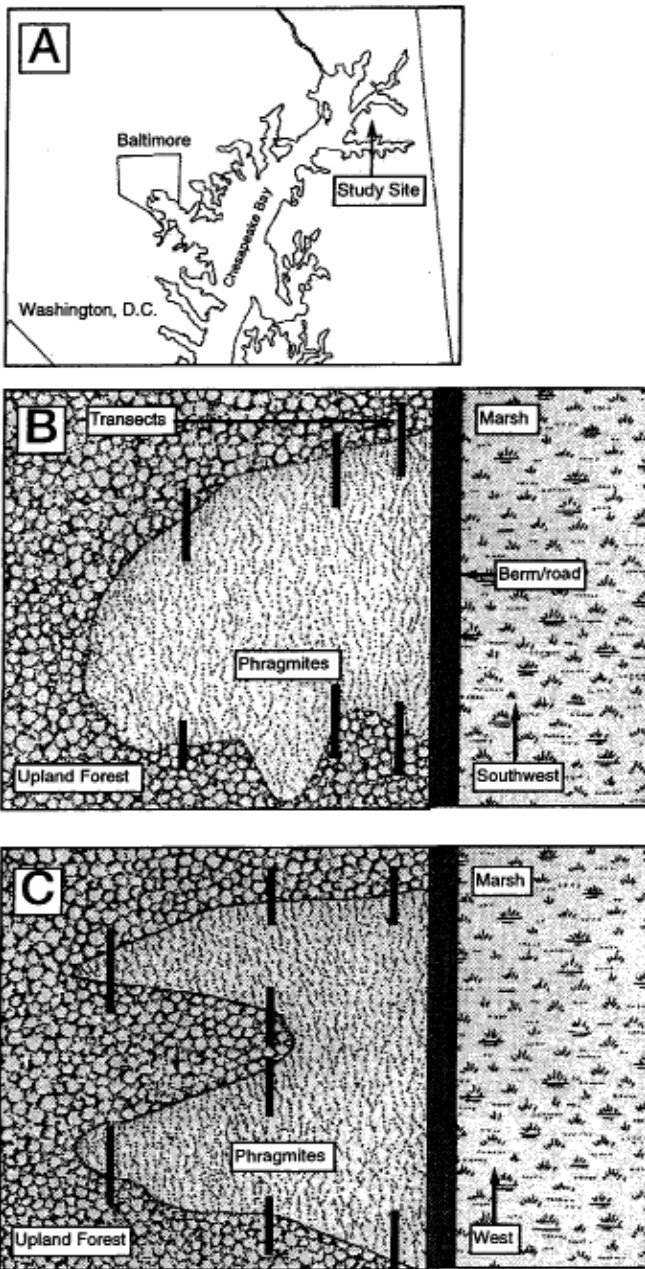
A 5-year study was then initiated to examine the effects of two *Phragmites* control programs, herbicide spraying or herbicide followed by burning, upon plant and animal diversity in nontidal wetlands. A second study examined the abilities of *Phragmites* to propagate in disturbed and vegetated soils. These studies were designed to determine: (1) whether chemical control is effective in reducing *Phragmites* population size; (2) if control leads to enhanced plant and animal diversity; (3) if removal of the above ground biomass by burning after herbicide treatment alters community development; (4) which propagules are most likely to survive and form *Phragmites* colonies; and (5) what types of marsh disturbance favor *Phragmites* establishment.

Materials and Methods

Study I: Effects of *Phragmites* Control

Two study sites were established at the Army Corps of Engineers, Stemmers Run Wildlife Management Area in Cecil County, Maryland on the upper Chesapeake Bay (Fig. 1A). They were natural nontidal wetlands prior to the development of the property as a dredge spoil repository in the 1960s. Interviews with adjacent property owners and area trappers indicated the wetlands prior to receiving spoil material were populated by many obligate hydrophytes such as *Typha* sp. (cattails), *Sagittaria* sp. (duck potato), *Pontederia cordata* (pickerel weed), *Acer rubrum* (red maple), *Polygonium* sp. (smartweeds), and *Scirpus* sp. (rushes). The sites were closely spaced, 12–14 hectares in size and located outside of the drainage ditch which surrounds the spoil impoundment. Both sites were dominated by stands of *Phragmites*. One wetland, identified as the "herbicide-burn" site (Fig. 1B), was sprayed with herbicide and burned four months later. The second, identified as the "herbicide" site (Fig. 1C), was treated with herbicide but not burned.

In October of 1987 and 1988 both sites were treated with the herbicide Rodeo™ [Monsanto Co., St. Louis, MO, active ingredient: isopropylamine salt of glyphosate, N-(phosphonomethyl) glycine], a commonly used herbicide for controlling *Phragmites* in aquatic ecosystems (Nir 1976; Riemer 1976; Seddon 1981; Nir & Raz 1985; Bucsbaum et al. 1985). A fall application was selected because of the abundance of foliage present for herbicide absorption, the increased selectivity made possible by having non-target deciduous species exposed after they had initiated dormancy responses, and the excellent *Phragmites* control that had previously been achieved utilizing this application time (Seddon 1981; Buhler & Burnside 1983; Prasad 1984). Herbicide was applied by hand-held spray and from a Bell 47 Solyo helicopter with an effective spray swath of 12.2 meters.



A volume trigger timer in the cockpit with clock cali-
 Figure 1. Site map (A) showing the location of the herbicide and herbicide-burn study sites. Maps of the herbicide-burn (B) and herbicide (C) sites show belt transect locations.

bration was used to regulate spray rates and to continuously monitor flow. Application was restricted to periods where wind speeds were less than 5 mph to avoid drift. Application rates were 1.9 liters per 0.4 hectare for a broadcast spray (or a 1 1/2 percent solution for hand-held spray equipment). For aerial application, the broadcast rate with surfactant was adjusted with 1.3 to 75.7 liters of water as a carrier (Riemer 1973; Sandberg et al. 1978; Evans 1987). Visual inspection showed that uniformity of

contact was excellent, averaging 5–7 droplets per leaf surface. Drift to areas outside of the designated spray areas was undetectable by visual inspection of plant surfaces during spraying and after two and 52 weeks when adjacent vegetation was evaluated for herbicide effects.

The non-tidal wetland site designated as “herbicide-burn” was burned in February 1988, four months after herbicide application, by Maryland Forest and Parks personnel. Burning was effective in most areas, reducing standing crop to 1.5 to 3 mm of fine ash. Burning was not successful in areas adjacent to standing water where dead *Phragmites* stems remained fully hydrated.

Both herbicide and herbicide-burn sites were surveyed in October 1987 before (pre-treatment) and after herbicide application or herbicide-burning (post-treatment) for vertebrate use, plant and macroinvertebrate diversity, and soil seed stock. Pre-treatment surveys occurred in October 1987, while post-treatment surveys were conducted in the late summer or fall of 1988, 1989, 1990, and 1991.

Vegetation surveys were conducted with belt transects, composed of 3.16 m by 0.32 m quadrats established around the periphery of the herbicide-burn and herbicide sites (Figs. 1B & 1C). Each transect began one meter outside of the dense *Phragmites* in order to sample adjacent vegetation, and extended into the stand until five consecutive quadrats included only *Phragmites* in the pre-treatment survey. Six transects (58 quadrats) and eight transects (61 quadrats) were established on the herbicide-burn and herbicide site, respectively.

For each survey, plants within each quadrat were identified and counted. These data were used to calculate a Simpson’s diversity index (Simpson 1949) for each site. Two 100-cm³ core samples (6.0 cm diameter, 3.5 cm deep) were also collected approximately 15 cm outside the midpoint of each transect. One sample, used for inventory of soil seed bank stock, was stored at 4°C for four days. This overcame stratification requirements common to plants in temperate environments. The cold-treated samples were spread over a sterilized commercial potting soil in 2 liter containers and were covered with 12.5 mm of vermiculite. Containers were bottom watered throughout to maintain uniformly high soil moisture. Plants were harvested after growth sufficient for precise identification. The second sample, used for invertebrate analysis, was placed in a Berlese funnel and extracted for four days. Invertebrates were stored in 70% ethanol prior to counting. A total of 16 and 12 core samples were collected during each survey at the herbicide and herbicide-burn site, respectively.

Study II: Surface Substrate Influences on *Phragmites* Recruitment

To evaluate the factors which contribute to the establishment of *Phragmites* colonies, its three naturally pro-

duced propagules—seeds, rooted shoots, and rhizome fragments—were planted in marsh environments that differed in elevation under three conditions normally associated with wetland habitats. These were: (1) naturally vegetated areas; (2) areas where surface vegetation has been burned as a part of normal marsh management programs; and (3) bare soil, a common result of many construction activities occurring in wetlands. Two locations, differing in elevation, extant plant species, and soil hydration, were selected in the Greens’ Island Wildlife Management Area in Dorchester County, Maryland. The first, representing a higher elevation marsh environment, supported *Panicum virgatum* (switchgrass) and *Hibiscus palustris* (marsh mallow) as the dominant cover species. The second, a lower elevation marsh environment, was dominated by *Spartina patens* (saltmeadow cordgrass), *Distichlis spicata* (seashore saltgrass), and *Juncus roemerianus* (black needle rush). At each site, twelve 1 m² quadrats were established. Four quadrats were left naturally vegetated, four were burned to remove above-ground biomass, and four were excavated to a depth which exposed the mineral soil surface.

At each location a single quadrat received either 0.5 g of *Phragmites* seeds (approximately 450 viable seeds), 10 rooted shoots, 10 rhizome fragments placed on the surface, or 10 rhizome fragments buried in the soil. Each rhizome fragment was approximately 10 mm in length

and contained a single, unexpanded bud. Growth of *Phragmites* from these propagules was evaluated biweekly for 12 weeks.

To control for predation and the influence of seasonal weather patterns, 12 quadrats (1 m²) were established in planting flats (1 m X 1 m X 0.2 m) under greenhouse conditions. These flats were filled with commercial potting soil (ProMix). Eight flats were planted with a one-to-one mixture of K-31 (tall fescue) and annual rye six weeks prior to inoculation with *Phragmites* propagules. This allowed the grasses to grow to a height of approximately 20 cm and completely cover the soil surface. Four flats were left intact and four were burned to the soil surface, prior to planting, using a propane torch. The remaining four flats, containing only potting soil, were used to simulate bare soil conditions. Survival and growth of different propagules were evaluated bi-weekly for 12 weeks.

Results

Study I: Effects of *Phragmites* Control

Effects on Plant Diversity. Before treatments, *Phragmites* was the dominant plant species at both the herbicide and herbicide-burn sites, with other species in low abundance. Both sites had similar, low Simpson’s diversity indices

Table 1. Pre- and post-treatment abundance of nine most common plant species recorded at the herbicide and herbicide-burn sites. Simpson’s diversity index (SI) was used to determine pre-and post-treatment plant diversity.

Species	# Individuals Pre-treatment		# Individuals Post-treatment	
	Herbicide Site (SI = 1.52)	Herbicide Burn Site (SI = 1.57)	Herbicide Site (SI = 6.91)	Herbicide-Burn Site SI = 3.76)
<i>Acer rubrum</i>	3	6	-	154
<i>Boehmeria cylindrica</i>	64	9	-	-
<i>Dichanthellum sp.</i>	51	16	-	-
<i>Erechites hieracifolia</i>	-	-	250	189
<i>Impatiens capensis</i>	-	-	127	-
<i>Leeria oryzoides</i>	-	-	127	-
<i>Liquidambar styraciflua</i>	-	16	-	-
<i>Lycopodium complanatum</i>	4	-	-	-
<i>Myrica sp.</i>	5	-	-	-
<i>Panicum verucosum</i>	-	-	1858	2469
<i>Parthenocissus quinquefolia</i>	15	-	-	-
<i>Phragmites australis</i>	691	878	331	275
<i>Phytolacca americana</i>	-	56	-	-
<i>Polygonum punctuatum</i>	-	-	777	169
<i>Polygonum sagittatum</i>	-	-	766	-
<i>Polygonum sp.</i>	-	88	-	580
<i>Prunus serotina</i>	7	-	-	-
<i>Rhus radicans</i>	-	5	-	118
<i>Rubus sp.</i>	-	6	-	150
<i>Scirpus cyperinus</i>	-	-	-	158
Unidentified grass (1)	-	-	1062	-
Unidentified grass (2)	-	-	236	-
<i>Vaccinium atrococum</i>	5	-	-	-

(Table 1). *Phragmites* declined in abundance following herbicide or herbicide-burn treatments (Fig. 2A) but did not entirely disappear. Data from both sites are similar and best described with a hyperbolic function, although only the herbicide-burn site data are significantly correlated with year (Pearson $r = 0.92$, $t = 4.18$, $p < 0.05$). By the end of the study, *Phragmites* had begun to recover from the treatments and was the fifth and third most abundant plant species at the herbicide and herbicide burn sites, respectively. However, examination of both sites four years post-treatment revealed a more equitable distribution of individuals among species and Simpson's diversity indices higher than pre-treatment (Table 1).

Both the herbicide and herbicide-burn treatments resulted in increasing numbers of plant species over the five-year study (Fig. 2B). These increases at both sites were significantly correlated with year (herbicide: Pearson $r = 0.98$, $t = 7.84$, $p < 0.05$; herbicide-burn: Pearson $r = 0.89$, $t = 3.32$, $p < 0.05$). The herbicide site, with its dense stands of dead *Phragmites* shoots, showed slow recovery

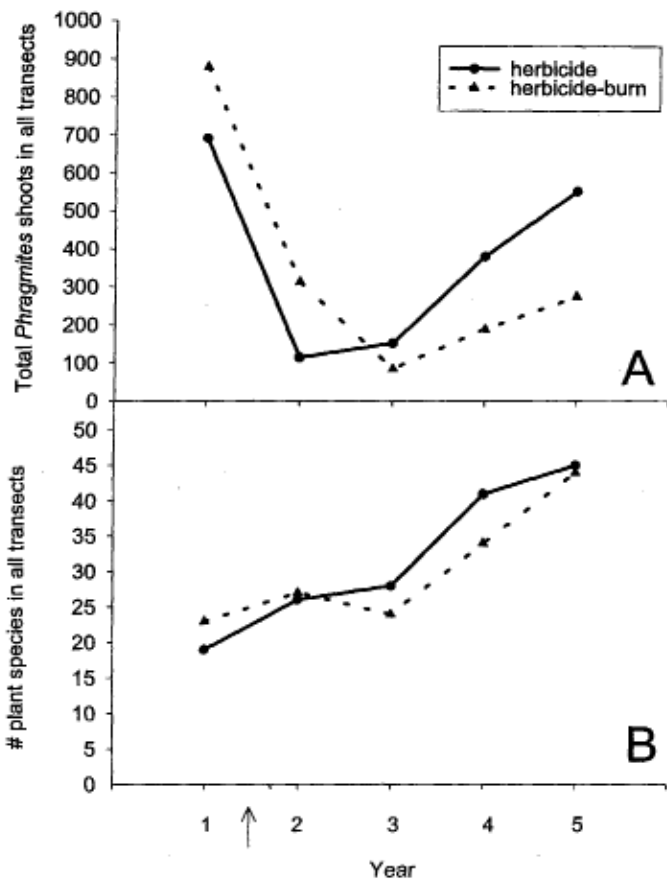


Figure 2. Total *Phragmites* shoots (A) and the total number of plant species (B) recorded by quadrat sampling at both study sites over the 5-year study. Arrow represents approximate time of treatment.

and little re-growth the first year except in areas where workers had flattened the shoots while collecting samples (Fig. 3A). The herbicide-burn site (Fig. 3B) exhibited rapid re-growth in the first year post-treatment and possessed a diverse plant community at the end of the first growing season. These effects are illustrated by the total number of plant individuals following treatment (Fig. 4A). Although both sites show increases, more plants were present on the herbicide-burn site for the first three years post-treatment plant density. The data from both sites are best described with an exponential function, although only those for the herbicide-burn site are significantly correlated with year (Pearson $r = 0.99$, $t = 9.76$, $p < 0.05$).

Calculations of Simpson's diversity index for the two treatment sites for each year of the study (Fig. 4B) showed that diversity increased significantly over four years post-treatment at the herbicide site (Pearson $r = 0.91$, $t = 3.73$, $p < 0.05$), while this steady increase was not evident at the herbicide-burn site. Examination of the nine most abundant species for both sites in the last

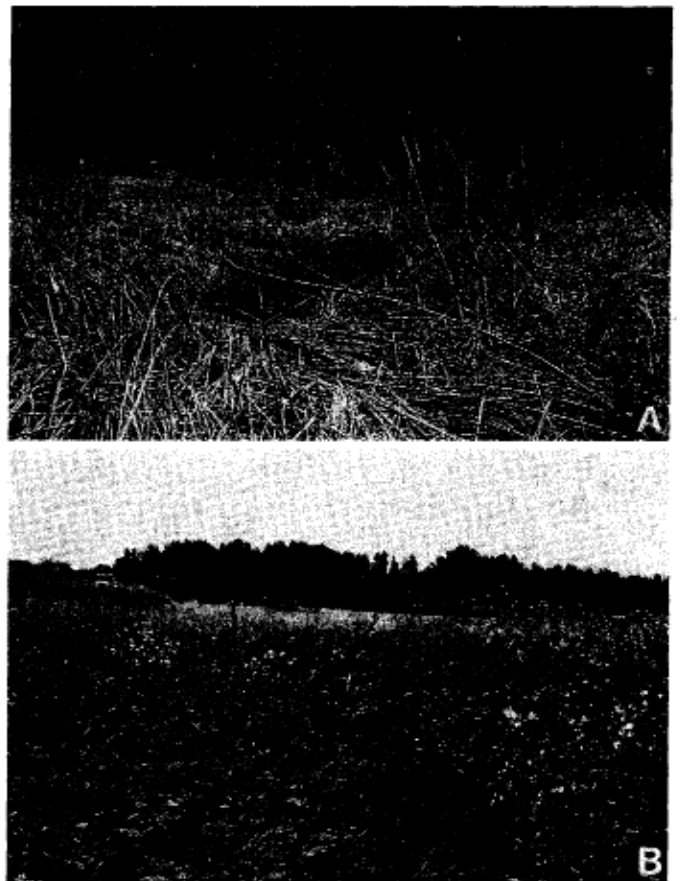


Figure 3. The herbicide (A) and herbicide-burn (B) sites at the end of the first growing season. Burning after herbicide application removed dead *Phragmites* stems and produced a rapid and diverse re-growth.

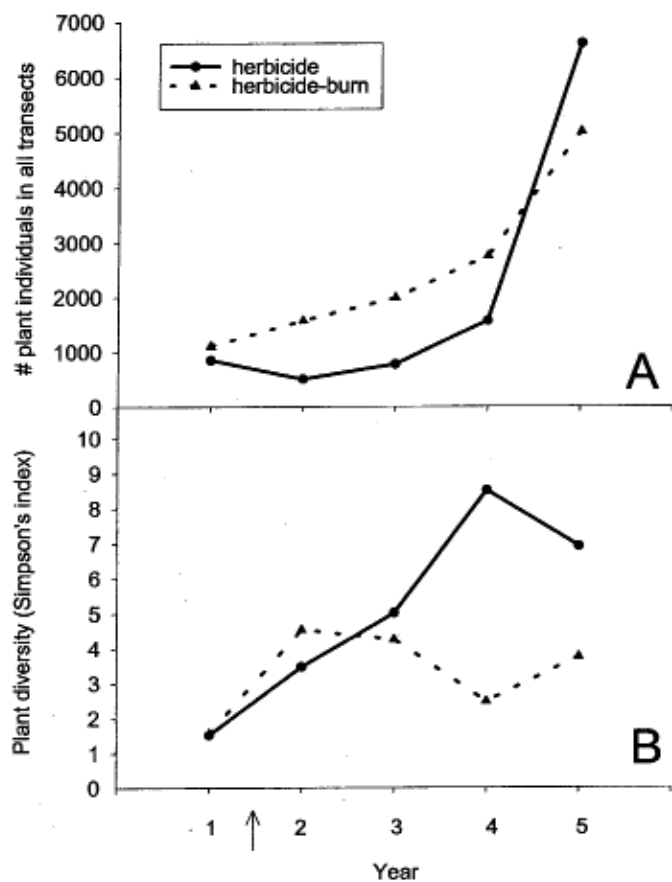


Figure 4. The total number of individual plants (A) and Simpson's index of diversity for plants (B) for both treatment sites over the 5-year study. Arrow represents approximate time of treatment.

year of sampling (Table 1) revealed one species, *Panicum verrucosum* (warty panic grass), very abundant at the herbicide-burn site, while a more even distribution of different species existed at the herbicide site.

Incubation of the soil core samples revealed an abundant and diverse soil seed bank at both the herbicide-burn and herbicide sites (Fig. 5). At neither site was *Phragmites* the most abundant plant germinated. Six plant species—*Agrostis hyemalis* (winter bentgrass), *Boehmeria cylindrica* (small spike false-nettle), *Phragmites australis*, *Ludwigia palustris* (marsh seedbox), *Dichanthelium* sp.(switchgrass), and *Cyperus* sp. (flatsedge)—had high abundance at least at one site, while the remaining nine species germinated were in relatively low abundance at either site.

Effects on Macroinvertebrate Diversity. Table 2 illustrates pretreatment abundance for the nine most common macroinvertebrate orders. The five most abundant groups—mites, springtails, beetles, flies and ants—had similar levels of abundance at both sites. At both the herbicide-burn

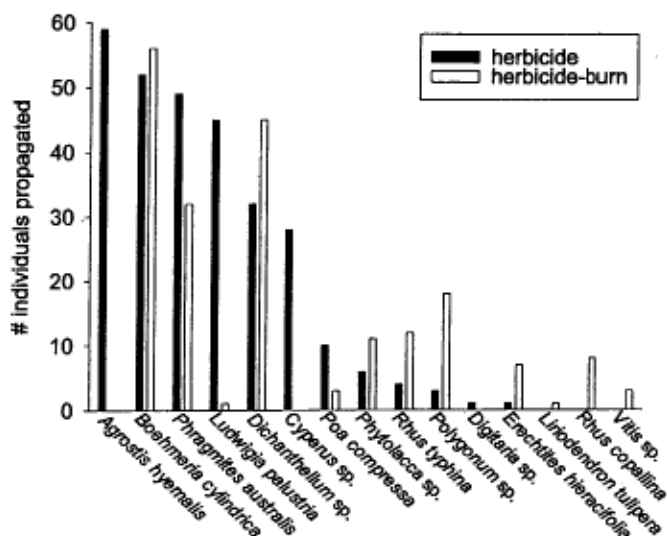


Figure 5. Plant species germinated from seeds in soil cores (100 cm³) taken near transects at both treatment sites.

and herbicide sites, invertebrate diversity increased following treatment, then returned by the end of the study to pre-treatment levels (Fig. 6). Both curves are best described by a hyperbolic function, although neither is significantly correlated with year. Changes in invertebrate diversity were not significantly correlated with any measured changes in plant diversity or abundance. An analysis of changes in total individuals, over the five-year study, for the five most common soil macroinvertebrate groups for the herbicide (Fig. 7A) and herbicide-burn (Fig. 7B) sites shows no consistent changes in abundance for any group at either site. Examination of the most common invertebrate orders in the second year post-treatment (Table 2), a time of highest diversity, showed greater abundance of some invertebrate types but a similar relative abundance as the pre-treatment condition. Insects and spiders were the predominant forms associated with above ground biomass. Most were found in the inflorescences at the top of the plant canopy or the surface of soil leaf litter. Areas of dense stem growth supported relatively few species. This may be attributed to problems with access and sampling in this type of cover.

Study II: Substrate Influences on *Phragmites* Establishment

Table 3 shows propagule survivorship after 12 weeks for each soil type, location, and propagule type. In the greenhouse, seeds thrived on bare soil but did not survive in vegetated or burned soil. In the field they survived in low numbers and only on bare soil in the high marsh. Rooted shoots in the greenhouse grew on bare or burned soil. In the field they survived in low numbers and only on bare soil in the high marsh. Surface rhizomes did not survive under any field condition,

Table 2. Macroinvertebrates collected from soil cores taken from the herbicide (eight cores) and herbicide-burn (six cores) survey sites. The table shows pre-treatment and 4 years post-treatment counts.

Orders	# Individuals Pre-Treatment		# Individuals Post-Treatment	
	Herbicide Site (SI - 1.82)	Herbicide Burn Site (SI - 1.37)	Herbicide Site (SI - 2.66)	Herbicide-Burn Site (SI - 1.70)
Arachnida (mites)	1,732	3,370	2,225	3,720
Collembola (springtails)	310	231	628	804
Coleoptera (beetles)	128	194	114	149
Diptera (flies)	89	45	484	145
Hymenoptera (ants)	71	39	376	53
Myriopoda (centipedes)	11	11	8	11
Hymenoptera (wasps)	8	-	-	-
Arachnida (spiders)	8	16	-	17
Hemiptera	7	-	-	-
Arachnida (pseudoscorpions)	-	22	17	19
Myriopoda (millipedes)	-	11	7	-
Annelida (oligochaetes)	-	-	21	-
Thysanoptera (thrips)	-	-	-	19

while they showed low survivorship in the greenhouse on vegetated or burned soil. In contrast, buried rhizomes had high survivorship under all soil condition in the high marsh and in bare soil in the low marsh. In the greenhouse, buried rhizomes exhibited 100% survival in all soil conditions.

Discussion

This study demonstrates that one-time herbicide application or herbicide followed by burning can significantly reduce the abundance of *Phragmites* in nontidal wetlands in the short term. Moreover, these reductions were followed by rapid re-growth by other species, with increases in species abundance and diversity. These treat-

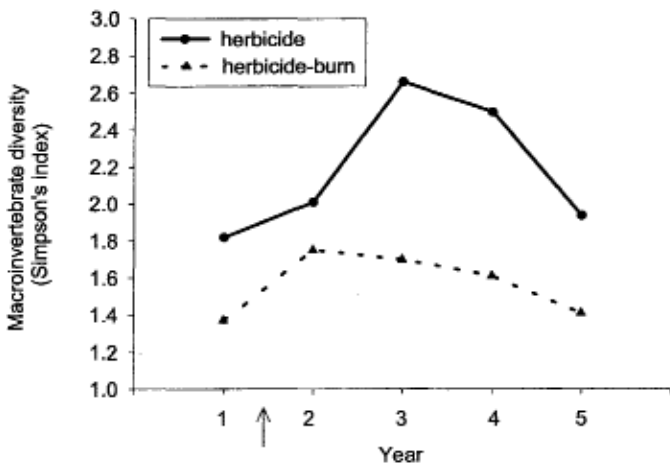


Figure 6. Simpson's index of diversity for macroinvertebrates for the herbicide and herbicide-burn sites over the 5-year study. Arrow represents approximate time of treatment.

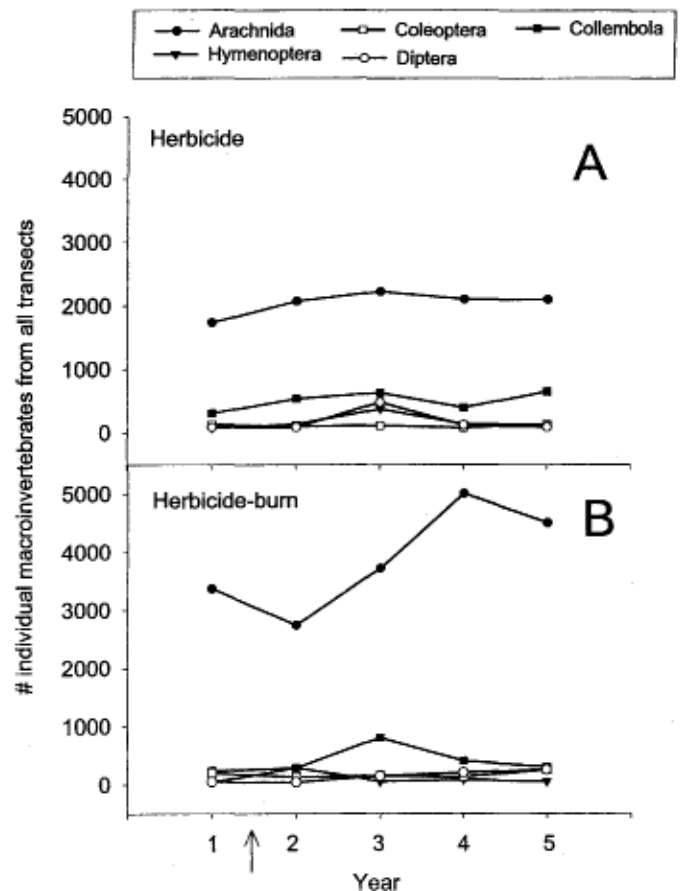


Figure 7. The number of individual macroinvertebrates, identified by order, collected by soil cores (100 cm³) at the herbicide (A) and herbicide-burn (B) sites.

Table 3. Twelve week survivorship of four types of *Phragmites* propagules placed in bare, vegetated, or burned soil. The study was conducted at a low marsh, a high marsh, and in the greenhouse.

Propagule Type	Soil Type	Twelve Week Survivorship (%)		
		Low Marsh	High Marsh	Greenhouse
Seeds	Bare soil	0	0.7	27
	Vegetated soil	0	0	0
	Burned soil	0	0	0
Rooted shoots	Bare soil	0	30	100
	Vegetated soil	0	0	0
	Burned soil	0	0	100
Surface rhizomes	Bare soil	0	0	0
	Vegetated soil	0	0	20
	Burned soil	0	0	10
Buried rhizomes	Bare soil	20	20	100
	Vegetated soil	0	30	100
	Burned soil	0	10	100

ments thus appear capable of returning *Phragmites*-dominated wetlands to a pre-colonization condition for 2—3 years. After the third growing season, expansion of *Phragmites* not killed in the initial application was significant. Therefore, additional spot applications of herbicide are needed to prevent re-growth of *Phragmites* in the long-term and thereby maintain plant biodiversity.

Observations of post-treatment re-growth of all plants at both sites suggest that there were short-term differences between treatments. Re-growth in the first year at the herbicide site was minimal, probably because of the shading effect of the large number of dead, erect *Phragmites* stems and the dense thatch of broken stems that accumulate approximately one foot above the soil surface in older *Phragmites* colonies. Growing plants including *Phragmites* were largely restricted to the paths used for quadrat sampling, where the stems and thatch had necessarily been beaten down during pre-application sampling. *Phragmites* re-growth in this area may have been evident because of disrupted vascular connections that can prevent herbicide translocation from the leaves to the rhizomes (M. S. Ailstock, unpublished data). The herbicide site necessarily experienced reduced wetland function in the first year post-treatment because of diminished re-growth, since nutrient uptake and transpirational water loss were confined to those few areas supporting live vegetation. In contrast, the herbicide-burn site, with no standing thatch, exhibited rapid regrowth of *non-Phragmites* vegetation within the first year and diverse plant community was present at the end of the growing season. This rapid recovery was evident in higher numbers of plant individuals and a higher diversity index in the first year post-treatment. Therefore, it is probable that the herbicide-burn site also showed a more rapid return to full wetland function.

Long-term differences between treatments were restricted to plant diversity. The herbicide-burn site, while initially higher in diversity, showed a reduction in the

calculated index after two growing seasons. In the 1990 enumeration, one newly-recruited species, *Panicum verrucosum* (warty panic grass) had nearly 2,000 individuals. This relatively high number had a depressing effect on the index value. In the 1991 census, the number of *P. verrucosum* individuals increased 25 percent (to 2,469) while new species appeared and individuals were more evenly distributed. The Simpson's index increased accordingly. In contrast, plant biodiversity at the herbicide site increased linearly through four growing seasons before experiencing any decline. We believe this difference is a result of the diverse microhabitats created as the dead *Phragmites* stems and thatch slowly decomposed. The resulting variation in habitat features, such as light regime and soil moisture, favored mixed species colonization and precluded extensive expansion of any one species.

Site-specific characteristics determine whether burning is a desirable component of *Phragmites* control programs. Burning produces greater site disturbance and thus temporarily leaves the site vulnerable to nutrient release from ash and surface erosion, which will vary according to a site's topography, soils, and hydrology. Burning also reduces overwintering vegetation cover for faunal habitat and may result in lower long-term plant biodiversity. However, burning does favor the rapid reestablishment of non-target vegetation, and thereby, likely restores habitat and wetland functions associated with full vegetative cover.

The rapid plant growth at both sites post-treatment was undoubtedly due to a large and diverse soil seed bank. Germination of soil cores showed some plant types, such as *Phragmites* and *Boehmeria cylindrica*, present as seeds and as adults in the pre-treatment survey. Others, such as *Agrostis hyemalis*, were present as seeds in high proportion but absent as adults. By maintaining a viable seed bank, these wetlands can respond to vegetation loss and disturbance, including herbicide application, with a

diverse plant community in the next growing season. Without such a soil seed bank, it is unclear how quickly a *Phragmites* dominated plant community could respond or how diverse would be the eventual re-growth.

Evaluation of *Phragmites* propagule survivorship suggests that human activity in wetlands favors the expansion of this species. Buried rhizomes with their abundant food reserves were successfully established in all high marsh and greenhouse environments. Although animal dispersal and natural erosion may detach, transplant, and bury rhizomes in a new area, a more likely scenario is the transplanting of rhizomes by the machinery used for construction activities occurring in and around wetlands. In one instance, 69 rhizome buds were removed from the treads of a tracked vehicle working in a *Phragmites* dominated community (M. S. Ailstock, personal observation). These rhizomes could be effectively transplanted in new locations by this machinery.

Human disturbance may also favor *Phragmites* seed establishment. Although recruitment by seeds was low on both bare and burned wetland soils, the large numbers of seeds produced and their effective dispersal adaptations make this method of *Phragmites* establishment significant with wetland manipulation practices that disturb soils or remove their vegetative cover. Anecdotal evidence suggests this method of recruitment is also important in tidal marshes that have experienced excessive predation by snow geese (M. S. Ailstock, personal observation at Bombay Hook National Wildlife Refuge, Leipsic, Delaware, U.S.A.)

The majority of animal species inhabiting *Phragmites* wetlands were macroinvertebrates. This animal community appeared unaffected by treatment at either site. Both sites showed increases in their animal diversity indices post-treatment, yet by the study's end both had returned to pre-treatment values and these changes in diversity were not correlated with any measured changes in any plant parameter. The invertebrate diversity changes may be related to detrital increases as *Phragmites* stems decay (Polunin 1982). However, without measurements from an untreated control site, invertebrate population fluctuations due to other factors are also possible. Survey of the five major invertebrate groups present at both sites showed no consistent changes in abundance over the course of the study. This suggests that in this ecosystem, major changes in the diversity and abundance of primary producers may occur with no resultant changes in the community' of primary and secondary consumers. Evidently, one plant species serves as well as another, at least for the major invertebrate groups. This is consistent with a report of tidal *Phragmites* use by the fish *Fundulus heteroclitus* (mummichog) (Fell et al. 1998).

Some aspects of this study support an active control program as part of *Phragmites* management. An increase

in the number of plant species, with a concomitant increase in diversity, may be generally interpreted as positive change in a natural environment for some communities, and is consistent with the goal of *Phragmites* control in nontidal wetlands. The protection of less abundant plant species in wetlands communities may be important in the face of *Phragmites* expansion and may eventually be necessary to avoid local extirpation of some species.

Several elements of this study argue for site specific planning when contemplating *Phragmites* control. First, successful conversion of *Phragmites* dominated wetlands using only chemical control requires the presence of a diverse soil seed bank and/or a nearby source of seeds of appropriate wetlands species for natural recruitment. Areas that do not possess such seed sources may require manual planting to hasten site recovery. Second, the effects of a *Phragmites* control program may be temporary, especially in areas prone to human disturbance. By year five of this study, *Phragmites* was increasing in abundance, and without intervention would likely have returned to its pre-treatment dominant status. The authors hold the opinion this re-growth could be minimized by second and third year spot applications to the few plants surviving the initial treatment. Third, a reduction in *Phragmites* does not appear to increase the diversity of soil macroinvertebrates, since they were similar and remained stable in *Phragmites* colonies and the more diverse plant communities resulting from *Phragmites* control. Thus, control efforts should not be construed as a significant benefit to these populations. Finally, *Phragmites*, like many wetland plants, stabilizes soil through root growth and thatch accumulation and enhances water quality by nutrient cycling and transpirational water loss. Management plans aimed at control should be timed to minimize barren soil resulting from *Phragmites* eradication.

Wise decisions concerning this plant species will be difficult without a more complete understanding of its biology and ecology. Future studies of *Phragmites* must examine the underlying ecological and physical changes in its habitat that likely have led to its expansion in recent years. Increases in anthropogenic soil disturbances in wetlands, with their capacity to spread and bury *Phragmites* rhizomes or provide unvegetated soils for direct contact of seeds to soil, favor the reproductive strategies of *Phragmites* over other types of wetlands vegetation. There is also evidence that in some areas of North America a non-indigenous, more invasive *Phragmites* ecotype has appeared (Hauber et al. 1991; but see Koppitz 1999). Anthropogenic disturbances would likely favor aggressive ecotypes of *Phragmites* (Hauber et al. 1991). Additionally, traditional marsh manipulation practices, like seasonal flooding or marsh burning, should be examined for their possible roles in favoring the competitive

for their possible roles in favoring the competitive strategies of *Phragmites*. Changes in hydrologic conditions due to increased runoff and the growth of urban areas may also be important. Until these parameters are understood, control programs must be evaluated on an individual basis to achieve the goals of enhancing biodiversity. Such programs must include site-specific management plans, multi-year herbicide application, and provisions to discourage *Phragmites* re-establishment while encouraging non-target plant recruitment. Any control program must be evaluated in light of costs, the goals of enhancing biodiversity, and the system attributes that influence the conversion of *Phragmites*-dominated plant communities.

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