Native and Introduced *Phragmites*: Challenges in Identification, Research, and Management of the Common Reed

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About This Document

Common reed, *Phragmites australis*, has recently been shown to have multiple lineages co-occurring in North America. Historical and genetic evidence confirm *Phragmites* (*P.a. americanus*) as part of the native North American flora, but today an introduced lineage, thought to originate from Eurasia, is the most common type. Today along the Atlantic Coast, the exotic lineage has displaced native populations, which are now rare in coastal marshes from New Jersey to Maine.

Introduced *Phragmites* is probably the most common invasive species in our coastal marshes and has been the subject of much research regarding its impacts on marsh communities. To help resource managers and scientists identify the morphological differences between native and non-native *Phragmites*, a workshop, entitled Field Identification of *Phragmites australis* and *Phragmites australis americanus* in New England, was held at the Great Bay National Estuarine Research Reserve. This document summarizes presentations from the workshop with additional information on native *Phragmites*.

The distribution of native and non-native *Phragmites* across North America is described based on genetic information. Morphological differences are described in a key as well as in photographs to outline the multiple characters needed to successfully distinguish between native and non-native plants. The current understanding of the ecology of both native and non-native *Phragmites* is also discussed, followed by a description of on-going work. Finally, a step by step guide to developing an effective *Phragmites* management strategy is provided to aid decision-makers in determining the best course of action.

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This document summarizes the information presented at the workshop "Field Identification of *Phragmites australis* and *Phragmites australis americanus* in New England: A Framework for the Field Identification of Exotic and Native *Phragmites*" held Sept. 15, 2005 at the Hugh Gregg Coastal Conservation Center, Great Bay National Estuarine Research Reserve in Stratham, NH. The GBNERR Coastal Training Program funded the workshop. GBNERR would like to acknowledge New Hampshire SeaGrant for providing microscopes used by the participants. We thank Alyson Eberhardt for assistance in setting up the workshop. Our thanks also to the three anonymous reviewers for their comments on this manuscript.

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Introduction

Common reed, *Phragmites australis*, has recently been shown to have multiple lineages co-occurring in North America. Historical and genetic evidence confirm *Phragmites* (*P.a. americanus*) as part of the native North American flora, but today an introduced lineage, thought to originate from Eurasia, is the most common type. Morphological and genetic differences have been used to describe the distribution of both native and introduced *Phragmite*s. Today along the Atlantic Coast, the introduced lineage has displaced native populations, which are now rare in coastal marshes from New Jersey to Maine. Introduced *Phragmites* is probably the most common invasive species in our coastal marshes and has been the subject of much research regarding its impacts on marsh communities. Current research also documents differences in how native and non-native *Phragmites* may respond to varied environmental conditions such as salinity. Management questions regarding *Phragmites* control now need to consider the origin of specific populations prior to determining a course of action.

To help resource managers and scientists identify the morphological differences between native and non-native *Phragmites*, a workshop was held at the Great Bay National Estuarine Research Reserve's (GBNERR) Hugh Gregg Coastal Conservation Center. The following proceedings combine elements of presentations from the workshop with additional information on native *Phragmites*.

The distribution of native and non-native *Phragmites* across North America is described below based on genetic information. Distinguishing between native and introduced *Phragmites* is challenging due to overlap in most morphological characteristics. These morphological differences are described in a key as well as shown in pictures to outline the multiple characters needed to successfully distinguish between native and non-native plants. The current understanding of the ecology of both native and non-native *Phragmites* is also discussed, followed by a description of on-going work. Finally, a step-by-step guide to developing an effective *Phragmites* management strategy is provided to aid decision makers in determining a best course of action.

Distribution of Native and Introduced *Phragmites* in North America

Historical evidence clearly indicates that *Phragmites australis* is native to the flora of North America. Preserved remains that are 40,000 years old have been found in the southwestern U.S. indicating that it is a part of the native flora of that region (Hansen 1978). In coastal areas, preserved rhizome fragments dating back 3000-4000 years have been found in salt marsh sediments (Orson 1999, Gorman & Wells 2000). Native American utilization of *Phragmites* includes the use of culms for arrow shafts, musical instruments, ceremonial objects, and cigarettes; and both leaves and culms for constructing mats (Kiviat & Hamilton 2001).

Genetic studies comparing *Phragmites* from historical and modern populations collected throughout North America and worldwide clearly indicate that both native and introduced lineages of *Phragmites* are found today in North America (Fig. 1; Saltonstall 2002, 2003a, b). Based on this genetic data and morphological differences between the two lineages, *Phragmites* originating from North America has been named a separate subspecies, *P.a. americanus* (Saltonstall et al. 2004; hereafter referred to as native *Phragmites*). Introduced North American *Phragmites* (Haplotype M in Fig. 1) is most closely related to *Phragmites* populations found in Eurasia and likely originated there. A clear designation of subspecies name has not been identified for this lineage, thus it will hereafter be referred to as introduced *Phragmites* in this document.

Today native *Phragmites* is still found throughout its historical range, which includes much of the United States and southern Canada (Fig. 2a). Although it was more common historically (Saltonstall 2002), remnant populations can still be found along the Atlantic coast, particularly on the Delmarva peninsula (Meadows & Saltonstall 2007). In the Midwest and along the west coast, native *Phragmites* is most common in wetlands that are not heavily impacted by human activities.

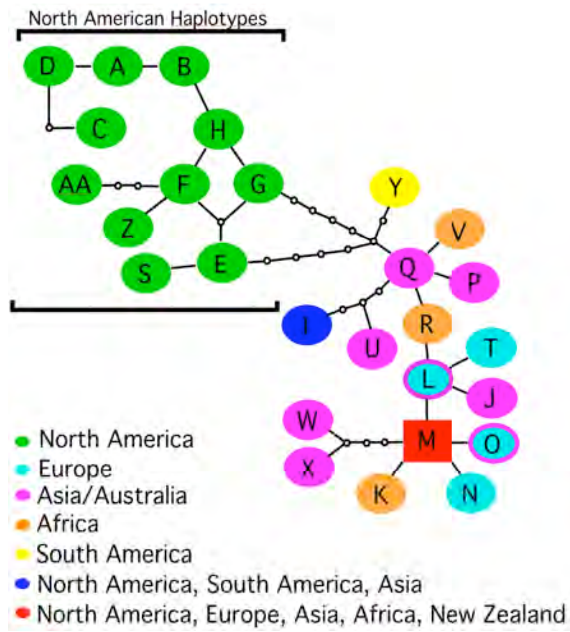
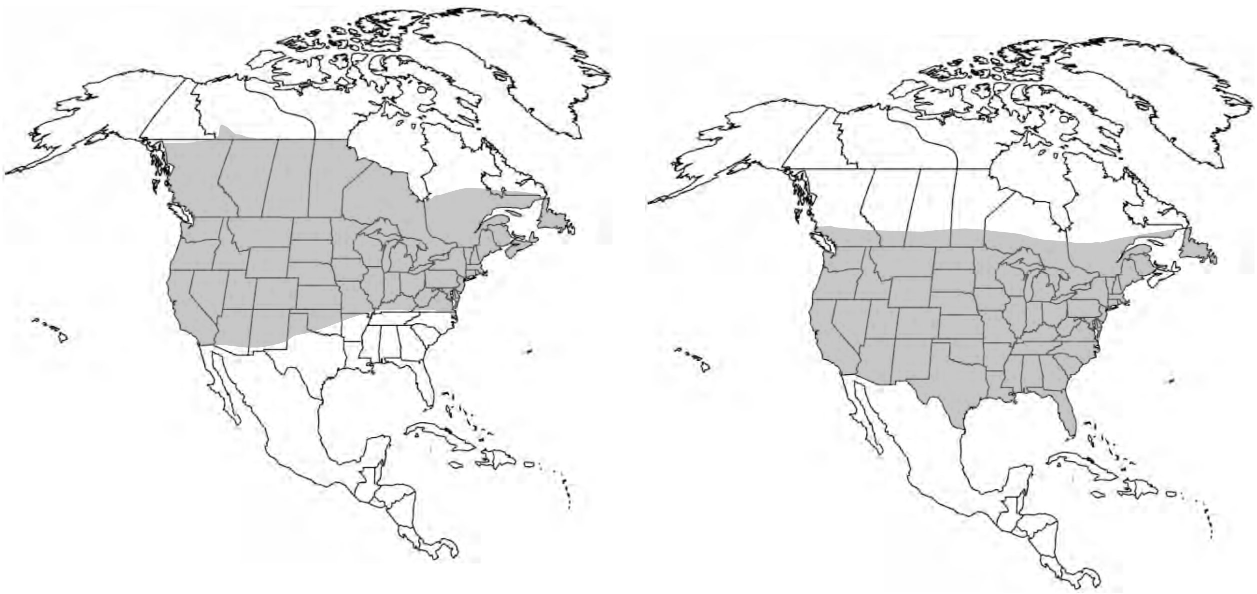


Figure 1. Network of *Phragmites* chloroplast DNA haplotypes found worldwide. The network was generated based on combined sequences of the *trnT*a-*trnL*b and *rbcL-psaI* intergenic spacer regions. Haplotypes are represented by letters and are color-coded by continent of origin. Lines connecting the haplotypes represent mutations. Eleven haplotypes (A-H, S, Z, AA) were identified that are unique to North America and share five mutations not found in haplotypes elsewhere. Haplotypes sharing these mutations are considered to be native *Phragmites*. Haplotype M is the most common haplotype worldwide but, while it is widespread today across North America, it was not found here historically. It is the genetic lineage found in introduced populations of *Phragmites* in North America. (From Saltonstall 2002.)

Introduced *Phragmites* is thought to have arrived in North America accidentally, most likely in ballast material in the late 18th or early 19th centuries. It established itself along the Atlantic coast and, over the course of the 20th century, spread across the continent. Today it is found in all of the lower 48 states and is particularly common along the Atlantic Coast, where it dominates many coastal marsh habitats (Fig. 2b). In the Midwest and western parts of North America, introduced *Phragmites* is found primarily along roadsides and waterways where human traffic is common (Saltonstall 2002, 2003a).



a b.[1]

Figure 2. Present distribution of a) native and b) introduced *Phragmites* in North America.

[1]Although not documented across the Gulf Coast except for the Mississippi River Delta (Saltonstall 2002), introduced *Phragmites* may already have invaded these regions and certainly has the potential to spread into them. The distribution of introduced *Phragmites* is not known south of the U.S. border and thus is not included in this figure. From Saltonstall et al. 2004.

Ecological Abilities of Native and Introduced *Phragmites australis* in Tidal Marshes[1]

Rapid Expansion and Ecological Impacts from Introduced Phragmites

Phragmites is expanding rapidly into tidal wetlands of North America (Chambers et al. 1999). In New England, *Phragmites* is replacing the short meadow grasses that once dominated tidal marshes. Encroachment is evidenced by staddles, used into the 20th century to dry salt marsh hay, some of which are now surrounded by pure stands of *Phragmites* (Figure 3).

Figure 3. Wooden pilings of a staddle previously in *Spartina patens* marsh, presently surrounded by a stand of introduced *Phragmites*.

[1] Based on: Understanding success of *Phragmites australis*, as it exploits human impacts to coastal marshes presented at *Phragmites australis*: A Sheep in Wolf's Clothing. January 6-9, 2002, Vineland, NJ, and published in the proceedings as: Burdick, D. M., and R. A. Konisky. 2003. Determinants of expansion for *Phragmites australis*, common reed, in natural and impacted coastal marshes. *Estuaries* 26:407-416.

The primary method of expansion for most *Phragmites* populations is through vegetative growth. In coastal areas where tides and currents can facilitate rhizome spread, establishment of new populations from fragments of rhizomes occurs readily (Bart and Hartman 2003). Although *Phragmites* culms may produce copious amounts of seed, seed viability is typically low (Harris and Marshall 1960, Tucker, 1990; Marks et al. 1994) and can vary greatly from year to year (KS unpub. data). New populations may also establish via dispersal of this seed but once established, rhizome spread and clonal growth can rapidly overtake other species.

A shift from a *Spartina*-dominated marsh to a monoculture of *Phragmites* results in dramatic structural changes and also a variety of functional changes. *Phragmites* invasions lead to declines in soil salinity, ammonium, sulfides, and topographic relief (Windham and Lathrop 1999, Bart and Hartman 2000, 2003); increases in production as well as decomposition; and decreases in biodiversity (Warren et al. 2001). Benoit and Askins (1999) reported a decline in use by marsh-dependent birds due to *Phragmites*. Reduced flooding accompanying *Phragmites* invasion has been found to depress secondary production and export of fish (Able et al. 2003). Aesthetic values are also negatively impacted by *Phragmites* invasion (Figure 4). Since functional changes impair such ecological services such as maintenance of biodiversity and support of fisheries, resource managers are compelled to plan and implement control measures.

Figure 4. Obstruction of views is one aesthetic impact of introduced *Phragmites*.

Abilities of Introduced Phragmites

To begin to understand its success, we need to know the abilities of *Phragmites* to tolerate physical stresses and compete for limiting resources. Salt water flooding is the most important physical stress that structures plant communities in salt marshes (Mitsch and Gosselink 2000). The tides bring about waterlogging stress, where roots are deprived of oxygen, as well as salinity stress. In addition, anaerobic soil conditions foster accumulation of sulfides as a byproduct of microbial breakdown of organic matter. High sulfide concentrations are toxic to plants and are thought to interfere with nitrogen uptake (Chambers 1997). Interestingly, nitrogen is a key nutrient needed to build osmotica, which are molecules accumulated to counter salinity impacts.

Like many invasive exotic plants, introduced *Phragmites* appears to have few predators, parasites, or diseases in the eastern U.S. However, even though the native subspecies appears so similar to the introduced European lineage that they have been described as the same species, native stands may host more consumers (Tewksbury et al. 2002). We need to know how the introduced *Phragmites* survives biotic stresses (competition, disease, predation, parasitism) and out-competes typical salt marsh plants.

Over the past 20 years, plant ecologists have developed a better understanding of plant competition through greenhouse and field experiments (Tilman 1988). Competition occurs mainly through aboveground interactions if soil factors are NOT limiting, but occurs belowground if soil factors ARE limiting. Their findings have been extended to plant interactions in salt marshes (Levine et al. 1998; Emery et al. 2001). However, competitive dominance can switch with changes in soil factors (e.g., nutrients) that occur in both space and time! Furthermore, our observations and experiments indicate introduced *Phragmites* doesn't adhere to the anthropocentric rules devised by ecologists to understand plant competition.

Field Experiment Using Introduced Phragmites

A field experiment was conducted (Konisky and Burdick 2004) whereby pairs of exhumed *Phragmites* culms attached to rhizomes were planted in open-bottom pots alone and with pairs of potential competitors (*Spartina alterniflora, S. patens, Juncus gerardii, Typha angustifolia* and *Lythrum salicornia*). *Phragmites* grew best at the high elevation, low salinity site. However, it also did well at the low elevation, high salinity site. This suggests that if established at lower elevations, this plant could invade large areas of salt marsh, not just the upper edges or upper brackish reaches of estuaries in New England.

Competition results based on relative growth show that the growth of *Phragmites* was not reduced by any salt marsh species. However, *Spartina alterniflora* was the native species most impacted by introduced *Phragmites*. Results from the field experiment show that *Phragmites* is a stronger competitor than *S. alterniflora* and if it can become established, a huge area of tidal marsh is susceptible to invasion by introduced *Phragmites*.

Descriptive Field Study of Phragmites

Expansion by *Phragmites* colonies at the upper edges of six natural and human impacted salt marshes in Massachusetts was examined in conjunction with soil salinity at three depths: 5-20, 35-50 and 65-80 cm (Burdick et al 2001). Two important points were made from this research. One is that introduced *Phragmites* growing in New England salt marshes is very salinity tolerant, successfully out-competing native grasses even though the salinity can average over 25 ppt in the latter part of the growing season. Secondly, in summer these plants may be maintaining health by accessing less saline water at depths unavailable to native marsh grasses (> 50 cm).

Phragmites Doesn't Play by the Rules

There are several ways that typical concepts of plant competition do not apply to invading stands of introduced *Phragmites*:

1) *Phragmites* can avoid physical stress by accessing resources unavailable to typical marsh plants as shown in the field study above.

2) It can also alter soil conditions (aerate and reduce toxic sulfides) as found by Windham and Lathrop (1999) and Bart and Hartman (2000), thereby altering the conditions where competition takes place.

3) Like many marsh grasses, *Phragmites* is a clonal plant. It can reproduce itself vegetatively, and many genetically identical stems can be connected by underground rhizomes to form one living plant. No one knows how large and how old a *Phragmites* clone can become. The size and length of its roots and rhizomes allow *Phragmites* to 'forage' for resources (light and nitrogen) and less stressful conditions (lower salinity and sulfides). *Phragmites* can also transfer resources through these rhizomes (such as water, sugar, nutrients) so established plants do not have to die off in areas with lethal conditions (Bart and Hartman 2000).

4) Very high tides in the fall carry floating senescent marsh vegetation around the estuary. Strong onshore winds can drive mats of dead plants upon marshes until tall plants block further movement and falling tides place the material on the marsh surface (Figure 5).

Figure 5. Wrack burial of native plants in competition with and adjacent to *Phragmites*.

Phragmites stands make perfect tall edges and the wrack deposits, as the mats are called, often wind up just seaward of *Phragmites* stands (Minchinton 2002). Unfortunately, native marsh plants are susceptible to burial and often are killed by wrack deposits. After several years, the wrack decomposes and disintegrates and the bare soil is easily colonized by the adjacent *Phragmites* stand without competition, as found by Minchinton (2002).

Other ways introduced *Phragmites* (and in some cases, perhaps native *Phragmites*) does not follow the paradigms established by plant ecologists are related to human activities.

5) Development and soil disturbance at the upper edges of marshes as well as spoil disposal from ditch creation and maintenance provide bare sunlit soil with low salinity (Figure 6). These are sites that can be colonized by *Phragmites* (Bart and Hartman 2003).

Figure 6. Exposed soils on salt marsh fill.

6) Fresh water runoff increases with greater areas of impervious surfaces surrounding marshes. Filling marsh edges and surrounding uplands to reduce flooding hazard also increases groundwater slope and thus fresh water flow to the margins.

7) Road and railroad crossings across marshes are plentiful, and the hydrologic alterations caused by the crossings have several impacts that foster establishment and spread of invasive *Phragmites*. Tidal restrictions from these crossings decrease flooding and salinity from tides, decrease sediment supply, impound fresh water (Figure 7), and can cause subsidence (fall in elevation of the marsh surface), which is likely to increase groundwater discharge along margins. By decreasing flooding and salinity, crossings encourage invasive species like *Phragmites.*

Figure 7. Introduced stand of *Phragmites* with fresh water impounded behind road crossing.

8) As populations rise along our coasts, so do biologically available forms of nitrogen in the atmosphere as well as in soils from runoff (e.g., lawn fertilizer). Higher nitrogen levels are thought to favor invading *Phragmites* (Bertness et al. 2002).

9) Furthermore, there is a global effect of atmospheric CO_2 enrichment, which favors plants with a C_3 photosynthetic pathway like *Phragmites*, over C_4 plants like *Spartina* (Ziska 2001)

In conclusion, it seems that introduced *Phragmites* is so successful because its morphology and behavior allows it to avoid physical stresses and competition with typical marsh plants. It can capitalize on windows of opportunity to establish in tidal marshes. It becomes a large clonal organism that shares resources via underground rhizomes to exploit spatial differences in stresses and resources. Finally, it avoids biological stress associated with competition because it is not competing for the same resources or exposed to the same stresses as adjacent *Spartina* plants. Are the incredible abilities of *Phragmites* restricted to the introduced variety from Europe or are they shared by our native varieties? This question needs to be addressed through greenhouse and field experiments.

Native Compared to Introduced Abilities

At present, no dramatic ecological differences between native and introduced subspecies of *Phragmites* have been established. However, the rapid expansion of the introduced form along the coastal marshes of North America suggests that significant differences exist between the lineages. Along the Atlantic coast, extensive research has been done on introduced *Phragmites* but research on native populations is preliminary. Scientists and managers have thought it likely that the native is less tolerant of physical stresses such as flooding, salinity, and sulfides, and less competitive than the introduced form. Preliminary evidence supports this claim. Field observations on the Delmarva Peninsula suggest that the native typically has lower culm density, lower aboveground biomass, grows in mixed communities, and is found primarily in freshwater or oligohaline tidal marsh habitats (League et al. 2006, Meadows and Saltonstall 2007). In New England, native *Phragmites* has also been found in salt/brackish marsh habitats where it typically grows in mixed communities with a lower culm density than introduced *Phragmites*.

Laboratory experiments using plants grown from rhizomes suggest that native *Phragmites* from Delaware has a lower salinity tolerance than introduced populations from the same region

(Vasquez et al. 2005). Another experiment looking at responses of native and introduced *Phragmites* to high and low nutrient conditions found that while both lineages grew better with increased nutrients, native *Phragmites* growing under high nutrient conditions grew no better than introduced *Phragmites* under low nutrient conditions suggesting that their nutrient uptake abilities may differ. Under all treatments in this experiment, introduced *Phragmites* had greater culm density, was taller, and had greater above- and below-ground biomass, clearly demonstrating its superior growth performance. Further, plants grown in competition and under the same conditions also demonstrated that introduced *Phragmites* was the superior competitor in all cases (Saltonstall and Stevenson 2007). On the other hand, a field experiment showed no differences in growth or survival between culms from adjacent native and introduced populations planted in a New England salt marsh (Peter et al. 2005). Additional studies comparing the growth of native *Phragmites* with other marsh plants are needed to better understand its competitive ability.

Morphological Differences between Native and Introduced *Phragmites*

Using morphology to distinguish between native and introduced *Phragmites* can be a challenging exercise due to overlap in characters between the two types and differences in interpretation of some characters by different individuals (human error). The following information to determine whether a *Phragmites* population is native or introduced should be used with caution, and multiple characters *must* be considered. No single character in isolation is diagnostic. Native plants originating from different parts of the country may look different, even if they have the same haplotype, and seasonal changes may obscure some characters while enhancing others.

If confirmation of native/introduced status is needed, a genetic test based on a RFLP diagnostic assay has been developed that can confirm this status (Saltonstall 2003c). Contact Kristin Saltonstall at kristin.saltonstall@aya.yale.edu for a detailed protocol.

Key to the lineages of *Phragmites australis* in North America
(From Saltonstall and Hauber 2007)

1. Ligules 1.0—1.7 mm long; lower glumes 3.0 – 6.5 mm long; upper glumes 5.5—11.0 mm long; lemmas 8.0—13.5 mm long; leaf sheaths drop off the culms with age; culms exposed in the winter, smooth and shiny; rarely occurs in a monoculture; chloroplast DNA haplotypes A-H, S, Z, AA, AB, AC (see Saltonstall 2002, 2003a)

P. australis subsp. ***americanus*** (Native lineage)

1. Ligules 0.4—0.9 mm long; lower glumes 2.5—5.0 mm long; upper glumes 4.5—7.5 mm long; lemmas 7.5—12.0 mm long; leaf sheaths held tightly with age; culms not exposed in the winter, smooth and shiny or ridged and not shiny; usually occurs as a monoculture; chloroplast DNA haplotypes I or M.

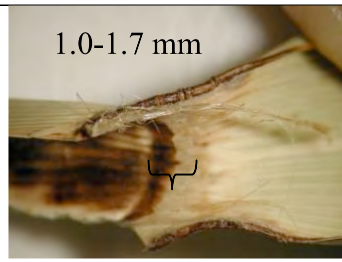
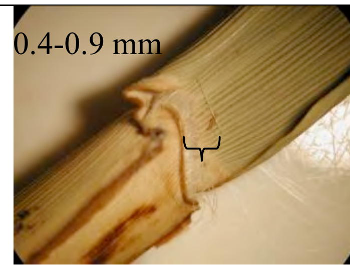
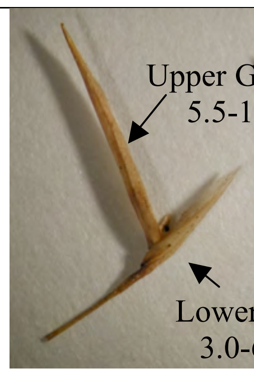
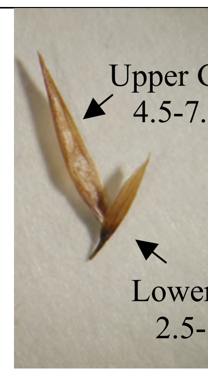
    2. Culms smooth and shiny; southern California, Arizona, New Mexico, Texas to Florida, throughout Mexico and Central America; chloroplast DNA haplotype I

    P. australis subsp. ***berlandieri*** (Gulf Coast lineage)

    2. Culms ridged and not shiny; southern Canada from British Columbia to Quebec south throughout the Continental United States; chloroplast DNA haplotype M

    P. australis (Introduced lineage)

Table 1: Examples of morphological characters used to distinguish native and introduced *Phragmites* populations. Characters marked with a * are the most diagnostic.

Character	Native	Introduced	Comments
Ligule*			Best measured under a dissecting microscope. Choose a fully expanded green leaf. Measure from the base of the membrane to the top of the fringe of hairs that borders it. Ignore any longer hairs—these break off easily and are not diagnostic. Take three measurements and average.
Glumes*			Can be measured with a ruler to the nearest 0.5 mm. Be careful to not break off the base of the upper glume when separating it from the lower one. Measure at least 10 upper and 10 lower glumes from a panicle and average.

Adherence of leaf sheaths*			Native: Most leaf sheaths missing or very loosely attached to dead culms. On live culms, leaf sheaths are also loose or dropped on lower nodes. Are easily removed if any remain. Introduced: Leaf sheaths tightly adhere to both live and dead culms (although the leaves may have dropped off). Are difficult to remove.
Culm color			Native: Live culms may have red-purple color at nodes and in internodes where the culm has been exposed to sunlight. May also be green. Dead culms turn chestnut brown where UV exposure occurred. Introduced: Typically green but may have some red color at the basal nodes. Dead culms are typically yellow.

Culm texture; Presence of fungus			Remove any leaf sheaths and run a thumbnail across the culm. Native: Culm is typically smooth and shiny. May have round spots on the culm clustering near the nodes. These typically appear in mid-summer and persist on dead culms (but are *not always present).* Introduced: Culm is typically slightly ridged and not shiny. Often has mildew-like fungus on the culm
Stem density	Typically lower than introduced with fewer standing dead stems. Monocultures are rare but can occur.	Typically high with both live and dead stems prevalent. Mature stands often form a monoculture. Younger populations or those growing in poor sites may grow in mixed communities.	
Timing of senescence			Native typically dies back earlier than Introduced, which remains, green later in the growing season.

Steps to Develop a Management Strategy for *Phragmites* Control

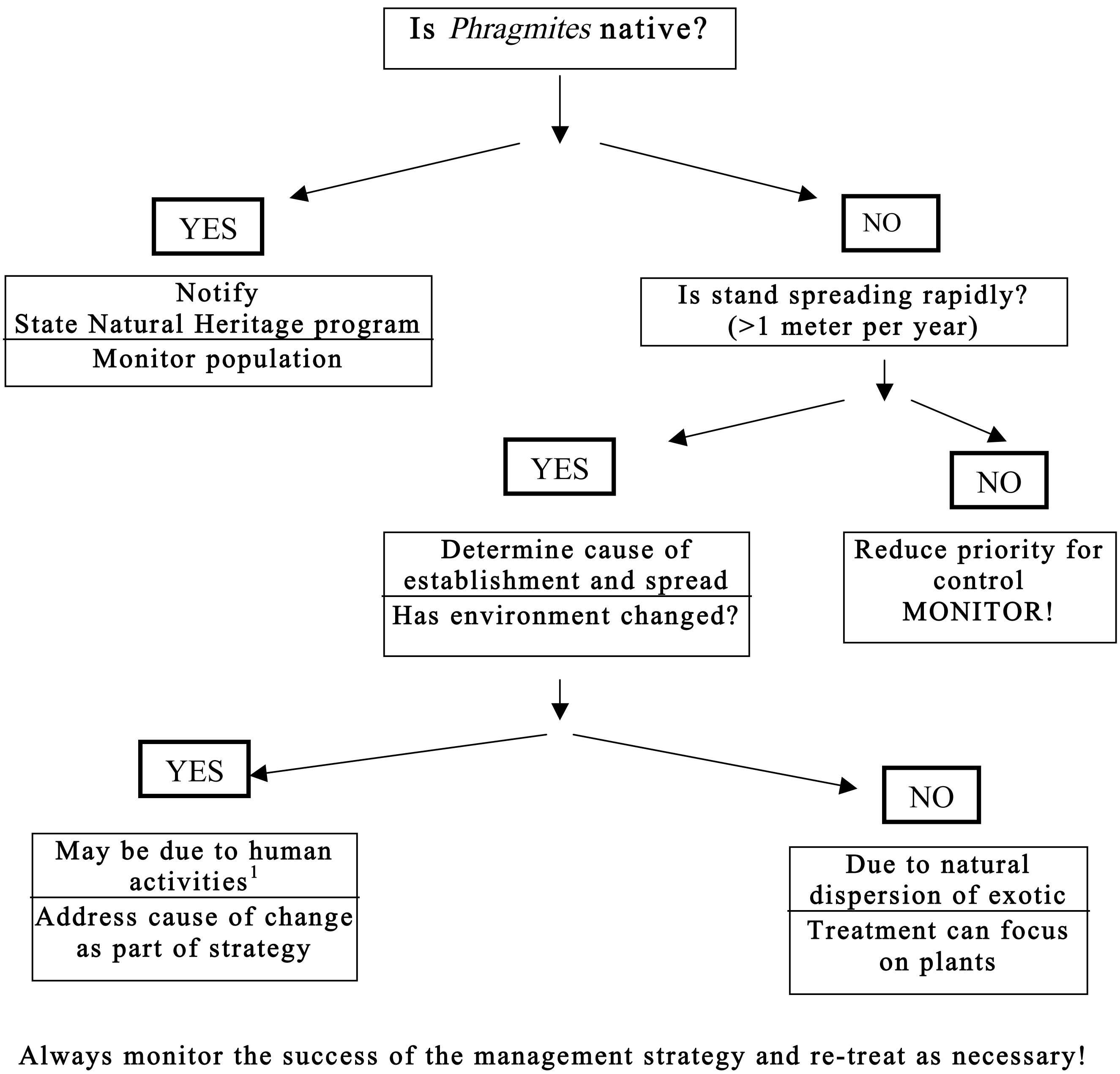
Resource agencies often wish to manage or control *Phragmites* due to its ability to alter ecosystems and disrupt functions that have important ecosystem services for humans and wildlife, such as fish production in tidal marshes. For resource managers reviewing or contemplating development in tidal and coastal marshes, an assessment should be made to determine whether the activities might result in *Phragmites* establishment and spread at the site. Bart et al. (2006) published a flow chart to help managers curb the proliferation of *Phragmites*. However, if *Phragmites* is already present in a resource area, there are a few important questions and steps that should be taken before a management strategy is developed. A management decision tree was created (Figure 8) to help resource managers determine if control is needed and develop a strategy for control. Managers should consult other resource agencies in their region to develop a control plan for introduced *Phragmites*. A useful plan should include specific goals, actions, monitoring and a mechanism to evaluate progress and determine next steps.

Baseline Questions

1) Is the *Phragmites* Native or Non-native?

Scientists or observers associated with your agency should use the information provided in this document to determine whether the population(s) you have are native or introduced. Have them collect and send plant samples for confirmation to the Invasive Plants Diagnostic Center at Cornell. Sample collection and shipment should follow the instructions found on the web site: www.invasiveplants.net/diag/diagnostic.asp/.

If your population(s) is believed to be native, take steps to protect it and notify your state's natural heritage program; your Coastal Zone Management Office (if it is in a coastal location); and Kristin Saltonstall (kristin.saltonstall@aya.yale.edu), who is maintaining a database of native *Phragmites* populations along the Atlantic Coast. If the stands are not native but introduced, develop a management strategy.



[1] These include activities that restrict tidal flooding (roadways or other transportation corridors across marshes), increase drainage or freshwater input (storm water from developed areas), or disturb soils (mosquito ditching, filling of marsh edges or adjacent uplands)

Figure 8. A Decision Tree for Developing a *Phragmites* Management Strategy.

Little work has been done regarding how to preserve and maintain native *Phragmites* populations. A good start is to document baseline conditions using methods such as:

a) photographing the stand;
b) using GPS to define the perimeter of the stand;
c) marking the edges to document whether the stand is declining or expanding in future years; and
d) identifying other plants in the community.

Should introduced *Phragmites* also be present, as it is in many sites where native *Phragmites* is found today, a management strategy for the exotic should be implemented as well.

2) What is the Rate and Nature of the Spread?

To determine whether introduced *Phragmites* is displacing native plants, see if there is any information available on the approximate date of appearance and changes over time of the stand. Sources might be anecdotal, such as interviews to document observations; or may be more objective, such as transect data, aerial photography, or GIS data. This may not be a simple task, but it is critical to understand the extent and immediacy of the problem. Management actions are less critical for stable populations.

If there are no data available, you can do a great service to your management group by documenting baseline conditions *right now*. Documenting presence can be accomplished by:

a) photographing the area using a specific photo location or aerial photography;
b) using GPS to define the outer circles of each stand;
c) marking the edges using stakes or flags; and
d) establishing the stand edges along a set of transects.

If quantitative rigor is desired, a clear method to define the edge of the stand needs to be incorporated into the sampling method. In 2001, Burdick et al. reported expansion rates based on plant cover, which defined inner (>95% of plant cover was *Phragmites*) and outer (<5% *Phragmites* cover) edges of each stand.

3) What Are the Most Likely Causes of the Invasion?

Introduced *Phragmites* populations can spread to new habitats and regions without the help of humans. On the other hand, expansion of introduced as well as native populations of *Phragmites* may often be due to human-induced changes in the invaded ecosystem. Observations have been made by many scientists that identify human activities as the most important factor that led to, or were associated with, establishment and spread of *Phragmites* (Roman et al. 1984, Bertness et al. 2002, Bart and Hartman 2003, Burdick and Konisky 2003). Indeed, this is likely true for most stands in New England tidal wetlands (personal observation DMB). Populations of introduced *Phragmites* can often be traced back to sites of soil disturbances, storm water runoff, or tidal restrictions.

Management Strategies

Development of a management strategy must include careful consideration of the human role in the establishment and spread of the stand. No amount of effort to control introduced *Phragmites* will be successful if the underlying cause of the invasion is not addressed. In many cases, *Phragmites* is the symptom of unintended effects of human activities occurring at a site. Determine what most likely led to the establishment and expansion of the stand and include management of the underlying cause, if present, in the strategy. It is also important to note that many states along the Atlantic Coast have cost-share programs that provide private landowners with funds and technical expertise to aid in initiating a *Phragmites* management control program.

Addressing the Human Role in *Phragmites* Expansion

If the stand is associated with human activities, tailor management objectives to treat both the symptoms and underlying causes of the invasion. A science-based approach should be used, but include other knowledge where appropriate (i.e., specific site and anecdotal information). It is important to fit resources to the problem and potential solutions. If resources are unavailable for the best rapid solution, then a longer-term approach or effort to procure resources needs to be considered. The best solutions should be long term and self-sustaining; key components of the plan should rely on natural processes to sustain native populations of marsh grasses. A useful exercise is to describe impacts of alternatives to management (including "do nothing"), so the full range of management options and their consequences are known and can be considered.

Currently, there are several approaches used to reverse the underlying causes of *Phragmites* invasions associated with human activities. Road and other transportation corridors have been built across tidal marshes resulting in restriction of tidal flows. In some cases, dikes have been built across marshes to convert marshes to agricultural lands. For marshlands where the tides have been restricted, tidal restoration is an important component of coastal restoration efforts in many states along the east coast (Rosza 1995, Cornelieson 1998).

Development adjacent to marshes is usually accompanied by an increase in storm water delivered to the surface of the marsh along its periphery. Water drainage from buildings, roadways, and other impervious surfaces is usually channeled to marshes. The added sediment and decreased salinity make these typical invasion sites. Solutions include treatment separators to remove sediments and other pollutants, and piped flow under marsh peat to intertidal channels. However, sediments built up in the marsh need to be removed along with the *Phragmites* as part of the restoration (Eric Hutchins, unpbl. results).

Both transportation corridors and development adjacent to marshes are associated with periodic soil disturbance along the corridor and edges. These are common invasion sites for not only *Phragmites*, but perennial pepperweed (*Lepidium latifolium*) and purple loosestrife (*Lythrum salicaria*) as well. Periodic soil disturbances are, by definition, without quick fixes. Management plans need to be developed that include regular education of people responsible for maintenance of roads and grounds so they know how to minimize disturbances, monitor likely invasion sites, and treat invading plants.

About half of the tidal wetlands in New England have been lost, mostly to filling (Gosselink and Bauman 1980). Many of the filled areas have been developed, but others, too wet for development, have been invaded by introduced *Phragmites*. Mosquito programs and transportation maintenance crews remove sediment from ditches and place the spoils on the marsh, the spoil fill provides sites for *Phragmites* invasion (Bart and Hartman 2003). Restoration programs in New England states have identified sites where removal of spoil is an important first step in tidal marsh restoration. Due to the threat of reinvasion, the Natural Resource Conservation Service in New Hampshire recommends excavation of filled sites to an elevation at or slightly below mean high water (Alan Ammann, personal communication).

Treating Introduced *Phragmites*

The following approaches can be used in a management plan if no human activities were linked to the establishment and spread of *Phragmites*, or if underlying causes have been addressed. Often direct treatment or removal of *Phragmites* is needed once physical processes are restored and human impacts minimized, since this plant can alter conditions to its benefit in tidal marshes. Treatment of newly established populations, while they are still small and before they completely dominate a marsh, may be the most effective way to control the spread of introduced *Phragmites*.

Physical removal is very effective as a short-term solution to *Phragmites* invasion if the belowground rhizomes are eliminated. Soil excavation and removal may be warranted where introduced monocultures have eliminated native plants. At other sites where invasive *Phragmites* is growing with native grasses, other treatments that harm only *Phragmites* may be more desirable.

Phragmites re-sprouting from rhizomes can render aboveground removal methods (such as mowing) ineffective. However, repeated driving over mowed areas appears to damage rhizomes and buds and slows recolonization. Burning is another treatment that removes aboveground portions, but allows deeper rhizomes to survive and re-sprout. Since it does not appear that native grasses are better at surviving burning or mowing treatments, neither method favors native plants over *Phragmites*.

Herbicides can be used indiscriminately on monocultures of introduced *Phragmites*, but also can be used on specific plants as follow-up treatment. Glyphosate, found in Rodeo™, which is approved by US EPA for use in wetlands, has proven effective at killing the aboveground portions and most of the rhizomes. However, it is unlikely that a population will be killed with a single application. Using these synthetic herbicides requires careful follow-up, with two or more years of targeted application. Selective application to *Phragmites* allows native plants to take over and help prevent reestablishment. Other herbicides are being investigated and natural organic acids (e.g., acetic) may be useful. Once all the rhizomes are killed, reestablishment can still occur through the seed bank or by new propagules (seeds or rhizomes sections) arriving at the site, so monitoring and retreatment is needed until native plant cover is restored.

Ongoing Work on Native *Phragmites*

The following list includes names of investigators who are themselves or have students currently working on questions associated with native *Phragmites*.

Harsh Bais (University of Delaware) is interested in understanding the mechanisms involved in invasion by *Phragmites australis*. His lab, in collaboration with Dr. John Gallagher, will elucidate the involvement of root-allelopathy in *P. australis* invasion. They are also working to identify the molecular targets of the produced toxin in *P. australis* using the model plant system Arabidopsis. The identification of a resistance gene against *P. australis* toxins would lead to the engineering of native plants to defend against *P. australis* invasion.

Mark Bertness (Brown University) has students currently pursuing questions associated with native *Phragmites*. Eric Von Wettberg (Brown University PhD candidate) is working with Christine Holdrege on her undergraduate research thesis. This project involves field trials comparing native *Phragmites* from New Hampshire's Great Bay to introduced plants in a Rhode Island salt marsh using a series of fertilization and salinity treatments.

Bernd Blossey (Cornell University) is interested in the ecological differences between native and non-native *Phragmites*, specifically looking at growing conditions and herbivore communities, differences in invasibility, and biological control of invasive stands.

David Burdick (University of New Hampshire) has been examining the distribution of native *Phragmites* in New Hampshire and comparing the ecological abilities of native and non-native plants in the field. He collaborates with Massachusetts Audubon to study the effectiveness of tidal restoration as a control measure. His graduate student, Chris Peter, has completed a thesis examining the role of native plants and plant diversity in preventing recolonization of restored sites by introduced *Phragmites*.

Richard Casagrande (University of Rhode Island) is working with his former PhD student Adam Lambert on the impacts of various organisms on native and non-native *Phragmites*, distribution of the two types in Rhode Island, as well as species diversity associated with each. He is also collaborating with Bernd Blossey on a long-term biological control project and with Laura Meyerson, also at URI, on hybridization between native and non-native *Phragmites*.

Randy Chambers (College of William and Mary) and a recent student, Tom Mozdzer, completed a project looking at the influence of salinity on emergence from rhizomes and growth of native *Phragmites* in tidal wetlands of the lower Rappahannock River. Tom is working on a PhD project on physiological differences between native vs. non-native *Phragmites* at the University of Virginia.

Jack Gallagher (University of Delaware) is focused on the rhizomes of native and non-native *Phragmites*. Specifically, he is looking at the dynamics of spreading, branching patterns, and response to salinity and nitrogen. He is interested in looking at how development in the watershed impacts the relationship between native and non-native *Phragmites*. He is working at the cellular level to determine differences between the two plants. His future research interests include determining how we approach maintenance of native strains while controlling the non-native ones.

Glenn Guntenspergen (US Geological Survey) was involved in the organization of the April 2003 special issue of the journal *Estuaries* dedicated to *Phragmites*. His interests for future work include determining how haplotype differences are manifested in terms of physiology and what that means in the field.

Laura Meyerson (University of Rhode Island) is investigating competitive relationships between native and introduced *Phragmites* in its native and introduced ranges, including hybridization between native and introduced *Phragmites* and the effect of environment on fitness in North America and Europe.

Kristin Saltonstall (Smithsonian Tropical Research Institute) has worked extensively on identifying genetic and morphological differences between native and introduced *Phragmites*. She is interested in the ecological differences between the two subspecies and what steps can be taken to preserve remnant native populations. She also hopes to determine the geographical origin of both introduced and Gulf Coast *Phragmites.*

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Appendix 1: List of Attendees

GBNERR Phragmites Identification Workshop Participants
September 15, 2005

Steve J. Miller
Coastal Training Program Coordinator, Great Bay National Estuarine Research Reserve

INSTRUCTORS

David M. Burdick, Ph.D., Associate Research Professor, Jackson Estuarine Laboratory

Kristin Saltonstall, Ph.D., Research Scientist, Horn Point Laboratory

PARTICIPANTS

Phil Brown, Sanctuaries Manager, NH Audubon

Jeremy Bell, Wetlands Restoration Program, MA Office of Coastal Zone Management

Peter Britz, Environmental Planner, City of Portsmouth

Nancy J. Cauvet, Great Bay Stewards

Dave Cowell, Vanasse Hangen Brustlin, Inc.

Matt Craig, Program Coordinator, Casco Bay Estuary Partnership

Kevin Cute, RI Coastal Resources Management Council

Patricia deBeer, Fremont Conservation Comm., UNH Marine Docent

James Dolansky, SeeKamp Environmental Consulting Inc.

Jen Drociak, Restoration Specialist, New Hampshire Coastal Program - NHDES

Alyson Eberhardt, University of New Hampshire, Jackson Estuarine Laboratory

Kathleen Giorgi, USDA, Natural Resource Conservation Service

Filson Glanz

Joanne S. Glode, Great Bay Stewardship Ecologist, The Nature Conservancy

John Halloran, Nock Middle School, Newburyport MA

Christine Holdridge, Ecology and Evolutionary Biology, Brown University

Beth Lambert, New Hampshire Coastal Program - NHDES

Eben Lewis, NHDES Wetlands Bureau

Mark Lickus, Maine DOT Environmental Office

Mike Morrison, Swamp, Inc.

Kate O'Brien, Refuge Biologist, USFWS Rachel Carson National Wildlife Refuge

Dr. Annamarie Pennucci, Northeast Turf and Ornamental Research

Eva Powers, Portsmouth Conservation Commission, Seacoast Land Trust

Edward Reiner, Senior Wetland Scientist USEPA

Frank D. Richardson, Ph.D., Senior Wetlands Inspector, NHDES Wetlands Bureau

Tim Smith, Wetlands Restoration Program, MA Office of Coastal Zone Management

Brian Smith, Research Coordinator, GBNERR

Rachel Stevens, Stewardship Coordinator, GBNERR

Jacob Tinus, CWS, Senior Environmental Scientist, Vanasse Hangen Brustlin, Inc.

Geoffrey Walker, NWR/MA DU Marsh Comm. Chair

Eric von Wettberg, Ecology and Evolutionary Biology, Brown University

Cathleen Wigand, Wetlands Ecologist, US EPA - NHEERL-AED

Chris Williams, Federal Consistency Coordinator, NH Coastal Program - NHDES

Geoff Wilson, Northeast Wetland Restoration

Appendix 2: Meeting Objectives and Agenda

Field Techniques to Identify Native and Introduced *Phragmites*: A Skills Workshop for New England Coastal Managers

Meeting Objectives

Recent scientific studies verify morphological differences between native and non-native subspecies of *Phragmites*. The goal of this workshop was to teach coastal land managers techniques in the identification of native and non-native *Phragmites* using morphological characteristics that have been confirmed by genetic studies. This one-day workshop afforded each participant the opportunity to gain experience in the identification of native and introduced *Phragmites* through field and laboratory work. Participants left the workshop with the skills necessary to identify native and non-native *Phragmites*, a notebook with keys and research papers, and data sheets to use in reporting native stands of *Phragmites*.

Workshop Agenda

8:30 Continental breakfast and registration check in

9:00 Welcome and introductions; Steve Miller

9:10 "Native or Introduced? Field Identification of *Phragmites australis* in North America." Kristin Saltonstall

9:50 "Ecological Abilities and Impacts From Introduced *Phragmites australis* on Coastal Marshes." Dave Burdick

10:30 Break

10:45 Field ID and specimen collection of native and introduced *Phragmites*: Travel to field sites of both native and introduced stands of *Phragmites* and examine plant ecology, morphology and stand characteristics of introduced *Phragmites*. Dave Burdick.

Examine plant ecology, morphology, and stand characteristics of native *Phragmites* with Kristin Saltonstall; collect samples of both types for laboratory examination.

12:15 Lunch at the HGCCC

1:00 Laboratory examination of native and introduced *Phragmites* to identify morphologic characteristics used in identification of types. Kristin Saltonstall and Dave Burdick.

3:00 Questions/discussion and evaluation

3:30 Centralized database: Introduce data collection sheets to be used to report native stands to central location. Kristin Saltonstall and Dave Burdick.

4:00 Adjourn