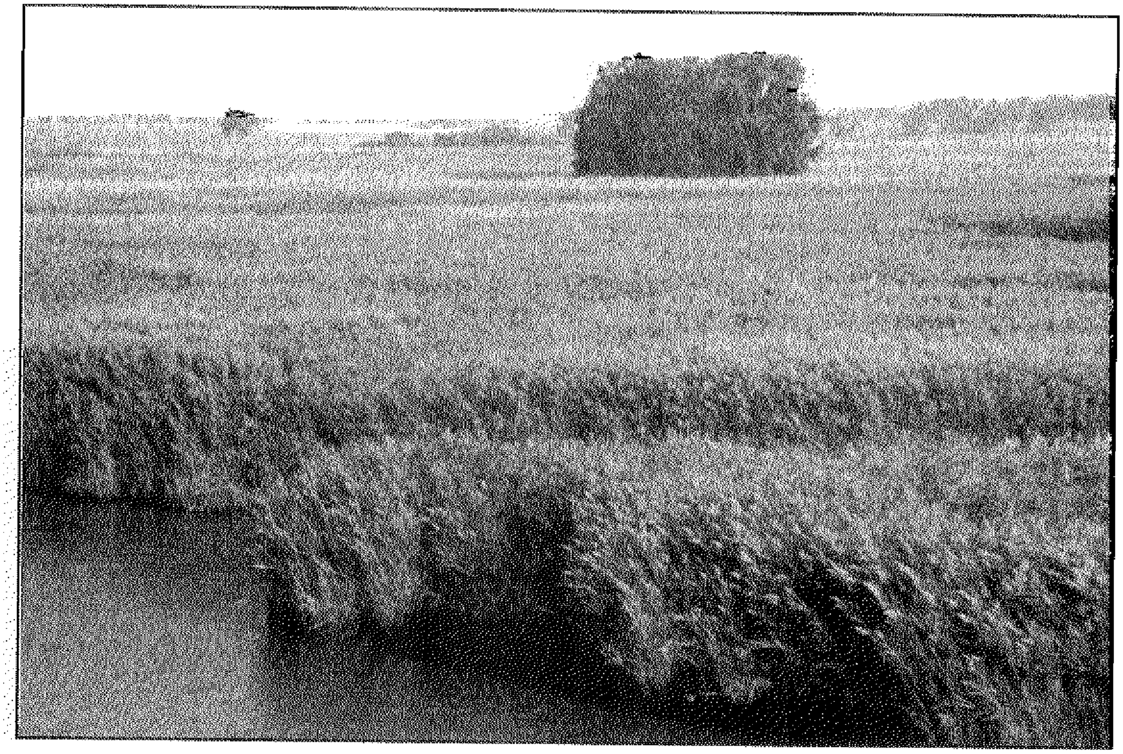
NJMSC-W-02-001 C2

Phragmites australis: A Sheep in Wolf's Clothing?



Proceedings from the Technical Forum & Workshop
6-9 January 2002
Cumberland County College
Vineland, NJ

NEW JERSEY MARINE SCIENCES CONSORTIUM

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Phragmites australis: A Sheep in Wolf's Clothing?

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PREFACE

A problem with national priorities for control or prevention of aquatic nuisance species (ANS) is that we often do not know the true extent of the problem, *if there is one*. To address this issue, we hosted a *Technical Forum* (Symposium and Workshop) -- Phragmites australis*: A Sheep in Wolf's Clothing?* -- with a focus on new research and critical reviews that address *Phragmites'* role as a "noxious weed". The extent to which *P. australis* affects habitat quality for fish and wildlife, alters the marsh landscape and its function, reduces ecological redundancy and contributes nutrients to the food web, both in the marsh and by export to coastal waters, were key topics in a day and a half of technical paper presentations and a facilitated workshop. Because so much effort was being placed on methods to eradicate *Phragmites*, including the use of herbicides and prescribed burns on a large scale, the topic was both timely and critical to future management decisions. Simply stated, is *Phragmites* the "villain" that many pose it to be, or does it have redeeming features worth an adaptive management approach rather than all out assault to eliminate it? Are efforts to control this native species, or its genetic analogue, well placed and are the causes of expansion being considered?

The specific goals of the Technical Session and Workshop were to:

1. Invite key scientists, currently active in *Phragmites* research, and managers/regulators to participate in a *Technical Forum* on the state of the science of *Phragmites* ecology in North America, its ecosystem function (or dysfunction), invasiveness, and control methods;
2. Conduct a *Facilitated Workshop* with a scientist panel and attendees to capture the needs of the management community for more informed decision making;
3. Publish a series of *Peer-Reviewed Scientific Papers* on key topics related to *Phragmites* ecology in North America; and
4. Publish a *Synthesis of Scientific Knowledge and Needs* (a "white paper") from the facilitated session to summarize for managers/regulators the current scientific thinking about *Phragmites* role in wetlands in North America.

The conference was designed to allow managers to hear directly from leading experts, and vice-versa. The peer-reviewed papers published from the technical session functions as a "one-stop" compilation of current knowledge and were disseminated widely in the form of reprints and on the Internet to Estuarine Research Federation members. The *Technical Forum* was timely because much of the research on *Phragmites australis*, although mostly of high quality, lacked national focus and was often fragmented. The Workshop helped focus the national effort in new multidisciplinary research to better understand the ecology of *Phragmites australis* and its ecosystem level effects on the "nursery" function of coastal wetlands.

We hope that you find this Proceedings useful:

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New Jersey Marine Sciences Consortium

Janet R. Keough
US Environmental Protection Agency

Glenn R. Guntenspergen
US Geological Survey

ACKNOWLEDGEMENTS

The Forum Organizers gratefully acknowledge the following Co-Sponsors for their support of the Forum and Facilitated Workshop:

Delaware River Basin Commission
USGS
National Sea Grant Office
NOAA National Ocean Service
NOAA Restoration Center
Port Authority of NY & NJ
PSEG Company
Sea Grant College Programs of:
- Connecticut
- Delaware
- Maine
- Mississippi/Alabama (Theme Team)
- New Hampshire
- New Jersey
- Rhode Island
- South Carolina
- WHOI

Society of Wetland Scientists
State of Maryland Department of Natural Resources
USEPA
USGS State Partnership Program

This conference could not have been successful without the efforts provided by our hosts Cumberland County College, especially Dr. Tim Jacobsen and the staff of the Guaracini Center. Hudsonia Ltd. provided logistical support to the conference.

This publication was supported by the National Sea Grant College Program of the U.S. Department of Commerce's National Oceanic and Atmospheric Administration under NOAA Grant # NA76-RG0091. The views expressed herein do not necessarily reflect the views of any of those organizations. This is New Jersey Sea Grant Publication # NJSG-03-516.

Table of Contents

PHRAGMITES TECHNICAL FORUM AND WORKSHOP: SYNTHESIS OF SCIENTIFIC KNOWLEDGE AND MANAGEMENT NEEDS

INTRODUCTION

*Phragmites australis (*Phragmites) is found in freshwater, brackish, and saline habitats in coastal and interior wetlands worldwide. In marine coastal areas of North America, Phragmites now occupies the full range of tidal habitats in large parts of Canada, New England, the Mid-Atlantic, the Southeastern U.S., and the Mississippi delta. Its range has expanded dramatically since the late 19th century, and, where it has become the dominant species, it often forms extensive monocultures.

The causes of recent expansions of Phragmites populations are actually poorly understood. Aggressive genotypes, disturbance of wetland soils and plant communities, sedimentation, nutrient pollution, and altered hydrology have all been cited as potential causes. Documentation of these factors, singly or in combination, causing the expansion of Phragmites and displacement of other wetland species is very scarce.

Considerable resources are being devoted to control or eradication of Phragmites in North America, with extraordinary efforts being placed in fresh to brackish habitats along the Atlantic coast by public and private land management agencies. The Nature Conservancy provides its stewards with explicit advice about the most effective ways to eradicate Phragmites locally. Managers for the U.S. Fish and Wildlife Service and the National Park Service place considerable emphasis on eradication, including the use of herbicides, prescribed fire, and mowing on a large scale. Private consultants are employed to restore wetlands, including control of Phragmites and enhancing other tidal marsh species. Unfortunately, much of this activity is justified by the belief that Phragmites is either an exotic species or that it provides no useful wetland function. Neither view has been strongly supported by scientific findings.

National priorities for control or prevention of aquatic nuisance species are limited by a lack of information about the extent of the problem, if there is one. At a time when concern over exotic and invasive species is increasing and managers are facing labor- intensive and expensive control and eradication costs, there is an urgent need for a state-of-the-science-based synthesis on Phragmites. Managers need to make informed choices in their allocation of resources toward several invasive/exotic species facing different refuges, parks, and conservation reserves.

This synthesis focuses on new research and critical reviews presented at the Technical Forum and Workshop; *Phragmites australis: A Sheep in Wolf's Clothing?* We have attempted to summarize state-of-the-science knowledge of the ecology and extent of wetland functions of *Phragmites australis* presented at the conference. We address the conundrum that Phragmites is either a villain needing an all-out assault for eradication or simply an aggressive marsh colonizer that has features worth an adaptive management approach. It is our intent that this white paper contributes to management and conservation organizations' needs in their decision-making processes.

ASPECTS OF PHRAGMITES ECOLOGY IN COASTAL WETLANDS

Phragmites Distribution

Phragmites australis, when mature, typically occurs in monotypic stands. Phragmites is one of the largest marsh grasses in North America. Phragmites stands are composed of dense culms supported by a dense network of rhizomes and roots. Leaves are relatively large and numerous, shading out other species that might be found in the subcanopy. Negative perceptions of Phragmites are due to the difficulty of working with dense clonal populations as well as the perception that monotypic vegetation is bad because there is little or no diversity. However, opposing views argue that monotypic vegetation is neither inherently good nor bad – there are both positive and negative features that depend on site conditions. This viewpoint takes into consideration the landscape setting, the nature of the habitats, successional processes, and the natural history of the species of concern, as well as the presence of other species. Many native species of North American coastal marshes occur in monotypic stands and we should consider the context of the stand before determining whether the site is impaired.

Phragmites australis is a clonal perennial grass found in freshwater and brackish water habitats worldwide. It tolerates a range of abiotic conditions, although it is limited by increased flooding, salinity, and sulfide levels. Small, more recently established plants grow well at salinities from 0-5 ‰, exhibit some reduction in growth up to 35 ‰, and have difficulty persisting when salinities exceed 35 ‰. Phragmites has been shown to form extensive stands in tidal marshes with salinities less than about 15 ‰.

Phragmites is a robust competitor relative to other salt marsh species. Its ability to form dense monocultures after establishment results in dense canopies that shade out other marsh species. After establishment, Phragmites expands rapidly into mesohaline and oligohaline sites but less rapidly into polyhaline marshes (perhaps because of the high salinity and sulfide concentrations found there) and has come to dominate large areas of tidal marsh along the Atlantic coast. Tidal creek banks and upper marsh edges appear most susceptible to invasion. Phragmites is physiologically integrated through its extensive rhizome system and probably avoids the stress of polyhaline sites and eventually expands into these habitats by accessing remote resources and ameliorating local conditions.

Wrack accumulation, erosion and ice-scour, and hydrologic disturbances due to ditching and anthropogenic development provide Phragmites with opportunities to become established. Human activities that disturb the soil, impact local hydrology, and result in nutrient enrichment appear to be among the most important factors facilitating its establishment. Dispersal and burial of large rhizome fragments into well-drained and low salinity sites improve the chances of successful establishment. Once established, poorly drained areas and sites with high salinity and sulfide levels tend to be invaded via clonal spread.

Geographic Expansion of Phragmites

A number of explanations have been invoked to explain the perceived change in the relative abundance of *Phragmites australis* from a minor component of North American tidal wetlands

200 years ago to widespread dominance in these same communities in the past century. Recent advances in genomics, including the ability to examine nucleotide sequences in chloroplast DNA, have shed considerable light on this question. Records from the 1800's typically described Phragmites as uncommon or rare. DNA sequencing of herbarium voucher specimens collected at that time indicate the presence of a number of distinct haplotypes (large blocks of DNA that contain variations that make individuals distinct from one another). Today, one distinct haplotype (Type M) dominates the tidal marshes of the Atlantic coast at the same time that Phragmites has expanded its range and has come to dominate many tidal plant communities. Type M is typically more common in Europe and Asia and much rarer in the herbarium specimens collected in the 1800's in the eastern United States.

Comprehensive analyses of herbarium specimens collected before and after 1910 reveal significant changes in the haplotype frequency in North American Phragmites populations. Phragmites populations show a striking and rapid expansion of the Type M haplotype in the tidal marshes of the East Coast. This haplotype is found in brackish and freshwater tidal marshes and nontidal wetlands throughout North America. Additional studies suggest that the Type M haplotype is genetically isolated from the historically more common haplotypes found in North America, suggesting a recent invasion of the Type M haplotype into North America and displacement of more historically-dominant haplotypes and increased dominance in tidal marshes. However, the exact mechanisms involved in this process are unclear, and anthropogenic modifications to the physical environment of North American tidal marshes should not be ruled out as a cause of this expansion. The eleven historically dominant haplotypes still persist in low frequencies in North America, although some haplotypes appear to have been extirpated from certain areas.

Impacts On Ecosystem Function

The idea that invasive wetland species have detrimental effects on the functions of ecosystems has been widely and uncritically accepted without sufficient scientific evidence. Quantitative information on the effects of invasive plant species on wetland ecosystems is largely lacking. Can changes in species abundances make a difference? How important are individual species in controlling ecosystem functions? We assume that the effects of species traits on ecosystem processes are generally so strong that changes in species dominance of ecosystems are likely to alter ecosystem function, but the extent the change is often difficult to predict.

We are only now beginning to see an accumulation of scientific results that shed some light on this topic for marshes that have been invaded and dominated by Phragmites. The evidence from these studies is still largely equivocal but has begun to change the paradigm that Phragmites-dominated marshes have no functional value.

Geomorphology

Managers are concerned that natural wetland functions are lost where Phragmites has invaded and is expanding. Of special concern are tidal marshes that provide extremely important functions in sustaining estuarine fish and wildlife populations. Many of the important functions of tidal marshes are associated with the marsh surface structure and topography relative to tidal inundation and channel patterns. The interaction between tidal inundation, the dense pattern of 1^{st} order to 5^{th} order channels and living plants and detritus on the marsh surface provide abundant food and shelter for many species and life stages of aquatic life and birds. There is a widespread belief that Phragmites stands do not support such critical interactions, but this belief is founded largely on hearsay and a small scientific literature. Managers lack authoritative sources of information on the impact of Phragmites on ecosystem function and on the causes of expansion.

Recent studies suggest that Phragmites can transform the marsh surface into a depositional environment constantly covered by plant debris. Phragmites exhibits high rates of primary productivity, resulting in standing crops exceeding that of the coastal marsh species by 3 to 5 times. This high productivity and accumulation of litter on the marsh surface, coupled with high inorganic sediment loading, can lead to increased sediment accretion rates.

The enhanced rate of sediment accumulation in Phragmites stands can alter the physical structure and function of tidal marshes by building up the marsh plain and filling in topographic depressions, thus altering the rugosity of the marsh surface environment. Over the long-term, Phragmites stands tend to lose topographic variation, including first order rivulets and smaller tidal channels. Because colonization and expansion of Phragmites can occur throughout the marsh landscape, including creek banks, upland edges, and marsh interior, there may be many impacts of this increased accumulation of sediments on ecological functions based on position within the marsh landscape.

The lower drainage density, changes in flooding frequency, duration of flooding, depth of flooding, and flatter marsh surface that results from increased rates of sedimentation may affect the trophic transfer of primary and secondary production from the marsh surface to the estuary. However, in certain environments, this increased rate of sediment accumulation may enhance marsh sustainability by maintaining the marsh surface above water levels increasing in the rate of sea level rise. Some coastal regions of North America are known to be more susceptible to wetland loss due to subsidence, increased rates of sea-level rise, and the inability of the marsh to compensate.

Secondary Production

Tidal marshes are important habitat for various life history stages of many fish and invertebrates. There is particular concern that habitat alterations due to changes in marsh vegetation can affect nekton populations. However, vegetation change alone does not appear to affect use of these habitats by fish and macroinvertebrates. There is some evidence that *Spartina alterniflora* marshes support a more diverse community of epifaunal organisms than Phragmites-dominated stands, but in general there are no differences in invertebrate use of these two vegetation types.

Studies of blue crab populations showed no difference in use of Phragmites-dominated vs. natural tidal marshes. However, Phragmites and *Spartina alterniflora* dominated stands exhibited differences in the age structure and age related molting frequencies that may reflect differential use by blue crab recruits and juveniles due to differing lengths of tidal inundation.

A greater number of studies have been published that examine the impact of Phragmites dominance on use of tidal habitats by fish. Although conducted over a range of sites and habitats, these studies generally conclude that fish species are capable of using Phragmites stands, but larval and juvenile fish may use tidal marsh surfaces dominated by Phragmites differently than other stands.

A series of innovative studies using the stable isotope ratios of carbon, nitrogen, and sulfur have clearly documented that the products of Phragmites primary productivity are reaching fish and contribute to the trophic transfer of materials from tidal marshes to the estuary. Nutrients from Phragmites contribute to the secondary production and biomass of estuarine resident and marine transient finfish and shellfish. Species of *Fundulus*, abundant marsh residents in Atlantic coast salt marshes, occupy a critical position in the transfer of marsh primary productivity to transient marine species. Phragmites clearly contributes to the trophic spectrum of many estuarine-dependent taxa.

As previously mentioned, Phragmites growth and deposition of litter can result in situations where first and second order tidal creeks are filled, leading to a homogenization of the topography of the marsh plain. This likely restricts tidal access of fish and crustaceans to the marsh surface and reduces access to nursery areas during low tide. The inconsistent results found in many of the current fish studies emphasize the need to recognize the role of Phragmites stand development stage and the importance of Phragmites stands in the context of the larger marsh landscape. In sites where Phragmites has recently established, adult fish use of these stands may be no different than undisturbed stands dominated by *Spartina* and other marsh species. However, as the hydrology of these sites change and marsh surface heterogeneity and topographic depressions disappear, there may be a lack of recruitment in these sites. More advanced stages in the invasion sequence may represent very different marsh depositional environments characterized by altered hydrology and flooding. At these later stages of stand development and dominance by Phragmites, fish recruitment may be entirely eliminated. A growing body of research suggests that *Fundulus* species respond to the structural changes that occur as sites dominated by *Spartina* become dominated by Phragmites, but that this response can be quite different depending on the chronology of Phragmites invasion.

Phragmites stands that can be managed with respect to sustaining both natural flooding regimes and geomorphology can be expected to provide appropriate habitat functions similar to that found in other tidal marsh stands. Managers should also be aware of the tradeoffs involved in Phragmites eradication and the restoration or creation of tidal marshes with native species. The best scientific evidence now available suggests that it may take decades for these restored or created marshes to reach the levels of diversity and secondary productivity of natural marshes.

Nutrient Flux

Macrophytes can play important roles in salt marsh biogeochemistry by active and passive modifications of the substrate. Phragmites is both morphologically and physiologically distinct from *Spartina alterniflora* and can alter edaphic conditions and nutrient cycling processes in sites where it becomes dominant.

The microbial community associated with macrophyte root systems is also critical to the performance of biogeochemical functions. Initial studies suggest that there are differences in microbial activity between Phragmites and *Spartina* root systems but that these subtle differences disappear in habitats with stressful or specialized conditions of disturbed anaerobic sites.

Phragmites dominance of marsh sites has been shown to result in higher concentrations of below-ground nitrogen when compared to stands composed of competing species because of the higher rates of primary productivity, increased standing crops, and allocation of nitrogen to recalcitrant tissues that have slow rates of decay. Brackish and salt marshes exhibit lower porewater dissolved inorganic nitrogen, unlike freshwater sites, where nitrogen is primarily present as NH_4^+ and strongly absorbed to the sediments. Unfortunately, the appropriate nitrogen flux studies have not been done in Phragmites-dominated systems and so we cannot make any generalizations about the impact on the tidal exchange of NH_4^+. The available evidence suggests that Phragmites may be able to affect nitrogen exchange in saline and brackish marshes but probably not in freshwater marshes. We are also not able to say with any certainty if Phragmites marshes can act as sinks or sources of nitrogen. Phragmites may redistribute nitrogen from normally unavailable pools in the sediment or it may process external sources of nitrogen from either atmospheric deposition or hydrologic inputs. Additional research is needed in this area.

Phragmites has been shown to concentrate and sequester certain metals in its root and rhizome system instead of translocating these elements into aboveground tissue as other marsh macrophytes do. The replacement of *Spartina alterniflora* by Phragmites has resulted in reduced bioavailability of Hg, Cr, and Pb in contaminated salt marshes. Although this trend needs to be substantiated by further research, wetland managers concerned with the bioavailability of metals in marsh sediments should consider the benefits of Phragmites before pursuing efforts that remove Phragmites in favor of *Spartina alterniflora.*

Wildlife Use

Despite the impression that Phragmites-dominated stands are deserts devoid of vertebrate species use, careful reviews of the literature suggest that many species of birds and other vertebrates can be found there. Generalist bird species appear to make good use of Phragmites-dominated stands, but certain habitat-specialists adapted to nesting in short grass marshes exhibit low frequencies of occurrence.

Phragmites appears to be more important to wildlife as shelter than as food, and wildlife tends to utilize the edges of mixed stands and patchy stands more than extensive dense interiors of Phragmites stands. Interestingly, colonial-nesting long-legged wading birds may benefit from the proximity of Phragmites stands. In certain sites in Delaware, for instance, Phragmites provides critical habitat for nesting colonial wading birds by offering substrate for nesting and buffer habitat from human disturbance.

These studies suggest that vertebrate use of Phragmites may depend on local situations, and efforts to eradicate Phragmites might be tempered by site-specific management goals. Adaptive management must include an understanding of the role Phragmites may be playing in the larger marsh landscape. It should be recognized that Phragmites stands can be effectively managed by cutting, burning, or dredging of topographic depressions designed to improve habitat for certain species.

Biological Control

The use of herbicides, followed by burning, mowing, or flooding, has been the most prominently effective means of Phragmites control. However, reductions in the abundance of Phragmites are usually temporary and need to be repeated frequently at great effort and expense. There are no published efforts that have systematically weighed the costs and benefits of various control efforts. A recent model that evaluates alternative herbicide application strategies suggests that annual applications of herbicide may be a better strategy than intermittent applications. However, the cumulative gain in habitat value in either approach is sensitive to the presumed habitat functions of Phragmites and *Spartina alterniflora*, and site-specific functions should be carefully evaluated.

The difficulty of traditional control efforts has led to consideration of the use of biological control agents. Insect herbivores of Phragmites from Europe, such as the lepidopteran, *Rhizedra lutosa*, have been found in Phragmites stands in North America. These herbivores have the potential to alter the structure and function of dense monospecific stands of Phragmites. Unfortunately, the introduction of new Phragmites herbivores from outside of North America as biological control agents poses many unknown risks to non-target plant species and to food webs. Such an effort requires an extensive process that evaluates the risks of the introduction of these insect herbivores vs. their benefits as biological control agents.

CONCLUSIONS

Despite the conventional wisdom that Phragmites has unduly negative impacts on salt marsh function, an increasing number of studies suggest that these stands can play a positive role in the ecology of tidal marshes. Although the replacement and dominance of tidal marsh communities by Phragmites can have population and ecosystem consequences, particularly in reducing biodiversity and in altering habitat functions, these changes must be evaluated in the larger context of marsh change.

Unaltered coastal salt marshes are rare. Originally, these systems were composed of networks of salt ponds, pannes, and channels in the high marsh where water floods the marsh surface temporarily. These sites were flushed by lunar high tides that facilitated the transfer of materials to the open estuary. Roads and other obstacles have impeded or reduced this flow of salt water. Many coastal marshes have also been ditched for mosquito control purposes. The impacts of an extensive network of ditching include: drainage of marsh pools, lowered water tables, vegetation changes, altered flushing rates, and associated effects on higher trophic levels. At the same time, eutrophication of these systems as a consequence of increasing deposition of nitrogen has altered both the structure and function of these systems.

It is against this backdrop that we must evaluate the impacts of the expansion and dominance of tidal marshes by Phragmites. Certainly, Phragmites stands are not the biological deserts portrayed in the popular literature, nor the villain that is the basis on which so much effort is being expended in eradication. Certainly, Phragmites has changed from being a minor component of these systems to one that threatens to dominate large areas. Whether this is due to anthropogenic changes or the introduction of novel haplotypes or a combination of both remains unresolved. Colonization and changes in species ranges have been and are still natural processes. It is the temporal and spatial scale at which the process is observed which will determine ones' view of the process as a problem or a natural range extension.

When it replaces other plant species, Phragmites does alter geomorphological processes, biogeochemical properties, and hydrologic regimes and can have an impact on the trophic dynamics of these coastal systems. However, the impact of Phragmites as a part of a larger diverse landscape depends on the appropriate spatial context. The impact of Phragmites might be neutral (exhibit no differences from the system it is replacing) or may even be preferred when stressors such as increased rates of sea level rise and erosion threaten to overwhelm coastal marsh habitats. The presence of Phragmites might be detrimental if it threatens endangered species or results in short-circuiting the trophic dynamic transfer to estuaries.

At larger and larger spatial scales, our understanding of invasive species becomes less certain because studies of entire landscapes are difficult to undertake. There are few long-term studies of Phragmites invasion in coastal wetlands. Yet, we need to understand how changes in the first few years of invasion result in more permanent changes in these systems. Results from individual sites are difficult to extrapolate to sites in other regions with different hydrogeologic settings (especially rates of subsidence or accretion). More research is required to determine how changes to Phragmites-dominated stands affect the transfer of materials and nutrients to adjacent estuaries. Additional studies are needed that examine the impact of Phragmites on ecosystem function in settings that allow for rigorous comparisons with appropriate habitat types, stage of invasion, and reference condition.

We conclude that an evaluation of the impacts of Phragmites invasion and dominance of coastal marshes needs to be site-specific. Too many unwarranted generalizations have extrapolated from local studies without understanding the appropriate context of region, space, and time. We also conclude that a site-specific approach to management decisions needs to be considered that also incorporates a firm scientific foundation and understanding of the full range of wetland services. The realization that we might be dealing with both native populations and a range of genetic analogues should be considered. And the realization that extensive and expensive control efforts may not be sustainable is critical to future management decisions.

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PHRAGMITES AUSTRALIS: A SHEEP IN WOLF'S CLOTHING?

FACILITATED WORKSHOP
(INVITED PANEL AND AUDIENCE)

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Glenn R. Guntenspergen
Erik Kiviat
J. Court Stevenson
Jeffrey Thompson
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MODERATOR:

Elizabeth (Bitsy) Waters

Guaracini Center
Cumberland County College
Vineland, New Jersey
9 January 2002

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Original Panel Discussion transcript prepared by Stephen G. Paull, Inc., and edited by the New Jersey Marine Sciences Consortium. Any errors, omissions, or misrepresentations in the edited text are wholly those of the NJMSC.

EDITED WORKSHOP DISCUSSION

DR. JANET KEOUGH: We would like to complete this Forum by addressing issues that are critical to wetlands conservation and management. This session is being recorded by the State of Maryland's Department of the Environment, Wetlands and Water Waste Program. Ms. Bitsy Waters, Session Moderator, will pose a series of the challenge-response questions to the panel, and then we are going to open it up to the audience for further discussion:

- Should I consider *Phragmites* to be a native or nonnative, am I dealing with an exotic, and should I care?
- In what situation(s) does *Phragmites* cause changes to ecosystem function?
- Should we manage *Phragmites* for adaptive uses like wastewater nutrient removal, erosion control, economic uses, and special wildlife values?
- Should we revisit the current management paradigm of *Phragmites* removal?

We also want to identify outstanding information needs and data gaps that would establish priorities for future research.

MS. WATERS: Panel, please respond to the first question.

DR. GALLAGHER: I think we agree that the species is native. The important question is: are the varieties that are currently invading coastal wetlands native or not? I think there is growing evidence that we are dealing with some exotic strain(s). Based on the recent work in Europe, and current studies in the US on non-coding segments of chloroplast DNA, it looks like we are dealing with an exotic. Then the question becomes: what do you do with the information? We clearly need to determine how these exotic varieties behave in nature. So I think we do care. Ultimately, what we need to know is the influence these introduced genotypes have on the behavior and interactions with native species.

DR. KIVIAT: Practical conservation biology suggests that genotypes of plants and animals should be preserved as part of native biodiversity. I think that introduced genotypes should be viewed in terms of their functions and values to the ecosystem, and that we should not necessarily be concerned whether they are exotic *per se*; I do not think we have the luxury to do that. It is far more important to assess functions and values of the introduced biota, rather than to simply try to get rid of the exotic genotypes. From the perspective of wildlife use, I think that most animals are probably not going to be able to tell the difference between an exotic genotype and a native genotype. What matters is whether biota are nesting in, or consuming *Phragmites*, or doing something else. And that is probably going to be a function of stand structure, landscape considerations, hydrology and perhaps other things, rather than focusing on the plant itself.

MS. WATERS: The point is, being "exotic" alone may not necessarily be bad; but we really need to investigate the situation.

MR. HUTCHINS, NMFS, Gloucester, MA.: Before undertaking a restoration project, especially the many small ones we deal with, should we be posing the same question in *each* case; i.e., are we dealing with a native or exotic form, or a combination of the two, *before* undertaking any management actions?

MS. WATERS: Here is a manager saying, should I place a moratorium on control or if I decide to go ahead, should I look more closely at the potential elimination of native populations?

DR. BURDICK: This is an important point. From the studies presented this week, we learned that the invasive form is an exotic genotype, perhaps solely the M type, and that its impact on the community and the ecosystem, is probably very severe; whereas it appears that the native haplotype is an integral and natural member of the community. So, the issue is: do we want to potentially destroy a member of the community that interacts in a noninvasive way. It might not be a good idea to get rid of areas of native genotype, because if you did that, it might severely impact native communities in general. Thus, it is important to identify which group of plants you are dealing with.

DR. BLOSSEY, Cornell University: I believe the question should not be whether you have a small or a large population; but whether it is a native population or not. This is because larger invasive populations all *began* as very small, isolated populations. So if you go to "small management" of small population until they are large, you may accrue a lot of negative impacts that you want to avoid. The best management technique that you still have early on is controlling small populations before they can have a major impact. I believe that you should identify morphologically or genetically whether you have the native or introduced genotype, and then do management accordingly. The size of the population should not play a key role, because you want to prevent future degradation. Hopefully, we can develop simple morphological characteristics that would be the easiest way to distinguish native and introduced forms.

DR. KIVIAT: I have not seen evidence that stands of the introduced genotype are necessarily any more aggressive in nature relative to native stands. It is possible that rather than directly competing with the native genotypes, that native forms were simply already gone for reasons such as livestock grazing or other impacts on the environment. Before we assume that we have an aggressive form in nature that needs to be extirpated, and another [native] form that is harmless and needs to be fostered, we ought to collect some data bearing on what the two different forms are doing ecologically. I think that is the next step following Dr. Saltonstall's research.

DR. BURDICK: Your suggestion is to do what?

DR. KIVIAT: Identify the kind of data and other information that you would need to assess the situation. Whether a stand of *Phragmites* is native or introduced, is simply one aspect of the situation to come up with a sensible and sustainable managed system.

DR. BLOSSEY: I think that Erik's approach is dangerous, I do not like it. I can not understand where he is coming from. But one thing is sure: if we wait for the impacts on native plants to play out, or other impacts of the introduced genotype to accrue, we will lose what we care most about. I invoke the precautionary principle, everything that I have seen with respect to *Phragmites*-dominated marshes might be equal to or *worse* than the native communities that are out there. So if we want to prevent any further degradation, we should implement preventive management, go in, do it early. That is the best approach. Otherwise you lose out.

DR. WARREN: I suggest that we do have some evidence at this time. Along with the genetic analyses, we have information from the old apple orchards that the *Phragmites* we have now is not the *Phragmites* that was here for a very, very long time. I do not think that the natives suddenly started to take over. Other plants, and animals that need the system, *do* indeed care if it is a different genotype; if the introduced genotype has a different growth pattern and stand character, and it consequently takes over the space that at one time was shared with the much richer flora, then I think it *does* make a difference.

MR. CAPOTOSTO, Connecticut DEP: We are doing lots of *Phragmites* control in Connecticut involving an invasive variety, probably the M type. I have seen too many wetlands being taken over by *Phragmites*. With the little management we do do, less than 200 acres a year, we can not keep up with the invasion that is taking place in Connecticut. You might have the opportunity in Delaware and New Jersey to do aerial application [of herbicides], but we have to do everything by ground. We can not burn, so it is all mechanical harvesting after ground spraying. I believe that *Phragmites* is something that we have to do something about – it is M type that we have to worry about, not the native stands.

MR. McCAULEY, U.S. Fish & Wildlife Service: We have confirmed the presence of native *Phragmites* stand along the Rappahannock River in Virginia. I can assure you that we will use this information as an opportunity to study the characteristics of that stand. We are going to see if it invades, i.e., if it is spreading rapidly. We are going to take the opportunity to examine the insect community in that stand. But, we also have clonal invasive stands in the same area. In the interior of the marsh there are circular stands that emerged in just the last 20 years, we know this from surveys going back to the 1970s. So we were quite sure that we have both situations [invasive and native forms] on the Rappahannock. I can tell you that we will not now go out and conduct aerial spraying or ground spraying without first confirming whether we are dealing with an invasive stand or a native stand. But we also have a situation where we have a federally threatened plant species, the jointed vetch that grows in the same habitat where we are seeing *Phragmites* invade; the plant grows along the branches of fresh water tidal marshes, exactly where we are seeing invasive *Phragmites* colonizing the area. And so we are going to maintain our aggressive approach, control invasive populations, with the caveat that we are going to look at them and make sure that they are the invasive form. And we are very interested in getting the field characteristics nailed down so we can go out in the field and determine whether the invasive form is present. We want to be able to do this without having to send a sample to Kristin.

DR. HARTMAN, Rutgers University: There is increasing evidence that *Phragmites* reproduces sexually through seeds, that it can colonize by new seed. Thus, the assumption that you can tell the difference, and isolate the invasive type will only be fruitful if there is only vegetative reproduction. If there is gene flow between the populations, there will be a very good possibility that some of the invasive characteristics will move between the native and the more exotic genotypes. One thing that is potentially important to note is that you can have genetic changes in a population without having rapid apparent morphological changes. We need to learn a lot more about the possibility of seed strain and seed colonization in this population, in the different populations.

MS. WATERS: Other comments?

DR. STEVENSON: There is some evidence that the native form was probably a hexaploid and the introduced form a tetraploid. Most of us would feel pretty comfortable if this was the case that you probably would not have much gene flow between the native and non-native populations. But, I do not think that that is nailed down right now. So that is something that I would be concerned about. The other thing that occurs to me in terms of native versus non-native is that I would like to see someone go back and look at the very early herbarium specimens to see if they are M or L, so that we can go back further that the 1800s -- back to 1700s, 1600s -- really do a comprehensive historical analysis so that we can assess the potential for cross-breeding.

MS. WATERS: I hear the group agreeing that we have both native and an introduced types; is that right? [Lots of heads nodding]. Does anybody want to comment on that?

DR. GALLAGHER: Rather than saying that there is a native and an introduced, it might be more correct to say that there are probably many natives and maybe several or many introduced.

MS. SALTONSTALL, Yale University: There are probably a number of native lineages of *Phragmites* here in North America. I do not necessarily suggest that we use the term native *species*, nor do I suggest that the invasive type and the different lineages evolved in different parts of the world. But, there *are* differences. I think we can safely say that *Phragmites* is native to North America, but it started out as *different kind* of native. As for the issue that Dr. Hartman brought up on pollen flow, I do have some data that gets at this question. When the data set is complete [in a few months] it should help to resolve this question, i.e., whether there is cross-pollination going on with M type.

DR. WEINSTEIN: Do native types have a relatively restricted distribution in the marsh; say to higher elevations, whereas the invasive form has the capability to invade the low marsh? Is that true?

MS. SALTONSTALL: Well, that is something that we really do not know much about. And we do not know how many native populations are out there in the marsh right now. If all of these people here go out and look for the native populations, then maybe we will start finding something. But the answer to the question at this point is we simply do not know.

MR. BAILY, Aberdeen Proving Grounds: Are we going to have an organization or some facility to be able to help us to look for native forms? And is there going to be a funding agency to help underwrite the effort?

DR. WINDHAM: I think the idea that there might be morphological differences to help identify native versus the invasive strains is fascinating. We really need to do "ground truthing" on it.

The people who send these samples to begin with, should go out and field check [further verify] the results reported by Dr. Saltonstall, so that we can build up the database. Then hopefully we will have something that could be printed, and/or sent out in a website, for future use.

DR. BLOSSEY: We have the money, so if you think you have the native genotype, send it to me at Cornell [University], or send it to the University of Rhode Island. We will go out and test ("groundtruth") the genotype and examine potential impacts, e.g., look for damage to native forms from insects that we tend to consider as control agents in Europe. Additional funding has been requested to make us the clearinghouse for documenting the presence of native genotypes. We will also grow these plants in standardized conditions, we will develop morphological measures: stem coloration, leaf coloration, etc. Maybe in a couple of years, completely good genetic information and morphological information will become available to help out everyone. Currently, we can handle several hundred specimens. So go out in the field, look for the native populations, and send us rhizome samples so that we can grow them up. And they will be taken care of, I assure you of that.

MR. MONTALTO, Cornell University**:** My comments and question address the third part of the first question, which is: why should I care? Although it is important to know whether a particular stand is native or not, I think we are equally interested in what the managers need to know. It seems that management should be based more on functional assessment of a particular stand in the area. The question then is how to manage that particular stand, based on the functions that it might be removing or adding to a particular area. Because it may be unpractical to develop labels, it may be dangerous to attempt to call something native, nonnative, exotic, or otherwise, and then find yourself in an untenable management situation.

MS. WATERS: Does anyone on the panel want to respond?

MR. THOMPSON: From that standpoint we are dealing with the siting of specific restoration areas. We may be dealing with an aggressive genotype at that location. Thus, it is not simply getting rid of *Phragmites* [the first time] it is a matter of controlling it so that it does not dominate the site again later. As part of our regulatory program we have to monitor the site for the first five years after it has been restored or created. After that, monitoring falls on others. So in selecting the site, the presence of the aggressive type may be a critical decision for going ahead, *as well as* looking at the functions and values that you might want to replace or maintain or create. So siting in this context may be critical factor.

DR. BURDICK: I disagree with both commentators! When you go and look at the site and make a decision if you want to manage *Phragmites* there, it should be your primary goal to determine if this *Phragmites* stand is rapidly expanding. If it is, the management decision becomes one of potential loss of most functions and values at the site. If you leave it alone in this circumstance, you may not have much left to address in the future.

MS. SALTONSTALL: Dr. Windham mentioned that I should send information back about the results that I have found. I am going to be doing that, I will be putting together a summary and send it to all those that have sent me samples. All relevant information that I have on habitats etc. will be sent along too. I will also put together a spreadsheet of what we think are native characteristics.

DR. GALLAGHER: I have a question for Ms. Saltonstall that relates to lineage. Is there essentially one genotype that you are looking at, or is this a lineage that would have a variety of functional characteristics to go with it. Or do you think that it is just a single clone that you are dealing with?

MS. SALTONSTALL: You mean a single clone that has reached North America and just dispersed all over.

DR. GALLAGHER: Yes.

MS. SALTONSTALL: No, I do not think it is a single clone based on my microsatellite DNA data and based on habitat data. I think there is a very similar European lineage, and some of that lineage is over here. So from a genetic standpoint, no it is not one clone.

MS. WATERS: Let us move on to the next question: In what situations does *Phragmites* cause changes to the ecosystem function?

DR. WEINSTEIN: Let me start, because I agree with Dr. Blossey's comments and many others on the inferences for a preventative maintenance type of approach. But I also think you have heard over the past two days that there are indeed some very severe negative effects of *Phragmites* invasion in coastal marshes where, at least in recent history, it was not present before. And if we look at the bottom line, it is cross cutting all those ecological factors, abiotic or biotic. It strikes me that the challenge facing scientists, managers, citizens and so on, is based largely upon *Phragmites'* ability to dry out the marshland. It is making wetlands drier. And if that is the case, then we are talking about a change in hydrology and a different hydroperiod, and all of the dominoes will fall with respect to functions that support fauna, whether it is trophic support or anything else; those functions will diminish or disappear altogether. *Phragmites* is certainly ecologically disruptive in a major way, and particularly in low marsh environments. Are we ready to suffer the consequence of a plant that is literally drying out our wetlands?

MS. WATERS: Well, I suppose the object of that is to ask other panel members and the audience whether they agree with that cross cutting conclusion that Dr. Weinstein presented.

DR. TURNER: Well, I agree, but.... There are also some things that happen with *Phragmites* that would not happen otherwise. If you live on an erosional coast, as Dr. Stevenson has pointed out, *Phragmites* is the only thing left in some places. So you might *prefer* to have *Phragmites* instead of open water. If you are doing a shoreline project, it is an excellent aid to protect the shoreline. We heard some other examples yesterday where avifauna appears to benefit from it. So it is not simply an either or case, but it is a matter of how you value the system in terms of what you have. I was struck by what Dr. Weis was saying [yesterday], that the Hackensack Meadows, which I presume is a restoration site that is successful, and there is *Phragmites* there. Perhaps something else could have been done there, but that is what you have there as a cross compilation of restoration, politics and all.

DR. WEIS, Rutgers University**:** The Hackensack Meadowlands is a huge area; it has been *Phragmites*-dominated for decades. There are small patches of *Spartina* here and there, in a few cases, some that have been restored in the past 10 or 15 years, through [404] marsh mitigation-type projects. One area in Sawmill Creek became a fairly large *Spartina*-dominated area after a storm came through in the 1950s. But overall, I would say that the Meadowlands is 97- 98 % *Phragmites*-dominated. From what we heard on the microtopography of *Phragmites*-dominated systems [and lack of minute tide pools therein], you would think that mummichogs (*Fundulus*) would be in low abundance. However, the Meadowlands are teeming with *Fundulus*; there are even commercial fisheries for them as baitfish. So, I think that there is a paradox, and to me that is one of the fascinating questions; where and how is our "old friend" [*Fundulus*] getting produced?

MR. ROZSA, Connecticut Department of Environmental Protection**:** What is missing from this discussion is a good classification of the plants in the tidal wetlands. Dr. George Nickel from Connecticut in the early twenties put forth the classification for *Phragmites* communities in Connecticut. Many of the slides that I saw in the last two days described *Phragmites* invasion in salt marshes that George would call brackish meadow dominated by *Spartina patens*. In order for us to come to some kind of consensus, we first have to come up with a community classification that we can agree to, so that we are talking about impact in a salt marsh, we are all talking about the same thing.

MS. THIESING, USEPA, Region II**:** I have been out in the Meadowlands for approximately twelve years, and we have been absolutely desperate for information about *Phragmites*. Published research has only been available to any degree in the last four or five years. And I have been literally sucking up every piece of information I possibly can. I am carrying away a head full of information [from this conference]. But I think the biggest thing that I am taking away is that if you are dealing with *Phragmites*, you absolutely have to look at context, and also have to consider temporal factors. The Hackensack Meadowlands has been invaded for a very long time. There have been major problems that started about 150 years ago. And the system is absolutely dominated by *Phragmites*. If you have a situation where the marsh is raising itself above the level of tidal inundation, and/or *Phragmites* is filling in the creeks, and you are losing not only open water, but the ability of that water to flood the marshland in tidal cycle, it does not take a great deal of foresight to know that this kind of trend does not bode well for fish support. And consequently, trophic transfer, fish and wildlife usage, etc. are all going to be negatively affected by the ability of *Phragmites* to close off the open water and to raise the elevation of the marshland. Now, that being said, if you are going to manage successfully, you have to take a look at context. We need to not just ask what is good for birds or are seabirds successful here. Not all *Phragmites* is equal. *Phragmites* that is located near the [creek] edge is not necessarily equal to that in the interior. We need more study to see what theory can support, because we do not want to "throw out the baby with the bath water" in terms of what we manage. We have to be able to know what is going to be supported, what is not going to be supported. I was very interested in that tide creek study, because I absolutely think that topography needs to be looked at as a factor in support of fish production. But again, there will be no fish. Mummichogs are absolutely critical to the whole food supply there. So what I would like to ask people before they do anything else is consider context, consider the location and consider the larger landscape.

The Meadowlands is an urban system and it is under enormous -- it has received enormous insults over the last 150 years. However, it is one of only two large estuarine systems left in the greater New York metropolitan area. And if you lose the ability of that area to support large populations of wading birds, or of small forage fish, what [for example] is that going to do to your larger flyway populations?

DR. WINDHAM: It is critical that we consider the situation, the context of these impacts. That was the burning issue for me these last two days. The landscape setting is critical: stand age, location, salinity; we have to take all of that into account. To me that is overriding consideration in the last two days.

MR. BART, Rutgers University**:** That points to the question I wanted to bring up; i.e., the situation(s) where *Phragmites* causes changing function. And up until the last couple of years, much of the literature that I have reviewed simply dealt with the observation that *Phragmites* is here, with little basis for understanding what is causing the effect, beyond just happenstance.

DR. WINDHAM: That is a really good point. I am going to use marshland microtopography as an example. We all seem to think that *Phragmites* make the marsh surface higher. As Mr. Bart suggested, the best way to show the effect of the plants is to measure marsh elevation before, during, and after their establishment. Many of these topographical changes induced by *Phragmites* marsh happen over a long time period, it is very difficult to show that happening over a couple of years. You need a long-term study or some sort of time-step approach, something to get at how *Phragmites* might be altering the ecosystem. The bottom line is that we need longer term studies.

MR. KANE, New Jersey Audubon Society**:** I would like to pick up points made by Ms. Theising just a few minutes ago. There is tremendous variety in *Phragmites* marshes, even within a single system like the Hackensack Meadowlands. There are some that are closed off over time; there are others that have not closed off over time. There are marshes which are functioning like they are potholes in the Hackensack Meadowlands. I think we need to give credit to that variety. Over a 30-year period, for one reason or another, either for building consensus or for other reasons, I have been involved in surveys of birds by helicopter, or surveys of habitat in the state, I have come to appreciate the uses of *Phragmites* habitat by birds. There are 34 species in New Jersey that breed in *Phragmites*; i.e., use *Phragmites* either as the nest material or as nesting substrate. And among these are a number of state designated, rare, threatened, endangered, or locally important populations. And that last category is important; an example of important local populations would be marsh wrens and least bitterns. And because many species are difficult to detect in marshes, I would ask that before anything is done in reed marshes, that we investigate the consequences of dredged soil deposition, or other dumping activities that may negatively impact bird habitat (we have had cases where dredged material has been dumped on an existing heronry because it was in a season of nonuse). What I'm asking for is that we be careful.

DR. WARREN: There seems to be an implication that ecosystems exist to serve fish, birds, and other animals. I would like to suggest that some of the habitat provides living space for a wide range of angiosperms, and that many of those angiosperms are in the brackish and fresh tidal areas, and are extremely threatened when these areas become *Phragmites* monocultures. This is a critical component of what happens in the process of local extinction, especially of rare and endangered plant species, when you convert a complex low brackish meadow into a *Phragmites* monoculture.

MR. SCHUELER, Eastern Ontario Biodiversity Museum: In Ontario, *Phragmites* expansion is associated with increased salinization due to use of road salt. In the context that *Phragmites* is invasive, and it is widespread, I ask why it does not invade the woods in Syracuse or Montreal? People working in the interior may help shed light upon what *Phragmites* is doing here, and time scale for invasion, e.g., are stands younger further in the interior, further north. We still have substantial numbers of colonies that look like native types in northwestern Ontario and eastern Ontario. I am interested in determining what percentage of our eastern Ontario stands are the native type. But in any instance, there are a lot of places where *Phragmites* appears to be doing different things than what it does in tidal wetlands.

DR. MEREDITH, Delaware Division of Fish and Wildlife: My agency has responsibility for managing wetlands, over tens of thousands of acres. We are involved in dealing with the *Phragmites* issue. When we talk about values, we ask: Who determines the values? Who sets the values? Over the last 50 years, many of our wetlands have been converted to undesirable habitat, habitat that is undesirable from the standpoint of the private landowner who does not like what has occurred. As a result, we go back 20 some years in Delaware to a cost share program for *Phragmites* control established by the general assembly. Private land owners put up a 1:1 share per acre. They have a real concern that wetland values -- what habitat quality used to be, whether it has been degraded -- will affect the main purpose of their interest, waterfowl hunting. To a lesser extent the interest is also tied in with muskrat trapping. The point on values is that we have to consider the people who actually own the marsh. These people go back 30, 40, 50 years. They are not pleased with the degradation of wetlands by *Phragmites*. They want something done about it, or at least the attempt at it, although the problem may not always be successful.

DR. CURRIN, NMFS, Beaufort: My comment addresses *Phragmites'* influence on the ecosystem. When *Phragmites* elevates the marsh surface there is a lot less photo-oxidation of organic matter at the surface. When this occurs there may be a conflict with algal production on the marsh surface. The algae serve several important roles, including serving as food for fish.

DR. BLOSSEY: Consider other members of the community that may lose out. Every plant species has incredible number of herbivores associated with them, many of which are specialists. Associated with those herbivores are a collection of predators and parasites, many of which are specialized on utilizing those herbivores. So using the food pyramid as an example, flip it upside down, and that is about what you lose if you lose a single plant species in the context of a marsh. The very simple arithmetic: one single plant species supports ten herbivores that are specialized. Those ten herbivores will support about a hundred specialized predators and parasites. Thus, the elimination of a single plant species from an area might cause the extinction of a hundred additional species. These things have not been looked at. Sometimes we do not have the expertise to identify the herbivores and even less expertise to identify the specialized parasites and predators. Do we care less about insects than we do about plants? I think it has to do with economic considerations. But all our information is biased towards the more charismatic species. If you consider insects, plants, and other vertebrates, I think you are seriously underestimating the effect of invasions, including *Phragmites*.

MR. LORENCE, New York State DEC: I work on Long Island, where *Phragmites* is becoming very extensive. I have some concerns regarding plant biodiversity versus the major changes we have seen over the years in *Phragmites*-dominated wetlands. What would help me tremendously in making management decisions to grant permits for altering *Phragmites*-dominated wetlands, or for doing restoration projects, is real good quantitative information on pre-invasion reference levels so that we could tell how wetlands functioned prior to the invasion of *Phragmites*. Some of the work that was discussed over the last couple of days touches on that. But I would like to see more work done in the area of the high marsh, where we see I think even greater impacts by *Phragmites* on a variety of biotic and abiotic factors. I would also like to see more work done on freshwater marshes. Many of us in the last two days cited the lack of good reference data, so that we know whether or not a given marsh should be managed or how it should be managed?

MS. WATERS: So more baseline information is needed?

DR. WEINSTEIN: Let me make some generic comments in terms of humans in landscape as well as comment on goods and services from both an ecological and human use perspective. What I have been hearing is that there are context and setting issues related to what I will call an urban baseline. There are, for example, societal values that range from the interests of the few -- more ducks to shoot -- to perhaps wider ranging aesthetic or ecological values -- biodiversity, ecosystem complexity, etc. But the bottom line that I am hearing is that the issue of management becomes more and more one of site specificity and setting, becomes more and more one of cost benefit, ecological goods and services considerations, and the societal components of it all. What I am hoping that I am hearing is that perhaps the knee jerk reaction that an all-out assault upon *Phragmites* needs to be revisited. And there might be a better way to develop adaptive management approaches to dealing with *Phragmites*.

DR. TURNER: If you look at the root paradigm, we seem to have set a zero value for *Phragmites* versus some other value for *Spartina*. There are basically two ways that we have been managing *Phragmites*. One is an intermittent spraying program - we spray it, let it come back, and after about six years, come back and spray it again. The other is continuous spraying - you are hoping to get *Spartina* in the long term but you basically have no plants after the first year's spray, at least at the one [site] we looked at.

If you value it [*Phragmites*] as half the value of *Spartina*, then you have a longer time to get back than if you value it [initially] at zero; i.e., you do not get to a break-even point for several years. In fact, for intermittent spraying you *never* get to a break-even point if you have 20 % [initial coverage] for *Spartina*. The results all depend on what your starting values are.

Under some *Phragmites* valuations whether under intermittent or continuous management, you do not actually end up with more habitat value under all circumstances, and for continuous spraying, sometimes not until you go beyond the five-year management window. If you spray continuously for seven or eight years, you easily come back to a net gain under most calculations, but not all. And so the points here would be, one: that a five-year window is important; second: how you value it is important in the final result, because it is not zero or one, but something in between, which of course is a tricky proposition. The third would be if you are interested in how much herbicide you are using and you are interested in the long-term, then if you spray once a year every five years or six, then you are spraying one hundred percent of the area every five or six years. But if you spray every year, then you are eventually coming to a point where you are only spraying five percent a year on the average. So your management window becomes important. Because after five years you have spent 20 percent on herbicides, and after 20 years you have spent four percent on herbicides. So how you value it, how long you look at it, is really crucial to management. You have to decide your threshold values for a lot of this. And you need to look at more than five years, absolutely.

MS. WATERS: Just a reminder of the broad question: Do you think we should revisit the current management paradigm, which is one of *Phragmites* removal?

DR. KIVIAT: The problem with *Phragmites* removal using broadcast herbicides is the probable non-target impacts of herbicides and the expense. This method also does not allow a fine degree of control over the architecture of a *Phragmites* stand. There is a lot of evidence from wildlife studies, and I believe also studies of the other components of *Phragmites* marshes, that the characteristics of the stand have a large influence on *Phragmites*' "behavior" and on the functions and values of *Phragmites*. One *Phragmites* stand may be quite different from another. That implies, as Dr. Weinstein has just suggested, that we want to have flexibility to manage differently from one stand, or site, to another. There have been many management approaches developed in Europe, in the delta marshes in Manitoba, and even in Central Park, Manhattan that are site-specific and that involve different goals and methods. I suggest that for some, perhaps many sites that we ought to think about managing *Phragmites* in a "softer" way, that is managing it to change the structure and characteristics of the stand to shape habitat for particular animal and plant species while retaining some of the water quality and soil stabilization benefits of *Phragmites*. The survey data collected on the site is important too, from an economic point of view: what is *Phragmites* doing to harm or help the site, and what are the constraints within the area, and what kinds of funds are available? And then a management program should be designed to also incorporate monitoring, and that data from that monitoring will then allow you to adaptively manage in relationship to your specific goals for that site. Sometimes a species may need to use a number of different sites within the landscape. So for that reason and for other reasons, management decisions should also look beyond the boundaries of the study sites.

DR. STEVENSON: I agree with everything that was said, but management also needs to think globally on some issues. To many users, it may really be important thing to think about CO_2 levels, and it seems like that has been totally missing from a lot of these micromanaged sites. It may be an overall positive outcome [*Phragmites* presence] in terms of reducing CO_2 levels in the atmosphere. There is also probably a lot of DOC leaking out and even though you might not have killifish reproduction on the site, you probably end up with a net killifish advantage by having a lot of *Phragmites* around. That is why in Maryland several studies show that there is no big difference in fish populations. So there may be a lot of benefits from *Phragmites* that we are overlooking.

MS. WATERS: If you want to speak about advocating adaptive uses, as well as management of a project, feel free to do it now.

MR. ROZSA: If spraying is not our approach, I ask the panel, do we have consensus on what an alternative management paradigm is? I cringe at the thought that without any constraints we are using type M *Phragmites* on wastewater management sites and dredge disposal sites without some kind of a requirement by federal and state government to make sure that those do not become new sites for invasion and we need to have those individuals using those plant stocks to be responsible for control, if the plants escape from those sites to neighboring wetlands.

DR. BUCHSBAUM, MA Audubon Society: I wonder if we have not been setting of a bit of a strawman by saying that the current management paradigm is completely wrong. We did a restoration project in Massachusetts and had to obtain permits as if we were developers, we had to show that we were replacing functions and values that were not degrading the habitat. My question is whether the conference here has considered this problem?

DR. GALLAGHER: One of the questions we addressed was using *Phragmites* for wastewater treatment. There is a lot of concern about putting little islands of [*Phragmites*] seed sources and rhizome sources in different places where the plant does not exist at the present time. One of the things that we have done is to develop varieties of *Phragmites* selected for sludge drying. We have one that looks good. It is one that came out of our tissue culture program, one that is variegated and thus has a visual marker. If it does escape, as was the concern raised, it can be identified and managers can assign the clean up to the proper group. So it has a genetic marker and a visual marker. When we try to come up with practical uses [for *Phragmites*], we should look into creating more genetic diversity through processes like tissue culture, where you do have the ability to capture useful traits.

MR. BALLETTO, PSEG Corporation: I can not help but think of the NJDEP's [New Jersey Department of Environmental Protection] reaction if we were to suggest that, as an offset for our fossil fuels problems up in North Jersey, we are going to convert pristine salt marshes in South Jersey into *Phragmites*-dominated marshes as a way of sequestering CO_2. I do not think that would go over too big. I want to ask a question of the panel, and of the federal regulators here. Why is [*Phragmites*] being treated differently than perhaps any other species that has been introduced? Why are the federal agencies not taking some sort of [direct] action? We hear pleas for basic research and for identification of different management techniques. Why is this not being done by the federal agencies that have responsibility [for managing *Phragmites*] under the Invasive Species Act?

DR. STEVENSON: One of the problems with going to an agency is that they do not have any guidelines on CO_2. Management has put a blindfold on vis-à-vis this global problem. It has become a pariah we just seem to ignore the issue. But my feeling is that a lot of these agencies need to take CO_2 into account. So when you do have some wild proposals, like in New Jersey here, it might be better achieved.

MS. MOSER, Maryland Sea Grant: The federal government is not just sitting on its hands, but they are just swamped with invasive species. There has been a lot of effort since the Aquatic

Nuisance Species Act came into existence in the 1990s. An Executive Order was issued several years ago to set up a National Invasive Species Council, that operates under the Fish and Wildlife Service and they just completed a Management Plan. We are one of the only countries in the world that have such a plan. It is available on-line. I want to emphasize that there is an important opportunity for local, state, and federal governments to develop a partnership to try to address this issue.

MR. FEDERICI, Management Consultant: My question references closure of landfills and the need to apply for a permit from the USEPA to fill surrounding areas for erosion control to protect nearby marshes [thereby creating a mitigation need to offset the fill]. My proposal for my client was, we will go in and do some preparation and remove *Phragmites* and put in *Spartina*. Now I am hearing about the potentially positive values of *Phragmites* meadows and it role as wildlife habitat, and the ability of *Phragmites* to sequester metals. So what are my options for mitigation here?

DR. BURDICK: I will speak in the general sense. We need to look at how the proposed action changes the hydrology of the site. If you do not change the hydrology back to where it will support an ecosystem, then you are going to spend a lot of time and effort trying to cure the symptoms of the problem without curing the underlying fundamental issue. So I think that we have to plan on the basis of site specificity. I think that in sites changing from wetlands to open water that stands of *Phragmites* might be very useful, especially non-invasive and native types that can be harvested and planted, and I think that this is a great restoration activity. But like my colleague pointed out, there may be a case where you have a wetland where *Phragmites* is going to turn the site into more of an upland, and you certainly do not want to oxidize the carbon that is already there because that will reduce the carbon storage function. So we are right back to site-specific measures to correct problems with hydrology as part of any *Phragmites* management program. Let us start by attacking some of the fundamental problems with some of our large management areas, and not to try developing a "one size fits all" approach.

DR. WEIS: When I got involved in this about five years ago or so, I was struck by the fact that the management/policy was so far ahead of the science. That is, the policy was to remove the plants on the assumption that they were ecologically useless or harmful, even though science had not studied or demonstrated that. The scientists in the past five years have been showing that the plant is *not* useless, but that it contributes to the food web and habitat functions for marsh organisms. The policy being far ahead of the science is in striking contrast to environmental policies dealing with toxic chemicals, an area I have been involved in for a much longer time. These policies generally require "sound science" before a chemical is regulated or restricted. So in most cases, the chemicals are out there until there is a huge amount of data showing that they are damaging the environment. In other words, the chemicals are considered innocent until proven guilty. This is in contrast to *Phragmites*, which is considered guilty until proven innocent. I think that in both arenas, the toxic chemical arena and the invasive plant arena, we may have things backwards. In any case, it is not generally good to have policies out there long before the scientific facts are known.

DR. BURDICK: I agree. This is really not a question of herbicide use or other kinds of approaches to address the issue of *Phragmites* management. Any generalized management decision that we can make today is not going to work in the real world. That is a really important point. We have to be more complex and subtle. And that means that we do need the science and we do need more public discussion. We cannot just stop here. One suggestion that I would like to make to this group is that we find some way of continuing this discussion on a website or electronic bulletin board or some other way after this meeting is over, because this is the start of a very valuable public forum. It can be expanded to include people that are outside this room. Another thing that I think is extremely important to remember is that when you change a *Phragmites* marsh or any other kind of ecosystem, there are trade-offs. It may become better for one thing and worse for another. Josh Collins from the west coast has said estuaries are more than just flows and fishes. I am very sympathetic to the issue of fish and fisheries. But if you only think about making marshes better for fisheries we may be making it worse for something else. And so again we have to look at the whole area -- the Hackensack Meadowlands, the entire Newark Bay complex, etc. and allocate different types of management schemes and different uses, and some kind of overall scheme for the region, the landscape, instead of saying let us tend to do this *particular* thing in the long term.

MR. McCAULEY: We have heard in several instances that *Phragmites* has functioned less than or at best equal to other macrophyte dominated marshes. We have seen some isolated examples where *Phragmites* has served apparently a very important function; e.g., as nesting habitat for birds at Pea Patch Island. I am certain that Dr. Parsons, who presented that information in her talk, readily agreed that this information is important to the managers of Pea Patch Island, period. But, you cannot simply take that information and extrapolate it to suggest that *Phragmites* is valuable and important as nesting habitat for wading birds across the plant's range. I think that would be dangerous to take that approach, and Dr. Parsons readily agreed with that. Moreover, we have heard many times this week that we should be taking a site-specific approach to *Phragmites* management, *Phragmites* control. Based on that, and my experience, would lead me to conclude that we should turn that statement around a little bit, and say that we should take a site specific approach to *not* controlling or not managing *Phragmites*. It may, in certain instances, be better than what is there. But I think it is more appropriate to take that approach, considering what we have seen from those studies where it is just completely dominating and taking over the marsh ecosystem. It is probably better to take this kind of approach. We should look at instances where we should not manage, not control, rather than the converse.

MS. WATERS: We are now going to ask the panelists for their "take-away" messages from this Workshop.

DR. BURDICK: Just to follow up on Dave Bart's theory question, I think the call here is for agencies to include *Phragmites* in exotic species programs. I think we have to change the way we word proposals and get a lot more agencies to support research on *Phragmites*. Right now I think Sea Grant is the only one. I may be wrong, I hope I am wrong. But the issues need to be dealt with and the applied questions are really important. But for those people crafting requests for proposals, please include the importance and value of some of the basic research questions raised today. One of the important ones that Mr. Bart brought up was the question of cause and effect. We are not going to get at the difference between cause and effect unless we address some of the basic research questions on *Phragmites* ecology.

MR. THOMPSON: My take home message is that if we are going to go out and manage *Phragmites*, as managers and resource managers, we must realize that it is a series of trade-offs. We have to look at soils, we have to look at plants, biodiversity, fish, birds, everything, before we make our decisions. And if we do not, we are shortchanging ourselves and the environment. We also have to look at the areas that we are trying to restore or create, and assess their existing functions, everything from habitat considerations to the various wetland functions that we have been dealing with, flood control or tidal issues or nutrient retention. We have to do all of this.

DR. WINDHAM: A fundamental question that you must address is: Are you going to be moving from a marsh to open water habitat or from marsh to an upland habitat. Where *Phragmites* fits into these alternative scenarios is a focus you should adopt. Also, from a site-specific context, not all sites are going to be impacted by *Phragmites* in the same way or even to the same degree. So it is fundamental that we consider *all* the things that will control whether *Phragmites* actually has an adverse effect or not. And dealing with landscapes is still very difficult, because there are many factors; e.g., that may affect fish production than just *Phragmites* versus something else. So the landscape context is very hard to address, and I'll just leave it at that.

DR. WEINSTEIN: On balance, it strikes me that there are enough "redeeming features" of *Phragmites* to warrant changing the paradigm on site specificity, baselines, virtually all of the ecological components and all the human components and landscape components that we must deal with. What I have not heard mentioned is the need for a holistic management approach, weighing all of the factors in a cost benefit fashion. And finally, I think that I would answer my own question -- is *Phragmites* a sheep in wolf's clothing? – by expressing concern that the M type as potentially doing great ecological harm

DR. TURNER: We ask why do we have *Phragmites* here? But you might look at some marshes and also ask why is *Phragmites absent* here? Another point is that almost all of our reviews seem to be from a *Spartina* point of view, because these marshes are relatively easy to walk around in most of the time. What we need to do with *Phragmites* marshes is pick our toughest graduate students and send them right into the middle of the biggest, angriest patch of *Phragmites* and find out what is really there in the long term. If you are looking at edge alone, it is almost certain that you will have transitional values. We do have some places that are before and after [scenarios], because there are sites that are still expanding. And so knowing that, we could go to the site ahead of time. Another one is that I want to make sure I want to back this long-term use. There are some long-term census data, but I have not seen people looking at muskrats, fisheries, birds or other fauna that may help explain why the landscape is what it is, or at least probe why the landscape has been affected, and whether it is due to the fish in the river or some other factor(s). We should be looking at sites in a comparative way, on an institutionalized basis, i.e., investigate *Phragmites* sites using the same methods at the same time across the region.

DR. WARREN: There is still a great deal to be done about the way estuaries function, and when you add *Phragmites* to the mix, there is even more that we do not understand about how *Phragmites* impacts those functions. With that in mind, I would hope that any management control approaches are undertaken with a great deal of humility, not the arrogance that one sometimes sees. We do not really understand a lot of the way these systems work. And I would urge funding agencies to always couple up research opportunities with management and control activities. Each of these has tremendous potential to do real good. And science can tell us much about the fundamental way these systems work, and also how *Phragmites* fits in. Control activities undertaken without research and monitoring efforts are squandering opportunities.

DR. STEVENSON: I think we are in a little bit of a quandary as to how to manage *Phragmites* in North American marshes. The best approach is not quite clear. The European scientists appear to be well ahead of us in terms of *Phragmites* management; i.e., they are beginning to understand what is going on in the ecology of 'diebacks' in central Europe; it appears that it includes a process of self-regulation. The same type of processes may be operational here, and may have already been initiated.

DR. KIVIAT: I agree that there is substantial site bias in many of the studies that we have undertaken in *Phragmites*-dominated marshes. But I also want to make sure that I was understood when I talked about a "softer" management approach. This approach considers the heterogeneity of *Phragmites*-dominated marshes. A stand may consist of extensive, dense *Phragmites*, or may contain openings, pools, or channels with submerged vegetation, woody plants, or areas where *Phragmites* is mixed with other species. Small *Phragmites* stands provide foraging habitat, song-perches, and roosting sites for many birds including some that are rare or declining. More extensive stands may support breeding northern harrier, a species that requires a buffer from direct human disturbance. Stand characteristics and their role in habitat function need to be considered in management decisions; it is more complex than just the decision to remove *Phragmites* or leave it alone. I favor making management decisions on a site-specific and species-specific basis, rather than spraying large areas of *Phragmites* or developing a biological control program that will effectively foreclose site-specific management options. I would like to make one additional point. We ought to be thinking about a *holistic* management approach that considers not just single targets such as fisheries or waterfowl, but the whole suite of functions and values including water quality amelioration, soil stabilization, carbon sequestration, and recreational amenities. It would be valuable if we could take some of the larger *Phragmites* marshes in the Hackensack Meadowlands or Delaware Bay and perform large-scale, replicated experiments that address different components of the ecosystem *simultaneously*. This would allow us to better understand certain preexisting characteristics [and functions] that each of these stands contributes. This will help us get to the next level of management.

DR. BURDICK: The issue of invasive versus non-invasive forms makes *Phragmites* management even more complex. Another complexity is how *Phragmites* affects the landscape. which my colleagues brought up, and which I am hoping to understand, in both a population and system context. At many sites *Phragmites* forms a barrier to movement of energy and materials across the landscape. Addressing this issue is what landscape ecology is all about. Ten years from now, we may all be talking about how exotic *Phragmites* stands have become "naturalized", as Dr. Stevenson was saying, as part of the landscape. Will we be talking about type M as integrated into the native species complex with only one genotype in the country, or will we be talking about "super" M, an M type that has evolved genetically so that it is now even better [more aggressive] than the original M type? That is something to think about on your ride home today.

DR. GALLAGHER: Just one last thought about the diversity in morphology and physiology that we see within a species of marsh plant. What we see in *Phragmites* we see it in a lot of other species. These differences in physiology and morphology vary from genotype to genotype. From marsh to marsh, they alter the intensity of the various marsh functions that occur there, due to the impact of this or that feature of the plant. I would like people to think about encouraging the growth of those varieties that will give the desired functional traits our society has decided have high value. Then we should aim to have the marshes we have left be even more functional in those desired values than the marshes were, when the Europeans first arrived.

DR. GUNTENSPERGEN: I think that the forum and workshop as Mike and Jan and I envisioned it has turned out to be excellent; i.e., bringing together the current research and activities and trying to understand the role and function of the *Phragmites* in the larger system. And so too the dialogue between the science community and the management community in trying to understand management concerns and trying to help science; i.e., drive science in the directions that will satisfy management needs. Two points that I would like to make are that *Phragmites* is not the only invasive species that threaten ecosystems. Future modernization of the world's population will result in other invasions occurring, and we have an opportunity with *Phragmites* to formulate how we are going to deal or how are we are going to view these continued insults and threats from the invasions on our existence. And the other issue is that *Phragmites* is not the only cause of degradation of our wetland systems, that there are many other factors that affect the systems that we see today, and that we have to take the issue of *Phragmites* in that broader context, both in invasion context and in a broader environmental context. And I'd like to end by making one additional comment. That is, that all of the technical papers that were presented in this workshop will appear as a special issue of [*Estuaries*], either at the end of this year or in the very beginning of next year.

DR. KEOUGH: We do hope, and we expect that there will be legacies from this conference, including trying to understand ecosystem functions of *Phragmites*. We would like all of you to take these Proceedings back to your organizations and say this is the research we need to do, or this is the approach to management we need to take; or this is the attitude and approach we need to manage or control *Phragmites*. Or maybe take your own direction. Thank you very much, all of you, for coming, for participating, for being so vocal, and for the research you are doing.

DR. WEINSTEIN: I just want to reiterate our gratitude to our host, Cumberland County College, especially Dr. Tim Jacobsen, and the hospitality that was afforded to us, and I certainly want to thank our dedicated staff at the NJMSC. I also want to thank the scientists and the management community, and whoever else is here, for a very productive and very useful discussion. We appreciate your coming.

(Session concluded at 11:20 a.m.)

OPINION ARTICLE

Phragmites and Environmental Management: A Question of Values

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ABSTRACT

For a common, widespread, and familiar plant, *Phragmites australis* engenders an enormous level of scientific controversy and emotional conflict. In parts of the world, *Phragmites* is an important component of healthy ecosystems and an integral (if now minor) contributor to human economies. In other places, it is an invading, unfriendly and ugly weed. To some scientists and environmentalists, *Phragmites* is an indicator of and key factor in landscape degradation and habitat deterioration. To others, it is a valiant remnant of nature, providing a relatively rich ecology where there might otherwise be only barren and eroding ground.

We present a literature review supporting the conclusion that *Phragmites* is simply a biological entity. It is not inherently "good" or "bad", its evolution, biology and ecology do not give it a direct value per se. The controversy over *Phragmites*, its role in the ecosystem, the need for and intensity of management efforts are all artifacts of human perspectives. Effective, consistent management decisions (for either control or enhancement of *Phragmites*) can only be made on the basis of site-specific scientific findings, a consideration of technologies with their needed level-of-effort, and explicit exposition of the human values driving the management options. We present a simple decision model to illustrate the interaction of these management components for *Phragmites* in the environment.

INTRODUCTION

Einstein's space is no closer to reality than Van Gogh's sky.

Arthur Koestler

Who provides the accurate characterization of reality: the scientist or the artist? And if it is both, how can they be reconciled? These seemingly abstract questions have a concrete reality where *Phragmites* is concerned. Decisions regarding where, when, and how to manage *Phragmites* have long-term consequences. We need to be right, both scientifically and from a values' perspective.

DISCLAIMER: This text contains minor edits which did not appear in version published in *Estuaries 26 (2B)* April, 2003. The opinions expressed here do not necessarily reflect those of NJMSC or New Jersey Sea Grant College Program.

For a common, widespread, and familiar plant, *Phragmites australis* engenders an enormous level of scientific controversy and emotional conflict. In parts of the world, *Phragmites* is an important component of healthy ecosystems and an integral (if now minor) contributor to human economies. In other places, it is an invading, unwanted and ugly weed. To some scientists and environmentalists, *Phragmites* is an indicator of, as well as a key factor in, habitat degradation. To others, it is a valiant component of nature, providing a relatively rich ecology where there might otherwise be only barren and eroding ground.

In reality, of course, biological entities are not "bad" or "good", or indeed possessed of any inherent value at all. They are simply manifestations of their ecological and evolutionary history (Hull 1980). Because change in exogenous parameters is inevitable and ongoing, for survival's sake, evolutionary change in organisms is also inevitable and ongoing (Jorgensen 1982). Which is not to claim that balance or harmony are critical or even real ecological concepts. The natural world is heterogeneous in space and time, and it is in fact the *imbalance* of nature that drives evolutionary change (Conrad 1983). The heterogeneous nature of the ecological and evolutionary landscape means that there will be many (perhaps most) places and times when particular organisms and their environmental matrix are out of balance in one way or another. By analogy to anatomy, species populations may be vestigial in one place or time because evolutionary change has not kept pace with environmental change. Examples of such imbalances are legion, and illustrate the kinds of evolutionary imbalances that can be brought on by habitat changes. Large dinosaurs may have been ecologically superfluous in an era of shrinking coastal plains, and evolutionarily incompetent in a time of global climatic change (Wilford 1985, Dodson and Tatarinov 1990). Critically endangered species like the California condor and extinct species like the passenger pigeon lost much of their ecological reason-for-being when humans fragmented the landscapes they evolved in. Remnant populations like massassauga rattlesnake and Blanding's turtle survive in small and disappearing habitat islands, extensions of their range into portions of New York state from which the ecosystems they evolved in and for are otherwise gone.

Alternatively, species may become overabundant in particular environmental circumstances. Human introductions are associated with many such cases (for example, the devastating microbiological exchanges of the 1500s, Crosby 1972). However, overproduction can be a natural process as well. The crown-of-thorns starfish, devastating to tropical Pacific coral reefs, may cycle through natural population peaks. Also, Arctic rodent populations over-multiply periodically to levels that cause serious habitat degradation (Nowak and Paradiso 1983).

Seen against the backdrop of evolutionary history and ecological heterogeneity, the values by which *Phragmites* is judged are not issues solely of natural science. A substantial component of human perception is involved and must be accounted for[1]. In addition, there is a long-standing intimacy in the ecologies of *Phragmites* and of people. The nature of human perceptions, and

[1] Two anonymous reviewers suggested that this paragraph (and the paper as a whole) over-values human perspective, and that some impacts—such as displacement of native species and suppression of biodiversity—are inherently, not only perceptually, negative. This is a valid alternative understanding. We contend, however, that even such seemingly "cut and dried" impacts as these only achieve negative value status through human perception. The ecosystem does not "care" what species are present—only people do.

the power of such perceptions to affect our understanding of *Phragmites* and its ecology are important adjuncts to purely scientific inquiry. The objectives of this paper are:

- To compile a representative sample of human perceptions about *Phragmites*
- To develop some basic understanding of human interactions with and valuation of *Phragmites*
- To briefly characterize *Phragmites* ecology as it is presently understood
- To provide a conceptual framework for *Phragmites* management decisions and the resulting implications for management.

This is not a scientific paper in the traditional sense. It is instead an attempt to capture and describe the relationship between humans (both scientists and non-scientists) and another species at a time when our technical understanding of that species is rapidly evolving. The exercise is worthwhile for the insight it can provide into the nonscientific context in which our scientific findings will be translated into environmental management actions.

PHRAGMITES IN THE ECOSYSTEM: GOOD NEWS AND BAD

The universal existence of and contrast between judgments and counter-judgments characterize and dominate the human perception of *Phragmites*. It is instructive to assemble a selection of thoughts from the published literature regarding the place of *Phragmites* in the ecologies of other organisms. On every question of ecosystem structure and function, there is an astonishingly dichotomous range of opinion regarding the value of Phragmites; e.g., on the issue of habitat support for wildlife:

- The extensive reed marshes of the Danube River Delta in Romania *are particularly valued for a variety of bird and mammal species, some of which are facing regional or worldwide threats* (Nevel 1996, p.9).

- On the east coast of the U.S., *Phragmites*-dominated marshes *support a great diversity of animal life*...[*Phragmites* in the Hackensack marshes in New Jersey supports] *a muskrat population capable of supplying more than 1000 pelts per year. Occasional foxes, many cottontail rabbits and some Norway rats reside in these marshes, over 200 species of birds have been observed* (Geller 1972, p. 11).

- *Phragmites reduces natural plant diversity and is not considered to be an important wildlife food or cover plant* (Ailstock 1990, pp. 1–2)

- *The change in wildlife food production* [following *Phragmites* invasion] *has reduced the habitat value of these marshes for many fish and wildlife species* (Tiner 1995, p.1)

- *It is of special concern to wetland managers because it grows rapidly, excludes other plant species, provides little wildlife habitat, and is of little aesthetic or recreational value* (Boone et al. 1987, p. 4).

Divergence of opinion is even greater when particular categories of wildlife are considered:

- *Phragmites* is a "plus", providing resting, foraging or breeding habitat or food web support for:
  - Waterfowl (Boorman and Fuller 1981; Cross and Fleming 1989; Kane 2001)
  - Wading birds and rails (Anderson and Ohmart 1985; Green 1996; Shogolev 1996)
  - Songbirds (Miller 1967; Insley and Boswell 1978; Fleming 1981)
  - Birds of prey (Bibby and Lunn 1982; De Swardt and Van Niekerk 1996; Elphick 1997)
  - Mammals (Hanson 1978; Ventura et al. 1989; Hjalten 1991)

- *Phragmites* is a "minus", offering relatively poor trophic support or less preferred habitat for:
  - Waterfowl (Bennett 1938; Whitman and Cole 1988; Hauber et al. 1991)
  - Wading birds (Burger and Miller 1977; Benoit and Askins 1999)
  - Songbirds (Ailstock 1989)
  - Mammals (Lynch et al. 1947; Martin 1953; Clark 1994).

The citations listed here are not taken out of context. In most cases, the authors of these reports have a point-of-view good or bad regarding the value of *Phragmites*. The reader will notice considerable overlap in these lists. In fact, a number of references could be used to build arguments both for and against *Phragmites* as a plus or a minus in the estuarine landscape. This is not surprising, as few hard data were available through the end of the 1990s.

Similar compilations of conflicting conclusions can be made regarding other ecological processes. There is little agreement in the literature about the effectiveness of *Phragmites* in sequestering pollutants (Biddlestone et al. 1991, Stott and Wright 1991), controlling sediment hydrogeochemistry (Chambers 1997, Templer et al. 1998), or supporting direct herbivory or detrital trophic webs (Lee 1990, Fell et al. 1998). Overall, it is clear that there is no generally agreed upon role of *Phragmites* in the ecosystems it has invaded. Assuming that the science that generates divergent conclusions is not biased (and there is certainly no reason to believe this), and in some cases has not undergone rigorous peer review, the simplest explanation is that *Phragmites* functions many different ways in the environment, and the science reflects this real ecological variability.

Ecological "multitasking" is, of course, widespread. The phenomenon achieves prominence when some functions impact human uses or perceptions of the biosphere. A group of mites, the Trombiculidae, might pass millennia in obscurity if the parasitic offspring of insectivorous adults that normally use reptiles as a definitive host did not occasionally infest man as chiggers (Wharton and Fuller 1952). *Conium maculatum* is a perfectly respectable minor roadside umbelliferous weed unless it is eaten with a batch of field greens, when its infamous nature as poison hemlock becomes apparent (Taylor 1955). There are many organisms that are, under some circumstances, at worst neutral and at best useful, and under others are pests or worse. The converse, is, of course, also true. The honeybee, which for some strains is still considered an invading scourge from the Old World, is now a crucial link in western hemisphere ecological and economic systems (Wilson 1974). Often the difference in perception between good and bad depends on context of time and place. Until recently, perception of a species place in nature was largely driven by consideration of its interactions with man.

Scientific conflict about *Phragmites* ecology is not universal. There are some important points that we conclude from our review are generally agreed upon across the range of published findings:

- Primary production is very high (Warren and Fell 1996)
- Sediment accretion in monotypic marshes is high (Ricciuti 1983)
- Large-scale management (of any kind) is very difficult (Marks et al. 1994).

These generally agreed upon points do not speak to any kind of inherent value for *Phragmites*, either ecologically or for human economies. Primary production is not inherently valuable, as eutrophic waterways throughout the northern hemisphere attest. Sediment accretion can help wetlands keep pace with sea level rise, and reduce solids loading to waterways (Rejmanek et al. 1988, National Research Council 1992). It can also raise the level of the sediment surface to the point where the wetland character of the ecosystem is greatly altered (Roman 1978, Roman et al. 1984). That *Phragmites* is not amenable to management is a strike against it on a human value scale. But it should be recalled that not all human associates are or were agriculturally compliant. For example, oats may well have started its domestic career as a weed that simply could not be sorted from barley (Janick et al. 1974).

Recently, a number of quantitative studies and objective literature reviews have been published. These provide a technically credible foundation for drawing conclusions about the state-of-the-science of *Phragmites*. Meyerson et al. (2000) evaluated how *Phragmites* ecology differs in different habitats and what consistent ecological indicators of *Phragmites* were discernible in the available literature. They reviewed a wide range of published findings, and concluded that a) scientific information regarding *Phragmites* is incomplete, and b) *Phragmites*' ecological functions are site-specific. Chambers et al. (1999) reported that, although plant community structure is drastically altered following *Phragmites* invasion, other ecological services might not be greatly impaired. Rooth and Windham (2000) suggested that management control decisions are best made at small spatial scales, because ecological functions vary from place to place. It has recently been revealed (Blossey, this volume) that a tendency to establish invasive monocultures is associated with specific, differentiable varieties of *Phragmites*, and is not a general characteristic of the species. The important message from research conducted to date is that ecology provides no easy answers as to how humans should or could value P*hragmites*. As discussed in the concluding section of this paper, the lack of easy resolution means that we have to apply sound science, intellectual rigor, and sociological care to our relationship with *Phragmites*.

ENVIRONMENTAL MANAGEMENT: A FRAMEWORK

Questions of *Phragmites* ecology are necessarily related to the potential for management. In the past few decades, human interactions with *Phragmites* have been dominated by management concerns, either for control (Niering 1988) or restoration (van der Putten 1997). To provide context for consideration of *Phragmites* management, it is useful to identify the most basic parameters that are fundamental to environmental decision-making. Such an exercise allows us to separate the "nuts and bolts" of *Phragmites* ecology from the abstract process of making and implementing management choices. Understanding the management process is as important as understanding ecology for effective decision-making.

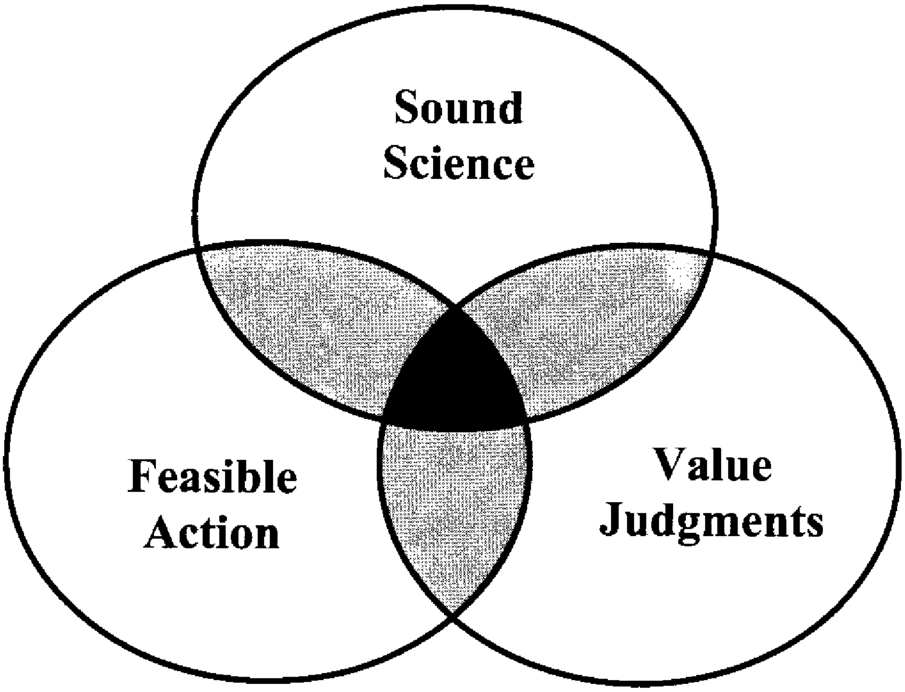

Fig. 1 presents a simple conceptual model for an environmental management framework.

There are three components in this model, each representing factors necessary for a successful outcome. When the factors in each component are appropriate to the case at hand, management success represented by the overlapping centers of each model element. Each component has unique aspects when considering the application of this framework to the case of *Phragmites* control.

The application of sound science would seem to be a *sine qua non* of effective environmental management. The matter is not quite so simple for *Phragmites*, however. We have seen that there is no universally valid scientific characterization of *Phragmites* in the environment. Current reviews suggest that what *Phragmites* is and what it does are strongly determined by where and when one is looking at it. Indeed, this may be the key to the sound science component: effective management requires site-specific scientific foundations.

The feasible actions component represents the technology; i.e., the engineering of the management enterprise. This component interacts with the others in specific ways. For example, whatever the scientific data might suggest about *Phragmites* in a particular place, if there is no control technology available, there is no feasible management alternative. In this case, the feasible actions component is an absolute switch (Ashby 1952), either management is possible or it is not. In the former case, we can proceed with our management decision-making. In the latter, we might as well stop worrying about this area of *Phragmites*, because there is nothing we can do about it anyway. To date, this seems to be the case for many management actions, both for control (in the U.S.) and restoration (in Europe), neither of which has been notable for widespread success. The only way through the switch is to increase our repertoire of management tools until we have one (or more) that will work in the case at hand.

The value judgments component is critical, and remarkably undeveloped in the environmental management context. It is conceivable that environmental management is a zero-sum enterprise (Thurow 1980), in that the sum of resources available for environmental management in the broadest sense is finite. If so, resources of money, time and expertise committed to an activity are not available for others, and we had best be certain that the management activity we are undertaking is sufficiently important to warrant the commitment. To date, our handling of *Phragmites* in the management context has been notable for a lack of subtlety. Sometimes we believe *Phragmites* is "good" and must be actively nurtured. Sometimes we believe *Phragmites* is "bad" and must be actively controlled. But there is little beyond geography in our beliefs (it is good in Europe and in the Mississippi Gulf coast delta, it is bad in east coast marshes). It is the value judgment component that takes us to the most important consideration of all.

AN ETHICS FOUNDATION FOR *PHRAGMITES* MANAGEMENT

It is far easier to address the question of site-specific scientific data needs than to resolve issues of ethical bases for management actions. However, *Phragmites* management under most circumstances is technically challenging and resource intensive[2]. By its very nature, it involves the deliberate, directed alteration of the environment by human intervenors (for reed marsh restoration, we destroy the habitat in place hoping to replace it with *Phragmites*, for *Phragmites* control, we destroy the *Phragmites* community itself). Such activities should not be undertaken lightly, automatically, or without due consideration of the ethics of destructive environmental management.

In seeking an ethics framework for management, objectivity is fundamental. It is important that decision makers understand that a biological entity is just that, it has no inherent goodness or badness. A plant is just a plant, and it is only in the human context that we can imbue it with qualities of desirability or undesirability.

In this context, it is useful to recall the history of some important domesticated plants. The potato, taken to Europe early from South America, was only partially successful as a food plant. In France, it was declared dangerous to eat by government decree. It was not until Parmentier, a chemist forced to live on potatoes in a German prison camp in the 1700s introduced potatoes to the royal court that they were accepted by the populace (Diat 1961). Similarly, the tomato was grown as an ornamental only, and was generally believed to be poisonous, even after it was widely used for food in Italy (McGee 1984). Conversely, rhubarb was taken from Old World to New. During World War I, rhubarb leaves were recommended as a vegetable supplement, and

[2] The exception to this statement is tidal marshes with restricted flow. When such marshes have been colonized by *Phragmites*, their restoration is relatively straightforward, although it still requires a significant per-unit-area investment in planning and implementation.

numerous cases of intoxication resulted (McGee 1984). The lesson is clear. Plants evolve in ecological contexts. But in a world dominated by people, the accidental history that overlays biological characteristics and human expectations determine whether they are considered good or bad and therefore how they are managed.

Human control of the biosphere underlies all management decisions. An argument can be made that humans can not and should not be making large-scale environmental management decisions, that nature knows best and that people will only interfere with the course of nature if we try to direct ecological change. Supporting this argument are cases where human misallocation of environmental management resources is associated with the complete collapse of societies (Ponting 1991, McNeill 1992, Redman 1999)[3]. This view leads to one-dimensional management Decisions, management to "put it back the way it was." In practice, this is shortsighted ignorance of history. We do not, after all value eastern U.S. woodlands because they might some day be returned to chestnut forests. We value them for their present attributes, and make management decisions on that basis.

An additional problem with this view is that human influence is now ubiquitous. We are managing the biosphere, all aspects of it, from its atmospheric thermal balance to its biodiversity (see McNeill 2000 for a catalog), and we are managing it by default. From a systems analytic perspective, we are simply allowing our technological capabilities to alter the environment as a random output of our input choices. The consequence of this is undirected global environmental management. We change the environment, but we do not direct the changes. The locomotive is powered up and running, but the engineer has moved on to the next train.

It is a hard lesson that the humble *Phragmites*, this common, widespread, and familiar plant--has to teach us: those questions about whether an organism is good or bad are really *value* questions. There is a design problem (Lyle 1999) inherent in our *Phragmites* management decision process. Before undertaking difficult, destructive, expensive action, we must decide what we want from the environment at that place and time. The best and most up-to-date science is now starting to tell us what *Phragmites* will and will not do biologically, chemically, and physically. It is up to us to decide if what *Phragmites* does is what we want from that bit of the natural world, and then to manage accordingly[4]. And deciding what we want is best done *a priori*, by understanding what we value in that place, is a difficult challenge for sure, but one that we must meet if we are to spend our collective environmental management capital wisely and prosper in the twenty-first century.

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[3] The evidence for some of these cases is not universally accepted. See Meiggs 1982 and Grove and Rackham 2001 for counter arguments.

[4] In this context, it is worth considering that *Phragmites* may well be a symptom, not a first cause, of environmental change. In that case, we will have to decide what we value from entire landscapes and whole watersheds (Burdick and Konisky, this volume).

ACKNOWLEDGMENTS

The literature compilation on which this paper is based was supported by PSEG. I. Ratsep compiled much of the literature cited here. The conceptual development benefited enormously from discussions with J. Teal, J.Balletto, J.Gallagher, C. Linder, K.Strait, and M.Weinstein. For conversations leading to ideas that were built into the manuscript following the Vineland conference, we thank B.Blossey, S.Findlay, and J.Rooth. Note, however, that none of these individuals necessarily agrees with the content of this paper. We also thank three anonymous reviewers for their diligence and contribution to clarity of the text, noting that at least one (and possibly all three) of these reviewers disagree with its content.

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Cryptic invasion by a non-native genotype of the common reed, *Phragmites australis*, into North America

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Edited by Barbara A. Schaal, Washington University, St. Louis, MO, and approved December 6, 2001 (received for review September 10, 2001)

Cryptic invasions are a largely unrecognized type of biological invasion that lead to underestimation of the total numbers and impacts of invaders because of the difficulty in detecting them. The distribution and abundance of *Phragmites australis* in North America has increased dramatically over the past 150 years. This research tests the hypothesis that a non-native strain of *Phragmites* is responsible for the observed spread. Two noncoding chloroplast DNA regions were sequenced for samples collected worldwide, throughout the range of *Phragmites*. Modern North American populations were compared with historical ones from herbarium collections. Results indicate that an introduction has occurred, and the introduced type has displaced native types as well as expanded to regions previously not known to have *Phragmites*. Native types apparently have disappeared from New England and, while still present, may be threatened in other parts of North America.

Biological invasions threaten species and ecosystems worldwide (1). An estimated 50,000 exotic species have been introduced to the United States, of which 5,000 are plant species that have escaped and now exist in natural environments (2). Both the actual number of invaders and the impacts of these species may be underestimated because of the presence of cryptic invaders, or species that cannot be easily classified as native or introduced (3). Over the past decade, use of PCR-based molecular techniques have revealed repeated occurrences of such invasions in marine ecosystems (4–6), and studies have demonstrated both genetic and physiological differences between invading and native populations (6). Given that cryptic invaders typically are unrecognized or are mistaken for native species, knowledge of historical trends in geographic distribution and population genetic structure in cases of suspected introductions are of particular interest when trying to reconstruct the invasion history of a species. In such cases, museum or herbarium specimens are an invaluable resource for reconstructing population history.

Common reed, *Phragmites australis* (Cav.) Trin. ex Steudel (hereafter referred to as *Phragmites*), has a cosmopolitan distribution and is abundant in marsh communities and along the borders of lakes, ponds, and rivers. It is a perennial grass that reproduces primarily through vegetative growth, although dispersal by seeds may occur at low frequencies. In North America, the fossil record indicates that it has been present in the southwestern United States for at least 40,000 years (7). Paleoecological investigations have shown it to have been present along both the Atlantic and Pacific coasts for several thousand years (8–10). However, over the last 150 years its distribution and relative abundance has increased dramatically, particularly along the Atlantic coast. Botanical records from the 1800s typically describe *Phragmites* as being rare or not common (11–14), and a historical gap in its distribution was found in the southeastern states (15). By the early 1900s the species was considered more common and spreading (16, 17). Today it exists in all of the mainland United States as well as throughout southern Canada and is considered an indicator of wetland disturbance. It is also expanding into undisturbed sites, particularly in inland areas. To explain the spread of *Phragmites*, it has been suggested that the rapid expansion could be the result of human activities causing habitat disturbances or stresses such as pollution, changes in hydrologic regimes, and increased soil salinity (18). Alternatively, non-native genotypes of the species may have been introduced to North America sometime during the past 200 years (19–21), although to date no studies have adequately supported this hypothesis.

This research asks the question of whether or not non-native strains of *P. australis* exist in North America by using sequencing of two chloroplast DNA markers. Although the rate of evolution of the chloroplast genome is relatively conservative, variation has been found in chloroplast DNA at the intraspecific level (22). It is maternally inherited in angiosperms and has been shown to be geographically structured in a diverse array of plant species (23, 24), and therefore is an effective marker for use in the study of intraspecific phylogeography. In this study, modern samples of *Phragmites*, collected across the continent, were compared with historical specimens, collected before 1910, to examine changes in the genetic structure of the North American population over the past 150 years. Modern samples were also obtained worldwide for comparison and to determine the source of the introduction.

Materials and Methods

Leaf tissues were collected from green *Phragmites* plants during the growing seasons of 1997–2001 by the author and collaborators worldwide, with a particular emphasis on obtaining samples from the present-day range of *Phragmites* in North America and Europe. When available, herbarium specimens also were obtained to increase the number of samples from locations outside of North America. Fresh specimens were dried by using silica gel and frozen on receipt in the laboratory. Total DNA was extracted from 2 cm^2 of fresh or dry leaf tissues using a 2% cetyltrimethylammonium bromide extraction protocol (25). Herbarium specimens were pretreated by scrubbing with 10% bleach to remove mounting glue, placed under an UV light for 5 min to remove surface contaminants, and extracted by using the same protocol. All herbarium samples used in historical comparisons were collected before 1910, which is before the time period when references to expansion of *Phragmites* populations began to appear in the literature (16). Where possible, modern samples also were collected at sites from which herbarium samples were obtained. Sample collection locations, herbarium accession numbers, and haplotype designations for each sample are available on request.

POPULATION BIOLOGY

This paper was submitted directly (Track II) to the PNAS office.

Data deposition: The sequences reported in this paper have been deposited in the GenBank database (accession nos. AY016324–AY016328, AY016332–AY016335, and AF457382–AF457402).

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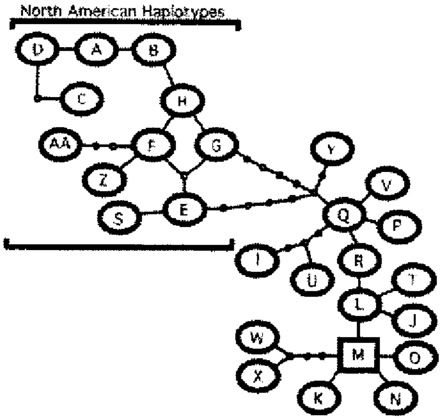

Fig. 1. Parsimony network of *Phragmites* chloroplast haplotype diversity obtained from sampling 345 populations worldwide. Each link between haplotypes represents one mutational difference, following coding of indels as single characters. Unlabeled nodes indicate inferred steps not found in the sampled populations. Loops in the network are the result of homoplasies in the number of repeats in some indels. The ancestral haplotype, or root of the network, is indicated by a square. Geographic distribution of haplotypes is as follows: North America = haplotypes A-H, S, Z, AA, I, and M; South America = I and Y; Europe = L-O, and T; Asia/Australia = I, J, L, M, O, P, Q, U, W, and X; Africa = K, M, R, and V.

Two noncoding chloroplast regions were PCR-amplified by using the primer pairs *trn*T(UGU) "a"–*trn*L(UAA)5′ "b" (26) and *rbc*L–*psa*I (27) with annealing temperatures of 56°C and 54°C, respectively. Smaller fragments were amplified in the herbarium samples by using the primer pairs *trn*T(UGU) "a"-*trn*TaR (5′-TAGATTATTCSTCCGAGCC), *trn*L(UAA)5′ "b"-trnLbR (5′-GGAGAAGATAGAATCATAGC), *rbc*L2F (5′-CGCAGCTTGTGAAATATGG)–*rbc*L2R (5′-CGTATTT-GATTCCATTATCGT), and *psa*I2F (5′-TGTCATAGAAT-AGGTGTCTC)–*psa*I2R (5′-GATTAGAAGGATAGAA-AGGC), which were designed around the variable regions found in the larger fragments. Double-stranded PCR amplifications were sequenced directly in both directions on an Applied Biosystems 377 sequencer using the amplification primers and two internal primers in the *rbc*L-*psa*I region (*rpL23*F 5′-AGGTAGTAGCTGTGAATAGC and *rpL23*R 5′-AGTCGAT-GGCTATTCACAGC). In total about 2,000 bp were sequenced for each modern sample and 1,400 bp for herbarium samples.

Because of the high incidence of large insertion/deletion mutations (indels), sequences were aligned by eye with SEQUENCHER 4.1. Two mononucleotide repeat regions in the *trnL* region, which showed intrahaplotype length variation, were not used when distinguishing haplotypes. Before analysis all indels were coded as single characters to treat indels as single events rather than multiple independent events. Where indels were composed of several copies of a multiple-site insertion, each copy was treated as a single unit and gaps were inserted in haplotypes with fewer copies of the indel (28). Parsimony networks were obtained with the software TCS (29), using the algorithms of Templeton *et al.* (30). Haplotype diversity measures (31), analysis of molecular variance (32), and an exact test for population differentiation (33) were calculated by using ARLEQUIN 2.000 (34). All analyses were performed on the combined data set.

Results

Based on sequencing of 283 modern samples and 62 herbarium samples collected before 1910, a total of 27 haplotypes were identified worldwide (Fig. 1). Where only partial sequences were obtained, samples were assigned to the most likely haplotype class based on the available sequence and geographic origin. There are 26 variable characters, of which 15 are indels (four type Ia, which are mononucleotide repeats, and nine type Ib, which are deletions or duplications of adjacent sequences, and two type II, which are all other types of indels (35) and 11 are base substitutions. Eleven haplotypes are unique to North America (haplotypes A-H, S, Z, and AA) and are considered to be native to the continent. These 11 are distinguished from all other haplotypes by five shared indels (two type Ia, one type Ib, and two type II). Two haplotypes have a widespread distribution on multiple continents (haplotypes I and M), with haplotype M being the most common type in North America, Europe, and Asia today (Table 1). This type is most closely related to other haplotypes found in Europe, Asia, and Africa (Fig. 1). It is also the predicted ancestral haplotype based on coalescent theory (36).

Within North America, the exact test of population differentiation indicates significant changes in haplotype frequencies between the historical and modern samples [$P < 0.001$ (33); Fig. 2]. The pre-1910 populations showed a widespread distribution of the 11 native haplotypes across North America from New England west to the Pacific coast (Fig. 2*a*). Haplotype I, which also is found in South America and Asia (Fig. 1), was distributed along the Gulf Coast. Haplotype M was found at four sites of the 62 sampled (New Haven, CT; Madison, CT; Camden, NJ; Chesapeake Beach, MD; Fig. 2*b*). In comparison, whereas the native haplotypes and haplotype I remain throughout much of their original range, modern populations show a striking pattern of expansion in the range of haplotype M (Fig. 2 *c* and *d*). This type has replaced native types in New England and expanded to the southeast where *Phragmites* historically did not grow. It is presently expanding to the west and becoming prevalent in the Midwestern states.

Measures of haplotype diversity show a decline in diversity between the historical population and the present (0.80 ± 0.04 vs. 0.58 ± 0.04). Further, analysis of molecular variance shows that among-population variation accounts for a larger proportion of the total variance in the historical population (35%) than the modern population (−9%) when compared with worldwide populations ($P < 0.001$), indicating that today the genetic structure of North American *Phragmites* populations is more like

Table 1. Frequencies of *Phragmites* haplotypes worldwide

Geographic region	Total no. of samples	% Regional haplotypes	% Haplotype I	% Haplotype M
North America, after 1960	195	31.3	7.2	61.5
North America, before 1910	62	83.9	9.7	6.4
South America	11	27.2	72.7	0
Europe	41	39.0	0	61.0
Asia/Australia	27	55.6	11.1	33.3
Africa	9	88.9	0	11.1

Regional haplotypes refer to those found only in the corresponding geographic region.

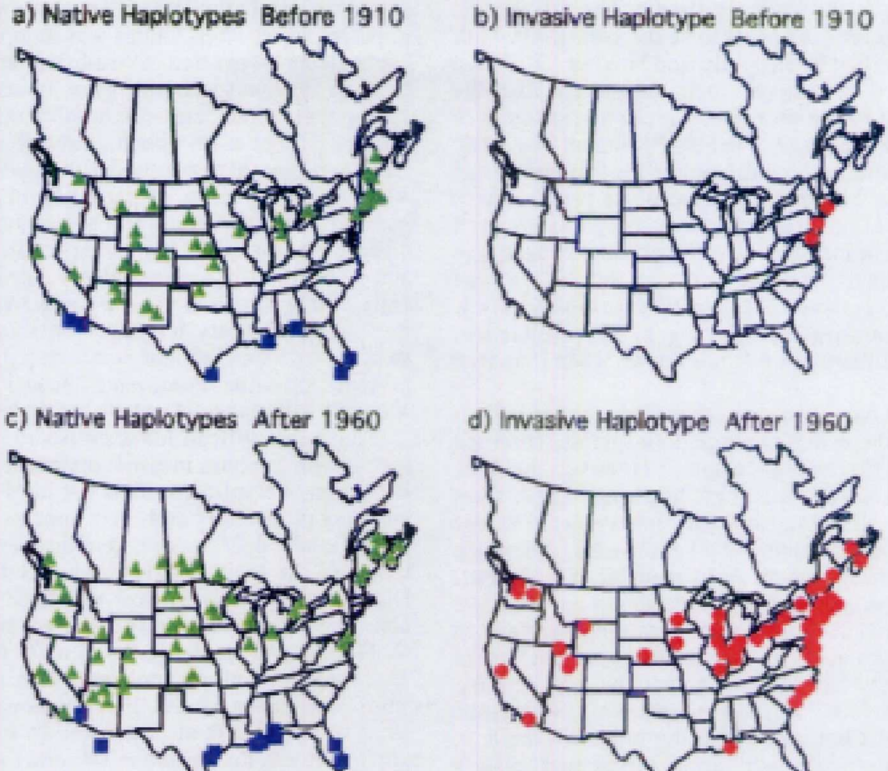

Fig. 2. Distribution of *Phragmites* haplotypes in North America. Green triangles represent the 11 native haplotypes, blue squares represent haplotype I, and red circles represent the invasive haplotype M. (*a* and *b*) The distribution of haplotypes in the 62 herbarium samples collected before 1910. (*c* and *d*) The distribution of haplotypes in 195 samples collected after 1960.

that of Europe and the rest of the world. Within-population variation increased between the historic and modern populations (52% vs. 79% of the total variance), reflecting the spread of haplotype M into new regions.

To examine the time frame over which the rapid expansion of haplotype M occurred, a chronology of haplotype frequencies in 20-year increments was examined for populations in Connecticut and Massachusetts (Fig. 3). Although the 19th-century samples were primarily native types (haplotype E = 47%, haplotype F = 29%, haplotype AA = 12%, and haplotype M = 12%), a changeover is seen and by 1940 all samples displayed haplotype M.

Discussion

Geographic structuring in *Phragmites* was found worldwide at continental scales. Closely related unique haplotypes were found in each geographic region with haplotype M being the most common worldwide (Table 1, Fig. 1). Haplotype M was found across Europe and continental Asia in high frequencies and is closely related to all other haplotypes found in these areas. It was not found in the islands of the Pacific or Indian oceans but it was present at one site in New Zealand. However, *Phragmites* may be a recent addition to the New Zealand flora (Paul Champion, personal communication). The estimation of haplotype M being the ancestral one, based on coalescent theory, corresponds well with the finding that higher levels of isozyme diversity are found in *Phragmites* populations from western and central Asia (37).

Today haplotype M is the most common and has the most widespread distribution of any haplotype in North America (Fig. 2*d*). However, network analysis suggests that it is not closely related to other North American haplotypes, which cluster together and are quite distinct from other *Phragmites* haplotypes (Fig. 1). Its extremely limited distribution in the historic sample (Fig. 2*b*) indicates that the present-day distribution of this haplotype does not reflect historical trends in North American *Phragmites* populations.

Haplotype I was found along the Gulf Coast of North America, as well as in South America, where it is the dominant type,

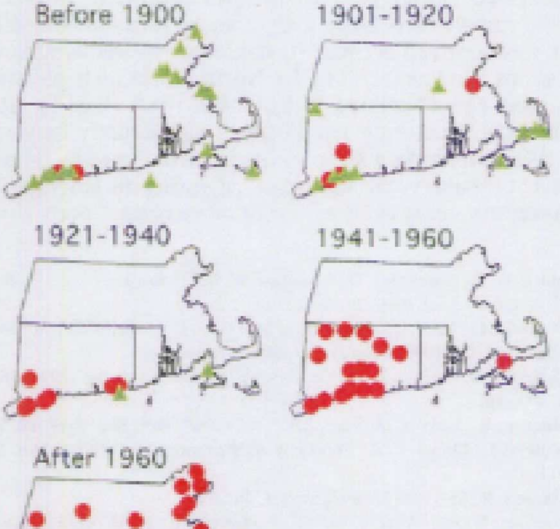

Fig. 3. Changes in *Phragmites* haplotype distribution patterns over 20-year time intervals in Connecticut, Massachusetts, and Rhode Island. Green triangles represent native haplotypes; red circles represent the invasive haplotype M.

POPULATION BIOLOGY

and on several islands in the southern Pacific. The distribution of this type in North America appears to be the same as the Gulf Coast phenotype identified by Pellegrin and Hauber (20) based on isozymes. These data support their suggestion that the presence of this type in a wide variety of habitats across southern North America may be the result of the establishment of a single genetic lineage with broad ecological tolerances that has spread throughout the region. However, because of its prevalence in other parts of the world, it is not possible to assign haplotype I to a category of native or introduced to North America although its distribution remained the same between the historic and modern samples (Fig. 2 *a* and *c*). Given that its mostly closely related haplotype is found only in Asia (Fig. 1), it is possible that haplotype I originated there but it is not known when it arrived in North America.

The 11 native North American types show little change in their distribution between the historic and modern samples from the Midwest to the Pacific Coast (Fig. 2 *a* and *c*). However, the three native haplotypes that were found in the historical sample from southern and central New England were not detected in the modern sample, despite resampling of all of the sites from which 19th-century herbarium specimens were available (Fig. 3). Further, haplotype AA was restricted to this region in the historical samples and is not found in any of the modern samples. Thus, in addition to local changes in haplotype frequencies, extinction of *Phragmites* lineages may have occurred over the past century. Native haplotypes were found in only two sites along the Atlantic coast (Allen, MD and Chance, VA) in the modern sample in contrast to their widespread distribution throughout eastern North America in the historic sample (Fig. 2 *a* and *c*). The lack of persistence of native types is surprising given the clonal nature of this species and suggests that haplotype M is highly competitive and aggressive. This is further evidenced by the rapid replacement of native lineages by the invasive one seen in marshes of Connecticut and Massachusetts by 1940 (Fig. 3).

The rapid proliferation of haplotype M throughout the Atlantic Coast could result from either an introduction of this type from elsewhere or a range expansion of an existing native type. Because this haplotype was present in historical samples it is possible that human-induced changes in the landscape or other unidentified causes gave it an advantage that allowed it to expand rapidly. It is more likely that an introduction of *Phragmites* has occurred because (*i*) haplotype M shares none of the mutations that link the 11 native North American haplotypes; (*ii*) it is most closely related to EurAsian types (Fig. 1); and (*iii*) population structuring has declined significantly between the pre-1910 and modern samples from North America. This introduction probably occurred sometime during the early part of the 19th century, most likely at one or more coastal ports along the Atlantic coast. In the 1800s, *Phragmites* was documented growing in places where ships ballast was dumped or used to fill marsh lands being converted to railroad and shipping hubs (38). Because *Phragmites* already grew in coastal marshes as a native component of the plant community and the introduced variety showed little or no morphological differences with native types, the establishment of non-native populations was not recognized. After several decades of persisting in low densities, rapid expansion of the type began and was probably facilitated by human dispersal by means of the widespread construction of railroads and major roadways across North America in the late 19th and early 20th centuries. Given the aggressive patterns of spread seen over the past century, it is likely that this expansion will continue to occur into western and northern parts of the continent. The presence of native *Phragmites* lineages throughout these areas will only complicate efforts to control this spread.

It has been difficult for scientists to predict whether or not a species will become invasive upon entering a new habitat (1). Detection of cryptic invasions is critical for quantifying both the numbers of invaders and their impacts. For species with widespread native distributions, genetic diversity may play an important role in their behavior when establishing at new sites. Differences in physiological tolerance and behavior may give non-native genotypes unforeseen advantages allowing them to proliferate and changing the genetic structure of the species. This study presents compelling evidence of a cryptic invasion in a terrestrial plant species. This invasion is on a scale comparable to (if not greater than) other known wetland invaders, such as purple loosestrife (*Lythrum salicaria*) and salt cedar (*Tamarix* sp.), but appears to still be in a phase of expansion into new areas. It is important to recognize that the structure and function of native terrestrial communities may be influenced by both cryptic and easily recognized invaders.

Thanks to J. R. Powell, G. Caccone, D. Skelly, M. Donoghue, J. Gleason, J. S. Hall, and two anonymous reviewers for comments and discussions. J. R. Powell kindly provided the laboratory space and facilities for this work. I thank the U.S. National Herbarium, Harvard University Herbaria, New England Botanical Society, George Safford Torrey Herbarium at the University of Connecticut, Connecticut Botanical Society, and Yale University Herbarium for providing herbarium samples. This research was funded by an Environmental Protection Agency Science to Achieve Results graduate fellowship, The Nature Conservancy Connecticut chapter, The Long Island Sound Fund administered by the Connecticut Department of Environmental Protection through the sale of Long Island Sound license plates and contributions, the New Jersey Public Service, Electric and Gas Company, and the U.S. Fish and Wildlife Service through the Biological Control of Nonindigenous Plant Species Program at Cornell University, and the National Oceanic and Atmospheric Administration Office of Sea Grant and Extramural Programs, U.S. Department of Commerce, under Grant MERP/SG 99-21.

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POPULATION BIOLOGY

Morphological differences between native North American *Phragmites australis* genotypes and introduced invasive European genotypes

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BACKGROUND

For decades, botanists, ecologists, and wetland managers have held various opinions about *Phragmites australis*, or common reed. Some considered it a native plant, others an introduced invasive species. In the 19th but particularly in the 20th century, *P. australis* began invading fresh and brackish wetlands in North America - greatly expanding its range and abundance. Mixed wetland plant communities are replaced by near monocultures of *P. australis* resulting in changed ecosystem processes and associated impacts on native wildlife, usually (but not always) considered detrimental (Marks et al. 1994, Meyerson et al. 2000). The population explosion of *P. australis* is often thought of being facilitated by changes in land use patterns and hydrologic regimes, increased disturbance, urbanization and eutrophication (Marks et al. 1994). However, the very same factors are thought to cause declines of *P. australis* in Europe (van der Putten 1997). Alternatively, it has been suggested that the invasiveness of *P. australis* is attributable to the introduction of more aggressive European genotypes (Metzler and Rosza 1987, Tucker 1990, Besitka 1996) but until recently little information was available to support this hypothesis.

GENETIC MARKERS IDENTIFY NATIVE AND INTRODUCED GENOTYPES

Peat core analyses suggest that *P. australis* has been an uncommon member of mixed tidal wetland plant communities in eastern North America for at least 3000 years (Niering et al. 1977, Orson et al. 1987). Research by Kristin Saltonstall (Saltonstall 2002) has now confirmed the present-day existence of native North American haplotypes[5] (lineages) and also of introduced European haplotypes. A total of 27 different haplotypes were identified of which 11 (A-H, S, Z, AA) are native to North America (Saltonstall 2002). Within the North American populations, a continuum of geographic substructuring exists for the native haplotypes. Types AA, F, Z, and S are known historically from the Northeast; types E, G, and H are found throughout the Midwest; and types A-D are found in the South and Intermountain West only. Type E is the most widespread native haplotype. Two haplotypes show worldwide distribution (I and M) with M as the most common type in North America, Europe, and Asia. Type I is found along the Gulf Coast and also occurs in South America and Asia (for more details see Saltonstall 2002).

[5] Haplotypes represent a lineage (or family tree) of maternally inherited genetic material. Chloroplast DNA (as analyzed in *P. australis*) is dispersed in seeds (or through rhizomes) but not through pollen. Chloroplast DNA is quite highly conserved and has been shown to display spatial structuring, such that the majority of the genetic variation is between geographic populations rather than within a local population

Comparing the genetic structure of present-day populations with those available in herbarium specimens collected before 1910 reveals significant changes in haplotype frequencies in North America. While the herbarium samples show a widespread distribution of native haplotypes across North America, modern populations show a striking range expansion of the M haplotype (Saltonstall 2002). Type M has entirely replaced native types in New England and expanded to the Southeast where no historic *P. australis* populations were known. Type M (which is most closely related to other European types) has spread to the West and is also becoming prevalent in the Midwest. At present, we know of fewer than 10 native populations that still grow along the East Coast from Maine to Virginia. It is likely that the introduction of type M material has occurred sometimes in the early part of the 19^{th} century, probably at several Atlantic coast ports (Saltonstall 2002).

MORPHOLOGICAL DIFFERENCES SEPARATE NATIVE AND INTRODUCED GENOTYPES

Phragmites has always been considered an extremely adaptable and variable species. With the recent discovery of native and non-native populations of *Phragmites* in North America, we began looking for morphological and habitat characteristics that may allow us to separate native and introduced genotypes without the need for elaborate (and costly) genetic analyses. If successful, it would enable genotype and site-specific management of clones based on their genetic heritage. To arrive at potential morphological differences we have examined genotypes of known genetic heritage (collected from clones that were used by Dr. Saltonstall in her genetic analysis). We have also visited native and invasive populations in VA, MD, DE, NJ, CT, MA, RI, ME, NY, MN, OR, WA, AZ, CA, and received samples from additional populations from NC, NH, IL, WI, IN, MI, UT, MT, Ontario, and British Columbia. Morphological characters in the field may be influenced by the genotype *and* the growing environment, therefore, we now grow clones of known genetic heritage in "common garden" environments under standardized conditions at Cornell University in Ithaca, the University of Rhode Island in Kingston, RI, and in Switzerland. We will examine morphological characters and development of clones over time in the field and in the common gardens.

Examination of growth characteristics in more than 60 different clones demonstrates that we are able to separate introduced from all native haplotypes using various morphological characters (for updates and details go to: www.invasiveplants.net). However, not surprisingly, we have also discovered differences in morphological characters among the native haplotypes (and potentially among different geographic regions; i.e. environmental factors), as well as among some of the more homogeneous introduced genotypes. We still need to increase our sample size (in particular of Type I, which is found in the southern US and around the Gulf of Mexico) to assess whether the evidence for morphological differences between native and introduced genotypes remains consistent across populations and lineages.

In general, native populations grow as small clones with a lower stem density, and thinner, more flexible stems, and, at least East Coast and Midwestern populations examined in the field grow in mixed plant communities. Introduced clones in the same region can cover extensive areas and exclude other plants in their interior. Stem height does not appear a good indication of native or introduced status because stems of native clones can still be the tallest plants in a wetland. Native clones in the Intermountain West can be very dense with stem densities of >100 stems m^2 but are usually small.

The best evidence of native or introduced status comes from leaf sheaths, stem coloration, and texture on the lower internodes of each stem, plus a combination of other characters. Please note that as stems grow, mature, and senesce that these characters will change over the course of the season. While it is possible to use morphological characters to identify native and introduced genotypes throughout the year, early in the growing season, characters used during the winter have faded somewhat while characters on green stems have not fully developed. When plants are regularly flooded, have been mowed, sprayed, grazed, or develop under drought conditions, characters may not be fully developed or become confusing. Green stems and leaves will also change their coloration and texture within a few days after being cut. In addition, no *single* morphological character has predictive value; positive identification requires a *combination* of characters listed below.

The following characters are ordered according to their "value" in predicting native or introduced status of *P. australis* clones starting with the ones of highest predictive value.

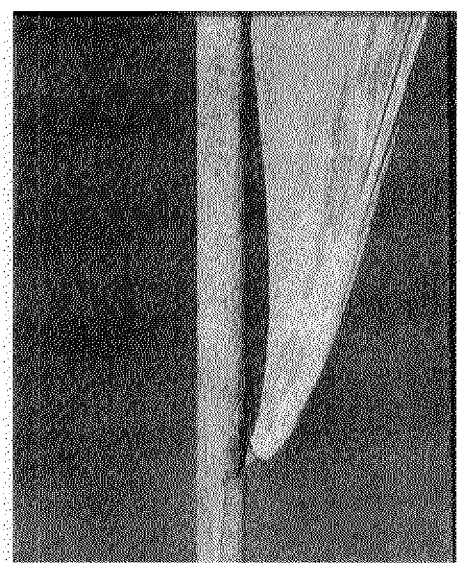

Fig. 1. *P. australis* leaf extending from a leaf sheath wrapped around the stem during winter 2001. Please note that the leaf sheath completely covers the stem on this introduced genotype.

Leaf sheaths

Leaf sheaths are an extension of the leaf and wrap around the stem (Fig. 1) ending at a juncture called a node. Most leaves fall off as plants senesce in the fall starting with the lowest ones dropping already during the growing season. Native and introduced genotypes differ in the tendency of leaf sheaths to remain attached during stem growth, maturation, senescence, and decay. Leaf sheaths on introduced clones remain firmly attached to the stem (Fig. 2 and 3), often for extended periods (several years).

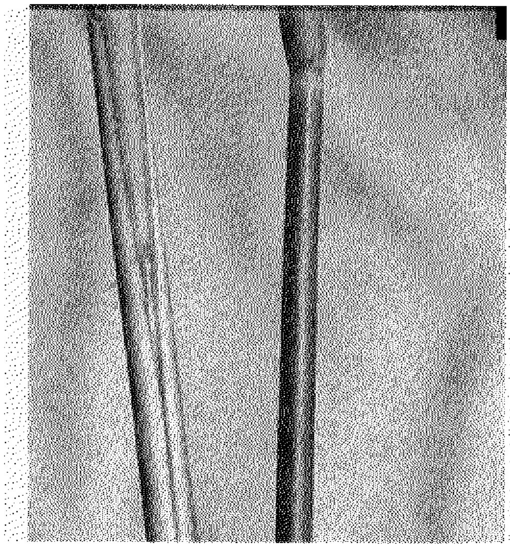

Fig. 2. Stem of a native genotype (right; note red coloration and stem gloss) with leaf sheath already dropped) and of an introduced genotype (left; note green coloration and barely split leaf sheath). June 2002, upstate New York.

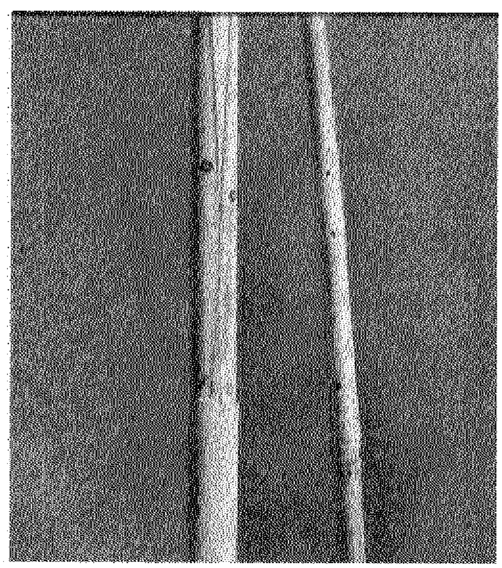

Fig. 3. Stem of a native genotype (right; note lack of leaf sheath and well defined fungal spots) and of an introduced genotype (left; note barely split leaf sheath still wrapped around stem) January 2002, upstate New York.

The exceptions are leaf sheaths on the lowest internodes, which may separate from the stem more frequently. Leaf sheaths on native genotypes become lose as the plants begin to senesce and drop to the ground (Figs. 2 and 3). In some genotypes many leaf sheaths remain on the stems (particularly at shot tips) but open widely and appear separated from the stem. In most other native genotypes, the majority of leaf sheaths drops off the stem in the fall and early winter but a few leaf sheaths may remain on the stem. "Looseness" of the leaf sheath can be tested with a twisting motion where leaf sheaths originate at a node. They should come off easily for native genotypes but it is more difficult for introduced genotypes and usually requires force.

Stem color

Almost all native genotypes develop "fall color" on the lower internodes. For many genotypes the redness of the lower internodes begins to develop early, sometimes before leaves have fully developed (Fig. 4).

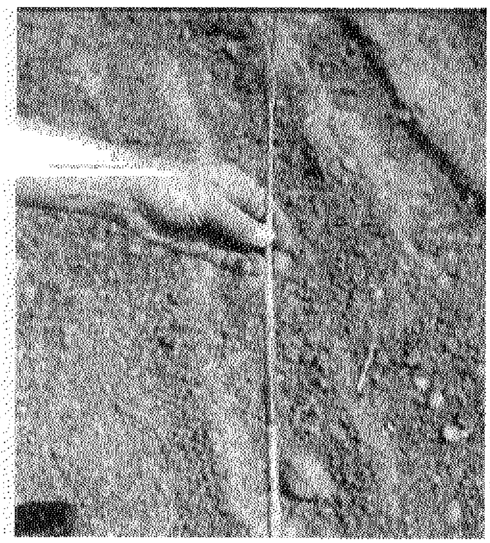

Fig. 4. Sprouting shoot of a native genotype with red stem coloration. Ellensburg, WA state, May 2002.

Areas where leaf sheaths separate or fall off develop a deep red, occasionally deep purple color (Fig. 5). The area oriented towards the sun develops the deepest coloration and areas covered by the leaf sheath may remain green. Stems in the interior of a clone may show less color than those at the edges because they differ in their exposure to sunlight.

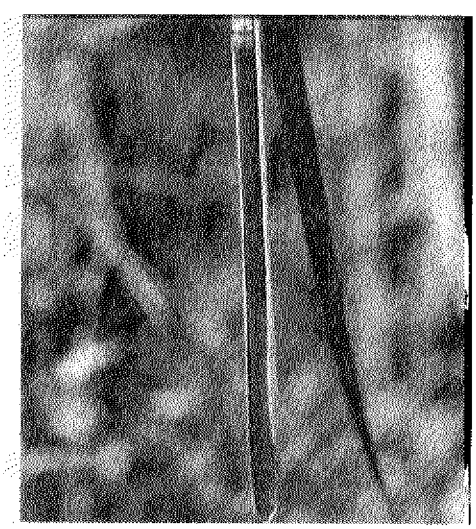

Fig. 5. Red stem of a native genotype. July 2002, upstate New York.

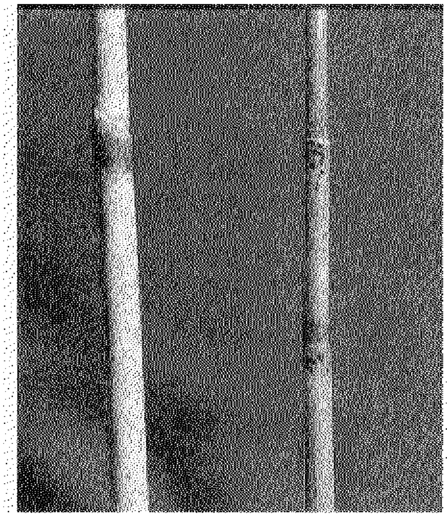

Fig. 6. Winter coloration of a native clone (right, note brown coloration, stem gloss, and fungal spots on the stem) and of an introduced genotype (left; note dull, tan color and that leaf sheath has been removed to expose the stem). January 2002, upstate New York.

The reddish color fades somewhat into a light chestnut brown (Fig. 6) in the late fall (or after cutting) but is still very obvious in October; in the winter the red stems turn light brown and then somewhat gray towards the spring. We have encountered several introduced clones where stems turned red at the lowest internodes but this coloration is never as intense as in native genotypes. The first coloration in temperate areas of North America may appear in early spring (Fig. 4) but coloration becomes more intense in the fall. Southwestern genotypes, some of which are evergreen, will retain their red stem coloration throughout the year.

Stem gloss

Stems of native genotypes develop a sheen and look polished as stems mature and senesce (Fig. 3 and 6). This sheen may not be recognizable on young stems or stems that have started to decompose in the spring; but is best recognized in early fall and through most of the winter. It is important to note that it is the stems that develop this gloss, not the leaf sheaths. If leaf sheaths remain on the stems, these need to be removed to assess this character. Running your fingers up and down the stem is a useful way to assess stem gloss and compare it among different genotypes. Introduced clones may develop some stem gloss or sheen on the lower internodes but not throughout most of the stems as is usually the case with native genotypes.

Fungal attack

A number of specialized and generalist fungi attack native and introduced clones. Native genotypes in the East and Midwest are attacked by a stem spot fungus (Figs. 3 and 6) with well defined, round black spots appearing on the stems (not the leaf sheaths). Fungal spots appear towards the end of the growing season (September), are particularly abundant around the nodes and progressively disappear over the winter with few remaining on older stems when new green shoots emerge in spring. This fungus is entirely absent on introduced genotypes. We have only encountered a very occasional fungal spot on leaf sheaths of introduced clones growing in close proximity to native genotypes. Introduced genotypes, however, are commonly attacked by a generalist fungus developing on the leaf sheaths. The fungal attack is restricted to the leaf sheaths; often covering large areas and is best described as a blackish smear. (Figs. 1 and 3)

Leaf color

Introduced genotypes typically exhibit gray-green leaf coloration while native genotypes appear lighter, yellow-green. While these characters may be strongly influenced by growing environments and management practices (herbicide or flooding treatments, for example), leaf coloration during summer may be a good first indication when surveying for native genotypes (Fig. 7). When lightly colored genotypes are encountered in the distance, closer examination of the above mentioned characters can then be used to assess native or introduced status.

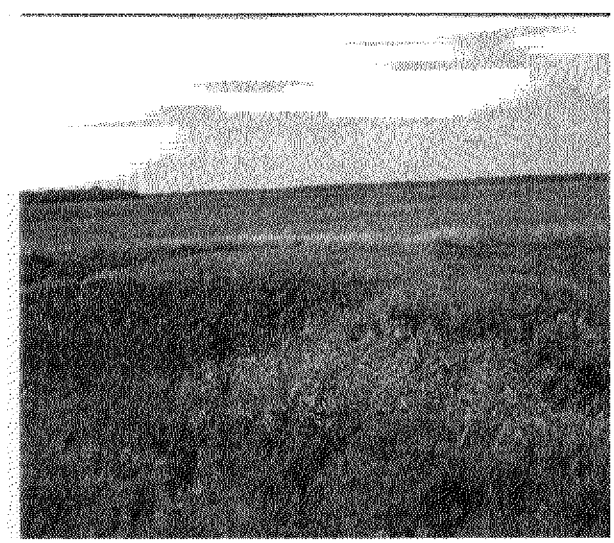

Fig. 7. Native (right, light yellow-green foliage) and introduced clone (left, dark gray-green foliage) at the Montezuma National Wildlife Refuge visitor center. September 2001, upstate New York.

OTHERS FACTORS DISTINGUISHING NATIVE AND INTRODUCED GENOTYPES

There are a number of other characteristics that may help distinguish native and introduced clones but they usually require the presence of native and introduced clones for comparisons. We do list these observations here because they may become helpful in detecting native genotypes.

In instances where native and introduced clones grow in close vicinity of each other, differences in stem toughness become obvious on windy days. Introduced genotypes remain sturdy and erect and move little while native genotypes bend easily and swing in the wind. Stems of introduced genotypes are almost perfectly straight while stems of native genotypes often grow crooked. In the fall and winter, differences in the density of inflorescences are also obvious; introduced genotypes appear to have much denser and larger inflorescences. Observations in New York and Virginia also suggest that native genotypes senesce earlier than introduced genotypes. Rhizomes of native genotypes are yellowish in the winter while introduced genotypes appear whitish. Excavations at various clones suggest that introduced genotypes may produced twice the amount of rhizome biomass compared to native genotypes but these observations need to be confirmed under standardized growing conditions. It also appears that growing conditions of native and introduced genotypes differ. While introduced clones can grow in permanently flooded conditions (and actually reach their peak performance under such conditions), our field visits and reports from collaborators appear to indicate that native genotypes are restricted to saturated or occasionally flooded soils and avoid permanently flooded habitat conditions.

WHERE TO FIND NATIVE GENOTYPES?

Introduced genotypes have become established throughout North America (Saltonstall 2002), but there is a distinct gradient of abundance from East to West in temperate North America. The number of native populations is lowest (and abundance of introduced populations highest) in the East and increases towards the Midwest and West. We need further detailed sampling to assess the current distributions of native and introduced clones throughout North America (see Diagnostic Service). Native clones along the Atlantic Coast (and in WA) are found in the upper tidal zones where they are occasionally inundated. Inland populations are found on saturated soils and often in fens. In other areas in the Midwest or West, *P. australis* populations are actually occasionally expanding.

HERBIVORE DIFFERENCES IN NATIVE AND INTRODUCED GENOTYPES

We have begun to analyze the herbivore communities in *P. australis* (Tewksbury et al. 2002). Our results show that two "character species" occur exclusively in native *P. australis*. These species have high "indicator value" for native status because they occur throughout the temperate distribution of *P. australis* (with the exception of islands in the Atlantic). However, they do not occur in every stem and attack rates may be as low as 5% or as high as 60% at the same site in consecutive years. These two species are a gall midge, *Calamomyia phragmitis* and a long legged fly, *Thrypticus* spp.. The latter may be an undescribed species. On the other hand, a number of European insects attacking *P. australis* have been introduced accidentally to North America (Tewksbury et al. 2002). Many of these species are now also attacking native *P. australis* with the exception of a gall midge, *Lasioptera hungarica*, which is restricted to the introduced *P. australis* genotypes. However, the distribution of these species is restricted to the Northeast, although they all are spreading westward.

DIAGNOSTIC SERVICE

We know that many scientists and managers are interested to know whether their local *P. australis* clone(s) are of the native or introduced genotype(s). While the diagnostic characters, as outlined above, should enable easy identification in the field, we are now also providing a free Diagnostic Service. Samples submitted to Cornell University in accordance with instructions posted at: www.invasiveplants.net will be checked for their morphological characters and native or introduced status will be determined. We will post updated distribution maps of native *P. australis* clones on the web. We hope that as many people as possible will participate and survey for native clones in their region and share their information to finally create nationwide distributions of invasive and native genotypes that then can be updated regularly.

IDENTIFICATION WORKSHOPS

Over the coming months and years we will host "hands-on" identification workshops to train people in field identification of native and introduced genotypes. Particularly in the Northeast, native genotypes are rare and uncertainty about morphological characters may remain even for those familiar with our website and the diagnostic characters. We will be present at various professional meetings with plant material and host several workshops across North America at (or close to) field locations. For listing of locations for upcoming workshops please check our website: www.invasiveplants.net.

STUDENT TEACHER SCIENTIST PARTNERSHIPS

We have developed a web-based protocol to assess herbivore communities across North America for students in high schools and colleges. We invite teachers and students at all levels to participate in this inquiry-based approach that will help us identify and follow the spread of introduced insects across North America. This partnership provides a forum for students to participate locally in original research covering all of North America. A further possibility now exists to survey and examine differences among native and introduced genotypes. Those interested in this partnership should follow the links on our website for further information.

AN INVITATION TO PARTICIPATE

We are unable to visit more than just a few select sites across North America ourselves and depend on your help to refine our ability to use easily visible field characteristics to identify native and introduced genotypes. We are particularly interested in:

1. Locations of native genotypes across North America. It appears that most native populations in the East have vanished or have been overrun by introduced genotypes. For genotype-specific management it will be important to record the presence of native genotypes.

2. Seed collections from native and introduced genotypes from as many different regions as possible. This will allow us to establish germination trials to better understand the differences in competitive ability of native and introduced clones.

3. Rhizome collections from as many native and introduced genotypes as possible. We need approximately 1-2 pounds of rhizome material to establish a common garden.

4. Stem collections (in the dormant season) to assess differences in insect herbivores attacking native and introduced genotypes. We have preliminary evidence from stands in New York that the insect communities in introduced and native genotypes differ significantly. Please contact us for a standardized sampling protocol if you are interested to participate.

The work outlined above is a collaboration of the Biological Control of Non-Indigenous Plant Species Program at Cornell University, Kristin Saltonstall at Yale University (now at Horn Point Laboratory, MD), and the University of Rhode Island. The work was sponsored (in part) by the US Fish and Wildlife Service, Sea Grants of Rhode Island and New York, the Bureau of Reclamation, and the New Jersey Public Service Enterprise Group. For further information or updates please visit: www.invasiveplants.net.

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APPENDIX A

APPENDIX A

ESTUARIES

Volume 26 April 2003 Number 2B

CONTENTS

KENNETH. W. ABLE, STACY M. HAGAN, AND S. A. BROWN. Mechanisms of Marsh Habitat Alteration due to *Phragmites*: Response of Young-of-the-year Mummichog (*Fundulus heteroclitus*) to Treatment for *Phragmites* Removal

CAROLYN. A. CURRIN, SAM C. WAINRIGHT, KENNETH W. ABLE, MICHAEL P. WEINSTEIN, AND CHARLOTTE M. FULLER. Determination of Food Web Support and Trophic Position of the Mummichog, *Fundulus heteroclitus*, in New Jersey Smooth Cordgrass (*Spartina alterniflora*), Common Reed (*Phragmites australis*) and Restored Salt Marshes

DIANA L. RAICHEL. The Influence of *Phragmites* (Common Reed) on the Distribution, Abundance, and Potential Prey of a Resident Marsh Fish in the Hackensack Meadowlands, New Jersey

DAVID T. OSGOOD, DAVID J. YOZZO, RANDY M. CHAMBERS, AND DANA JACOBSON. Tidal Hydrology and Habitat Utilization by Resident Nekton in *Phragmites* and Non-*Phragmites* Marshes

PAUL E. FELL, R. SCOTT WARREN, JOHN K. LIGHT, ROBERT L. RAWSON, JR., AND SEAN M. FAIRLEY. Comparison of Fish and Macroinvertebrate Use of *Typha angustifolia, Phragmites australis*, and Treated *Phragmites* Marshes along the Lower Connecticut River

STEVEN Y. LITVIN AND MICHAEL P. WEINSTEIN. Life History Strategies of Estuarine Nekton: The Role of Marsh Macrophytes, Benthic Microalgae, and Phytoplankton in the Trophic Spectrum

THOMAS M. GROTHUES AND KENNETH W. ABLE. I. Response of Juvenile Fish Assemblages in Tidal Salt Marsh Creeks Treated for *Phragmites* Removal

THOMAS M. GROTHUES AND KENNETH W. ABLE. II. Discerning Vegetation and Environmental Correlates with Subtidal Marsh Fish Assemblage Dynamics during *Phragmites* Eradication Efforts: Interannual Trend Measures

PAUL R. JIVOFF AND KENNETH W. ABLE. Blue Crab, *Callinectes sapidus*, Response to the Invasive Common Reed, *Phragmites australis*: Abundance, Size, Sex Ratio, and Molting Frequency

KATHARINE C. PARSONS. Reproductive Success of Wading Birds Using *Phragmites* Marsh and Upland Nesting Habitats

RICHARD A. CASAGRANDE, G. BALME, AND BERND BLOSSEY. *Rhizedra lutosa*, a Natural Enemy of *Phragmites australis* in North America

BERND BLOSSEY. A Framework for Evaluating Potential Ecological Effects of Implementing Biological Control of *Phragmites australis*

R. EUGENE TURNER AND R. SCOTT WARREN. Valuation of Continuous and Intermittent *Phragmites* sp. Control

DAVID F. LUDWIG, TIMOTHY J. IANNUZZI, AND ANTHONY N. ESPOSITO. *Phragmites* and Environmental Management: A Question of Values