# *Phragmites* Management Sourcebook for the Tidal Hudson River (and beyond)

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**Abstract**. *Phragmites australis* (common reed) is an invasive marsh plant spreading in many wetlands on and near the tidal Hudson River. *Phragmites* is generally considered a pest with low value to wildlife and threatening rare plants, but scientific documentation is ambivalent. Some organisms are favored by *Phragmites* invasion and some are not. *Phragmites* appears to have considerable value for water quality amelioration and soil stabilization. Ecological functions of *Phragmites* vary greatly depending on site and stand factors. Important site factors include depth and duration of flooding, salinity, soil organic matter content, and microtopography; important stand factors include *Phragmites* height, density, dominance, prevalence of inflorescences (tassels), vine loads, presence of trees or shrubs, stand size, and interspersion of *Phragmites* patches with other plant communities. *Phragmites* is often encouraged by, and a symptom of, underlying problems, such as siltation, nutrient loading, and hydrological alteration. Yet *Phragmites* does not necessarily indicate poor habitat quality. Many restoration and management projects seek to remove *Phragmites* despite poor understanding of its ecology, the nontarget impacts of removal, and the sustainability of alternate species. I conducted a review and synthesis of information pertinent to the ecology and management of *Phragmites* on the Hudson River estuary and in nearby areas. This synthesis is unique in focusing on the Hudson River, considering a wide taxonomic and functional range of *Phragmites* impacts, and including extensive published and unpublished data and observations. I describe *Phragmites* ecology, address management issues on the Hudson, outline management techniques and their nontarget impacts, and suggest how research needs can be defined. Depending on management goals, site and stand factors, the surrounding landscape, and the local biota, it may be appropriate to take no action, remove a *Phragmites* stand, or alter the stand to change its habitat functions and ecosystem services. An explicit and documented decision-making process should be used to justify decisions and acquire information about management outcomes that can inform subsequent management.

Key words: Biodiversity; Birds; Fishes; Herbicides; Heterogeneity; Hudson River; Invasive plants; *Phragmites australis*; Restoration; *Spartina*; Tidal wetlands; *Typha*; Wetland management

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## Introduction

This paper addresses the ecology, impacts, and management of an invasive marsh plant, common reed *Phragmites australis* (= *P. communis;* hereinafter *"Phragmites*"*). Phragmites* is spreading rapidly in many Hudson River tidal marshes, and if left alone might constitute the majority of the vegetation cover in at least half the marshes within a few decades. This invasion, if it progresses that far, may change plant and animal communities, ecosystem processes, marsh physiography, and the availability of fishery, wildlife, and recreational resources for human use. Management decisions will be made that will be expensive and have substantial non-target impacts. Although prevailing technical and public opinion considers *Phragmites* a serious pest in tidal marshes, evidence from recent research shows that many claims about *Phragmites* impacts are incorrect or exaggerated, and suggests that *Phragmites* is not all "negative" from a human point of view. Scientists, managers, regulators, and policy-makers need to strengthen the scientific basis for management of *Phragmites* to avoid errors that may eventually be costly ecologically, politically, and financially. The first step is to thoroughly and objectively review existing information pertinent to *Phragmites* in the Hudson River. In this paper I present information and ideas that will help biologists, managers, and policy-makers develop management approaches for the tidal Hudson River, individual sites on the river, and other nearby areas.

Phragmites was evidently an uncommon and local species in both tidal and nontidal wetlands of the Hudson Valley, despite a few pockets of abundance, before the 1960s (Muenscher 1935, 1937, Foley and Taber 1951, McVaugh 1958, Winogrond and Kiviat 1997). In an exhaustive survey of Hudson River wetlands ca. 1950, Foley and Taber (1951) reported *Phragmites* in only 6 sites (Bronck Island, Stockport-Nutten Hook, Peekskill Bay, Grassy Point, Croton River Marsh, and Piermont Marsh); the amounts of *Phragmites* increasing from north to south. In the 1960s-1970s, *Phragmites* was still uncommon and local in the Mid-Hudson region. Since then, *Phragmites* has proliferated, especially in many Hudson River tidal marshes; Piermont Marsh is saturated with *Phragmites*, Iona Island Marsh is rapidly becoming *Phragmites*-dominated (the expansion rate is logarithmic), and small colonies are spreading rapidly in Tivoli North Bay (Winogrond and Kiviat 1997, C. Nieder unpublished data). Some supratidal pools are dominated by *Phragmites* (e.g., on Sleightsburg Spit south of Kingston, and on the north side of the mouth of Mill Creek). Furthermore, there are many patches of *Phragmites* on dry or ephemerally flooded, supratidal dredge spoil, e.g., on Steward Island (Inbocht Bay). *Phragmites* has also appeared in many nontidal sites in roadside ditches, ponds, and marshes. *Phragmites* is capable of dominating dry infertile mineral soil such as on inactive sanitary landfills or dredge spoil deposits.

Strong concerns have been voiced about impacts of *Phragmites* expansion on flora, birds, fish, recreation, fire hazards, and other aspects of marsh ecology in North America (summarized in Howard et al. 1978, Kiviat 1987, Cross and Fleming 1989, Marks et al. 1994, Meyerson et al. 2000) and specifically on the Hudson River (Winogrond and Kiviat 1997, Anonymous 1998). Some ecologists, nonetheless, have questioned the scientific basis for this strongly negative assessment of *Phragmites*, and have produced data indicating that *Phragmites* is not always detrimental to biological diversity and marsh function (Meyerson et al. 2000, Kiviat 2005). Many ecological restoration proposals and projects for Hudson River marshes and other Hudson Valley wetlands prominently include removal of *Phragmites*. A *Phragmites* removal project was conducted by the National Audubon Society at Constitution Marsh on the Hudson River several years ago, and another project is underway there. Half of about 45 marsh restoration projects suggested by the U.S. Army Corps of Engineers (ACOE) in 1994 for the Hudson River Habitat Restoration and Enhancement Project cited problems with *Phragmites* or called for *Phragmites* removal (Anonymous, no date). Two ACOE restoration projects including *Phragmites* removal are currently underway or anticipated in the near future (E. Blair, personal communication). The NYS DEC began herbicide treatment of 3 of 6 small *Phragmites* stands in the open marsh in Tivoli North Bay 2006 (W.C. Nieder, pers. comm.). Many other *Phragmites* removal projects are underway or proposed in tidal and nontidal wetlands in the Hackensack Meadows of New Jersey, New York City, the Long Island Sound drainage of Westchester County, and the Connecticut River estuary; completed, current, and planned projects in the Hackensack Meadows projects total ca. 1,000 acres (New Jersey Meadowlands Commission 2006). Approximately 4,000 ha of *Phragmites*-dominated marshes in Delaware Bay are being restored either by re-establishing saline tidal flushing in historically diked salt hay impoundments, or by use of herbicide, burning, and bed-lowering (Weinstein et al. 2001). Very few scientific data are available on “before and after” conditions at these restoration sites, impacts of *Phragmites* control on other plants and animals, and long term sustainability of replacement plant communities. I believe that, before additional large sums of money are spent on *Phragmites* removal projects that may not be supported by good science and may not be beneficial or sustainable, we must carefully assess the state of knowledge concerning the impacts of *Phragmites* on Hudson River marsh ecosystems and the ecological benefits and costs of *Phragmites* management.

Invasive plants have been an important topic of applied and theoretical studies in the during the past two decades. Plant invasions can not only displace native flora, fauna, and biological communities, but can also alter ecosystem processes such as biogeochemical cycling and fire regimes, and may be responsible for the degradation of many ecosystem services to society (Drake et al. 1989, Luken and Thieret 1997). Ecologists are realizing, however, that many of the concerns about plant invasions are either not supported by scientific data or are exaggerated. Current controversy about the invasive salt-cedar (*Tamarix*) illustrates this problem. Although salt-cedar has been considered a serious pest and very large efforts have been invested in its removal from riparian habitats of the southwestern U.S. for at least 30 years, recent information indicates that the ecological picture of salt-cedar invasion is not simple. Levels of 22 of 30 ecological functions did not differ between salt-cedar stands and stands of the native cottonwood (*Populus fremontii*) (Stromberg 1998); biomass and diversity of insects in salt-cedar were comparable to those in cottonwood and willow (*Salix)* (Anderson 1998); the invasion of salt-cedar may have been a result of anthropogenic change including flood control, lowering of groundwater tables, increased salinity, and overgrazing (Everitt 1980, 1998); and salt-cedar dominated areas may be difficult or impossible to restore to functional native plant communities (Anderson 1996). A recent article (Cohn 2005) summarized the controversy regarding salt-cedar.

Although it is not well known to the public and to many managers, invasive plants may have substantial positive as well as negative values for fisheries, other fauna, and ecosystem services (e.g., Williams 1997). *Phragmites* is a partly native plant that, at least in some environments, supports substantial benthic and terrestrial invertebrate communities, foraging by fish, breeding and foraging by a variety of water and marsh birds, and removal of nitrogen and phosphorus from eutrophic waters (e.g., Meyerson et al. 2000). Relative values must be assessed in relation to management goals on a site-specific basis in order to plan management that will prove correct in the long term. The first step in developing an appropriate, scientifically robust, regionalized and integrated strategy for management of an invasive plant is to review and synthesize available information on the ecology of the plant.

Most quantitative research on faunal relationships of *Phragmites* began only in the mid or late 1990s. The scarcity of this work on the Hudson River requires attention to other northeastern estuaries, and the recent and frequently unpublished state of much research requires time-consuming searches for gray literature and unpublished data, in order to complete a comprehensive and effective synthesis document. Prior synthesis documents on *Phragmites* (Howard et al. 1978, Kiviat 1987, Marks et al. 1994) covered the entire continent and are out of date. Much of the information on *Phragmites* ecology, however, is still based on preliminary or localized studies, and only a few of these studies have been conducted on the tidal Hudson River. My goal was to prepare a synthesis of scientific and natural history information relevant to the management of *Phragmites* and the restoration of *Phragmites*-dominated areas along the tidal Hudson River, and analyze the scientific accuracy of existing *Phragmites* management policy for Hudson River tidal wetlands. The variation in levels of different ecological functions provided by *Phragmites* relative to other plant communities, and the spatial and temporal variability of *Phragmites* ecology, indicate the need for more sophisticated management policy and procedures. Sutherland et al. (2004) have stated, "Much of current conservation practice is based upon anecdote and myth rather than upon the systematic approaisal of the evidence..." This conclusion appears to pertain to *Phragmites* management in the northeastern U.S. In general (not specifically on the Hudson), the current *Phragmites* management policy, combined with the generally coarse-grained approach to management and restoration methods and the scarcity of good post-management monitoring data, are potentially a recipe for wasted money and unnecessary ecological damage.

Some regulators, managers, funders, and scientists may argue that this Sourcebook contains too much detail and that simpler guidance is needed for making decisions. My answer is that the current approach to *Phragmites* management costs too much in dollars and ecological side-effects to forego scientific nuances and consideration of missing information in decision-making. Furthermore, without sufficient knowledge the method of applied science will not work - we will not be able to make informed decisions, arrive at a management approach that considers different goals and sites, design management projects to accomplish specific goals at specific sites, determine if management accomplishes goals, and modify procedures to better accomplish our goals. This report is a work in progress, due to the constant flow of new information and the changing availability of old information on *Phragmites*, as well as the development of new paradigms in invasive plant management.

This report emphasizes goal-directed and site-specific management of *Phragmites*, with special consideration of management methods that alter rather than remove *Phragmites* stands. This is not a new idea in North America, and was referred to by, e.g., Ward (1942), Cross and Fleming (1989), and Kane (1978, 2001a, b). The rationale for this "soft" approach to management and an appropriate decision-making process with broad applicability have not been set out in detail for applications in North America for *Phragmites* or any other plant to my knowledge (excepting in certain agricultural weed situations).

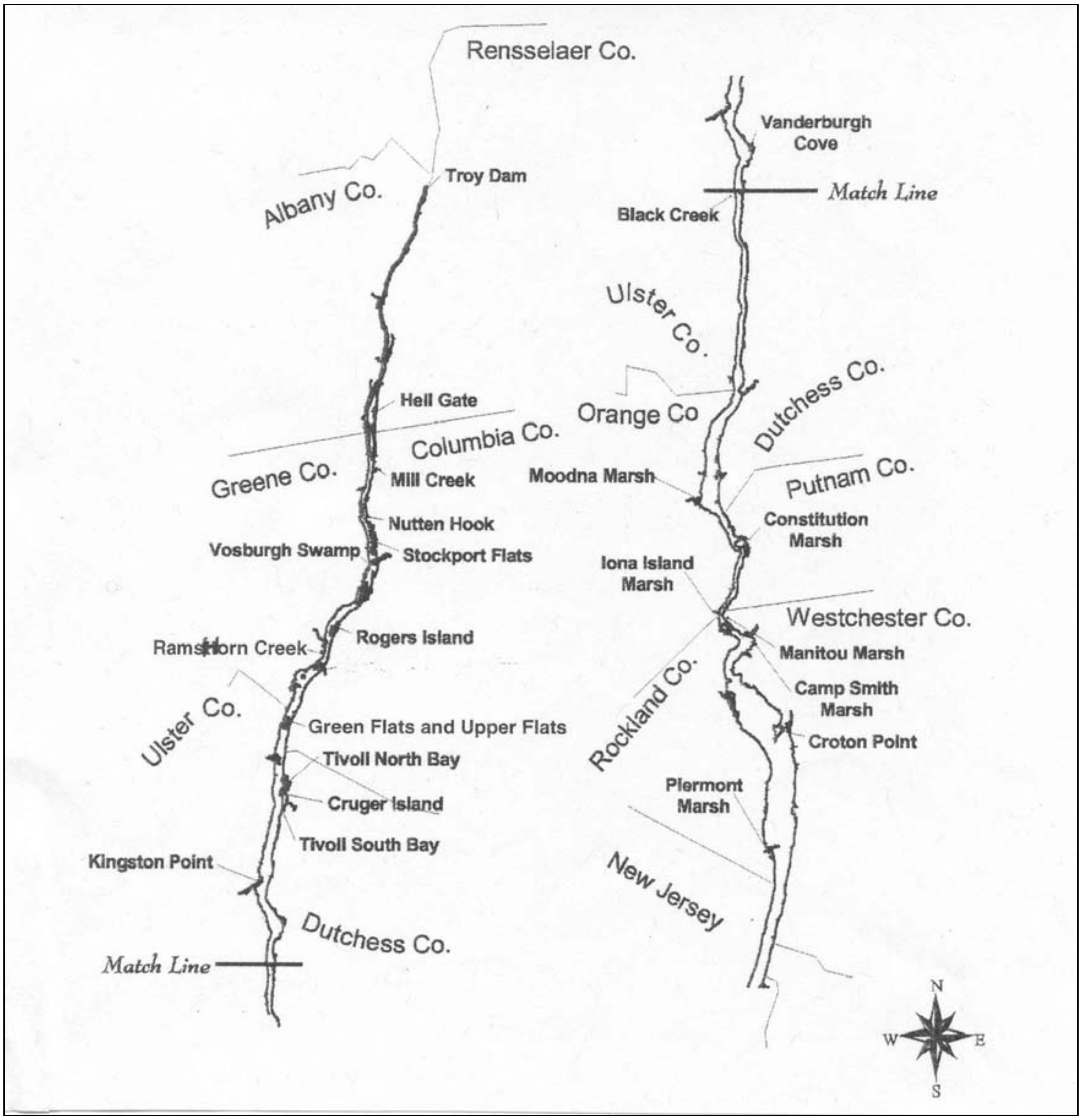
For the purpose of this report, “invasive plants” are either native or introduced species that spread at the expense of natural native plant communities. I refer to "alternate" communities or vegetation, which means non-*Phragmites* (e.g., *Spartina, Typha*) in comparison to *Phragmites*. By "community" I mean groups of plant species that tend to occur together under similar conditions of substrate elevation, hydrodynamic energy, natural and human disturbance, propagule availability, etc. Chance is also important in structuring communities although tidal marsh communities are simpler than many upland and nontidal marsh communities. A "stand" of *Phragmites* or alternate vegetation is a patch or bed of *Phragmites* (i.e., a "reedbed" in European terminology) or other plant(s). The *Phragmites* stand is a discrete entity which in many cases represents a single clone (genetic individual) of *Phragmit*es with many underground and aboveground branches. I use "hyperdominant" or "highly dominant" instead of "monodominant," "monospecific," or similar terms, with reference to *Phragmites* stands that contain few other plants species and individuals. A *Phragmites* "marsh" is usually a group of *Phragmites* stands generally interspersed with other communities or water features. “Graminoid” refers to grass-like plants, including grasses, sedges, and rushes, as distinct from “forbs” which are broad-leaved herbs. Scientific names of vascular plants follow Gleason and Cronquist (1991). I use the term “management” in preference to “control”; management includes a wide range of approaches from no treatment to altering stands to local eradication.

Due to the rapidly changing knowledge base, today’s analysis or recommendations may prove incorrect tomorrow. This report is a state-of-the-art compilation and should not be considered the final word for *Phragmites* management; the report should be used as a general guide and not as a “cookbook.” Some decisions are simple (e.g., eradicate very small patches of the introduced genotype of *Phragmites* immediately when first discovered on a site, because this is cheap, effective, and low in risk). Many decisions are complex and nuanced, however, much as are decisions about managing human health or many other aspects of nature.

## Hudson River Study Area

Every estuary is different, and the tidal Hudson River has high levels of nutrients and suspended sediment, abundant PCB contamination, and is generally steepsided with pervasive and longstanding shoreline alteration due to the railroads and other present and past human land use. This report focuses on the tidal Hudson River, i.e., the nominal Hudson River and its associated tide-affected habitats from the Battery (the southern tip of Manhattan Island) north to the Troy Dam. Tidal wetlands and the tidal lower reaches of tributaries are included; in some cases this includes 1 km or more of tributary (e.g., Rondout Creek at Kingston). Habitats supporting *Phragmites* that are not regularly flooded by tides but are subject to irregular tidal flooding are included. “Irregular” flooding constitutes flooding by spring tides, storm surges, unusually heavy runoff, and ice jams (e.g., supratidal pools *sensu* Kiviat *and* Stevens [2001] and many dredge spoil deposits up to 1 m or more above Mean High Water [MHW]). The upper reaches of the tidal Hudson (about Kingston northward) are always freshwater, and in the lower reaches salinity varies spatially and temporally from freshwater to more than one-half Atlantic Ocean salinity. Mean tide range varies from 0.8 m in the Hudson Highlands, to about 1.4 m at Manhattan and the Troy Dam (Geyer and Chant 2006). Means, however, do not convey the great variation in high and low tide elevations due to lunar phase, runoff into the river, and wind; "storm" tides can be 1 m or more higher than MHW. There are about 2895 ha of tidal wetlands in the estuary (Kiviat et al. 2006). All shorelines and wetlands have been altered to a greater or lesser extent by railroads, roads, dredging, filling, and dumping, and pollutants include PCBs, herbicides, and metals. Herbicides have been used heavily on the railroads (I have been unable to find documentation of the substances applied) as well as in agriculture and other vegetation management in the watershed. The tidal Hudson River was described in detail in Levinton and Waldman (2006). Figure 1 shows many of the Hudson River localities mentioned in this report.

Figure 1. Map of tidal Hudson River showing many of the on-river localities mentioned in the text. (Adapted from Kiviat et al. 2006.)



## The Plant

*Phragmites* is a "habitat-modifying organism" (Rooth et al. 2003) that can modify soil, hydrology, microclimate, and vegetation. Table 1 summarizes morphological and ecological characteristics of *Phragmites* most relevant to this discussion of management in the tidal Hudson River. *Phragmites* is a giant, rhizomatous grass that forms dense, high-biomass colonies (clones) capable of covering large areas. Although a few authors have referred to *Phragmites* as “woody,” it is not woody in the sense of many bamboos, and the perennating buds of *Phragmites* are located below, or just above, the ground surface. Reproduction is principally vegetative: both local spread of colonies by rhizome or stolon extension, and longer distance dispersal by water, animal, or machinery transport of rhizome fragments. Stolons are fast-growing horizontal stems with long internodes, produced on the ground surface and apparently capable of crossing unfavorable substrates such as pavement (Kiviat, pers. obs.). Although seeds are very small and have been reported to be often inviable, seeds germinate readily and seedling establishment can occur in the wild (Harris and Marshall 1960, Gervais et al. 1993, Ahearn-Meyerson et al. 1997, Baldwin and Derico 1999). Nonetheless, establishment of stands from seed is probably rare. In southern France, Alvarez et al. (2005) concluded that vegetative and the less-common sexual colonization both played roles in the long-term dynamics of reed marshes.

In tidal marshes, *Phragmites* stands commonly become established either adjoining upland shorelines, or on the margin of a creek or pool (e.g., Winogrond and Kiviat 1997) although stands may become established in marsh interiors as well. Shorelines and banks are probably loci of establishment because elevations are higher and vegetative propagules (rhizome fragments) become stranded there. Areas of fill, such as the spoil along ditch banks, allow *Phragmites* to establish on aerobic soil and thence extend into wetter marsh habitat (Bart and Hartman 2002). Stands occur in all sizes and shapes. Often, new stands expand in all directions, evincing roughly circular form, until physical or biological barriers (including other *Phragmites* stands) are reached. Hudson River *Phragmites* is normally in the supratidal zone or upper intertidal zone, and at some locations in the middle intertidal zone (Kiviat, pers. obs.). Buckley and Ristich (1977) stated that *Phragmites* appeared restricted to elevations above mean high tide (i.e., MHW) in the marshes from Constitution to Piermont. *Phragmites* does not normally grow in the lower intertidal zone in the Hudson.

Monospecific stands? *Phragmites* is commonly stated to form monospecific or pure stands, or monocultures, i.e., patches of *Phragmites* in which other vascular plants do not grow. I have found this incorrect, although the interpretation depends upon scale. The outermost 1 m wide belt of a *Phragmites* stand, i.e., the outer stand edge, typically contains an admixture of several other species of plants. In the freshwater tidal marshes of the Hudson River, these species are likely to be spotted jewelweed, arrow arum, purple loosestrife, narrowleaf cattail, and several other species. Occasional woody plants (e.g., false indigo, willow) may be present. Farther into the *Phragmites* stand, plant species richness declines rapidly. In many stands, there are only scattered and usually stunted individuals of spotted jewelweed and arrow arum. At the scale of a hypothetical 1 $m^2$ quadrat, many quadrats may contain only *Phragmites*. At the level of a 10 x 10 m quadrat, other plant species are usually present. Should this be called monospecific? No; ecological terminology needs to be accurate and monospecific or pure means “one species.” The nearly-pure kind of *Phragmites* stand should be referred to as highly dominated, or hyperdominated, by *Phragmites.*

Although vascular plants are typically of most concern in discussions of vegetation, it should be remembered that algae and sometimes mosses are also present in *Phragmites* stands. Mosses are more likely in nontidal wetlands where standing water is very shallow or absent, and water levels are relatively stable. Shallower, nontidal wetlands with stable water levels are also more likely to have mixed stands in which several other vascular plant species share space with *Phragmites*, although the other species in some cases comprise a small fraction of the aboveground biomass compared to *Phragmites*. A countervailing observation is that in 2006 mosses (number of species unknown) constituted significant minor cover beneath *Phragmites* on an eroding *Phragmites* turf at the water edge of a small marsh on the east side of Middle Ground Island between Hudson and Athens; several other vascular plants were also present in this *Phragmites* stand edge in the upper intertidal zone (Kiviat, pers. obs.).

Hyperdominant stands are formed by many native as well as introduced plant species (Sipple unpublished), and are not necessarily symptomatic of anthropogenic stress nor bad for biodiversity or ecosystem services. Some of the native species that form hyperdominant stands in or near the Hudson Valley are narrowleaf cattail, smooth cordgrass, spatterdock (in tidal marshes), and buttonbush, leatherleaf, swamp loosestrife, hybrid cattail, and softstem bulrush (in nontidal wetlands).

No herbivory? It has been stated or implied that *Phragmites* is little-used as food by native animals in North America (e.g., Marks et al. 1994). Rhizomes, culm bases, and young shoots of *Phragmites* are eaten by common muskrat and probably by American beaver. *Phragmites* marshes in the Hackensack Meadowlands often support substantial muskrat populations (Kiviat, pers. obs.). Young shoots are eaten by cottontail (Richard Casagrande, Yale University, pers. comm.). Several insects eat *Phragmites* leaves (including the meadow katydid *Orchelimum vulgare*, the larva of Henry's marsh moth *Simyra henrici*, and the larvae of broad-winged skipper *Poanes viator* in the East and Yuma skipper *Ochlodes yuma* in the West). The mealy plum aphid *Hyalopterus pruni*, a sap-sucking insect, alternates between *Phragmites* and *Prunus* (cherries, etc.); the aphid often becomes hyperabundant on *Phragmites* leaves in summer. Ladybug adults and larvae feed on the aphids. The reed scale *Chaetococcus phragmitis* sucks sap beneath the leaf sheaths. Reed scale is nearly ubiquitous on Eurasian *Phragmites* in the northeastern states, may reach a high biomass in Hudson River tidal marshes (e.g., 1 $g \cdot m^{-2}$), and is avidly consumed in winter and spring by black-capped chickadee, Carolina chickadee, red-winged blackbird, and apparently by downy woodpecker. Other insects feed within the culm (Krause et al. 1997, Schwärzlander and Häfliger 1999, Tewksbury et al. 2002). Downy woodpecker and probably other birds peck into culms to feed on overwintering insects, and the holes left by bird foraging can easily be found in the previous year's culms in many areas. Lewis and Casagrande (1997) reported downy woodpecker and black-capped chickadee extracting insects from within *Phragmites* culms. An agromyzid fly larva feeds within the leaf blade creating a patch mine (an area of tan translucent tissue of ca. 2-3 $cm^2$). White-tailed deer (Self et al. 1975) and apparently Canada goose (Kiviat, pers. obs.) eat the leaves to a limited extent. Cattle, sheep, goats, and horses eat the young shoots or leafy culms; horses are said to eat culms after they are too mature for cattle (Duncan 1992, Tesauro 2001a, b). Young shoots are rich in saccharides and proteins and are good food for horses and cattle, but older shoots lignify and lose their value as forage (Zheng et al. 2005). Tree sparrow, swamp sparrow, and song sparrow eat *Phragmites* seeds (Russak 1956; Marks et al. 1994; Lewis and Casagrande 1997; Jean Bourque, Brooklyn, NY, pers. comm.; Kiviat, pers. obs.).

Table 1. General characteristics of *Phragmites australis* in the northeastern states.

| **Characteristic** | **Detail** | **References** | **Significance** |
|---|---|---|---|
| Taxonomy | Poaceae (grass family), tribe Arundinoideae | Tucker 1990 | Close relatives include *Arundo*, *Cortaderia*, *Neyraudia* |
| Height | 100-350 cm (max. ca. 400) | Kiviat, pers. obs. | Larger than most N. American graminoids (introduced *Arundo donax*, woody *Arundinaria,* and possibly the largest bulrushes are exceptions) |
| Density | Ca. 14-31 culms per $m^2$ | Kiviat, unpubl. data (tidal Hudson River) | Less room for other plants beneath stand |
| Visibility, penetrability | Low visibility & penetrability (*sensu* Egler 1977:111) into dense stands | Kiviat, pers. obs. | Humans avoid stand interiors thus nesting, resting, & roosting animals undisturbed |
| Buffer function | Attenuates wave & current energy; moderates microclimate | Baldi 1999 | Provides sheltered environment for nesting & other activities |
| Solar collector | Stand edges (& interiors?) warm in sun | Kiviat pers. obs. | Microhabitat for basking |
| Peak aboveground biomass | 1000-4000 g dry weight per $m^2$ in better-developed stands | Ristich & Buckley 1977, Whigham et al. 1978, Meyerson et al. 2000 | Physical shelter; microclimate modification |
| Regrowth | Lost foliage not replaced | Kiviat, pers. obs. | Grazing has strong effect? |
| Woodiness | Not woody | Kiviat, pers. obs. | Attracts graminoid-using fauna |
| Architecture | Graminoid; numerous erect stems (culms) from horizontal & vertical rhizome system; minimal branching of culm | | Support & conceal nests, cocoons, active animals; may exclude larger animals from dense stands |
| Strength | Culms usually strong | Kiviat, pers. obs. | Support weight of animal activities |
| Texture | Leaves & culms siliceous, abrasive; cut or broken culms knife-like | Kiviat, pers. obs. | Physically resists chewing insects, abrades feathers? |
| Noisiness | Live & dead material very noisy | Kiviat, pers. obs. | Warns of approaching predators & humans |
| Shoot phenology | Moderately early spring growth | Kiviat, pers. obs. | |
| Flowers | Tiny, inconspicuous, wind-pollinated | | No flower visitors reported |
| Seeds | Small (1 mm); often aborted? | | Too small to attract many vertebrate predators |
| Chemistry | Polysaccharide, anthocyanin, alkaloid, other compounds studied | Wassel et al. 1985, Fang et al. 1990, Tsitsa-Tzardi, E. et al. 1990, | Toxic or distasteful to some animals? |

| | | | |
|---|---|---|---|
| | | Fossen & Anderson 1998, Zheng et al. 2005 | |
| Pharmacology | Various; also see above | Duke 1992 | Potential medicine |
| Nutritional value | Rhizomes & young shoots apparently nutritious, leaves intermediate, culms less so | Kiviat, pers. obs. | Eaten by insects, less by vertebrates; feeding selective on plant parts |
| Winter cover | Considerable | Krause et al. 1997 | Provides winter shelter & spring nest sites in otherwise open areas |
| Hollowness | Culms become hollow (during summer?); broken dead culms collect water? | Kiviat, pers. obs. | Space for arthropods; insulating, floating nest material for birds, mammals |
| Lodging | Culms bend over or break gradually or under weight of snow | Kiviat, pers. obs. | Provides structure for animals |
| Decomposition | Leaves decompose rapidly, culms very slowly | Mason & Bryant 1975, Meyerson et al. 2000, Windham 2001 | Deep litter & long-lived wrack provide structure for invertebrates |
| Host for vines | Frequent, sometimes lush, in wetland edges; overall species richness high | Kiviat pers. obs. | Complex habitat structure & foods for animals; many native & introduced species |
| Host for mosses | Uncommon or local on old culm bases or water-edge turf | Kiviat, pers. obs. | Component of diversity |
| Host for insects | Many summer & winter; an aphid & a scale especially prominent; Lepidoptera, Orthoptera locally common herbivores; bees nest in hollow culms | Krause et al. 1987, Garcia 1998, Schwärzlander & Häfliger 1999; Tewksbury et al. 2002; Yurlina 1998; Kiviat, pers. obs. | Attracts predatory insects, spiders, birds, etc. |
| Host for spiders | Spiders use hollow stubble for shelter; diversity & abundance unknown | Kiviat pers. obs. | Could support rare or microhabitat-dependent stenotopic spp. |
| Muskrat use for food, lodge material, habitat | Low to high (varies in different studies)[1] | Kiviat, unpublished. | Muskrat activity creates substrate & vegetational heterogeneity, may facilitate or prevent establishment of *Phr*. |
| Patch size, interspersion, mixing with other plants | Highly variable | Kiviat, pers. obs. | Provides varied habitats |
| Flotage | Rhizome segments, clumps, or whole mat may loosen & float | Kiviat pers. obs. | Perches for animals, refuge from humans |
| Habitat affinities | Broad niche (moisture, other soil properties, etc.) | Kiviat, pers. obs. | Used by aquatic, wetland & terrestrial spp. in various habitats |
| Pollution tolerance | Apparently high | Geller 1972; Kiviat, pers. obs. | Often thrives in urban-industrial areas |
| Geographic distribution in the Americas | Widespread in U.S. & Canada except far N Can.; also Méx., C. & S. America | Clevering & Lissner 1999 | Widespread plant spp. have larger associated faunas |

[1] The late Everett Nack (pers. comm. 1981), a Claverack, New York, muskrat trapper, stated that muskrats liked to eat the underground parts of *Phragmites* in the Hudson Valley. I have observed muskrat cutting of *Phragmites* material many times on the Hudson River and in the Hudson Valley and neighboring regions in a variety of different kinds of wetlands. .

## Materials and Methods

The ecological relationships of *Phragmites* are highly variable, as are the Hudson River marshes, thus it is critical to have broad information to apply in a wide variety of potential management situations. I have extensively searched formal literature, “gray literature," and nontechnical (popular) literature, and consulted practitioners for unpublished data and observations. In the discussions that follow, I emphasize information in order of decreasing relevance: 1. Hudson River; 2. Hackensack Meadowlands, Jamaica Bay, and nearby areas; 3. Other East Coast estuaries; 4. Other tidal wetlands and nontidal wetlands in North America and Europe. I screened reports first by judging if, in fact, the author clearly referred to *Phragmites* (references to the common name only, e.g., “reed,” were rejected unless the term “common reed” or “reedgrass” was used or I could determine on the basis of context, a photograph, or other evidence that the report referred to *Phragmites* rather than *Typha, Scirpus,* or other robust wetland graminoid plants (this is a problem with some of the older literature and nontechnical literature). I also judged if other organisms were correctly identified and if the author or observer was evidently qualified to conduct the report study.

Much has been written about *Phragmites*. For example, a Google$^{TM}$ search on the keyword “phragmites” on 14 July 2006 found 757,000 Web sites. (For perspective, a search on “george pataki” found 1,520,000 sites.) Searches of scientific literature databases for “*Phragmites*” literature also yield abundant results. No one can review all the information about *Phragmites*. However, most practitioners focus on one or two aspects of the plant, and it is rare for a researcher to review literature on a broad spectrum of taxa and ecosystem services. Different researchers with differing interests reach different conclusions based on the literature, original data, and their attitudes towards *Phragmites*. I call this, “Feeling the taxonomic elephant” by analogy to the parable of the blind men and the elephant (in the parable, several blind men felt different parts of an elephant and perceived different kinds of animals). The impacts of, and management of, invasive plants are expensive financially and ecologically, and we can no longer afford to feel this elephant with our eyes closed. This Sourcebook is intended to help open your eyes to a broader spectrum of *Phragmites* ecology.

## Prehistory and History of *Phragmites* in the Study Area

Although published paleoecological data demonstrate that *Phragmites* has been present in the northeastern U.S. for perhaps 10,000 or more years (Waksman 1942-43, Orson et al. 1987, La Porta et al. 1999, Orson 2000) and in the southwestern states for more than 40,000 years (Hansen 1978), many biologists and managers have considered it a historically introduced species.

Recently, Saltonstall (2002a, b) has shown that several North American *Phragmites* genotypes appear to be native whereas one genotype that is common in the northeastern states is the same as a common Eurasian genotype. Apparently this form ("Haplotype M," hereinafter "Eurasian form") evidently arrived from Eurasia and became invasive about 100 years ago in the Northeast.

Most material from New York, southern New England, and New Jersey examined by Saltonstall belonged to the Eurasian form (two samples from Tivoli North Bay were identified as this form; K Saltonstall, personal communication). In the Midwest, as well as in Delaware and Maryland, both Eurasian and native forms are widespread, and in the western states, most *Phragmites* belongs to native forms except that the Eurasian form occurs in disturbed areas such as roadside ditches (Saltonstall 2002a). Saltonstall et al. (2004) named the native genotypes collectively *Phragmites australis* subspecies *americanus*, and stated that *americanus* differs from the introduced Eurasian genotype in the length of the lemma (an element of the grass flower).

Table 2 shows prehistoric and historic records of *Phragmites* in and near the Hudson River. I found no data on *Phragmites* palaeoecology in the Hudson River proper, with the exception of La Porta et al. (1999) who reported ca. 7000 year old *Phragmites* material in the lower Hudson River estuary. Waksman (1942-43) reported fossil *Phragmites* rhizome material in the Hackensack Meadowlands (one site) and in numerous nontidal, lowland wetlands around the state. These materials were not dated but likely were several thousand or more years old. Many *Phragmites* fossils recovered from salt marsh peats on the Connecticut and Massachusetts coasts were dated stratigraphically at up to 3000 years of age (Orson et al. 1987, Orson 2000). Several palaeoecological studies of Hudson River tidal marshes did not report *Phragmites* (e.g., Newman et al. 1969), perhaps for methodological reasons. I have found no report of prehistoric *Phragmites* remains dated by other than stratigraphic methods (e.g., no radiocarbon dates). Because *Phragmites* rhizomes that had grown vertically down through the soil might have distorted stratigraphic dating of *Phragmites* fossils, radiocarbon dating should be a high research priority. Although Orson (2000) inferred from *Phragmites* fossils in the Connecticut coastal marshes that *Phragmites* was a common but minor component of vegetation at the wetland-upland edge, it is unclear whether the resolution of his core studies allows such a definitive interpretation of abundance and distribution. What seems clear, however, is that *Phragmites* was common and widespread in both tidal and nontidal wetlands during the Holocene before European settlement of North America.

During the 1900s, *Phragmites* invaded the Hudson River estuary from both ends. In the 1970s, it was a prominent species in Piermont Marsh and certain other major marshes of the southern river, as well as Papscanee Creek Marsh and certain other marshes of the northern river, while marshes of the middle river such as Tivoli North Bay had small *Phragmites* patches or none (Buckley and Ristich 1977, Winogrond and Kiviat 1997; Kiviat, pers. obs.). The invasion has since accelerated in the middle river, although most marshes in this segment still have minor or no *Phragmites* cover (Kiviat, pers. obs.). Inland, the coverage by *Phragmites* is still minor in some areas, for example Harriman State Park and Sterling Forest State Park (McGowan 2005).

The history of *Phragmites* in the Hudson Valley and Hudson River has been one of reports beginning in the mid-1800s with gradual spread and consolidation throughout the valley and the river (Table 2). It is unclear whether the early historic reports refer to native or introduced genotypes of *Phragmites*; this could be resolved to some extent from study of herbarium specimens and possibly from historic color photography of culms. In the late 1960s and early 1970s, when I was learning field botany in northern Dutchess County, *Phragmites* was uncommon enough that I considered it an interesting find (I did not record any at inland localities and it was rare on the river between Barrytown and Cementon). *Phragmites* evidently invaded

Piermont Marsh in the early 1900s or late 1800s, and Iona Island Marsh in the 1960s (Winogrond and Kiviat 1997). However, the first three major (now) *Phragmites* stands appeared in the open cattail marshes of Tivoli North Bay in the 1970s and a stand that established in the early 1980s along Cruger Island Road in the Cruger Island Neck tidal swamp also persists today (Kiviat, pers. obs.).

Although certain *Phragmites* stands continued to expand after establishment, other stands remained stable or disappeared. For example, a small crescentic stand among herbaceous and woody plants in the Cruger Island South Marsh observed on 21 February 1972 was of roughly similar size when revisited in February 2000 (Kiviat, field notes). A single culm observed 29 August 1971 at the delta of a small perennial stream debouching into the middle of Tivoli South Bay was not seen subsequently (Kiviat, field notes). A "straggling growth" of *Phragmites* I noted in 1982 on the old spoil bank along the tributary at Sycamore Point in the north end of Tivoli North Bay is no longer present. In 1975 I observed a small stand in the northeastern corner of Mandara South Cove (the small tidal marsh just north of the Kingston-Rhinecliff Bridge; Kiviat 1978); in 2005 this stand was still confined to the same corner of the marsh although perhaps twice as large.

The establishment and spread of *Phragmites* in inland (nontidal) habitats of the Hudson Valley seems to have resembled what happened in the Hudson River. For example, no *Phragmites* was present in 1974-1975 when I conducted intensive field studies of the 40 ha circumneutral bog lake at Thompson Pond in the Town of Pine Plains, Dutchess County (Kiviat and Zeising 1976). Prior to 1992 two substantial *Phragmites* stands were present, and in 2000 there were six stands. In 1975 *Phragmites* was absent or rare in "Mt. Rutsen Pond" in Ferncliff Forest (Town of Rhinebeck, Dutchess County), whereas in 2005 this pond was largely occupied by *Phragmites*.

Table 2. Historic and prehistoric *Phragmites* status information from the Hudson River and Hudson Valley region. *Phr* = *Phragmites*; ybp = years before present. Localities are in New York State unless noted otherwise.

| **Source** | **Location** | **Period** | **Status of *Phragmites*** |
|---|---|---|---|
| ***Historic*** | | | |
| Mills et al. 1997 | Pine Plains NY & Schenectady NY | 1844 | Specimens; hypothesized to have arrived in solid ship ballast |
| Mills et al. 1997 | Philadelphia | 1876, 1877 | On ship dry ballast |
| Willis 1880 | Westchester Co. | 1880 | Borders of ponds |
| Wiegand and Eames 1926 | Cayuga Lake Basin (central New York) | Early 1920s | Locally abundant |
| McVaugh 1958 | Columbia Co. & near | 1930s | Local in alkaline or fresh-tidal wetlands |
| Roberts & Reynolds 1938 | Dutchess Co. | 1930s | Not reported |
| Domville & Dunbar 1970 | Ulster Co. | Mid-1900s (< 1970) | Common to abundant in damp open places |
| Foley & Taber 1951 | Hudson Valley | ca. 1950 | |
| Winogrond & Kiviat 1997 | Hudson R National Estuarine Research Reserve sites | Late 1900s | Stockport Flats: 0.34% in 1967 to 0.85% in 1991<br>Tivoli North Bay: 0% in 1967 to 0.48% in 1991<br>Iona Island: 0.37% in 1965 to 26.83% in 1991<br>Piermont Marsh: 33-42% in 1965 to 73-77% in 1991 |
| Lehr 1967a, Senerchia-Nardone et al. 1985 | Iona Island Marsh | 1967, 1985 | Not reported in 1967; 7.77% of "high marsh" community in 1985 |
| Lehr 1967b, Wong and Peteet 1999 | Piermont Marsh | 1967, 19991970s | Not reported in 1967 (but see Winogrond and Kiviat 1997); 76% coverage of marsh in 1999 |
| Ristich and Buckley 1977 | Major marshes Piermont to Constitution | | Present in all major tidal marshes |
| Buckley 1992 & pers. comm. | Croton Point Marshes | 1970 | Shift from *Typha* to *Phr;* due to metals in leachate from unlined municipal landfill? |
| Kiviat & Zeising 1976 | Thompson Pond, Dutchess Co. | 1974-75 | Not reported; *Phr* invaded Thompson Pond later |
| Kiviat 1978 | Hudson R east bank,, Clermont to Staatsburg (Dutchess & Columbia cos.) | 1975-76 | Rare in tidal marshes between Clermont and Norrie, but common species in higher-elevation marshes north and south of study area |
| DeVries & DeWitt 1986 | Hudson River Estuary tidal marshes | 1985 | Present but confined to small areas except at Iona Island, where it occurred in large circular patches |
| Tashiro et al. 1994, Kiviat 2003; Kiviat, pers. obs. | Croton River Marsh | 1980s-90s | Dense stands of *Typha* and *Phragmites* in late 1980s; virtually all *Phr.* 2000-2002 |

| ***Prehistoric*** | | | |
|---|---|---|---|
| Waksman | New Jersey | As old as ca. 10,000 ybp? | Widespread in lowland nontidal wetlands & at 1 station in Hackensack Meadowlands |
| Heusser 1963 | Hackensack Meadowlands | | No information; did not differentiate *Phr.* from other grasses |
| Wong and Peteet 1999 | Piermont Marsh | | No information; did not differentiate *Phr.* from other grasses |
| La Porta et al. 1999 | Hudson R. near New York City | Ca. 7000 ybp | Precolumbian *Phr.* found |
| Orson et al. 1987, Orson 2000 | Connecticut coast | 3500 ybp | Interpreted as minor component of vegetation at upper border of salt marshes |
| Carmichael 1980 | Hackensack Meadowlands | 240 ± 110 ybp | Became significant ca. 150 ybp |
| Sipple 1971-72 | Hackensack Meadowlands | 1919 | Probably very abundant |

Phragmites in 1991 covered move than 66% of Piermont Marsh, 29% of Iona Island Marsh, and 0.5% of Tivoli North Bay, and it continues to spread in all three marshes (Winogrond and Kiviat 1997, Kiviat et al. 2006). Phragmites apparently covers more than 50% of Iona Island Marsh now (Kiviat et al. 2006). Increase in area of *Phragmites* patches has been exponential (W.C. Nieder, Hudson River National Estuarine Research Reserve, pers. comm.).

**What Favored *Phragmites* Establishment and Spread?**

*Phragmites* was well established and in some locations already covered large areas of the marshes at both ends of the estuary before invading mid-estuary marshes. This suggests that higher nutrient levels or more rapid sediment deposition (and possibly smaller muskrat populations) associated with these more urbanized and industrialized reaches facilitated the invasion. *Phragmites* replaced *Typha* at Croton Point and Piermont Marsh where there were garbage landfills, but not at Hudson North Bay where there was also a landfill. Salt hay harvest and its cessation may have made Piermont Marsh vulnerable to invasion. *Phragmites* colonies often established on banks of major tidal creeks then spread into the intercreek marsh (Winogrond and Kiviat 1997). Creek banks were probably favorable sites for establishment because they are often slightly higher in elevation due to natural levees (Kiviat and Beecher 1991), they are subject to disturbance of soil and vegetation by ice, muskrats, and other agents (Connors et al. 2000), and floating *Phragmites* fragments could readily become stranded there. Creek banks are also preferred sites for duck blinds which cause disturbance to soil and vegetation, and sometimes import potentially-viable *Phragmites* material for blind camouflage. (For example, In Tivoli North Bay I noticed three blinds camouflaged with *Phragmites* in 1976 and one in 1987.)

The muskrat population in Tivoli North Bay crashed in 1975, and populations probably crashed in most other Hudson River tidal marshes around the same time; recovery has been slow and incomplete. In the late 1970s and early 1980s, I observed “normal” muskrat lodge densities only in the northeastern corner of Hudson South Bay and at Piermont Marsh. The Piermont muskrat lodges were at the border of *Phragmites* and the low graminoid salt meadows characterized by

*Spartina patens, Distichlis spicata,* and *Carex hormathodes*. Muskrat cutting of *Phragmites* for food and lodge material may have inhibited its establishment in Tivoli North Bay and the Piermont salt meadows, and the 1975 muskrat crash at Tivoli may have allowed *Phragmites* to invade faster. *Phragmites* invasion speeded up in the Connecticut River estuary concurrent with a muskrat population decline, but the relationship between these two changes was ambiguous (Benoit 1997). Large-scale *Phragmites* consolidation could cause muskrat decline; however, it is also possible that muskrat declines reduced grazing pressure on *Phragmites* and facilitated its establishment or spread, or muskrat declines and *Phragmites* increases were unrelated. In the Hackensack Meadowlands, muskrats are sometimes abundant in extensive *Phragmites*-dominated marshes (Kiviat, pers. obs.). There seemed to be widespread declines of muskrat populations around New York State during the 1970s (Kiviat 1980), and it is unknown what relationship this may have had to *Phragmites*. During the 1970s, *Phragmites* establishment and spread were beginning in Tivoli North Bay (Winogrond and Kiviat 1997; Kiviat, pers. obs.).

*Phragmites* is readily eaten by livestock (cattle, sheep, goats, horses) (van Deursen and Drost 1990, Uchytil 1992, Kiviat and Hamilton 2001, Zheng et al. 2005), and it is common in the Hudson Valley (1990s-2000s) to see *Phragmites* flourishing just outside, but not inside, the fences of actively-grazed pastures (Kiviat, pers. obs.). When livestock were removed from pastures containing wetlands or watercourses during the 1900s as livestock farming declined in the Hudson Valley, it is likely that *Phragmites* established and flourished where it had previously been inhibited by livestock grazing and treading. *Phragmites* fragments are transported by construction equipment (Ailstock no date) and presumably farm equipment, providing a means for *Phragmites* to disperse from one old pasture to another. Fragments of *Phragmites* loosened from streambanks by ice or muskrats would have been able to drift downstream, in some cases to the Hudson River where they may have initiated infestations of the tidal marshes. Most of the Hudson River tidal marshes are located in low-energy environments sheltered by railroads, roads, and dredge spoil deposits created during the second half of the 1800s and the first half of the 1900s. During that time, and since, those environments have more-or-less filled with deposited sediment from a watershed that was in turn intensively logged, used for crop and livestock production, and again being deforested for residential, commercial, and industrial development. Rapidly-depositing, high-nutrient, moderately alkaline, freshwater tidal and mildly brackish-tidal marshes tend to be excellent habitats for *Phragmites* and this appears to be true in the Hudson.

*Phragmites* commonly invades inactive or under-active beaver dams and abandoned, partly-drained beaver ponds (Kiviat, pers. obs.). The American beaver population “exploded” in the nontidal streams and wetlands of the Hudson Valley from about the late 1970s to the present, creating large aggregate areas suitable for *Phragmites*. During the past ca. 20 years, the beaver has populated the fresh-tidal Hudson where these habitats may also be favorable for *Phragmites* establishment.

Headlee (1945:280-281) referred to the use of living *Phragmites* material in dike construction in New Jersey tidal marshes; the transplanted *Phragmites* sod sprouted and stabilized the newly-constructed dikes. Bart and Hartman (2002) showed that once established on a favorable substrate such as a slightly raised and more oxygenated patch of fill, *Phragmites* can spread vegetatively into chemically less favorable, lower elevation, areas.

## What Comes Before and After *Phragmites*?

What plant communities does *Phragmites* replace, and what communities replace *Phragmites* stands? *Phragmites* is generally considered to replace *Spartina* spp. in mesohaline tidal marshes and *Typha* in oligohaline and freshwater tidal marshes. In Hudson River marshes, *Phragmites* generally replaced *Typha*, but in Piermont marsh also replaced a mixed community dominated by *Spartina patens* and a mixed community dominated by *Scirpus americanus* (= *S. olneyi*) (Winogrond and Kiviat 1997). Few if any observations have been made on spontaneous (i.e., non-human-aided) replacement of *Phragmites* by other plant communities on the Hudson (Buckley and Ristich [1977] stated that sediment builds up in *Phragmites* stands until the habitat is suitable for shrubs and trees, but provided no documentation). Woody vegetation with gray birch *Betula populifolia* and other species has replaced *Phragmites* on a supratidal area at Jamaica Bay Wildlife Refuge (David Taft, U.S. National Park Service, personal communication). In Europe, replacement of *Phragmites* by carr (shrub swamp) is well-known (e.g., Rodwell 1995). Possibly the time scale involved (several decades?) in woody plant invasion and consolidation in *Phragmites* stands has prevented much of this from occurring to date in the Hudson, or vegetation development has been retarded by tidal fluctuation or muskrat cutting.

Will *Phragmites* continue its exponential expansion and consolidation in individual marshes in the Hudson River? Or will it be inhibited by local and general conditions? Local inhibitors include expanding stands encountering barriers such as shorelines or tidal creeks. General inhibitors might include sea level rise outpacing sediment deposition in marshes. (Although zebra mussel is considered responsible for reducing turbidity in the fresh-tidal Hudson River, this is due to filtering of phytoplankton rather than abiotic material; David Strayer, Institute of Ecosystem Studies, pers. comm. 2006).

## Claims and Data Concerning *Phragmites* Impacts

Table 3 lists published claims regarding *Phragmites* impacts on wetland functions and values, with reference to the data or observations bearing on those claims. I consider these claims about invasive plants “hypotheses.” Most such hypotheses (reasonable as they may seem) are in need of testing, and most studies that have been performed on *Phragmites* need replication in other habitats and geographic areas to determine the generality of the results. Some claims have been made, in the conclusions of papers or reports, that seem to have no logical relationship to the results of the study reported (e.g., D. Casagrande [1996]). Kiviat (2005) briefly reviewed claims of *Phragmites* impacts.

Some hypotheses seem reasonable, even trivial, on the surface. The idea that *Phragmites* has negative impacts on rare plants, for example, is such a hypothesis. I have found no direct documentation, however, of *Phragmites* causing decline in any population of rare plants. In most cases, this claim seems to be based on the fact that rare plants are not typically found beneath *Phragmites*, and that floristic diversity seems low beneath *Phragmites* (i.e., synchronic rather than diachronic comparisons; see, e.g., Meyerson et al. 2000). This kind of observation does not demonstrate that rare plants, or even higher floristic diversity, were present before a *Phragmites* stand existed. Confounding factors may pertain, e.g., changes to hydrology or salinity could have made the habitat unsuitable for certain plants while making it more suitable for *Phragmites*.

Conversely, the habitat where a rare plant occurs (e.g., goldenclub *Orontium aquaticum* in the mouth of Stony Creek in Tivoli North Bay, the sedge *Carex hormathodes* in the high salt marsh at Piermont Marsh, or the grass *Tripsacum dactyloides* in a nontidal wet meadow at Pelham Bay Park in the Bronx) might somehow be resistant to *Phragmites* invasion. Or the correct habitat simply might not have been present to support a rare plant. Yet it does seem likely that *Phragmites* sometimes overgrows and outcompetes rare plants. Rigorous diachronic studies with repeated sampling over time, at locations having rare plants and which are susceptible to *Phragmites* invasion, will be necessary to test this hypothesis. (See **Research Needs**, below.) Similar flaws in scientific method pertain to some of the other claims made about negative impacts of *Phragmites*.

### *Phragmites*, Biodiversity, and Ecosystem Processes

The purported negative impacts of *Phragmites* on native biota (e.g., Howard et al. 1978, Cross and Fleming 1989, Uchytil 1992, Marks et al. 1994, Anonymous 1998:31-32), have generally fueled sentiment for *Phragmites* control more than any other factors. Rationales for specific *Phragmites* management projects also included replacement of an introduced plant with native species, among others (Kiviat, pers. obs.). On the Hudson River estuary, decision-making about tidal marsh management seems to be driven principally by concerns about fish and birds. Although *Phragmites* is widely stated to have low value to wildlife, recent reviews and field studies have provided striking examples to the contrary in certain situations. Much of the information available on both the negative and positive impacts of *Phragmites* is based on one or a few observations or studies, usually restricted in space and time.

Table 3. Conspectus of available information on *Phragmites* pertinent to the tidal Hudson River. *Phr = Phragmites, Sa = Spartina alterniflora, Ty = Typha*.

| **Component** | ***Phragmites* impacts claimed**[1] | **References** | **Comments** |
|---|---|---|---|
| Plant communities | Decreases plant species diversity & patch diversity | Stalter & Baden 1994, Winogrond & Kiviat 1997, Meyerson et al. 2000 | Conclusions have often been based on synchronic observations or inference where *Phr* may have colonized low-diversity sites or has not yet greatly reduced diversity. Evidence of increased diversity with *Phr* removal. |
| Shoot density | Higher in *Sa* than in *Phr* | Able et al. 2003 | |
| Rare plants | Outcompetes rare plants | e.g. Stalter & Baden 1994, Lamont & Young 2004 | No quantitative diachronic data found to support negative impact; two qualitative examples of apparently positive impact (see text) |
| Plant production, biomass | Increases aboveground productionn and biomass [1] | Whigham et al. 1978, Meyerson et al. 2000 | *Phr* commonly has greatest standing crop biomass & production of any marsh plant |

| | | | |
|---|---|---|---|
| Plant biomass | Lower in *Phr* than in *Sa* (1400-6500 $g/m^2$ in *Phr*) | Ravit et al. 2003 | Few sites |
| Winter cover | Increases winter aboveground biomass[1] | Krause et al. 1997 | One site |
| Mosquitoes | *Phr* marshes are important mosquito producers | Ferrigno et al. 1969 | No quantitative data found |
| Macroinvertebrates in general | Some taxa denser, some less dense, in *Phr* compared to alternate communities | Fell et al. 1996a, b[3] | |
| Benthic meiofauna & macrofauna | Taxon richness higher in *Phr* but more individuals of common taxa than in *Sa* | Yuhas 2005 | See Fell (above) |
| Benthic macrofauna | Mites (Acari) more common in benthos of native brackish marsh community than in *Phr* benthos; springtails (Collembola: Poduridae) more common in reed benthos than in native marsh community | Talley & Levin 2001 | |
| Benthic macrofauna | Taxon richness & density similar in *Phr* and *Ty* | Osgood et al. in press | |
| Litter invertebrates in fresh-tidal marsh | Density & richness of identified taxa similar to *Typha* (one springtail sp. denser in *Typha*)[1] * | Kiviat & Talmage 2006 | |
| Epifaunal invertebrates in brackish-tidal marsh | Abundance & diversity generally lower on *Phr* than *Sa* | Robertson & Weis 2005 | |
| Terrestrial invertebrates | Different taxa associated with different plants; biomass & density higher on *Phr* in late winter[1]* | Krause et al. 1997, Kiviat et al. submitted | |
| Nektonic invertebrates | Comparable to non-Phr. dominant wetlands.[1] Similar to *Sa* if elevations similar.[3] Blue crab & grass shrimp more abundant in *Sa*, mud crab more abundant in *Phr*.[3] | Able & Hagan 2000, Meyer et al. 2001, Hanson et al. 2002, Osgood et al. in press | Apparently variable; more study needed. |
| Fish | Weinstein and Balletto 1999; also see Hellings and Gallagher 1992, Kay 1995 | Detrimental to populations and diversity | See Table 4 |
| Mummichog | Adults equally abundant, biomass equal, but early life stages more abundant in *Sa* than *Phr* | See Table 4 | Results need replication in other geographic areas, and causality needs elucidation |
| Amphibians & reptiles | Short-stature plant community may have higher abundance than | Kiviat & Gruner 2001 | |

| | | | |
|---|---|---|---|
| | Phr[3] | | |
| Diamondback terrapin | Interferes with terrapin nesting migration; renders nesting habitat unsuitable? | Simoes & Chambers 1999 | |
| Birds | No difference between small*Phr* marshes and non-*Phr* marsh[1] | Stevens 2001 | |
| Breeding birds | Reduces diversity in some situations[1]*; red-winged blackbird nesting density can be high; reduces breeding populations of species dependent on short-grass dominated marsh[3] | Swift 1987, Benoit 1997, Lewis & Casagrande 1997, Stevens 2001; Kiviat & Talmage 2006 | Surveying birds in *Phr* stands subject to methodological problems |
| Roosting birds | Important habitat[1]* | e.g., Lyon 1979, Burgess et al. 1995, Peterson 1995, Kiviat & Talmage 2006 | |
| Foraging birds | Used by marsh wren, ruby-throated hummingbird (summer), etc.; downy woodpecker, black-capped chickadee (winter)[1] | Lewis & Casagrande 1997, Stevens 2001; Kiviat & Talmage 2006 | |
| Wintering waterfowl | Low numbers compared to *Spartina* spp. marshes; some *Phr* marshes good habitat | Ferrigno et al. 1969, Kane 2001a | |
| Micromammals | *Peromyscus* use equivalent to *Typha, Lythrum*[1] | McGlynn & Ostfeld 2000 | |
| Muskrat | Variable importance in diet; sometimes abundant in *Phr* marshes although *Typha* generally considered more favorable | Kiviat, unpublished review | |
| Other mammals | White-tailed deer (cover), black bear & striped skunk (hibernation); domestic cat (foraging, escape cover) | Kucera 1974, Mutch 1977, Burger 1996; Brian Hardiman, pers. comm.; Kiviat pers. obs. | No quantitative data found |
| Wrack | Rafts of *Phr* wrack may smother *Spartina* stands | Don Smith, pers. comm. | No quantitative data found |
| Sedimentation | Increases deposition, binds soil | Windham & Lathrop 1999, Rooth & Stevenson 2003, Rooth et al. 2000, 2003 | No data for HR |
| Microtopography | Smooths marsh plain by filling small creeks & pools | Weinstein & Balletto 1999 | Windham & Lathrop 1999, Able et al. 2003, Raichel et al. 2003 |
| Energy flow | | | No data found |

| | | | |
|---|---|---|---|
| Carbon storage | | | No data found |
| Biogeochemistry | Similar to *Typha, Lythrum;* good at removing nutrients from water | See Table 5 | |
| Microbial community composition & metabolism | Differences between *Phr* & *Sp* small and variable | Ravit et al. 2003 | Two sites |
| Hydrology | Many small shallow pools in *Sa*; pools absent in *Phr* | Able et al. 2003 | One site |
| Visual environment | Blocks view of water or rocks; softens industrial landscape | Geller 1972, Casagrande 1997; Kiviat pers. obs. | |
| Recreation | | | No data found |
| Other human activities | Conceals illicit or unwanted activities | See text | |
| Plant products | Valuable but often underutilized for thatch, dried flower arrangements, rehabilitation of damaged areas, wastewater treatment; other potential uses | Uchytil 1992, Gray & Biddlestone 1995; Kiviat pers. obs. | Important for wastewater treatment |

* Limited data e.g., one site only.

Geographic source of data: 1 Hudson River; 2 Neighboring estuary (Hackensack Meadowlands, Jamaica Bay, etc.); 3 Other East Coast estuary; 4 Other estuary; 5 Nontidal area.

Terrestrial insects in winter and spring. *Phragmites* in Tivoli North Bay supported a high biomass of terrestrial insects (Krause et al. 1997, Kiviat et al. unpublished); some of this insect biomass is harvested by birds. Insect biomass was higher in *Phragmites* than in *Typha angustifolia* or *Lythrum salicaria*. Numbers and biomass were overwhelmingly concentrated in a single species, the reed scale (*Chaetococcus phragmitis*), beneath lower leaf sheaths. Biomass was as high as 1 gram dry weight per square meter, equivalent to 1 metric ton in 1000 hectares.

Flying terrestrial insects. Some insects use *Phragmites* culms for perches. The Needham's skimmer dragonfly (*Libellula needhami*) seems to favor *Phragmites* for perches in the Meadowlands (Kiviat, pers. obs.). *Phragmites* patches tied for a distant second in habitat use by butterflies at Dubos Point Wetlands Sanctuary in Queens, New York (Künstler, no date).

Macroinvertebrates in litter. A preliminary study (Kiviat and Talmage 2006) at a single *Phragmites* stand in summer in the fresh-tidal marsh at Tivoli North Bay separated macroinvertebrates from samples of standing and unattached *Phragmites* and *Typha angustifolia* litter in Berlese funnels. Most invertebrates were identified to Order; springtails (Collembola) and mites (Acari) were identified by specialists to the lowest practicable taxa. A single species of springtail in the genus *Pseudobourletiella* was more abundant in *Typha* litter than in *Phragmites* litter; no other invertebrate taxon differed between the two plant communities. Litter invertebrates, which are important in decomposition of dead plant material and are potential food for small fishes and small birds, bear further study.

Macroinvertebrates (estuarine and terrestrial) in growing season. In *Phragmites* stands of Connecticut River tidal marshes, mollusks were generally more abundant, crustaceans about equally abundant, spiders more abundant, and harvestmen less abundant, than in stands of other graminoid plants (Fell et al. 1996a, b). *Phragmites*-invaded marshes appeared to be functioning similarly to non-invaded marshes for macroinvertebrates and foraging mummichogs (Fell et al. 1998).

Small fishes. On the Connecticut River, mummichogs (*Fundulus heteroclitus*) and other small fishes foraged about equally in *Phragmites* and non-*Phragmites* stands (Fell et al. 1996a, b, Rilling et al. 1998), whereas in a southern New Jersey estuary there were more fish in smooth cordgrass (*Spartina alterniflora*) than in *Phragmites* at the same elevations (Able 1999). Raichel et al. (2003) found lower abundance of larval and small juvenile mummichogs, an abundant and ecologically important small fish, in *Phragmites* stands compared to smooth cordgrass stands in the Meadowlands. Fewer larval and small juvenile mummichogs in *Phragmites* compared to *Spartina alterniflora* have also been found in Connecticut (Osgood et al. 2003) and in a Delaware Bay marsh (Able et al. 2003). Some researchers have suggested that environmental factors are more important than plant species *per se* in shaping nekton use of tidal marshes (Fell et al. 1998, Meyer et al. 2001, Hanson et al. 2002).

Raichel et al. (2003) believed that differences in microtopography and sizes of potential prey explained the lower abundance of larval and small juvenile mummichogs in *Phragmites* in the Meadowlands. They found fewer potential prey in *Phragmites* compared to *Spartina alterniflora*, and by manipulating the substrate in experimental plots so that *Phragmites* stands resembled *Spartina* stands, they were able to increase abundance of larvae and small juveniles. This study has important implications for marsh food webs but needs wider replication and elucidation of the causal mechanism of lower abundance of young mummichogs. Osgood et al. (in press) found juvenile fish less abundant in *Phragmites* than in *Typha* at Iona Island Marsh. Yozzo et al. (2005) suggested that *Phragmites* stands become less suitable for juvenile and adult fish as the stands become larger and older. In the Able et al. (2003) study, the sampling stations in a restored marsh were a few centimeters lower than the *Spartina* stations which were a few cm lower than the *Phragmites* stations, and the flat microtopography of the *Phragmites* marsh after restoration to *Spartina* developed water-holding depressions used by small fish. It is unclear from the Able et al. (2003) paper whether the depressions were caused by the mechanical actions of restoration, or if there is something germane to the geomorphology and hydrology of *Spartina* compared to *Phragmites* that produces and maintains such pools. In the Housatonic River tidal marsh studied by Osgood et al. (2003), the *Phragmites* stands had substantially lower frequency, depth, and duration of flooding than the *Spartina* stands, at least partly explaining lower fish use of *Phragmites*. Interestingly, Ferrigno et al. (1969) referred to "Mosquito breeding depressions on the troublesome, higher, tidal salt hay and reed grass marshes." Possibly these depressions were only accessible to fish during spring high tides.

Fish communities. Table 4 summarizes studies comparing fish communities in *Phragmites* stands and alternate vegetation stands in East Coast tidal marshes. Most of these studies compared *Phragmites* with *Spartina alterniflora*. Some studies compared *Phragmites* to "restored" marshes where *Phragmites* had been replaced with *Spartina*. Some *Phragmites* marshes were tide-restricted and some not. In many cases the water depths (duration of tidal flooding) were not measured in *Phragmites* and alternate community, therefore depth may have been a confounding factor. Able and Hagan (2003) stated that depths varied < 15 cm among sampling stations; however, 15 cm can be a substantial difference in a tidal marsh. Many studies covered a single site or a few sites, and many reported data collected in only one or two years (i.e., spatial and temporal replication was limited). The fish community results varied from one geographic area to another, and this set of studies shows how *Phragmites* habitat functions can differ from one site or stand to another. The studies listed in Table 4 illustrate how variable are *Phragmites* marshes and *Phragmites*-alternate vegetation pairs. Nonetheless, most studies indicated that fish communities were generally similar between *Phragmites* and alternate vegetation stands (Table 4). Able (1999), however, found the *Phragmites* fish community less diverse compared to *Spartina alterniflora* in southeastern New Jersey (also see Table 4). Results from different studies comparing *Phragmites* to alternate communities vary enough that it would be risky to predict the impacts of *Phragmites* removal on the fish community in any one Hudson River marsh. The results of such a treatment would depend on marsh surface elevation, vegetation, salinity, hydrodynamic energy (including tidal restriction), river mile (see Mihocko et al. 2003), year of sampling, sampling method, and probably other factors, and would not necessarily even be predicted by studies in the same or another Hudson River marsh.

<u>Carbon base for fish food chains in Delaware Bay</u>. Several studies were completed on the sources of carbon (i.e., the base of the food chain) for common fish species in Delaware Bay, using multiple stable isotope ratios in fish (e.g., Bolsey et al. 2000, Wainwright et al. 2000, Weinstein et al. 2000). The results generally indicated that *Phragmites*, *Spartina*, phytoplankton, and mud algae (microphytobenthos) all contributed about equally to the base of the fish food chains. Marsh grasses, of course, do so via detritus (dead plant material) particles and their associated microfloras. It is unclear whether the organisms in the food chains between these carbon sources and the fishes studied were just obtaining their nutrition from the most readily available sources, and whether one food chain is better for fish than another.

Table 4. Findings on tidal marsh fish communities in *Phragmites* compared to alternate vegetation.

| **Alternate[1]** | **Locality** | **Comparison** | **Reference** |
|---|---|---|---|
| *Jg, Sp, Ty* | Connecticut R | Mummichogs equally abundant in *Phr* & alternate | Fell et al. 1998 |
| *As, Ds, Jg, Sp,* etc. | Connecticut R | Abundance & biomass of mummichogs similar; biomass of mummichog prey in gut contents was similar but taxon composition differed | Rilling et al. 1998 |
| *Sa* | Mullica R, NJ | Lower abundance of fish in *Phr* than *Sa* | Able 1999 |
| Various | Hudson R | Densities of mummichog & nektonic crustaceans in *Phr* in Piermont Marsh similar to, or slightly lower than, densities in non-*Phr* stands in other Hudson R marshes; hydrology & geomorphology affect nekton use of *Phr* stands | Hanson & Osgood 1999 |
| *Sa* | Mullica R, NJ | *Fundulus* spp. more abundant in *Sa* in pit traps; similar abundance in flumes | Able & Hagan 2000 |
| *Sa* | Laboratory | Mummichogs selected *Phr* and *Sa* equally, and preyed similarly on grass shrimp in both choices | Weis & Weis 2000 |
| *Sa* | Chesapeake Bay | No differences in abundance, biomass, or species richness | Meyer et al. 2001 |
| *Sa* | Cape Cod, MA | Density, richness, and species composition were similar in creek and marsh surface habitats, but pools in a tide-restricted *Phr* marsh had equal or greater fish density than an adjoining unrestricted *Sa* marsh | Raposa & Roman 2001 |
| *Phr* only | Hudson R | Mummichog density similar to non-*Phr* stands elsewhere in estuary | Hanson et al. 2002 |
| *Sa* | Mullica R., NJ | Mummichogs reproduce in both communities but larvae & juveniles many fewer in *Phr* | Able & Hagan 2003 |
| *Sa* | Alloways Creek, Delaware Bay, NJ | Use of restored *Sa* stands by mummichog larvae & | Able et al. 2003 |

| | | | |
|---|---|---|---|
| | | small juveniles comparable to natural *Sa* & greater than *Phr* | |
| *Ty* | Connecticut R | Fish community composition & species abundances, & mummichog size structure, biomass & diet similar; fewer larval & juvenile mummichogs in *Phr* | Fell et al. 2003 |
| *Ty* | Hudson R | Larval mummichogs less abundant in large *Phr* patches but not in small patches, compared to *Ty* | Harms et al. 2003 |
| *Sa* | Housatonic R | Total fish density similar but fewer juvenile mummichogs in *Phr*; decreased flooding frequency in *Phr* can affect fish use | Osgood et al. 2003 |
| *Sa* | Hackensack Meadowlands, NJ | Mummichog spawning occurs in *Phr* & *Sa* but larvae & small juveniles more abundant in *Sa* (juveniles > 20 mm TL similar in *Sa* & *Phr*) | Raichel et al. 2003 |
| *Sa, Sp,* etc. | Cape Cod, MA & southern RI | Density & richness less only in most-restricted *Phr* marsh (not different within other 2 pairs) | Raposa & Roman 2003 |
| *Sa* | Ipswich, MA | *Phr* marsh restored by increasing tidal flushing had lower catch-per-unit-effort of fish but more small mummichogs | Buchsbaum et al. 2006 |
| *Ty* | Connecticut R | Fish assemblages and mummichog numbers were similar in untreated *Phr*, herbicided-mowed *Phr*, & *Ty* within a few months of treatment; mummichog diets were somewhat different | Fell et al. 2006 |
| *Ty* | Hudson R | Adult mummichog density similar in *Phr* and *Ty* when hydrology similar; juvenile mummichogs more abundant in *Ty* | Osgood et al. in press |

[1] *As = Agrostis stolonifera, Ds = Distichlis spicata, Jg = Juncus gerardii, Sa = Spartina alterniflora, Sp = Spartina patens, Ty = Typha* (cattail).

Reptiles and amphibians. Very little work has been done on the impacts of *Phragmites* invasion on herpetofauna (reptiles and amphibians). A number of amphibian and reptile species may be found in *Phragmites* stands, including American toad, spring peeper, New Jersey chorus frog, southern leopard frog, green frog, snapping turtle, and eastern garter snake (Kiviat, pers. obs.), but quantitative data are virtually nonexistent on relative densities and other important measures. Kiviat and Gruner (2001) compared herpetofauna on time-constrained strip transects in *Phragmites*, *Typha*, and mixed low vegetation in fresh-tidal and oligohaline marshes of the Connecticut River in spring. Few animals were encountered overall. The numbers were similar in *Phragmites* and *Typha*, and non-significantly higher in low mixed vegetation. It is unclear to what extent this finding was influenced by the greater ease of seeing small animals in low vegetation. Whitlock (2002), in a detailed radiotelemetry study of bog turtles at a nontidal wetland in Massachusetts, found that certain males used small *Phragmites* stands regularly although overall the population did not use those stands much. Cook (1996), in a radiotelemetry study of translocated eastern box turtles in nontidal habitats at Floyd Bennett Field in Queens, New York, found that overall *Phragmites* patches were avoided. Yet 7 of 21 individuals that demonstrated nonrandom habitat use preferred *Phragmites*, and only 12 of 40 individuals overall avoided it. The box turtles appeared to use *Phragmites* patches as a substitute for woody vegetation. Box turtles overwintered in *Phragmites* in proportion to its availability at Floyd Bennett Field. Some individual eastern box turtles at Jug Bay Wetlands Sanctuary on the Patuxent River estuary in Maryland visited stands of *Phragmites* and *Typha* in the tidal marsh for extended periods in summer (Quinlan and Swarth 2002; Chris Swarth, pers. comm.). Whether the bog turtles and box turtles in these studies were foraging in *Phragmites* stands is not known. They may have been using *Phragmites* stands for thermoregulation (i.e., avoiding summer heat) or for the dense escape cover. Clearly, much more needs to be learned about herpetofaunal use of *Phragmites*. On the Hudson River, few amphibian and reptile species use the open tidal marshes, although herpetofaunal diversity is higher in supratidal marshes and pools (Stevens 2001, Kiviat, pers. obs.).

Breeding birds. More than 75 species of birds have been reported to breed in *Phragmites* in North America, and at least a few species commonly use *Phragmites* stands (Kiviat et al. submitted). Red-winged blackbird and marsh wren have been reported most often breeding in *Phragmites* marshes, but there are also good numbers of reports of less common species such as least bittern. Data are sparse on most of the *Phragmites*-breeding species.

Use of *Phragmites* by breeding birds in Hudson River marshes and other northeastern tidal marshes may vary with stand size, stand edge vs. interior, presence of pools within stands, degree of ecological specialization of bird species, and other factors, and at times may be similar to bird use of cattail stands (Swift 1987, Benoit 1997, Holt and Buchsbaum 2000, Stevens 2001). However, fewer listed species (species of conservation concern) breed in *Phragmites* marshes compared to the short-graminoid habitats of high salt marsh, and three species (willet, seaside sparrow, and saltmarsh sharp-tailed sparrow) are dependent upon the short-graminoid community (Benoit 1997).

The study of bird use of *Phragmites* is fraught with methodological problems. In tall marsh vegetation (*Phragmites*, *Typha*, some *Scirpus* species, *Spartina cynosuroides*, some *Spartina alterniflora*, etc.), birds can be heard but often are not seen during bird surveys. It is difficult to estimate the distance from an observer of an unseen vocalizing bird, and difficult to calibrate such estimates. Thus it is difficult to accurately gauge location in a particular size plot or plant community. When playback of vocalizations is used to stimulate birds to vocalize, some birds move towards or away from the playback before they vocalize in response. Thus the observer may not know in which plot or community the bird was originally, potentially introducing error into density estimates and habitat use estimates. The movement of an observer through *Phragmites* often is very noisy which disturbs birds; waiting a typical time before conducting a count (e.g., 5 min) may not be enough for an unbiased estimate of the numbers of birds on a plot. These problems are more severe than in many kinds of vegetation. Conducting bird surveys from the edges of a marsh or *Phragmites* stand may result in a lower probability of detecting marsh-interior species. In many of the available studies, difficult-of-access areas in marsh interiors or remote locations were not sampled, potentially biasing the results because of the well-known variation in *Phragmites* stands and their associated avifaunas. Some rails, least bittern, and other marsh birds are more likely to vocalize at night than during the day, and this seems especially true where population densities are low; however, nighttime surveys are rarely performed and this probably results in fewer detections of rare species. Many observers do not have enough experience with the variable and frustrating vocalizations of, e.g., rallids, to accurately identify a call that may be heard only once or faintly or juxtaposed with the background sounds of more common birds. Rallids and certain other marsh birds may occur at low density (e.g., one pair per marsh) and not vocalize much because of the lack of auditory stimulation from conspecifics. Problems aside, Swift (1987), Wells et al. (2005a, b), Seigel et al. (2005), and Kiviat and Talmage (2006) reported lower levels of breeding bird activity in *Phragmites* than in other plant communities.

Patterns of the use of *Phragmites* marshes and stands by nonbreeding birds are complex, and *Phragmites* effects on these birds may be negative, positive, or unknown (Kiviat, unpublished review). One striking aspect is that *Phragmites* stands are selected for roosting by nonbreeding songbirds of several species and often in great numbers (see Table 3). *Phragmites* is good roosting habitat, probably because it provides isolation from predators and human activity, and perhaps also because of the robustness of *Phragmites* in bad weather and floods. At least two songbirds known to roost in Hudson River *Phragmites*, bobolink and rusty blackbird, are severely declining rangewide and it is unknown to what extent processes in the nonbreeding (e.g., migration stopover) habitats are affecting populations. It seems likely that *Phragmites* would be favorable rather than unfavorable roosting habitat for nonbreeding songbirds (see Burgess et al. 1995, Kiviat and Talmage 2006).

<u>Micromammals</u>. White-footed mouse (*Peromyscus leucopus*) use and average mouse weights were statistically similar in *Phragmites*, purple loosestrife, and cattail stands in Tivoli North Bay, a Hudson River fresh-tidal marsh (McGlynn and Ostfeld 2000); mouse abundance was nonsignificantly greater in *Phragmites* than in the other two communities. When live-trapped mice were released they sometimes climbed *Phragmites* culms (Cathy McGlynn, pers. comm.). White-footed mouse and especially house mouse (*Mus musculus*) used the dense cover of standing dead *Phragmites* material in tidal marshes of the Farm River estuary in Connecticut; meadow vole (*Microtus pennsylvanicus*) was also found in *Phragmites* (Holland and Smith 1980). *Phragmites* may have been a refuge from white-footed mouse competition for house mouse; meadow vole, more typically associated with short grass (*Spartina patens* etc.) marsh,

seemed to be replaced by house mouse after *Phragmites* invasion (Holland and Smith 1980). In a limited study of dry habitats on an inactive garbage landfill in the Hackensack Meadowlands, Rawson (1993) trapped more white-footed mice in *Phragmites* than in three other plant communities including a tree community. Much smaller numbers of house mice (*Mus musculus*) also were trapped in *Phragmites*. I found no data on bat use of *Phragmites* marshes for foraging or roosting.

Large mammals and meso-mammals. White-tailed deer commonly use *Phragmites* stands for escape cover and resting (Kucera 1974; Kiviat, pers. obs.) and seem to avoid dogs and humans there. Deer graze *Phragmites* but little (Self et al. 1975). A black bear was observed hibernating in an open nest it constructed of *Phragmites* material 3 of 4 winters in a *Phragmites* stand in northwestern New Jersey (Brian Hardiman, pers. comm.). Raccoons made substantial use of *Phragmites* stands for foraging and resting near Islip on Long Island, New York; resting sites were often under mats of lodged *Phragmites* culms (Feigley 1992). Striped skunks were recorded denning in upland soil beneath *Phragmites* in Manitoba (Mutch 1977). Various other species have been observed to use *Phragmites* stands but little is known about this behavior. I found virtually no quantitative data on middle-sized or large mammal use of *Phragmites*.

Muskrat. Muskrat use of *Phragmites* stands for food, construction material, and shelter is highly variable (Kiviat, unpublished review). At certain times and places muskrats have been abundant in *Phragmites* in the Hackensack Meadowlands of New Jersey and the Patuxent River estuary of Maryland (Kiviat pers. obs.). Ca. 1980, muskrat lodges were common at the *Phragmites* - salt meadow edge in Piermont Marsh although at that time muskrats were rare in most Hudson River marshes (Kiviat, pers. obs.). I have observed muskrat activity, sometimes indicating substantial populations, in marshes overwhelmingly dominated by *Phragmites* in the Hackensack Meadowlands, and inferred that *Phragmites* was the primary muskrat food because other vascular plant biomass was small and there was no evidence of medium-to-large species of bivalves suitable as muskrat food. The contradictory evidence concerning *Phragmites* from observations and from the several available quantitative studies of muskrat diets may be due to different *Phragmites* subspecies, other local variation in *Phragmites,* availability of alternate food resources, or differences (behavioral or other) in muskrat populations. *Phragmites* is known to vary genetically on small scales, even within a wetland (Clevering and Lissner 1999); Maltz and Stabile (2005) found high levels of genetic variation within the Hudson River.

Vascular plants. *Phragmites* potentially could affect vascular plant diversity, rare plant species, or plant communities. It is generally believed that *Phragmites* invasion reduces vascular plant diversity (Meyerson et al. 2000). On transects in fen meadows at Moore Brook (Salisbury, Litchfield County, Connecticut), *Phragmites* stands had lower vascular plant species richness than non-*Phragmites* communities (Meyerson et al. 2000). However, these are "space for time substitution” data and prior conditions were not documented. Because it is a common observation that many *Phragmites* stands are highly dominant (i.e., few other plant species and often few individuals of those species are admixed), the assumption is made that *Phragmites* has invaded and outcompeted more diverse vegetation. In fact, *Phragmites* may have established on bare soil (e.g., the exposed sediments of drawndown abandoned beaver ponds at Moore Brook) or in pre-existing low diversity communities (e.g., highly dominant *Typha* or *Carex stricta* stands). It is reasonable to assume that *Phragmites* invasion reduces vascular plant diversity in some situations, although few data are available. Diachronic (over time) studies are needed to confirm this supposition and understand in what sites, habitats, and environmental conditions *Phragmites* is likely to threaten rare plants. In Hudson River tidal wetlands, most rare plants occur at the mouths of nontidal tributaries, along the upland edge, in intertidal and supratidal swamps, and in the lower intertidal zone. *Phragmites* tends to invade along the banks of tidal creeks and pools, near areas of fill or other alteration, and in some cases along upland edges. *Phragmites* is perhaps most likely to threaten rare plants at and near upland edges of the tidal marshes. Examples of likely trouble spots are the occurrence of cylindrical bulrush *Scirpus cylindricus* at the upland edge of Iona Island Marsh, and the occurrence of goldenclub *Orontium aquaticum* in a small tidal creek in *Typha* in the Stony Creek marsh of Tivoli North Bay (*Phragmites* is absent from this latter location). In my 35 years of field work in Hudson River wetlands, I have the impression that herbicide use (on the railroads, formerly for water-chestnut control, and proposed for *Phragmites* management) and construction in the wetlands (e.g., the boat landing at Tivoli North Bay and causeway improvements at Iona Island Marsh) are the *types* of impacts most likely to harm rare plants. Rare plant occurrences in all Hudson River wetlands need to be mapped and considered more stringently in management and planning.

I know of two instances where rare plants occur only beneath *Phragmites* and the *Phragmites* appears to be facilitating the rare species. In the brackish-tidal marsh on the south side of the outer portion of Croton Point (Westchester County), mudwort (*Limosella subulata*) is common on eroding marsh peat in the outer (lower) edge of highly dominant *Phragmites* (Kiviat, pers. obs.). At this site, *Phragmites* appears to provide shelter and a degree of soil stability for mudwort. On an old dredge spoil deposit, now upland or "dry end" wetland, at Jamaica Bay Wildlife Refuge (Queens County, New York), the regionally-rare ragged fringed orchid (*Habenaria lacera*) grows beneath an open stand of *Phragmites* with admixed woody species; here also the *Phragmites* appears to be facilitating the orchid (Dave Taft, Gateway National Recreation Area, pers. comm.; Kiviat, pers. obs.). At two stations in the Moore Brook fen meadows, sweet coltsfoot (*Petasites frigidus* var. *palmatus*) co-occurs with *Phragmites*, but I can not discern whether the coltsfoot is being facilitated or outcompeted. Where a rare plant co-occurs with *Phragmites* it should not be assumed that the rare species is at a disadvantage unless longitudinal observations are made.

*Phragmites* removal has increased diversity of vascular plants (Meyerson et al. 2000). We need to know more about the long-term effects of removal, because removal constitutes a disturbance to soil and vegetation that would be expected to cause a short-term "bloom" of plant diversity followed by a relaxation of species numbers. Ca. 18 years ago, *Phragmites* was removed from the Hartz Mountain brackish-tidal marsh mitigation site in the Hackensack Meadowlands using herbicide, sediments were re-contoured, and *Spartina alterniflora* planted. In 2006, only small patches of *Spartina* remained, extensive stands of *Phragmites* had re-established, and some areas were mid- or upper-intertidal zone mudflats with submergent species (*Zannichellia palustris, Ruppia maritima*). This case history suggests that *Phragmites* removal and the accompanying vascular plant community diversification may be short-lived without active maintenance.

<u>Effects on agricultural crops</u>. *Phragmites* is the summer host of the mealy plum aphid (*Hyalopterus pruni*) which alternates generations between *Phragmites* (summer) and woody plants of the genus *Prunus* (winter). In California, the mealy plum aphid is an important pest in

prune orchards, and *Phragmites* is considered undesirable near the orchards because it promotes aphid infestations of the prune trees (Amanda Thimmayya, University of California at Berkeley, pers. comm). I do not know if mealy plum aphid is a pest of peaches, plums, or other cultivated *Prunus* in the Northeast. I have found no evidence of *Phragmites* itself as a weed in crops, gardens, greenhouses, or pasture in our region.

Lower Organisms. *Phragmites* (and *Typha*) seems generally not to provide much microhabitat for bryophytes. *Sphagnum* and other bryophytes may be observed attached to *Phragmites* culm bases, especially those older than the current year's growth. However, *Lythrum salicaria* stem bases and root crowns are a much more favorable substrate for mosses (and occasionally liverworts) (Kiviat, unpublished data) than *Phragmites* or any other robust emergent marsh herb I have observed. Exceptions occur in nontidal peatlands where moss layers are particularly well developed, and soils are saturated but not flooded; there mosses may use *Phragmites* for support more than in other habitats (Kiviat, pers. obs.).

Macroalgae, macrofungi, and microbiota associated with *Phragmites* aboveground have apparently not been studied, except that lists of fungi associated with *Phragmites* have been compiled (see Schwärzlander and Häfliger 1999). Some research has been conducted on belowground microbial communities associated with *Phragmites* (Ravit et al. 2003).

Biogeochemistry. Similarly, in the last few years studies have been conducted on the effects of plant invasions on biogeochemistry in tidal marshes (Table 5). Stands of *Phragmites,* cattail, and purple loosestrife (*Lythrum salicaria*) appear generally similar in their abilities to remove and retain nutrients from surface waters (Templer et al. 1996, Otto et al. 1999; Mihocko et al. 2003). Otto et al. (1999) performed a fertilizer experiment in the Hudson River fresh-tidal marsh and found few differences in microbial biomass and activity, and in response to the nitrogen addition, among *Phragmites, Lythrum salicaria, and Typha angustifolia* stands although plant biomass and nitrogen content differed markedly. Meyerson et al. (2000) reviewed biogeochemistry studies and reported that aboveground standing stocks of nitrogen were higher in *Phragmites* compared to alternate communities. *Phragmites* is one of the most widely used plants in wetlands constructed for waste treatment and nutrient removal (e.g., Gray and Biddlestone 1995).

Sequestering of heavy metal contaminants. A series of studies in the Meadowlands compared how *Phragmites* and *Spartina alterniflora* handled heavy metals (Burke et al. 2000, Windham et al. 2001a, b, J. Weis pers. comm.). The roots of both plants take up considerable amounts of metals from the sediments, but in *Spartina* more of the metals is translocated to aboveground parts. *Spartina* leaves released more mercury, copper, chromium, lead, and zinc than *Phragmites*. Therefore, in areas with heavy metal-contaminated sediments, *Phragmites* may retain metals in the system whereas *Spartina* may remobilize metals.

Table 5. Studies of nitrogen and phosphorus biogeochemistry in *Phragmites australis* stands. *Phr* = *Phragmites*; *Sa* = *Spartina alterniflora*.

| ***Phragmites* vs. alternate vegetation** | **Reference** |
|---|---|
| *Phragmites* vs. *Typha* | |
| No difference in porewater ammonium | Templer et al. 1998 |
| Nitrate undetectable | Templer et al. 1998, Meyerson et al. 1999 |
| No difference in porewater P | Templer et al. 1998 |
| Porewater P greater in *Phr* | Meyerson et al. 1999 |
| N concentration in aboveground plant matter greater in *Phr* | Templer et al. 1998, Otto et al. 1999 |
| No difference in N concentration in aboveground plant matter | Meyerson et al. 1999 |
| Standing stock of N and P greater in *Phr* | Templer et al. 1998 |
| Standing stock of N greater in *Phr* (P not measured) | Meyerson et al. 1999 |
| No difference in microbial activity (including denitrification) | Otto et al. 1999 |
| *Phr* sequesters 2x nitrogen in living aboveground tissue than *Typha* but differences in microbial biomass and production of litter were small | Findlay et al. 2002 |
| *Phragmites vs. Spartina alterniflora* or high salt marsh community | |
| No difference in porewater P | Chambers 1997 |
| Porewater ammonium greater in *Spartina* spp. | Chambers 1997, Meyerson et al. 2000 |
| *Phr* has higher redox potential (greater N availability to *Phr)* | Windham and Lathrop 1999 |
| *Phragmites* vs. removal | |
| *Phr* removal resulted in decreased capacity of site to act as a sink for N, at least in short term | Findlay et al. 2003 |

Energy Flow. Although several sources (e.g., Raichel et al. 2003) refer to energy flow, I have found no quantitative data comparing energy flow in *Phragmites* and an alternate plant community. If live *Phragmites* biomass were grazed less than alternate plants due to the high silica and cellulose content of *Phragmites*, I would expect less energy flow through grazing pathways and more through detritus pathways (i.e., consumption of dead plant material and associated microorganisms). Furthermore, because different insects feed on *Phragmites* compared to, e.g., *Spartina alterniflora* or *Typha*, food webs and therefore probably energy flow to higher consumers should differ.

Carbon Storage. *Phragmites* stands often accumulate organic matter efficiently. The high production of living and dead organic matter by reed stands, and the accumulation of portions of this material in soils beneath reed (Windham 2001), suggest that reed might be important as a carbon sink. Carbon accumulation in sediments vs. losses to air and water may vary greatly (J. Ehrenfeld, personal communication). Because *Phragmites* produces more biomass than most herbaceous marsh plant communities, and because *Phragmites* tends to build up the soil elevation by accumulation of organic and inorganic materials more than, e.g., *Spartina* or *Typha*, *Phragmites* stands may be better carbon sinks. The relative function of different wetland plant communities as carbon sinks may be important to consider in the overall strategy of reducing global warming. However, emissions of methane, dissolved and particulate organic carbon, and other materials from *Phragmites* stands would have to be considered in the carbon balance equation along with plant production and deposition of organic matter in the soil.

Fire Regimes. Dry, standing and lodged, *Phragmites* litter of previous years carries fire readily (Anonymous 2002) and burns hot. *Phragmites* fires are dramatic (Quinn 1997) and it is often considered a fire hazard where it occurs in urban areas or near built structures (Steinke 1986, Lacinski and Bergeron 2000, Anonymous 2002; Jennifer West, pers. comm.). Methane from organic soils may be more responsible for the fire behavior than the *Phragmites per se* (Hartig and Rogers 1984; Ellen Hartig, Columbia University, pers. comm.). I found no data comparing fire behavior in *Phragmites* vs. alternate communities. Considering how fire-prone *Phragmites* seems, it is surprising there has not been more research on its fire ecology. Fire research has focused on fire effects on *Phragmites* stands and the use of fire for managing *Phragmites* (Schlichtemeier 1967, Ward 1968, Shay et al. 1987, Thompson and Shay 1989; but see Uchytil 1992).

Sedimentation. Although sedimentation (in the geological sense of erosion, transportation, and deposition of particles) is generally considered part of the abiotic environment, it is much subject to biological influences thus is included here as an "ecological" process. *Phragmites* is generally considered to increase deposition rates within its stands, both from allochthonous suspended sediment (organic and mineral particles) and from autochthonous *Phragmites*-produced matter. In a Chesapeake Bay study, older *Phragmites* stands produced more live biomass and more litter, and had higher sediment accretion rates, than younger stands (Rooth et al. 2003). However, there have been few studies of these processes or their consequences (see Windham and Lathrop 1999, Rooth and Stevenson 2000). Sediment deposition, including the collapse (lodging) of *Phragmites* culms into creeks, tends to decrease water depths within *Phragmites* stands, fill in small creeks and pools on tidal marsh surfaces, and smooth microtopography within *Phragmites* stands (Windham and Lathrop 1999, Weinstein and Balletto 1999, Able et al. 2003). The raising of substrate elevation and filling of small creeks and pools interferes with nekton (fishes, blue crab, grass shrimp) access to the intercreek marsh. The massive underground biomass of *Phragmites* stabilizes soils against water erosion. Soil-building by *Phragmites* can be a “negative” impact (e.g., where nekton habitats are adversely affected in tidal marshes) or a “positive” impact (e.g., where tidal marsh soils are protected from erosion due to rising sea level). Most sediment deposition rates measured in Hudson River tidal marshes (Kiviat et al. 2006) are less than the ca. 0.5-1.5 cm per year predicted rate of sea level rise during the next 20 years (Rosenzweig and Solecki 2001); thus *Phragmites* might play an important role in maintaining marsh elevations and reducing marsh loss on the Hudson. It has been stated that *Phragmites* can have the opposite effect of lowering the marsh surface because *Phragmites* stands have a high rate of evapotranspiration of water causing compaction and subsidence of the soil (Cronk and Fennessy 2001); I doubt that this pertains to regularly and deeply flooded tidal marshes such as most Hudson River tidal marshes.

Microclimate. *Phragmites* stands may be warmer or cooler than their surroundings. In spring, ice may remain within *Phragmites* stands after it has melted from surrounding vegetation (Kiviat, pers. obs.). On cool days, the sunny side of a stand may warm above ambient temperature. Birds and insects seem to use this favorable microhabitat for basking (Kiviat, pers. obs.). On a hot day, the interior of a stand may remain cool; songbirds have been reported to take shelter from the heat within *Phragmites* patches on a Maryland marsh (Ed Frantz, New York State Department of Transportation, pers. comm.). Baldi (1999) found that microclimate factors (e.g., temperature, humidity) demonstrated an edge effect as far as 15 m into a *Phragmites* stand in Hungary.

<u>Human activities</u>. Many people consider *Phragmites* aesthetically pleasing in aggregate or as individual culms with tassels. The positive visual aspects of *Phragmites* were described eloquently by Brown (1985) and alluded to by Geller (1972), among others. *Phragmites* is commonly collected (or purchased from florists) for indoor dried plant arrangements, alone or mingled with other native or introduced plants (Kiviat, pers. obs.). *Phragmites* is sometimes considered aesthetically negative where it obstructs views of water or other landscape features (Casagrande 1997), or is believed to occupy space that would otherwise be occupied by more desired plants. *Phragmites* was controlled in The Pond in the southeastern corner of Central Park (Manhattan), apparently because it blocked views of rock outcrops, and I have observed cutting of *Phragmites* at Middle Ground Island on the Hudson River and in South Florida apparently to open up views of the water. In 2006 I observed where *Phragmites* had been cut ca. 1.5 m above the ground in a narrow belt along a footpath at Sleightsburg Park (Sleightsburg Spit) in the Hudson River near Kingston. There are probably cases where *Phragmites* expansion has interfered directly with boating or other recreational activities by blocking access, but this does not seem to be a major concern. .

I have seen *Phragmites* harvested for "cane" fishing poles in southern Florida; I do not know how common this use is. *Phragmites* fencing can be purchased from garden stores; however, fencing is apparently imported from Europe. *Phragmites* finds local use for roof thatch (domestic, commercial, and ceremonial) in the northeastern states. For example, on Route 23 between Cairo and Windham, Greene County, New York, there are two buildings thatched with *Phragmites*. One is the Blue Pearl restaurant just east of Windham. The other building, farther east, was reported by the owner to have been thatched by visiting European thatchers. I do not know if local *Phragmites* was used in these two cases. *Phragmites* is grown in Annapolis Royale, Nova Scotia, Canada, for thatching in the Maritime provinces by Jef Achenberg (pers. comm.). Thatching reeds (*Phragmites*) must be tended in particular ways to yield materials with desired qualities (slender strong culms) that give the thatch its handling characteristics and long life on the roof (up to 70 years in Europe; Hawke and José 1996). Hasidim harvest *Phragmites* annually from a small area of the Hackensack Meadowlands for ceremonial thatch (Kiviat and MacDonald 2002).

Notwithstanding the existing and potential uses of *Phragmites* for thatch, fencing, fishing poles, dried flower arrangements, and other products, by far the most important use of *Phragmites* is in wastewater treatment. Hundreds, perhaps thousands, of domestic reedbed systems have been installed widely in the U.S. for dewatering of sludge from sewage treatment plants (e.g., Heinss and Koottatep 1998, Saltman and Gallagher 1998), and for wastewater treatment *per se* (usually nutrient removal in tertiary treatment of sewage; e.g., Gray and Biddlestone 1995). There is now a large literature on this subject. Local examples of treatment reedbeds in Ulster County are at the Town of Highland sewage treatment plant (sludge dewatering), Zumtobel Staff Lighting (also Town of Highland; wastewater treatment), and Village of New Paltz (sludge dewatering) (Shapley 2006; John Jankiewicz, pers. comm.). These applications exploit the great capacity of

*Phragmites* to take up nutrients and water from the rooting medium. Closer to the Hudson River, the Village of Tivoli (Dutchess County) has just installed a reedbed for sludge dewatering at the municipal sewage treatment plant that discharges into Stony Creek and Tivoli North Bay. The concern has been expressed that propagules might escape from domestic reedbeds and initiate *Phragmites* invasions in natural wetlands. This could occur by loss of rhizome fragments (separated by ice, muskrats, or equipment), or by seed dispersal in the wind or on water. Fortunately, establishment of *Phragmites* by seed is believed to be rare. A *Phragmites* cultivar with variegated leaves has been developed for use in domestic reedbed systems so that the source of escapes can be identified (John L. Gallagher, University of Delaware, Lewes, pers. comm.). To my knowledge, variegated *Phragmites* has not been used in the local projects mentioned above.

Several years ago, *Phragmites* in the remnants of the Boston, Massachusetts, fens was used for concealment by gay men having sex and by "gay bashers" attacking the gay men, according to a local resident involved in management of the park where these incidents occurred. In 1999, economic refugees from Rumania were using *Phragmites* stands on the Hungary-Rumania border for concealment and illegal migration into Hungary (Brandon Anthony, Central European University, pers. comm.). There are many other examples, contemporary and historic, of *Phragmites* stands and marshes being used for concealment of human activities that are considered undesirable by other groups of people.

## Conflicts of Interpretation of the Available Data

In general, emotions run high about invasive species. The impacts of *Phragmites*, and its appropriate management, are controversial, and there is a wide spectrum of opinions among researchers and managers. I believe there are several reasons for these differences of opinion.

1. Policy and management generally lag years behind research, and many important research findings are less than a decade old (see References Cited, below).

2. Impacts of *Phragmites* (i.e., the functions and values of *Phragmites* stands) differ among stands, wetlands, and geographic areas. Opinions are generally driven by experience in one locality although that experience may not necessarily apply to another locality.

3. The genetics data indicating the existence of native and nonnative genotypes of *Phragmites* (Saltonstall 2002a, b) are only a few years old, and many practitioners are unaware of those data. There is little firm information about differences in ecological function of the genotypes.

4. Practitioner attitudes are founded on more than science. Social factors influence attitudes towards management of *Phragmites* (Kiviat, unpublished data).

5. Goals of management vary. For example, a practitioner concerned about economical treatment of wastewater likely will have a different attitude towards *Phragmites* than someone interested in rare plant conservation.

6. Individuals base their approaches on available information, and few practitioners do extensive searches for, and analyses of, information. Many students and scientists who use available electronic databases only skim the top of the literature (e.g., the best-known scientific journals), and miss less well-known journals, chapters in books, PhD and Master's theses, unpublished agency reports, older literature, and other materials that may contain good, useful data. Most observations on *Phragmites*, and results of management projects, are never disseminated, forcing each new management project to start from scratch.

7. The quality of research on *Phragmites* varies. Many practitioners do not carefully assess the methodology or interpretations of the literature they read.

8. Remember the parable of the "blind men and the elephant" in which several persons felt different parts of an elephant and reached different conclusions about what animal they were perceiving? We are all feeling the "taxonomic elephant" insofar as each of us focuses on different groups of organisms or ecological processes, leading us to different conclusions about whether *Phragmites* is “bad” or “good.”

*Phragmites* is too abundant, its ecology too full of nuances, and its management too expensive economically and ecologically to leave policy to simplistic bad vs. good approaches. Goals must be defined, sites assessed individually, and experiments reported to the public. Scientific information must be distinguished from cultural and social beliefs, individual experience, attitudes, and opinions, although both types of information should be considered in making management decisions.

## Goals of *Phragmites* Management on the Tidal Hudson River

Removal of *Phragmites* is a common goal of tidal marsh restoration in many regions including the Hudson River, the Hackensack Meadowlands, Connecticut, and Delaware Bay (New Jersey and Delaware). *Phragmites* removal is often expected to produce specific desired results and not cause nontarget damage. Yet an examination of the restoration and management policies often finds a weak or no basis in quantitative scientific data, little hard information on the ecology of marshes before *Phragmites* removal, superficial consideration of the sustainability of restoration, and little effort or planning for monitoring the results. Even in large, well-funded projects, monitoring typically focuses on one, two, or three taxa or processes. Regulatory agencies often require monitoring only of vegetation composition. The assumptions of restoration may or may not be correct, and, at least, different sites probably merit different management strategies. A hard look at the state of knowledge is badly needed to assist policy makers and the public in determining if money directed at the restoration and management of *Phragmites*-dominated wetlands is being well spent, and to find better ways to conserve and manage the natural resources of the Hudson as environmental conditions and marsh vegetation change. Table 6 summarizes assumptions underlying most recent, current, and planned *Phragmites* management projects in the northeastern U.S. Given the scarcity of information, goals and assumptions must be carefully examined. In many cases, it may be better to wait until more information is available before making management decisions. Middle-of-the-road alternatives could include focusing management on those sites and stands where *Phragmites* is clearly an immediate threat to a taxon or process (e.g., a rare plant), and conducting small-scale experiments (e.g., *Phragmites* removal on plots) and then monitoring and assessing the results in view of the goals and assumptions. Practitioners or decision-makers may argue that it is wiser to take action while funding and public support are available, and before further spread and consolidation of *Phragmites*. This is similar to the controversy about treatment for certain human diseases, e.g., prostate cancer, where the disease may have little impact on well-being for many years but the treatment includes a risk of severe side effects.

There are two notable exceptions to many of the problems listed in Table 6: *Phragmites* management techniques that appear to be relatively inexpensive with few undesirable nontarget impacts. One, very small stands of *Phragmites* (e.g., a few $m^2$) can often be removed easily by excavation or individual-culm herbicide treatment with small nontarget impacts. Two, polyhaline and some mesohaline marshes where *Phragmites* replaced *Spartina* due to tidal restriction (e.g., old salt hay impoundments) may be re-opened to saline tidal flushing with resultant reversal of the vegetation change.

Table 6. Common assumptions of the prevailing approach to managing *Phragmites australis* in the northeastern United States.

| **Issues** | **Assumptions** | **Comments** |
|---|---|---|
| Underlying ecological conditions | Will not prevent establishment & maintenance of alternate plant community | Substrate elevations, soil fertility or pH, hydrodynamic energy, herbivory, or contaminants factors often interfere with restoration |
| Historic plant community is known | Plant community preceding *Phr.* often assumed on synchronic basis or anecdotal evidence | Very little is known about plant communities before 50 years ago, and historical or paleoecological data are usually sparse and difficult to interpret |
| Sustainability | Plantings to replace *Phr* will persist without maintenance | Most or all vegetation restoration will require maintenance to prevent loss of plantings, reinvasion of *Phr*, or invasions of other undesirable plants such as purple loosestrife |
| No remobilization | Restoration will not remobilize harmful amounts of sediment, organic matter, nutrients, or contaminants, | No data are available |
| Taxonomic | Restoration that increases one desirable taxon (or ecological function) will increase another | This has been proven incorrect wherever studies have been conducted |
| No nontarget impacts | Herbicide (and accessory techniques) does not harm other plants or animals | Recent laboratory and epidemiological studies of glyphosate and its |

| | | |
|---|---|---|
| | | formulations indicate this is unlikely; the same probably true of imazapyr & other herbicides |
| Achievement of goals | Will successfully achieve goals of habitat function or ecological process restoration or enhancement | Where restoration projects have been monitored at all, much of the data is weak or ambiguous, or goals are substantially not achieved |
| *Phragmites* is nonnative genotype | Disturbed or developed areas do not have native *Phragmites* genotypes | Often true in Northeast but exceptions occur |

## Management Techniques

Table 7 contains a brief conspectus of management techniques including herbicide, mowing, crushing, burning, water level and flow manipulation, dredging, livestock grazing, covering with plastic, manual removal, biological control, and harvest.

Table 7. Management techniques (treatments) that have been used on *Phragmites australis* (not limited to the United States).

| **Treatment** | **Indications or contraindications** | **Advantages** | **Disadvantages** | **Selected references** |
|---|---|---|---|---|
| No treatment | No funds, no impacts, no threat of spread | Saves resources for other stands; may conserve habitat functions or ecosystem services of *Phr* | Potential source of propagules; unnoticed or unexpected spread or impacts may occur; forgoing of improvements resulting from treatment | |
| “Watchful waiting” (monitoring only, or monitoring with intent to take action) | Impacts or spread are undesirable or unpredictable | As above | As above | Bailey 1997, Brown et al. 2001 |
| Spray herbicide | Large stand, eradication desired | Less expensive than some techniques; produces dramatic effects | Effects on other biota, water supply, public relations | Cross and Fleming 1989, Marks et al. 1994, Capotosto 1997, Ailstock et al. 2001 |
| Individual culm herbicide application (clip & drip, etc.) | Small stand; rare plants present | Narrowly targeted | Effort intensive | Kay 1995, Martin 2001 |
| Frequent cut: manual (scythe, etc.) | Small stand; nontarget plants present | Narrowly targeted | Effort intensive; cut material should be removed | Sabine Guesewell, pers. comm., Marks et al. 1994 |
| Frequent cut: mechanical | Firm substrate; variable stand size; no concern re nontarget plants (unless cut above their height) | Relatively inexpensive | Cut material ideally should be removed | Howard et al. 1978, Cross and Fleming 1989, Marks et al. 1994, Guesewell et al. 1998, Smith-Fiola 1998 |
| Disc, plough | | | | Haslam 1968, Cross and Fleming 1989, Smith- |

| | | | | |
|---|---|---|---|---|
| | | | | Fiola 1998 |
| Graze: livestock | Livestock available; no concern re nontarget plants or nontarget plants are unpalatable; no soil or WQ sensitivities | Some selectivity; no need to remove *Phr*. biomass | Must have dry ground or platform available for most livestock breeds; fencing required; concern for desirable plants | Howard et al. 1978, Cross and Fleming 1989, Kantrud 1990, van Deursen & Drost 1990, Marks et al. 1994, Tesauro 2001, Joyce & Burnside 2004 |
| Graze: muskrats, also coots, geese | Thinning desired; platform construction possible | Relatively inexpensive; low nontarget impacts | Platform construction & maintenance required for muskrat; difficult to control? | Fiala and Kvet 1970, Cross and Fleming 1989; see Bednarik 1956 on platforms for muskrats |
| Cut in winter (harvest) | Use for increasing *Phr* biomass | Operate machinery on ice or frozen soil | | Hawke & Jose 1996 |
| Burn: spring | Tolerance for rapid regrowth; no threats to structures, etc. | Inexpensive; creates short-lived low vegetation habitat for spring migrant birds & certain breeders | Permit required; firebreaks may be needed; rapid *Phr* regrowth from rhizomes | Ward 1942, Howard et al. 1978, Cross and Fleming 1989, Burgess et al. 1995; Kiviat pers. obs. |
| Burn: summer | Dry organic soil | Patchy kill of rhizomes, pool creation | As above | Ward 1942, Martin et al. 1957, Howard et al. 1978, Cross and Fleming 1989 |
| Burn: various seasons | | | | Kantrud 1990 |
| Crush or mulch | Eradication desired | Relatively inexpensive? | Nontarget impacts | Martin et al. 1957, Cross and Fleming 1989, Capotosto 1997 |
| Raise water level (impound) | Hydrology controllable | Inexpensive; benefits to waterbirds & certain fishes | Impacts on flood-sensitive spp. | Kane 1978, Cross and Fleming 1989, Marks et al. 1994, Smith-Fiola 1998 |
| Drain water (dry site) | | Allows more desirable plants to compete | May require several years | Haslam 1968, Cross and Fleming 1989 |
| Cut beneath water, or cut & raise water | Small stand?; eradication desired | | | Martin et al. 1957, Baldassarre and Bolen 1994, Kiviat pers. obs. |
| Increase salinity: remove barriers to tides | Impounded formerly tidal salt marsh | Inexpensive; well-tested | Loss of species of fresh nontidal marsh impoundment, locally including rare birds | Sinicrope et al. 1990, Weinstein et al. 1997, Covington et al. 1999, Teal and Weinstein 2002 |
| Increase salinity: divert freshwater | Ditching possible | Inexpensive | Impacts on salinity-sensitive spp. | R. Buchsbaum, pers. comm., S. Hoeger, pers. comm., T. Burke, pers. comm. |
| Increase sulfide | Formerly more saline | Relatively inexpensive? | | Chambers et al. 1998 |
| Excavate (includes bed-lowering) | Equipment access; spoil disposal possible | Reduces potential for reinvasion | Expensive; mobilization of pollutants | Haslam 1968, Cross and Fleming 1989, S. Nack, pers. comm. |
| Hand pull | Very small stand | Low impact | | Kiviat, pers. obs. |
| Cover with plastic (solarize) | Small stand; stable environment | Impact localized | Must anchor, protect, dispose of plastic | Boone et al. 1988, Keene 1994, Kiviat, pers. obs. |
| Competitive planting | High elevations needed (e.g., supratidal) | Low impact? | Expensive? | |
| Replacement planting | Ability to remove | Potential return to | Expensive; maintenance | Berger 1992 |

| | | | | |
|---|---|---|---|---|
| | *Phr* & sediment first | *Spartina* or *Typha* | required | |
| Containment: ditching | Acceptable to maintain small stand; equipment access | No biomass displosal and limited spoil disposal; preserves habitat functions of *Phr* for roosting birds, etc. | Potential escape of propagules; possible erosion of ditches in tidal marshes | Hawke & Jose 1996 |
| Containment: subsurface barrier | As above | As above | Little tested; durability? Nontarget impacts of installation? Requires annual maintenance | DeepRoot Partners 2000 |
| Biological control: classical | Western Hemisphere-wide acceptability; no concern re nontarget impacts or habitat functions of *Phr* | Self-maintaining after initial investment (if successful) | Expensive R & D; may be ineffective; unacceptable impacts to domestic *Phr*.systems, other economic uses, habitat functions, native genotypes | Schwarzländer and Häfliger 1999, Blossey and McCauley 2000, Rooth & Windham 2000, Tewksbury et al. 2002 |
| Biological control: augmentative | Using fungi, microorganisms, or invertebrates with narrow host range | Localizable (applied only where & when needed) | Technology not developed | No references for *Phr* |
| ***Combinations of techniques*** | | | | |
| Late summer - fall spray herbicide, winter burn | | | | Jones and Lehman 1987, Marks et al. 1994, LaFleur 1996, Ailstock et al. 2001 |
| Fall herbicide, summer cut | | | | Findlay et al. 2003 |
| Summer spray herbicide, spring cut with mulching machine | | | | Gumbart 1997, Anonymous 1998 |
| Cut (mechanical), burn and multiple diskings | | | | Martin et al. 1957, Cross and Fleming 1989 |
| Spray herbicide, grade, replacement planting | | | | Berger 1992 |
| Cut (mechanical) winter, spring, summer, fall plus burn winter and summer | | | | Bjork 1972, 1976 |
| Spray herbicide, then mulch | | | | Capotosto 1997 |
| Increase salinity (restore tidal flow), repeated cut (mechanical), raise water level, plastic, competitive plantings | | | | Dobberteen and Jarman 1991 |
| Increase salinity (restore tidal flow), repeated cut (mechanical), plastic | | | | Lelito et al. 1994 |
| Drain, then burn | | | | Marks et al. 1994 |

## Advantages and Disadvantages of Different Management Techniques

Any change to a habitat benefits some species and harms others. All techniques available for managing *Phragmites* have advantages and disadvantages. The disadvantages have not been studied or analysed well in the literature. Managers and biologists need to have this information to allow state-of-the-art management projects or recommendations. I briefly analyse the pluses and minuses of various techniques below, raising questions where I have been unable to find specific information. This analysis is based on information from many geographic areas, habitat types, and sites, and may not be exactly applicable to the Hudson River or nearby areas.

Herbicides. Chemical management of *Phragmites* appears cheap and easy, and it is thought to meet the objective of eradication. Herbicides can be applied by aircraft to large areas, and they can also be applied one culm at a time to small stands (see below). Herbicides are often considered relatively nontoxic to animals (but see next paragraph).

Glyphosate (various formulations, including Roundup™ and Rodeo™) is the chemical most commonly used to control *Phragmites* in the U.S. (as well as being used on hundreds of millions of cropland hectares around the world [Lu and Snow 2005]). Glyphosate is a systemic herbicide that is translocated into root systems and which is capable of killing the entire plant not just the top. Although glyphosate and its formulations have been generally considered innocuous (i.e., to have a low probability of nontarget impacts) in the management of both invasive vegetation and agricultural vegetation, recent studies suggest otherwise. Surfactants (detergent-like compounds) and other materials are added to glyphosate formulations for specific purposes, e.g., terrestrial vs. aquatic use. These incredients may not be identified on the label, yet the surfactants might be more toxic to some organisms, including humans (Sawada et al. 1988), than glyphosate (Scott et al. 1994). A nitrosamine contaminant with potential human toxicity may be present in glyphosate (Moses 1989). A surfactant used in certain glyphosate formulations, polyoxyethyleneamine (POEA) and an associated contaminant, 1,4-dioxane, are toxic to humans and other mammals (O'Brien 1990). Glyphosate inhibits steroidogenesis in cultured mammalian cells in the laboratory (Walsh et al. 2000) and could have negative effects on reproduction. Also in the laboratory, Roundup™ alters DNA (Peluso et al. 1998) and is therefore a potential mammalian mutagen (this effect was apparently due to a chemical other than glyphosate in the formulation tested). Glyphosate may be a human carcinogen (Hardell and Eriksson 1999). Aspects of Roundup toxicity to humans were discussed earlier by Moses (1989). Glyphosate formulations had toxic effects on frogs, possibly due to endocrine disruption by the surfactants (Howe et al. 2004). Glyphosate residues in soil can kill seedlings of *Phragmites* and other species (Ahearn-Meyerson et al. 1997). Glyphosate-resistant horseweed (*Conyza canadensis*) has been found in Delaware (VanGessel 2001).

In spring 2006, Habitat™, a formulation of imazapyr, instead of glyphosate, was used to control *Phragmites* in the Secaucus High School Marsh. Although less toxicological information appears to be available on imazapyr compared to glyphosate, imazapyr can potentially cause a variety of problems. For example, imazapyr or its formulations can cause irreversible eye damage in humans, is potentially toxic to rare plants, has produced resistance in several species of vascular plants and an alga, is toxic to fish, and there is evidence that imazapyr is a carcinogen (reviewed by Cox 1996, BASF 2004). If imazapyr damages the human eye, does it damage the eyes of muskrats, birds, and other vertebrates that may be in a sprayed *Phragmites* marsh?

Herbicides may be applied by "clip-and-drip," in which an individual stem is cut by hand and a small amount of glyphosate or other herbicide is introduced on or into the cut stump (tools are available that perform both operations at once). Clip-and-drip or injection greatly reduces the amount of chemical used and its effect beyond the target stems. However, the potential still exists for loss of herbicide from the stem or roots to the soil. The Nature Conservancy and the Massachusetts Department of Fisheries and Wildlife Biodiversity Initiative have used clip-and-drip glyphosate to manage common reed in a fen in Massachusetts (Garnett 1998), and no damage to other plant species was observed for several years (Kay Sadighi, Nature Conservancy, pers. comm.). However, glyphosate applied to *Phragmites* in cut-stem treatments at the same Massachusetts study site, as well as at sites in New Jersey and Connecticut, apparently left the *Phragmites* material and harmed non-target plants under hot and humid conditions (Jessica Murray, Nature Conservancy, Sheffield, Massachusetts, pers. comm. 2006). I have found no reference to monitoring herbicide levels in soil after clip-and-drip applications. If *Phragmites* is managed with clip-and-drip or just cutting, the cut material is best removed from the habitat to prevent rooting of cut culms, and to remove organic matter and nutrients from the stand.

A commercial firm suggested that glyphosate could be applied to *Phragmites* culms by means of a machine that rides over the culms with a bar that releases chemical directly onto the culms. The firm recommended this technique for the Cranberry Lake fen (an inland site in Westchester County), but there has been concern about impacts to rare plants growing among the *Phragmites* (Danniela Ciatto, Cranberry Lake Preserve, pers. comm. 2004).

Glyphosate typically must be applied for two or three years (e.g., a broadcast application the first year and spot applications to surviving *Phragmites* the second year and later) to achieve thorough control; this was necessary, for example, at some of the sites managed in the Hackensack Meadowlands and in the Delaware Bay tidal marshes (New Jersey) (e.g., Nogaki 2001). Glyphosate application(s) may be combined with burning, crushing, mulching, or bed-lowering (i.e., removal of surface sediment layers to reduce marsh elevation and provide better habitat for native plants with affinities to wetter habitats) (Table 7).

Biological Control. "Classical" biocontrol, which involves liberation of introduced stenophagous insects or nematodes (or host-specific pathogens such as fungi) is intended to be highly host-specific. Insects are screened for food selection in the laboratory, using crop and ornamental plants as well as wild species. Of course, not all wild plants can be tested for consumption by a particular insect. Furthermore, an insect that has never been recorded eating anything but a single host species can switch to another host (Strong et al. 1984); host-switching is common among herbivorous insects. Even without host-switching, the full host range of a particular species of insect may not be apparent in laboratory investigations. Although there is a number of insects that appear to be monophagous on *Phragmites* in Europe or North America, it is apparently not well known whether these species also feed on closely related or morphologically similar plants, such as canes *(Arundinaria)*, which are ecologically important and declining in the southeastern US, or giant reed (*Arundo donax*), Pampas grass (*Cortaderia* spp.), Burma reed (*Neyraudia reynaudiana*), or Eulalia (*Miscanthus sinensis*), all of which are introduced ornamentals as well as significant invasives in their own right. Proponents of classical biocontrol argue that no insect introduced for biological control has exterminated any plant, weed or nontarget species (Harris 1988). Other ecologists have cautioned that nontarget impacts are likely, hard to detect, and usually not monitored (Simberloff and Stiling 1996). It may take many years for host switching to occur, or it may happen quickly; the time frame is unpredictable.

An important example of a biocontrol insect gone awry, albeit on a forb (broad-leaved herb) rather than a grass, is *Rhinocyllus conicus*, a weevil introduced to control the exotic *Carduus* thistles in the western U.S. The weevil has expanded its host range to include three native North American thistles in the genus *Cirsium*, one of which (Platte thistle, *C. canescens*) is an endemic species of Sandhills prairie (Louda et al. 1997). Since the arrival of the weevil, seed production of Platte thistle has decreased as have native picture-winged flies (Tephritidae) associated with another species of weevil-attacked native thistle (Louda et al. 1997).

Classical biocontrol takes many years (e.g., 15) for prospecting, laboratory investigation, and field testing in enclosures, before the U.S. Department of Agriculture will approve field releases of introduced biocontrol insects. Research and development has begun for classical biological control of common reed (Schwärzlander and Häfliger 1999, Blossey and McCauley 2000). I see risks of at least four types of irreversible damage if a reed biocontrol program is implemented: 1. Functions of reed for, e.g., soil stabilization, water quality amelioration, and wildlife habitat may be greatly reduced in urban-industrial and other altered or damaged environments where alternate plant species may not survive or perform as well as reed; 2. The monophagous Yuma skipper butterfly that depends entirely on reed in the western U.S. may become endangered or extinct, the broad-winged skipper that depends largely on reed in the Northeast may suffer a population crash, and other perhaps as yet undocumented species of specialized reed-using invertebrates in the West and possibly the East and Latin America may be harmed or eliminated; 3. Hundreds (perhaps thousands) of waste treatment facilities across the continent that use constructed reedbeds for tertiary treatment of municipal and industrial sewage, sludge dewatering, and other purposes may be harmed economically and some may be unable to continue operation; and 4. In North America and Latin America, Native American peoples that use reed as an important, even crucial, material resource, may be affected ecnomically, culturally, or medically. Once a biocontrol organism is imported and released, and if it becomes established, it is here to stay; in other words, it is hard to "take back" classical biocontrol once a program has been implemented. Some of the potential negative impacts of reed biocontrol have been discussed elsewhere (Rooth and Windham 2000, Kiviat and Hamilton 2001).

At any rate, classical biocontrol is not yet available (and may never be) for *Phragmites*, so this is not an option currently for managers. There are other biocontrol methodologies that may have applications to *Phragmites*. A fungal pathogen that is already present in a region may be applied locally to a plant as a mycoherbicide. This approach is being explored for purple loosestrife (Nyvall 1995) indepedent of the existing classical biocontrol program for loosestrife. Or an insect that is already present in a region and that attacks a plant may be reared in captivity and released in large numbers (or earlier in the season than it would develop naturally) to manage the plant in the wild; this is referred to as augmentative or inundative biocontrol. Possibly a chemical attractant (e.g., a pheromone) could be used to attract more individuals of a grazing insect or other animal to *Phragmites*. These techniques can have their own nontarget impacts, but because they use organisms that are native or already introduced, they do not have as great a risk of widespread and uncontrollable negative impacts. To my knowledge, the prospects of such techniques for controlling *Phragmites* have not been thoroughly investigated.

Cutting. Mowing can harm nontarget species that are intolerant of being cut, e.g., plants that must reach a greater height in order to reproduce. Mowing can also cause compaction or erosion of soil. Low-ground-pressure machinery is available to reduce impacts to wet soils. (However, several years ago I photographed deep ruts made by low-ground-pressure equipment on a *Phragmites* management area on the New Jersey side of Delaware Bay.) Cut material of common reed should normally be removed from the managed habitat. It took six years of mowing twice each summer (June and September) to substantially reduce reed biomass and increase plant species richness in Swiss fen meadows (Güsewell 1998, Güsewell et al. 1998; Sabine Güsewell, Geobotanical Institute ETH, pers. comm.). *Phragmites* was mowed in the Delta Marshes of Manitoba to improve habitat for duck nesting (Ward 1942) but the technique was not described in detail. Possibly a single mowing in fall, winter, or early spring removed the standing dead culms and created a temporarily more open habitat for early-spring nesting birds.

Burning. Fall, winter, or early spring burns remove dead aboveground material of *Phragmites*, producing a shorter-stature and more open habitat in the spring until new *Phragmites* shoots grow tall; this habitat may be attractive to open-ground birds like common nighthawk (Kiviat, pers. obs.). Burns at any season when standing water is absent or very shallow result in removal of accumulated *Phragmites* litter which reduces soil buildup. Summer burns on organic soil when the water table is low can remove some soil and kill *Phragmites* rhizomes, creating shallow pools (Ward 1968, Uchytil 1992). Summer burning that does not remove soil can reduce culm density (Uchytil 1992). Fire can also harm intolerant nontarget species. Even where vegetation is considered to have frequently burned in the past, increasing a fire-intolerant species (plant or animal) may be the goal of management. Prescribed fire can also escape and threaten other areas of vegetation, buildings, or human life, including upland areas. Prescribed burns may degrade air quality, and remobilize stored carbon into the atmosphere as carbon dioxide which is a “greenhouse gas.”

Prescribed fire may not be feasible in developed areas unless effective firebreaks can be created. Burgess et al. (1995) recommended 3 m wide firebreaks. Local fire departments may be reluctant to issue permits for prescribed burns. If substrate remains wet during burn, only aboveground *Phragmites* material will be removed and rapid resprouting is likely to occur. If removal of dead aboveground material is desired, or temporary removal of live aboveground material (e.g., to create low-stature habitat for migrant bird foraging), burns on wet substrate may be acceptable. Burns on dry organic substrate (which may be unattainable in tidal habitats) will result in combustion of dry organic soil, lowering substrates and potentially creating pools, often in a patchy manner. Even removal of just the dead aboveground *Phragmites* material may be helpful in reducing soil buildup where soil elevation increase is undesirable (e.g., in tidal marshes where flooding of the marsh surface and maintenance of access to the marsh by estuarine nekton are management goals).

Manipulating water levels. Rooted wetland plants can be killed by raising water levels temporarily or permanently. Because the hydropattern (spatial and temporal pattern of water depth) determines the biota of a wetland, a substantial change (e.g., a 30 cm increase in water depth) can cause many changes in the plant and animal community (and in ecosystem processes) besides killing invasives such as common reed or purple loosestrife. Lowering of water levels could expose *Phragmites* rhizomes to grazing animals; however, drawdowns (in general) can be harmful to animal populations including rare species (e.g., Hall and Cuthbert 2000). If water supply is sufficiently reduced, *Phragmites*, which has a high rate of evapotranspiration and requires a large supply of water, might be weakened and replaced by other plants. Nonetheless, common reed in our region is often able to survive in “dry end” (minimally wet) wetlands and on upland soils, and drainage is usually harmful to rare wetland biota.

Impoundment, i.e., raising water levels, can be used to weaken and break up (fragment) extensive dense stands of *Phragmites*. In the Kearny Marshes and Kingsland Impoundment, slightly brackish-tidal impoundments of the Hackensack Meadowlands, raised water levels produced high quality habitat for marsh and water birds (Kane 1978; Kiviat, pers. obs.). Chironomid midges are abundant in both impoundments and may help explain the attractiveness of these marshes to dabbling ducks for which midge larvae are a high quality food. The "National Park dredge spoils" adjoining the Delaware River west of Camden is an impoundment with extensive, hyperdominant *Phragmites* interspersed with small and large, shallow, open pools; this site is excellent for marsh and water birds (Paul Driver, pers. comm.; Kiviat, pers. obs.). The Killcohook dredge spoil disposal area adjoining Delaware Bay in Salem County, New Jersey, is another example of an impounded area with *Phragmites* stands and open pools that is apparently good habitat for frogs as well as birds (Kiviat, pers. obs.). Impoundment of tidal wetlands, although once a common practice for waterfowl management and mosquito control, is often considered undesirable because it reduces or eliminates movement of nekton and detritus between marsh and estuary. Impoundment also may create favorable situations for other invasive species such as common carp and water-chestnut, and may eliminate rich shorebird foraging habitat. Semi-impoundment can potentially be practiced to raise mean water levels but still permit exchange of water and nekton between marsh and estuary. Impoundments may be drawn-down seasonally to permit foraging by migrant shorebirds and regeneration of nutrients from accumulated organic matter.

<u>Manipulating water or soil chemistry (including re-establishment of tidal flooding in impounded salt marshes)</u>**.** Many salt marshes were impounded before the mid-1900s to improve conditions for harvesting salt hay from high salt marsh (salt meadow) dominated by saltmeadow cordgrass *Spartina patens* or other low graminoids. The elimination of saline tidal influence and continued input of fresh water from the uplands, as well as the cessation of salt hay harvests, allowed many such diked marshes to become dominated by *Phragmites*. It is now common practice on the New England coast and in Delaware Bay to re-open such diked marshes to tidal flooding (e.g., Weinstein et al. 1997). Increased salinity reverses the vegetation change, reducing *Phragmites* dominance and allowing *Spartina alterniflora* to invade. Salt marsh communities return gradually; equilibration of some components may take as long as 25 years (Warren 2003). Hydrological control by means of flap valves or other devices at tidal inlets may be necessary to prevent flooding of adjacent developed areas during storm surges (these devices generally allow water to exit a wetland but prevent incoming storm surges from entering the wetland).

In some marshes, freshwater entering the marsh from upland, via surface runoff or groundwater, allows *Phragmites* establishment and expansion into *Spartina* or other brackish or salt marsh communities. Diversion of freshwater via a diversion ditch can successfully contain or reverse *Phragmites* invasion in some situations. A brackish marsh at the Rye Golf Club (Westchester Co.) in which a diversion ditch was constructed to halt *Phragmites* expansion into *Spartina* (Sven Hoeger, Creative Habitat, pers. comm.), lost the king rails that had been breeding in the *Phragmites* habitat (Tom Burke, pers. comm., 2005), presumably a result of hydrological or salinity changes.

Excavation or dredging (bed-lowering, *sensu* Hawke and José 1996). Lowering of the soil or sediment level both physically removes invasive plant populations and effectively raises water level (increases water depth). Unless desired species can thrive in deeper water and can be planted or arrive spontaneously after excavation, the removal of invasive plants with soil or sediment is likely to create sites for establishment of weedy introduced or native species. Furthermore, unless the excavated area is in a closed basin, excavation may result in intense mobilization of sediments and nutrients (and contaminants, if present) with off-site impacts. The U.S. Fish and Wildlife Service has raised the concern about contaminant mobilization in connection with *Phragmites* management projects in the Hackensack Meadowlands. The advantage of bed-lowering, at least with regard to *Phragmites*, is that water depth can be increased beyond that which *Phragmites* tolerates.

"Scrapes" are large shallow pools (e.g., 50 m diameter) exavated within extensive *Phragmites* stands on relatively dry wetland substrates. This technique is practiced, e.g., in the British Fenland, to create habitat for marsh, water, and shore birds.

Scrapes (dredging of large shallow pools) and other bed-lowering techniques require disposal of sediment which may be problematic if contaminated. Disposal of spoil in berms or islands to create habitat may yield unstable soils with low value habitat susceptible to other invasive plants (this has occurred in Meadowlands restoration projects; Kiviat, pers. obs.).

Livestock grazing. Grazing has been responsible for creation and maintenance of many communities of conservation value as well as for the invasion of undesirable, grazing-tolerant weeds. The explicit use of livestock grazing to manage communities for conservation is practiced widely in Europe (e.g., Joyce and Burnside 2004) but less commonly in North America. Grazing can damage soils (compaction, erosion), concentrate nutrients undesirably or make them more available, and result in inhibition or elimination of grazing-intolerant plant species other than *Phragmites* (Uchytil 1992). Because livestock often prefer to eat *Phragmites*, however, grazing can eliminate or thin *Phragmites* and make space for other plants (Joyce and Burnside 2004). Livestock grazing need not be permanent (year-round); short-duration seasonal grazing can be effective. Livestock grazing has been used to manage *Phragmites* in nontidal wet meadows used by the bog turtle (Tesauro 2001a, b). A short-term experiment using goats to manage *Phragmites* in a Delaware Bay tidal marsh was unsuccessful (Clanton et al. 2003), perhaps because the grazing regime was too light and brief; possibly another livestock species would have done more damage to *Phragmites*. I know of no other attempt to use livestock to manage *Phragmites* in American tidal wetlands. Prescribed livestock grazing is feasible only if upland habitat or platforms are available to livestock in addition to wetland.

Muskrat grazing. Muskrats readily harvest *Phragmites* underground and aboveground material for food and construction. This results in thinning and creation of clearings in emergent vegetation. Because muskrat impacts are concentrated within a radius of about 5-10 m of the winter lodge (e.g., Connors et al. 2000), and muskrats can be attracted to build lodges on elevated artificial structures (e.g., hay bales or wooden platforms), provision of such structures has been used to increase local muskrat effects and manage *Typha* and *Phragmites* (Bednarik 1956). I am not aware of the use of this technique in tidal marshes. Little information has been published on this technique and muskrat populations may not always respond as desired. Muskrats are present in all Hudson River tidal marshes, and often build lodges on elevated substrates such as duck blinds and logs. The low population levels of muskrat on the Hudson River from ca. 1974 to the present coincided with the establishment and spread of many of the *Phragmites* stands in Tivoli North Bay and Iona Island Marsh (Winogrond and Kiviat 1997). Apart from providing artificial lodge substrates, it would be worthwhile to see if reduced trapping pressure would cause an increase in muskrat numbers and some degree of containment of existing *Phragmites* stands in Tivoli North Bay. Muskrats were easily trapped in a freshwater tidal marsh on the Quinnipiac River in Connecticut, and trapping was believed to easily reduce populations in this habitat type (Smith and Jordan 1976, Smith et al. 1980).

Smothering with plastic (solarization). This technique (Boone et al. 1988) is limited to very small stands of *Phragmites*. In 2005-2006, plastic was being used to manage a *Phragmites* stand west of the Bow Bridge in the Lake, Central Park, Manhattan (Kiviat, pers. obs.). Covering with plastic leaves areas of bare, “sterilized,” soil that are vulnerable to invasion or reinvasion by undesirable plants. Furthermore, solarization of common reed may kill only superficial and not deep rhizomes (Simmons 1992).

Hand pulling. Usually limited to very small, recently established stands of invasive plants (e.g., up to a few square meters), hand pulling has fewer potential nontarget impacts than other techniques. Hand pulling, however, disturbs soils by the treading of the control workers as well as the physical removal of root systems. Even small areas of disturbed soils may become sites of establishment of the same or different invasive plants by means of germination from the seed bank or *de novo* immigration of seeds. Hudsonia has hand-pulled very small, recently established, *Phragmites* clumps (ca. 0.1 $m^2$) that appeared in tree planting holes at a habitat restoration site off-river in Dutchess County. A shovel or other hand tool may be used as an adjunct to the hands to pull *Phragmites* clumps. Hand-pulling of *Phragmites* with deeply established rhizomes may result in residual rhizome fragments in soil that can re-sprout.

Competitive planting. It should be possible to plant native woody species in *Phragmites* stands to create patches of woody vegetation with eventual loss of vigor and density of *Phragmites* beneath the woody canopy. This would have a low negative impact and could be used to create habitat for, e.g., American woodcock and songbirds in urban areas. Native *Phragmites* could be planted in stands of introduced *Phragmites* following limited or extensive removal of the introduced *Phragmites* (e.g., by clip-and-drip or grubbing). Native *Phragmites* is believed to generally be less competitive than introduced *Phragmites* (Kristin Saltonstall, pers. comm.). In the southeastern U.S., *Typha domingensis* or *Zizaniopsis miliacea* might be suitable for competitive plantings, but it is unclear if any native herb in the northeastern states would be competitive with *Phragmites* in fresh or oligohaline water. A naturally non-persisting cover crop of Japanese millet *(Echinochloa frumentacea)* was tested as a preventative planting on mudflats of drawn-down wildlife refuge impoundment pools to prevent invasion by seed of purple loosestrife (Rawinski 1982). A similar concept might work where *Phragmites* is being removed.

Containment of *Phragmites* stands. Ditches (Hawke and José 1996) and subsurface vertical rigid plastic sheeting (DeepRoot Partners 2000) have been used to create barriers to vegetative expansion of *Phragmites* stands. The Nature Conservancy installed a filter fabric (silt fencing) barrier 60 cm into the soil to block *Phragmites* spread threatening rare plants in the Mt. Bethel Fens, Pennsylvania; the barrier was not maintained and was ineffective (Su Fanok, Nature Conservancy, pers. comm. 2005). The barrier approach seems suitable for containment of small stands in Tivoli North Bay that are important roosting habitat for songbirds (Kiviat and Talmage 2006). The lifetime of plastic barriers is unknown. Machinery for mosquito-ditching could probably be used for containment ditching of Hudson River tidal marshes. Spraying of spoils to create a shallow layer within the contained *Phragmites* stand would eliminate the need to dispose of spoils elsewhere. Rhizomes and stolons that grow from contained stands into intertidal ditches are presumably kept trimmed by muskrats and common carp, but these vegetative extensions might be able to "jump" a ditch occasionally. Fragments cut by carp and muskrats could float away and initiate establishment of new stands (this is probably a mechanism of *Phragmites* dispersal under normal conditions, and this risk would not necessarily worsen).

Monitoring for spread (temporarily foregoing treatment;"watchful waiting"). Smaller stands, and the edges of larger stands, may be monitored for spread and other changes. Monitoring for spread may be effected by marking stand boundaries with stakes and re-examining boundaries each year or two, or by sequential analysis of ground photos or aerial photos. Satellite imagery may prove to be useful for large wetland complexes (Artigas and Yang 2004). Stands that are stable, declining, or very slowly expanding may be left untreated as long as treatment may be applied promptly if a stand begins to spread significantly and threaten wetland functions or values. This technique is more appropriate where a stand does not pose much threat (e.g., no rare species or community threatened by stand; low risk of propagation into more valuable habitat). It should be remembered that the status (declining, stable, spreading) of a stand may change or fluctuate. For example, *Phragmites* in ornamental ponds or beaver wetlands may expand when water levels are low and stabilize or retreat when water levels are high; I have observed this type of fluctuation in calcareous wet meadows at Moore Brook in Litchfield County, Connecticut. Examples of Hudson River stands for which watchful waiting may be appropriate are the apparently stable small stand in Cruger Island South Marsh, the small expanding stand in freshwater tidal swamp of the Cruger Island Neck, the small, slowly expanding stand in Mandara South Cove, and the small shoreline stands of Middle Ground Island.

No action. This option is appropriate for wetlands in which *Phragmites* has more-or-less filled all available space and cannot expand further, and in which, on balance, *Phragmites* is not considered a detriment (beneficial habitat functions or ecosystem services outweigh those that are detrimental, in view of management goals and potential nontarget impacts of management). No action may be the appropriate option for the nontidal pond in Ferncliff Forest (Town of Rhinebeck, Dutchess County), where sora has been heard. There may be small Hudson River tidal marshes (e.g., near Beacon or in Westchester County) where no action is the appropriate alternative.

## Achieving Particular Goals

There follow some general guidelines concerning management of *Phragmites* for certain goals that may be most important on the Hudson River. Management must be planned with consideration of management goals, habitat type and local habitat and landscape conditions, *Phragmites* stand size and trend (Tables 8-9), environmental and human constraints on management approach and methodology, and monitoring.

Water quality. To maintain or improve water quality (in the wild), especially to reduce levels of nutrients or metallic contaminants, there should be large areas of dense, vigorous *Phragmites*. The water should flow gently through the *Phragmites* stands.

Sediment stabilization. To stabilize sediments, reduce marsh erosion, or keep pace with rising sea level, large areas of dense, vigorous *Phragmites* are desirable. Water flowing gently through the stands will result in deposition of suspended sediments within the stands. Dense fringing stands of *Phragmites* may be desirable to stabilize banks that are threatened by erosion due to currents, wind waves, and boat wakes.

Biodiversity in general. Managing biodiversity is sometimes thought of as fostering the maximum possible numbers of species ("achieving multiple organisms"?). However, there are high quality and low quality species, depending on the geographic area, environmental setting and other factors. Typically, higher quality species are those species that are rare, habitat specialist, economically valuable, keystones, "watchable," or that have another special ecological or social significance in the region or local area. Managing for the greatest number of species *per se* may be appropriate at certain educational facilities but is often not appropriate in parks and reserves or in larger regions. (If all we did was manage for maximum species richness, we would eschew low-diversity habitats such as salt marshes, cattail or spatterdock stands, and leatherleaf bogs.)

Estuarine nekton. To maintain or restore use by estuarine nekton (fishes, grass shrimp, crabs) of marsh production, either nekton must be able to swim or drift into and out of the marshes, or marsh production (especially plant detritus and small animals) must be able to wash out of the marshes into the open estuary. It should be possible to regulate tidal flux in and out of the marsh to maintain higher water levels in *Phragmites* stands while allowing nekton to enter and leave the marsh, at least part of the time. Deeper water in the marsh will help prevent the *Phragmites* from becoming too dense or homogeneous, while allowing aquatic animals to gain access to the *Phragmites* cover and its production of detritus, microorganisms, and invertebrates.

Marsh and water birds. Although different species have different requirements and tolerances, a *Phragmites* marsh where there is plenty of standing (or tidally flooding) water and *Phragmites* stands are interspersed with large shallow pools is generally good habitat for a variety of species.

Muskrat. Muskrats use various kinds of *Phragmites* stands. However, a *Phragmites* marsh with plenty of standing, gently flowing, or tidally fluctuating water, and in addition to *Phragmites* other plants beneath the *Phragmites* or in patches interspersed with *Phragmites*, is likely to be good muskrat habitat.

## Constraints on *Phragmites* Management on the Tidal Hudson

The potential hazards of glyphosate, imazapyr, and their formulations are noted above. Rare plants (e.g., *Limosella subulata*, *Carex hormathodes*, *Bidens* spp., *Heteranthera reniformis*) often occur near *Phragmites* stands on the Hudson, and herbicides represent a hazard to rare plants. Most Hudson River tidal marshes are too wet for prescribed fire to do anything more than burn off standing dead culms which will not contain or reduce the stands (the resulting short-lived, low *Phragmites* sprout habitat might be attractive to waterfowl, shorebirds, and muskrats in spring). The frequent and deep flooding of most of the marshes would also be an impediment to prescribed grazing as most livestock breeds cannot tolerate wet feet for extended periods (however, certain livestock breeds are preferentially used for managing wetlands in Europe). Possibly elevated platforms could be built to provide dry substrates for livestock. Soft substrates limit the use of mowing machines; however, arm-mounted mowers could be operated from a barge to mow *Phragmites* stands on creek banks. Barriers are somewhat experimental and would require careful monitoring; there is a need to develop effective barrier technology.

## Suggested Management

Recommendations for managing *Phragmites* stands on the Hudson River are organized by stand size in Table 8 and by habitat type in Table 9. Many of these management techniques have not been tested on the Hudson River or similar estuarine systems. Clip-and-drip techniques, hand cutting or pulling, and covering with plastic are suitable for small stands, e.g., recent nodes of infestation. These techniques may also be suitable for edges of larger stands where spread of the stand is undesirable, or for the interiors of larger stands where it is desirable to fragment the stand or to create interspersion of *Phragmites* with other plant communities.

Management decision-making should include consideration of scales larger than the individual *Phragmites* stand or site. The landscape (collection of sites) and the catchment or region should be considered. People and other animals move around the landscape and region, as do plants over longer periods. Patch, site, and habitat diversity are important for many organisms. Factors to be considered in the large-scale context of management include how much *Phragmites* is present and how it is providing (or not providing) habitat and ecosystem services.

Table 8. Suggested *Phragmites* management according to stand size.

| **Stand size** | **Management goal** | **Suggested treatments** | **Notes** |
|---|---|---|---|
| No stand | Prevent establishment; monitor for establishment | Avoid change that promotes establishment (including in neighboring or up-flow areas); do not import propagules | Cost-effective and low-risk approach with many other benefits |
| Very small stands (e.g., a few m$^2$ or less) | Eradicate or monitor for spread | Cover with plastic; clip-and-drip; excavate; frequent pulling or cutting; cut under water | Inexpensive and low-risk for incipient stands in most cases |
| Small stands (e.g., 10-100 m$^2$) | Prevent or slow spread; take advantage of habitat functions and patch diversity; monitor for spread | Treat edges or portions: cover with plastic; clip-and-drip; excavate; frequent cutting or pulling; encourage muskrat activity; cut under water or raise water level; burn; barrier to prevent spread; competitive planting | Relatively inexpensive and low-risk; optimization |
| Intermediate stands (e.g., 100 m$^2$ to 0.5 ha) | Prevent or slow spread or consolidation; take advantage of habitat functions and patch diversity | Treat edges or portions, or selectively thin, fragment, or remove stands: Frequent cutting; cut underwater or raise water level; encourage muskrat activity; prescribed livestock grazing; barrier to prevent spread; burn; competitive woody planting | Certain treatments may be laborious at this scale |
| Large stands (e.g., 0.5-2 ha) | Thin *Phragmites*, create clearings or pools within stand, remove dead aboveground biomass to alter spring habitat, or other modification of habitat function without loss of, e.g., water quality maintenance and soil stabilization functions | Frequent mowing; prescribed grazing; encourage muskrat activity; cut under water or raise water level; burn; scrapes; competitive woody planting | Expense and nontarget impacts of management may be troublesome |
| Very large stands (e.g., >2 ha) | Same as above | Frequent mowing of patches; cut patches under water; raise water level; encourage muskrat activity; prescribed livestock grazing; scrapes; burn; competitive woody plantings in patches | Eradication difficult or impossible without large expense and nontarget impacts; altering stand architecture preferable in some (perhaps many) cases |
| Edges of large stands | Slow or prevent spread; diversify habitat | Treatment suitable for small or large stands; if not too wet, plant native vines | |

Table 9. Suggested *Phragmites* management by habitat type on the Hudson River. Choices must be tailored to local goals and site conditions, and if possible treatments should first be tested on small plots. In some situations it may be appropriate to monitor without treatment.

| **Habitat** | **Example** | ***Phragmites*** | **Suggested treatments** |
|---|---|---|---|
| Lower intertidal zone and below[1] | None? | Little or no *Phr* invasion; unlikely to be vigorous | No action needed |
| Upper intertidal marsh (fresh) | Middle Ground Island;<br>Tivoli North Bay;<br>Mandara North Cove | May occur intercreek or on creekbanks | Encourage muskrat grazing; frequent cutting; prescribed livestock grazing?; clip-and-drip; containment; scrapes (if stand sufficiently extensive); partial impoundment |
| Upper intertidal marsh (oligohaline or mesohaline) | Iona Island; Croton Marshes; Piermont Marsh | | As above |
| Supratidal marsh (fresh) | Mill Creek mouth | | Prescribed fire during dry season; prescribed livestock grazing; frequent mowing; scrapes |
| Supratidal marsh (oligohaline or mesohaline) | | | |
| Supratidal pool (fresh) | Mill Creek mouth;<br>Sleightsburg Spit | | Encourage muskrat activity; cut below water or raise water level; watchful waiting |
| Supratidal pool (oligohaline or mesohaline) | | | As above |
| Upper intertidal or supratidal swamp | Cruger Island Neck | *Phragmites* may be inhibited by woody plant competition | Competitive planting (woody)?; raise water level?; watchful waiting |
| Impounded polyhaline or mesohaline tidal marsh | None known | | Re-establish saline tidal flow; raise water level or cut below water |
| Nontidal marsh, pool, or meadow | Stuyvesant dredge spoils | See Table 8 | |
| Dry soil adjoining tidal habitats | Steward Island interior | | Frequent mowing; prescribed livestock grazing; competitive planting (woody); removal of fill |
| Floating mat | Constitution Marsh near railroad[2] | | Encourage muskrat activity |

[1] *Phragmites* is thought to be extending its lower elevation limits in some areas on the East Coast, thus development of stands in the lower intertidal zone should be watched for.

[2] Unverified report by the late Jim Rod (National Audubon Society, pers. comm.).

## The Management Decision Process

In its most basic form, management decision-making involves consideration of goals, methods, and outcomes. The decision process for *Phragmites* management should include the following steps.

Biodiversity assessment. The site or landscape to be management should be subject to a biodiversity assessment following, e.g., the Hudsonia methodology (Kiviat and Stevens 2001) or an equivalent methodology. This assessment identifies habitats likely to support rare species or other elements of biological diversity of conservation concern. The assessment may point out a need for biological surveys for particular rare species. A biodiversity assessment should be conducted even where previous assessments or surveys have been performed, unless those were recent and thorough. Decisions about invasive plant management frequently do not consider rare species. For example, decision-making about *Phragmites* management in Hudson River marshes has largely overlooked questions of the rare plants that are almost universally present and that are likely to be susceptible to harm from herbicide applications to *Phragmites*. Although New York Natural Heritage Program (and sometimes other) biodiversity assessments and surveys have been conducted at many Hudson River sites, these studies have not necessarily been comprehensive, especially in larger tidal wetlands. Furthermore, knowledge of rare species in Hudson River tidal wetlands is in a constant state of development. Only a decade ago, dredge spoil shores and wetlands on the Hudson River were generally considered worthless for biodiversity. Hudsonia found several species of rare plants typical of dredge spoil areas (Kiviat and Stevens 2001, Stevens 2001), and these areas have also proven important for nesting bald eagle and cerulean warbler (Stevens 2001). Open tidal marshes and their upland edges and tributary mouths support many rare plant species at sites such as Iona Island Marsh and Tivoli North Bay where *Phragmites* management is being considered or planned, and supratidal pools and marshes may support pool-breeding amphibians in locations such as the mouth of Mill Creek (Stevens 2001) where *Phragmites* management is also being considered.

Habitat. Different types of habitats, and their characteristic hydrology, salinity, soils, vegetation, and landscape context are differentially invasible by *Phragmites* (and other invasive plants). Forested intertidal and supratidal swamps, for example, support *Phragmites* stands (e.g., at Cruger Island Neck in Tivoli Bays and on Castleton Island), but because of competition from tall shrubs and trees these *Phragmites* stands apparently are less aggressive than in the open tidal marshes. Different habitats, also because of the environmental factors mentioned, have different kinds of *Phragmites* stands that provide different habitat functions (and probably different ecosystem services). American toad breeds in the supratidal or uppermost intertidal, low energy, flooded *Phragmites* stands at Nutten Hook but does not breed in the upper intertidal, higher energy stands in the open marsh at Tivoli North Bay. For management decision-making, the habitat *of* the *Phragmites* stands, and the habitat *within* each stand, should be documented. It may be necessary to walk within the stand to observe conditions in the stand interior. The stand characteristics listed in Table 10 should be noted. Apart from eradication or no action, management will usually be oriented to changing stand characteristics to shape habitat functions or ecosystem services provided by the stand.

Table 10. Characteristics of *Phragmites* stands relevant to habitat functions and management decisions (emphasis on the tidal Hudson River). This table lists characteristics of the habitat (environment) of the stand (e.g., salinity), and the architecture of the vegetation itself. Stands do not necessarily need to be characterized quantitatively.

| **Stand characteristic** | **States** | **Notes** |
|---|---|---|
| Tidal fluctuation | Intertidal - supratidal - nontidal | May provide access to *Phr* stands for estuarine fish, crabs, shrimp, and other swimming animals. *Phr* may serve as refuge from unusually high tides. |
| Hydrodynamic energy level | High energy (exposed) to low energy (sheltered) | |
| Soil drainage | Very poorly drained to very well drained | Faunas seem more diverse in wetter stands, but little is known about dry stands. |
| Water depth and duration | Maximum water level (above or below surface) and pattern of water levels | See above. |
| Water salinity | Fresh to polyhaline | *Phr* seems most vigorous and competitive in fresh to oligohaline water but is favored over freshwater species by a degree of salinity. |
| Water features | Number and size of channels or pools | Interspersion of *Phr* with water increases diversity of fauna and use by marsh & water birds. |
| Soil organic matter | Organic matter content | *Phr* seems most vigorous in mineral soils and low- to moderate-organic soils. |
| Soil penetrability | Soft to firm | Affects equipment use for management, e.g., mowing |
| Soil texture | Clayey - silty - loamy - sandy - gravelly | In dry habitats, *Phr* seems especially vigorous in sandy soils; in wet habitats, silty, loamy, & sandy soils are all favorable |
| Soil acidity (pH) | Alkaline - neutral - acidic | *Phr* is favored by alkaline or neutral soils. |
| Stand size (extent) | In square meters or hectares | Small stands provide more external edge which is favorable for foraging by birds & other animals. Large stands provide isolation for disturbance-sensitive fauna (e.g., northern harrier). |
| Stand (culm) density | Culms per square meter (dense to sparse) | Affects penetrability by larger animals & refuge for smaller animals.. |
| Culm height & basal diameter | Reflects vigor of *Phr* | |
| Openings | Presence & size of clearings with shorter vegetation | |
| Tasseling (fertile culms) | Proportion of culms with tassels (flowering or fruiting culms) | Seeds provide food for sparrows |
| Admixture of other plant species | Highly dominant to highly mixed | |
| Presence of woody plants | Trees or shrubs within or adjoining | Birds may nest in woody plants |

| | | |
|---|---|---|
| | stand; tree canopy above stand | within *Phr* stand |
| Presence of vines | Using *Phr* for support at stand edge or interior | Vines provide food & shelter to animals |
| Litter depth | Depth of detached dead plant material | Affects habitat functions; fire fuel |
| Standing dead culms | Presence of standing culms from previous years | Provides overwinter structure; food (insects, etc.) & shelter for animals |
| Lodging | Bent or broken live or dead culms | Creates dense near-ground structure used by animals for shelter |
| Herbivory | Livestock, muskrat, insect, or other grazing (removal of culm or leaf material) | |
| Presence of muskrat or beaver lodges | | Substrate for bird & turtle nests, animals perching above water, & other activities |
| Stand shape | Circular, elongated, irregular, etc. | Affects edge-to-interior ratio (edges used by foraging animals) |
| Relationship among stands | Distances and number of nearby stands | |

Native vs. introduced *Phragmites*. North American *Phragmites* consists of native and non-native genotypes (subspecific entities) which apparently do not hybridize (Saltonstall 2002a). All of the Hudson River *Phragmites* analyzed to date belongs to the non-native Eurasian "haplotype M" (Kristin Saltonstall, pers. comm.). Native *Phragmites* occurs at least as close as central New York and southern New Jersey, and will likely be found in the Hudson Valley (albeit more likely in nontidal calcareous wetlands than in the tidal Hudson River). Managers and biologists should look for *Phragmites* with early-deciduous leaf sheaths and reddish culms late in the growing season or in the non-growing season (other morphological characters may also be helpful in distinguishing native from Eurasian forms [Meadows 2004] although morphological distinctions may not be foolproof). Saltonstall et al. (2004) stated that the flowers of native genotypes and the Eurasian form are distinguishable by the length of their lemmas (a flower part).

Although native *Phragmites* is stated to be usually less invasive than the non-native *Phragmites* (Kristin Saltonstall, pers. comm.), this is not always the case (Lynch and Saltonstall 2002). Generally, native and non-native plants are similar; however, there are unpublished reports of, for example, different species of insects associated with native and non-native *Phragmites*. I have found the reed scale *Chaetococcus phragmitis* nearly ubiquitous and sometimes very abundant beneath the leaf sheaths of non-native *Phragmites* in the Hudson River and nearby areas (see Krause et al. 1997), but did not find this insect on probably-native *Phragmites* in North Dakota and southern Manitoba. There are likely many other subtle differences between native and non-native forms, yet the two are probably more alike than *Phragmites* is to its closest relatives occurring in North America (*Arundo*, *Cortaderia*, and *Reynaudia*).

It is too early to say much about native - non-native distinctions for management purposes, other than that some decision-makers take the purist viewpoint that all non-native invasive wild plants should be removed or reduced where possible, including non-native *Phragmites*. As I have shown above, this is not practical nor is it everywhere desirable, as stands of non-native *Phragmites* provide important habitat functions and ecosystem services, depending on stand character, landscape context, and other factors, and non-native *Phragmites* is also an important resource for direct human use.

The management corollary of removing or reducing non-native *Phragmites* is conserving or propagating native *Phragmites*. As yet I know of no experiments in planting native *Phragmites* in wetland management projects in the Hudson Valley or nearby. This should be considered as a management option as new information becomes available. Native *Phragmites* should also be tested for viability in wastewater treatment wetlands.

Biota. Plant, animal, and other species present within or among *Phragmites* stands are of interest. Rare or vulnerable species and economic species are of primary importance; however, other species may also be locally significant. Numbers and seasonal patterns of use may be important. Some important species using Hudson River *Phragmites* stands are: muskrat, ruby-throated hummingbird, rusty blackbird, bobolink, and mudwort (*Limosella subulata*). Animals that use the site but avoid the *Phragmites* stands (or use the stands at lower density or at a disadvantage) are equally important, as such species might find habitat in the alternate stand architecture or community created by *Phragmites* management. Some of these species may be common snipe and diamondback terrapin.

Sea level rise and marsh stability. Sea level is predicted to rise approximately 11-30 cm during the next 20 years (Rosenzweig and Solecki 2001). Sediment deposition rates in Hudson River tidal marshes, based on limited study, are about 0.2-0.5 cm per year in the upper intertidal zone (Robideau 1997) where *Phragmites* grows but not necessarily in *Phragmites*, or about 4-10 cm in 20 years. High-energy marsh edges unprotected by barriers (such as railroads) at Piermont Marsh, Croton Point Marsh, and the east side of Middle Ground Island (Columbia County) are eroding (Kiviat, pers. obs.). Low-energy interior pools in at least some tidal marshes (e.g., Tivoli North Bay) are accreting (filling), and high-energy pools associated with the railroad trestles (bridge pools) are apparently stable (Kiviat et al. 2006). It is unclear to what extent *Phragmites* stands in Hudson River marshes are causing accretion of sediment and the development of higher soil elevations within stands, or are colonizing higher elevations caused by sediment deposition unrelated to *Phragmites* presence (e.g., on natural levees of tidal creeks or on spoil banks).

Hudson River marshes do not currently seem to be experiencing wholesale sediment erosion as are some marshes in Jamaica Bay and Chesapeake Bay, but *Phragmites* may be important for stabilization of soils in local areas of marsh loss (e.g., *Phragmites* may be slowing erosion at Piermont, Croton, and Middle Ground). However, the fact that the predicted sea level rise is approximately three times the apparent rate of elevation increase in upper intertidal marsh sediments should be cause for concern. If sediment input to the estuary decreases or sea level rise accelerates, this picture could change.

Contaminants. It may be prudent to leave *Phragmites* on contaminated sites alone for now. *Phragmites* may immobilize metals better than *Spartina alterniflora*, although the comparative study has not been made on *Phragmites* and *Typha*. Also, contaminated sediment dredged during management projects may be difficult and expensive to dispose of.

Carbon storage. Until detailed studies are performed, we should probably assume that *Phragmites* is generally more effective at storing carbon than most alternate plant communities. Local benefits (e.g., habitat functions) that may accrue with *Phragmites* removal must be balanced against the global benefit of existing *Phragmites* stands to carbon storage and reduction of global climate change due to the greenhouse effect.

Locations of *Phragmites* stands within a marsh. Location at tributary mouths, creek or pool banks, intercreek areas, or upland margins, for example, may change the habitat functions or ecosystem services provided by a stand, as well as affecting the access for and techniques of management. All characteristics listed in Table 10 may be affected by stand location. Lathrop et al. (2003) concluded that within-marsh distribution of *Phragmites* stands affected marsh functions.

Human use. Use of *Phragmites* as sites for, or camouflage for, duck blinds (Ricciuti 1982), habitat for biota of interest for nature observation or consumptive use, or a source of material to harvest for dried floral arrangements, thatch (Lacinski and Bergeron 2000), or other uses affect the values of *Phragmites* stands and therefore their management. There has been little documentation of human use of *Phragmites* in Hudson River marshes or elsewhere in the eastern U.S.

## Management recommendations for Selected Sites on the Hudson River

For the sake of these recommendations, I assume that the management goals are estuarine nekton (access to marsh surface), breeding and nonbreeding marsh and water birds, and water quality maintenance. These recommendations are preliminary and need careful examination in the light of this report and other information.

1. Small stands (e.g.,, Tivoli North Bay, Manitou Marsh): Containment (Tivoli, Manitou); watchful waiting (Mandara South); clip-and-drip (Stockport).

2. Larger stands in fresh-tidal marsh threatening *Typha* stands, etc.: Alter stands by quasi-impoundment with regulated nekton passage, encouragement of muskrat activity, by livestock grazing, cutting, or burning.

3. Larger stands in oligohaline or mesohaline marsh threatening *Typha* (e.g.,, Iona Island Marsh): as for 2 (above).

4. Large stands in polyhaline marsh, threatening high salt meadows (Piermont): livestock or muskrat grazing; cutting and harvest for products; salt additions. Try cutting or grazing at edges of salt meadows to prevent further encroachment of *Phragmites* on salt meadows, or to push the *Phragmites* - short grass boundary back and expand the salt meadows.

The underlying ecological problems facilitating or causing the invasion of *Phragmites* must be studied and corrected if *Phragmites* management is to be successul. Tidal restriction, partial filling, and water quality degradation are prominent factors that facilitate *Phragmites* invasion (Tiner 1995). I would add lowering of the water table (drainage) and physical disturbance of the soil to Tiner's list. At Piermont Marsh *Phragmites* spread appears to threaten the only remaining occurrences of salt meadow plant communities in the Hudson River. The *Spartina patens* salt meadow community appears to be sensitive to high nitrogen levels (Catherine Wigand in lecture at Institute of Ecosystem Studies, April 2006). If *Phragmites* is removed without reducing nitrogen levels, stunted *Spartina alterniflora* or other plant species may invade rather than *S. patens*, *Distichlis spicata*, etc. Also, the surrounding *Phragmites* stands possibly serve to buffer the *S. patens* by removing nutrients from inflowing tidal waters.

## Research Needs

Most *Phragmites* research has been performed in polyhaline tidal marshes. Future research should emphasize missing information about the ecology and manipulation of *Phragmites* stands in freshwater, oligohaline, and mesohaline tidal marshes, and in nontidal wetlands and dry habitats. Different scientists and managers are likely to recommend different research topics based on local needs or investigator interests.

The most important research needs relate to knowledge of habitat functions and ecosystem services (i.e., how do *Phragmites* invasion and removal affect functions and services, what are the impacts of *Phragmites* invasion and removal). Different habitats, seasons, taxa, sites, ecological processes, stand character, and management techniques require study.

Given the pressures to use herbicides for *Phragmites* management, and the assumption that *Phragmites* invasion is harmful to rare plants, studies of the impacts of *Phragmites* invasion and herbicide treatment on rare plants are needed. For example, studies could be performed in Tivoli North Bay (on *Heteranthera reniformis, Bidens*, *Orontium*), at Iona Island Marsh (on *Scirpus cylindricus* and other species), at Croton Point Marsh (*Limosella subulata*), or in Piermont Marsh (on *Carex hormathodes*).

The role of *Phragmites* in carbon balance needs study.

*Phragmites* fossils found in the northeastern states need to be radiocarbon dated.

The crux of applied invasion ecology is learning precisely the impacts of plant invasions on the functioning of habitats and ecosystems. It is necessary to distinguish the degree to which change (in, e.g., population density, fitness, community composition, or ecosystem functions) is caused by an increase in the population of *Phragmites* distinct from various confounding factors. Studies need good controls (e.g., comparison of *Phragmites* and non-*Phragmites*). Studying the relationship between *Phragmites* and other species (or processes) at one or two locations, or at one or two times, may be a good first step but it is not enough. These studies must be replicated spatially and temporally, preferably at many sites and geographic areas, or in long time series. Furthermore, *Phragmites* and the decreasing or increasing species or process must be linked causally (i.e., functionally). Findings from one geographic area, site, plant community (e.g., saltmarsh cordgrass), season, or year may not be representative of a different geographic area, site, plant community, season, or year. One way to approach this linkage is with field experiments with four blocks: *Phragmites* changed to non-*Phragmites* (i.e., *Phragmites* removal), non-*Phragmites* changed to *Phragmites* (i.e., *Phragmites* planting), *Phragmites* unchanged (control), and non-*Phragmites* unchanged (control). The "change" can occur either through manipulation (removal and planting) or naturally (invasion and regression of *Phragmites*). I know of no studies of *Phragmites* using this four-block design, although there have been a few studies of *Phragmites* before and after removal (e.g., Meyerson et al. 1999, Fell et al. 2006). There have been very few *Phragmites* studies with extensive spatial replication: Benoit (1997) conducted such a study of marsh birds in *Phragmites* and saltmarsh cordgrass on the Connecticut coast (but see the somewhat different findings of DiQuinzio [2001-2002] regarding saltmarsh sharp-tailed sparrow in Rhode Island). All investigations of the impacts of plant invasions should begin with the null hypothesis of no difference among treatments (e.g., no difference between *Phragmites* and alternate community), because the available data indicate that there is no *a priori* reason to expect particular (negative or positive) impact on taxa or processes, and because of the great variation among *Phragmites* marshes and stands.

## Discussion and Conclusions

There are two contrasting ways to view the current situation on the Hudson River:

1. DO MORE RESEARCH - Before we spend large amounts of money, make long term commitments to maintenance, and cause nontarget impacts of unknown dimensions, we need to have the results of rigorous scientific research to underpin management policy and decision-making.

2. TAKE MANAGEMENT ACTIONS PROMPTLY - *Phragmites* covers large areas of the marshes, it continues to spread rapidly, impacts are probably more negative than positive, and even if *Phragmites* is not as bad as we think we cannot afford to risk dominance of very large areas in marshes such as Iona Island or Tivoli North Bay.

An interim or intermediate view is to manage now those *Phragmites* stands that are clearly threatening local resources such as rare plants or plant communities, and leave along for the time being (with monitoring) those *Phragmites* stands that are not an immediate threat.

A paradigm shift is occurring. *Phragmites* in particular, and long-established invasive plants in general, are being seen more as complex ecological phenomena requiring a nuanced, goal-directed, and site-specific management approach rather than a one-size-fits-all “kill the invaders” approach. Many analogies from the ecological management literature could be invoked; I like the analogy of predator-prey relationships. In the first half of the 1900s, many wildlife biologists and wildlife managers, and the public in general, viewed predatory higher vertebrates (i.e., birds and mammals that preyed on other birds or mammals) as “bad” animals that should be killed. In the 1950s and 1960s, Paul Errington and certain other biologists propounded the idea that predators culled only the sick, old, or unfit individuals from a prey population - the “biological surplus” that would die soon anyway. Predators did not control populations, according to this view. The pendulum (at least in some quarters) swung to the other extreme - predators were “good” or at least "neutral" and should be conserved. Current ecological theory (e.g., Odum 1971) states that a predator can have a controlling effect (causing reductions in populations), a regulatory effect (evening out peaks and troughs in prey populations), or no effect, on its prey. Most wildlife managers now manage predators on a goal-driven and site (or region) specific basis. For example, predators on eggs and incubating females of gound-nesting ducks are controlled in certain areas where waterfowl production is a primary goal, and left alone in other areas. We are leaving the paradigm “all *Phragmites* is bad” and moving towards goal-directed and site-specific management with the additional consideration of *Phragmites* genetics.

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