Invasion of Phragmites australis in the Tidal Marshes of the Hudson River

A Final Report of the 1996 Tibor T. Polgar Fellowship Program

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ABSTRACT

The tidal marshes of the Hudson River vary in the abundance and distribution of Phragmites australis (phragmites), an invasive, emergent grass. Phragmites dominance alters the structure of the marsh and may reduce plant species diversity, alter habitat functions, and affect nutrient cycling. In this study we compared the spatial extent of past and present phragmites colonies, quantified the invasion rates, estimated colonization dates and identified the plant communities replaced by phragmites. Data were collected for four Hudson River tidal marshes ranging in mean salinity from 6 ppt to fresh water using historical aerial photographs and a geographical information system. Total area of phragmites for the tidal freshwater marshes at Stockport Flats and Tivoli North Bay increased exponentially, with invasion rates averaging 0.05 $ha^{-1}yr^{-1}$. Phragmites made up less than 1% of the marsh areas at both of these sites in 1991. At Iona Island, phragmites spread exponentially invading 23% of the marsh at a rate of 1 $ha^{-1}yr^{-1}$ between 1980 and 1991. Piermont Marsh lost between 35 to 40% of the total marsh area to phragmites from 1965 to 1991, with invasion rates as high as 5 $ha^{-1}yr^{-1}$. Phragmites at Piermont mixed with and then replaced cattail (Typha angustifolia), Olney threesquare (Scirpus americanus) and salt meadow cordgrass (Spartina patens) communities. At all the study sites, phragmites replaced more cattail area than any other plant community. Phragmites stands at Iona Island and Piermont Marsh established and spread 7 to 27 times more from tidal creek banks than other locations. The mesohaline (3-6 ppt mean salinity) marshes at Iona and Piermont had greater coverage and higher invasion rates for phragmites than the freshwater marshes. We estimated the phragmites colonization date at Piermont Marsh to be between 1790 and 1858; dates for the other sites varied from 1956 to 1965. If current rates of spread at Piermont and Iona continue, the higher marsh may be entirely dominated by phragmites within 35 years. At Tivoli Bays and Stockport Flats, this threat is not imminent.

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INTRODUCTION

Phragmites (Phragmites australis), an emergent grass, has invaded many tidal marshes on the Hudson River. At Piermont Marsh, for example, more than half the marsh area is now dominated by phragmites (Blair and Nieder 1993). Dense phragmites stands can alter the structure and function of marshes by replacing plant communities, threatening rare plants, and possibly decreasing the capacity to support stenotopic animal communities found in marshes (Roman et al. 1984, Marks et al. 1994).

Phragmites invasion may increase the high productivity of freshwater tidal marshes. Although phragmites primary production is higher than the plant communities it replaces, much of this production is slow to enter the detrital food web (Warren and Fell 1996). Differences in the rates of decomposition in high marsh plants may be attributed to their cellulose levels (Odum et al. 1984). Invasion by phragmites, a plant with high cellulose levels and slow rates of stem decomposition, could affect the amount of available nutrients in the marsh (Buck 1995).

There is little quantitative information on phragmites invasion in the U.S. and none for Hudson River tidal marshes. Qualitative observations of vegetation at Piermont Marsh and Tivoli North Bay have indicated expansion of phragmites since the early 1970's (Foley and Taber 1951, Kiviat, personal observations). Salt marshes on the Connecticut River estuary are being invaded by phragmites at 1-3% yr^{-1}, partially due to restriction of tides and salinity by tide gates (Roman et al. 1984, Warren 1994, Buck 1995, Warren and Fell 1996).

Phragmites Distribution

Consistent with studies of other tidal marsh plants (Odum et al. 1984, Kiviat 1991), phragmites distribution seems to be determined in part by substrate elevation and tidal inundation. Phragmites occupies the middle elevations (mean 106-115 cm above sea level) of Connecticut River salt marshes, while other plants dominate the higher and lower areas (Buck 1995). In Hudson River marshes phragmites occurs in the upper intertidal and supratidal areas. Disturbance may also determine the distribution of phragmites, although many marshes without obvious recent disturbance contain large stands of phragmites. Lower salinities have been positively correlated with increased phragmites invasion in Spartina spp. salt marshes and phragmites populations have decreased in areas where salinity was restored to pre-tide gate levels (Roman et al. 1984, Warren 1994, Warren and Fell 1996).

Phragmites reproduces by seeds and rhizomes or stolons. Vegetative reproduction is typical in established phragmites stands (Haslam 1973). The rhizomes play a critical role in the survival of phragmites by storing carbohydrates and nutrients, providing a structural anchor in the substrate, and acting as the perennating organs. The spreading underground rhizomes and aboveground stolons, which produce new shoots at intervals (Bernard 1995), may allow plants to establish in areas where seed propagation would not be successful. Rhizome fragments can establish new clones but it is not known if phragmites establishes and spreads primarily by rhizome or seed in the Hudson River marshes.

Status

The U.S. Fish and Wildlife Service considers phragmites a native plant (Cross and Fleming 1989). Phragmites has been found in core segments from a Connecticut estuary dated at 3000 yr B.P. (Orson et al. 1987). Phragmites was also found in prehistoric archaeological contexts in the Southwest (Adams 1990).

Here we report on the rates and patterns of phragmites invasion within the four Hudson River National Estuarine Research Reserve (HRNERR) sites. The purpose of this study was to document the historical extent of phragmites by creating a chronological sequence of maps of plant communities. The objectives of the study are to: (1) compare the spatial extent of past and present phragmites colonies in Hudson River marshes; (2) quantify the invasion rates of phragmites and estimate the ages of phragmites stands; and (3) identify which plant communities are being replaced by phragmites.

Study Sites

The study areas are the four HRNERR sites at Piermont Marsh, Iona Island, Tivoli Bays, and Stockport Flats (Figure 1). All the study sites are tidal and vary considerably in the amount of phragmites present (Table 1). The sites have all undergone anthropogenic disturbances ranging from nutrient enrichment to tidal restriction.

METHODS

We used historic aerial photographs to delineate plant communities. The resulting overlays were transferred to a base map and digitized into a geographical information system (GIS) database. We used the GIS to determine changes in phragmites distribution over time.

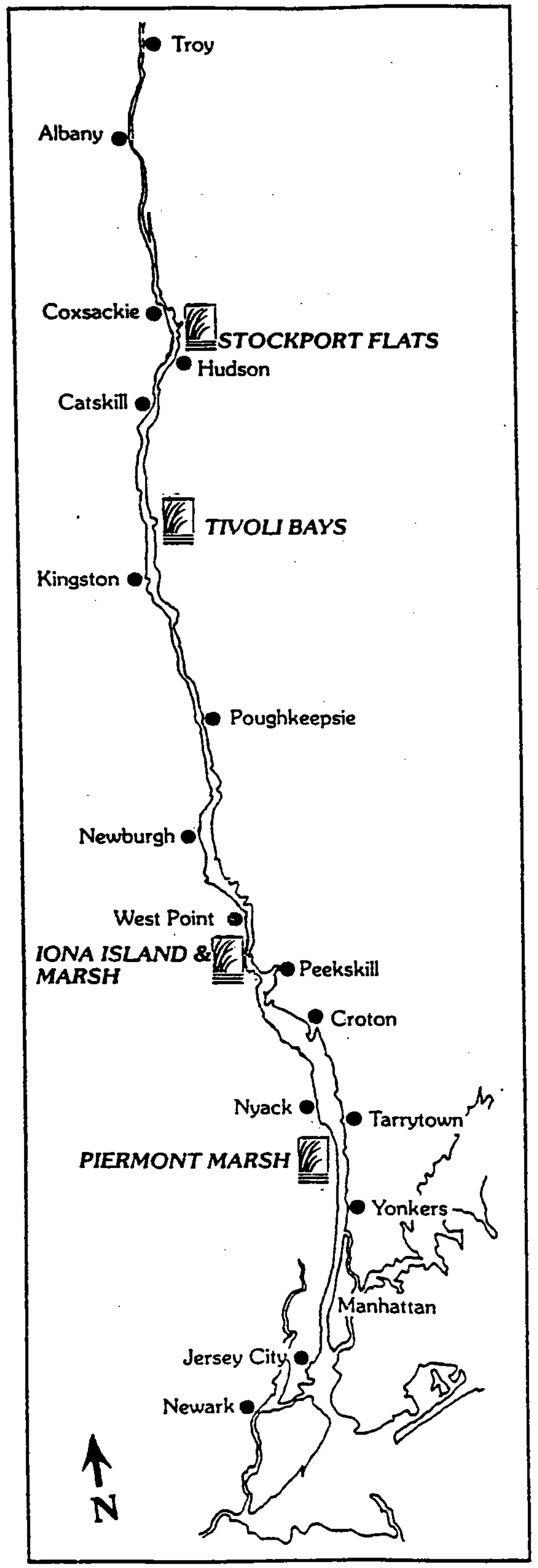

Figure 1. Study sites. Hudson River, New York.

Table 1. Site descriptions (see Figure 1).

Sites	River km[a]	Mean tidal range (m)	Mean salinity (ppt)	Marsh area (ha)	Phragmites % cover in 1991
Stockport Flats	201	1.22	<0.1	242	0 .85
Tivoli North Bay	161	1.20	<0.1	146	0 .48
Iona Island Marsh	72	0.85	3.0	54	27.00
Piermont Marsh	40	0.98	6.0	107	65.00

[a] Distance above the Battery (southern tip of Manhattan).

Aerial Photography

Vertical, black-and-white aerial photographs were obtained from the United States Department of Agriculture (USDA) for Stockport Flats and Tivoli Bays for 1967 and 1980 at a scale of 1:7200. Photographs of Tivoli North Bay for 1984 were obtained from The New York State Department of Environmental Conservation. Black-and-white aerial photographs of Piermont Marsh and Iona Island flown in 1965, 1974, and 1980 were available from the USDA at 1:7200. These were compared to the HRNERR vertical color photographs and resulting vegetation maps (1:7200) completed in 1991 (Blair and Nieder 1993).

Aerial Photograph Interpretation

The classification of plant communities was based on structurally different vegetation patches that can be identified from aerial photographs (Blair and Nieder 1993). This technique has been used by other researchers to successfully delineate marsh vegetation along a gradient from brackish to freshwater (Gallagher and Reimold 1973).

Communities were delineated based on the spectral signatures of the dominant plants (Reschke 1990). At Stockport Flats and Tivoli North Bay populations of short, broad-leaved emergents, including pickerelweed (Pontederia cordata), arrow arum (Peltandra virginica) and spattterdock (Nuphar advena) contrasted clearly with the aerial appearance of the tall graminoids such as cattails (Typha spp.), purple loosestrife (Lythrum salicaria), wild rice (Zizania aquatica), and phragmites. Iona Island was dominated by tall cattail and phragmites plant communities which contrasted with small areas of broad-leaved emergents, primarily pickerelweed, as well as spatterdock and arrow arum.

Piermont Marsh was the most heterogenous marsh, with identifiable communities of cattail, phragmites, Olney threesquare (Scirpus americanus), salt grass (Distichlis spicata), distinctive salt meadow cordgrass (Spartina patens) meadows as well as large areas of cattail mixed with phragmites. The minimum and maximum percentages of phragmites within the mixed communities at Piermont were visually estimated from the aerial photographs. The area of phragmites within the mixed communities was calculated for both minimum and maximum percentages and added to the area of monotypic phragmites stands to estimate the range of total phragmites coverage.

Studies documenting the species composition at our sites (DeVries and DeWitt 1986, Kiviat 1991, Blair and Nieder 1993), coupled with historic aerial and ground slides, oblique color aerial photographs and the 1991 HRNERR vegetation maps, were used to assist in identification of the species within the dominant plant communities. Although our methods were effective for identifying the dominant plant communities, we recognize that there are many other plant species at the marsh sites that were not identifiable by these methods due to their growth habits.

Phragmites has a distinctive signature on aerial photographs characterized by a fine texture, circular colonies, lighter or darker color depending on the season, a shadow caused by the greater height of the stands, and a consistent texture and color throughout the stand. This distinctive signature allowed consistent identification of phragmites stands. We developed a non-dichotomous key of significant features in order to make the identification objective (Appendix 1 p VI-26). Phragmites stands that

we refer to as "monotypic" or "monocultures" imply only that they contain no other species discernible on the aerial photographs.

The accuracy of aerial photo-interpretation can be improved by careful training of the photo-interpreter (Lillesand and Kiefer 1979). We used interpreted and ground-truthed black and white aerial photographs to train ourselves in aerial photo-interpretation of marsh plant communities. Possible sources of misidentification include phragmites stands that taper in height toward the edges and areas of phragmites mixed with other plant communities. The probability of missing smaller stands that were no longer present (if such stands existed) was minimized by the tendency of phragmites to consistently expand once established. Changes in the areal coverage of phragmites have been measured successfully by several researchers using historical aerial photographs (Boorman and Fuller 1981, Warren 1994, Buck 1995, Rice and Stevenson 1996).

GIS Mapping

The plant communities were traced from the aerial photographs onto clear overlays. Using TOSCA version 2.12 (Tsoft Inc., Worcester, MA 1995) digitizing software, the map overlays were digitized and imported into the IDRISI Geographical Information System version 1 (IDRISI Production, Worcester, MA 1995). Control points from the HRNERR 1991 vegetation maps (12 m accuracy at a scale of 1:2400) and Institute of Ecosystem Studies control points (2 m accuracy) were used to reference each map to the New York State Plane Coordinate system. A raster-based digital map of plant communities for each time period was created. We imported Arc/Info PC Version (Environmental Systems Research Institute, Inc., Redlands, CA) files of the 1991 HRNERR vegetation maps into the Idrisi GIS for analysis. Paper maps for Tivoli, Iona and Piermont were generated by importing IDRISI bmp files into WP Draw version 3.0 (Novell Inc. Orem, UT 1994). We generated the 1991 paper map of Stockport Flats using ArcView version 2.1 (Environmental Systems Research Institute Inc., Redlands, CA 1995).

Accuracy

The systematic distortion of aerial photographs from the nadir or center to the perimeter of the photographs (Avery 1977) was corrected for by the establishment of control points on the photographs. The distortion was then expressed as the discrepancy between an ideal Cartesian grid and that formed by the control points and their digitized positions. This difference, expressed as the root mean square (RMS) (Eastman 1995, Jones 1995), is an expression of both the errors in the location of the control points on the base maps and the distortion of the source aerial photographs. This linear distance varies by site and is randomly distributed throughout the map as a location error (e.g., any point may be 12 m from its true location). Areal calculations will have an average error of the RMS squared (Jeff Jones, Tsoft Inc., personal communication). Although not a systematic bias, it is an accuracy limitation, and along with the resolution, limits the ability to make inferences on changes in area smaller than 144 m^2 or 0.0144 ha.

The calculation of area for marsh plant communities is not affected by random location error such as RMS as long as the relative area is maintained by the grid system (Paul Barten, Yale University, personal communication). Because we calculated changes in area independent of the maps, these figures remain independent of location errors between maps of different time periods.

Digitizing error (the possibility of digitizing a line inaccurately) is neither additive nor systematic because a given pixel has a 50% chance of falling on either side of a digitized line. When polygons were digitized twice, and the resulting areas compared, the difference was less than 19 m^2.

Establishment dates

The establishment dates at all four marshes were calculated based on the invasion rates between the first and second dates of aerial photography and the assumption that the expansion rate had remained constant since phragmites

establishment. This assumption is supported at the sites by the linear expansion of phragmites stands during the early study periods.

RESULTS

Stockport Flats

Phragmites at Stockport Flats increased exponentially with time (Figure 2, $r^2=0.9995$) for a total increase of 1.47 ha in 24 years. The invasion rate varied from 0.05 $ha^{-1}yr^{-1}$ for the period 1967-1980 to 0.09 $ha^{-1}yr^{-1}$ for 1980-1991 (Table 2). By 1991, phragmites still covered less than 1% of the total marsh area.

We identified five stands on the 1967 aerial photographs and no new stands had

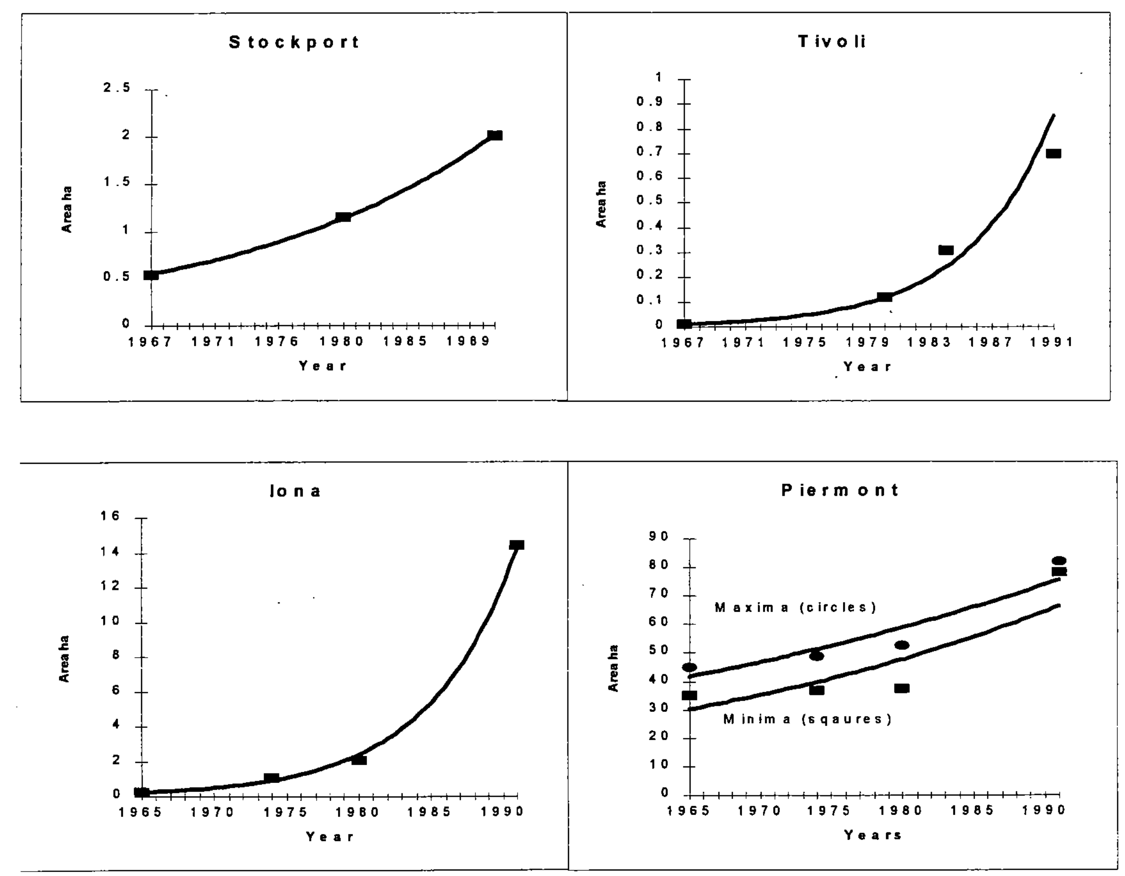

Figure 2. Phragmites areal coverage at the four marsh sites with exponential curves fitted to the data. Y scale varies. The curves for Piermont represent the upper and lower estimates of phragmites within the mixed plant communities.

Table 2. Phragmites (P) area in hectares, phragmites percent cover (%) of the marsh, phragmites percent change and invasion rates $ha^{-1}yr^{-1}$.

Site	Year	P Area	P %	P % Change	Inv Rate
Stockport	1967	0.54	0.34	n/a	n/a
	1980	1.15	1.47	1.13	0.05
	1991	2.01	0.85	0.62	0.09
Tivoli	1967	0	0	n/a	n/a
	1980	0.12	0.08	0.08	0.01
	1984	0.31	0.21	0.13	0.05
	1991	0.70	0.48	0.27	0.06
Iona	1965	0.20	0.37	n/a	n/a
	1974	1.07	1.99	1.62	0.10
	1980	2.11	3.92	1.93	0.21
	1991	14.45	26.83	22.91	1.12
Piermont	1965	35-45	33-42	n/a	n/a
	1974	37-49	34-46	1-4	0.20-0.42
	1980	38-53	35-49	1-3	0.12-0.64
	1991	78-82	73-77	38-28	2.66-3.70

established by 1991 (Figure 3A). The stands were all in cattail marsh, with two on creek banks and one at the head of a small tidal creek. We identified two new phragmites stands in the field in September 1996 which were not included in the data analysis.

The islands at Stockport Flats were about 75% non-vegetated dredge spoil in 1967. One of the four stands which is currently surrounded by cattail established in the sandy dredge spoil that created the Little Nutten Hook peninsula. There was no evidence, however, that dredge spoil deposits encouraged phragmites invasion. Although cattail decrease comparable to phragmites increase was not detectable over the entire marsh area, cattail was the plant community replaced by the expansion of phragmites at all four stand locations. If the invasion rate of phragmites from 1967 to 1980 is extrapolated back to year 0 (no phragmites cover) the phragmites establishment date is 1956.

Stockport Flats

1991

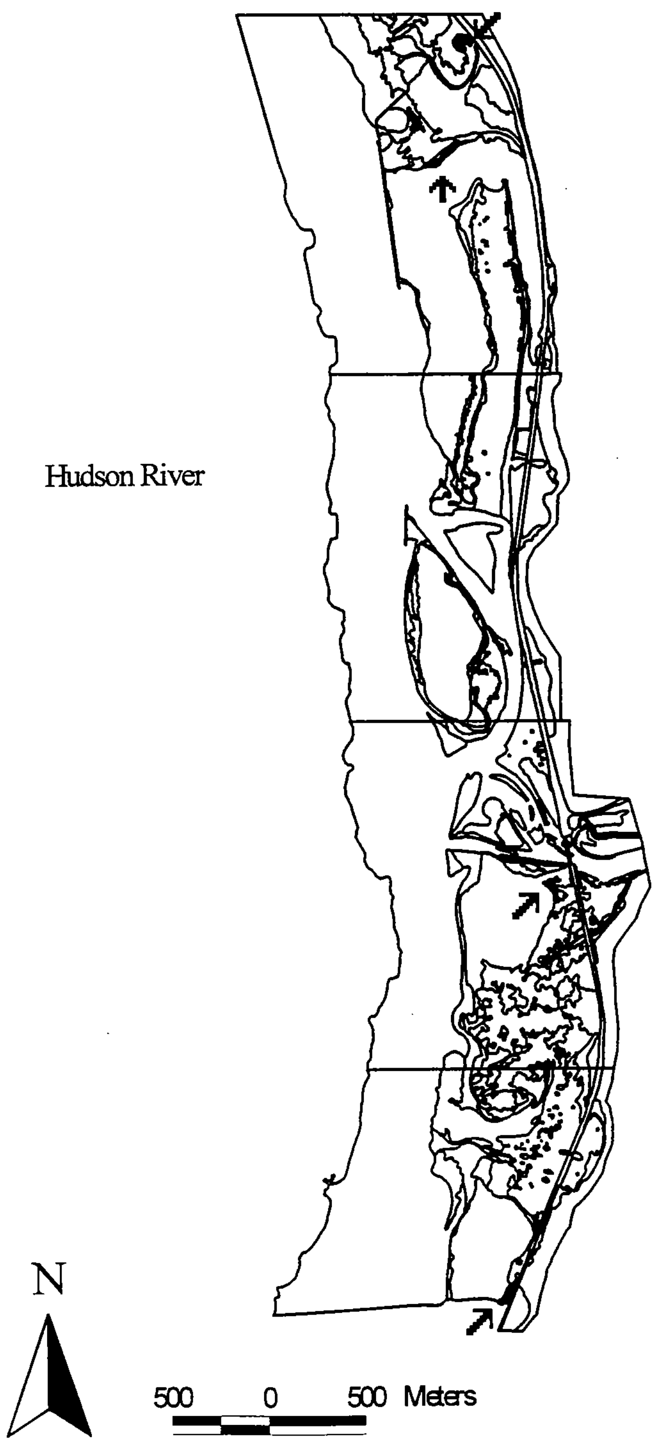

Figure 3A. Phragmites coverage at Stockport Flats. Phragmites colonies indicated by arrows. Earlier years are not shown because the colonies were not visible at this scale.

TIVOLI NORTH BAY

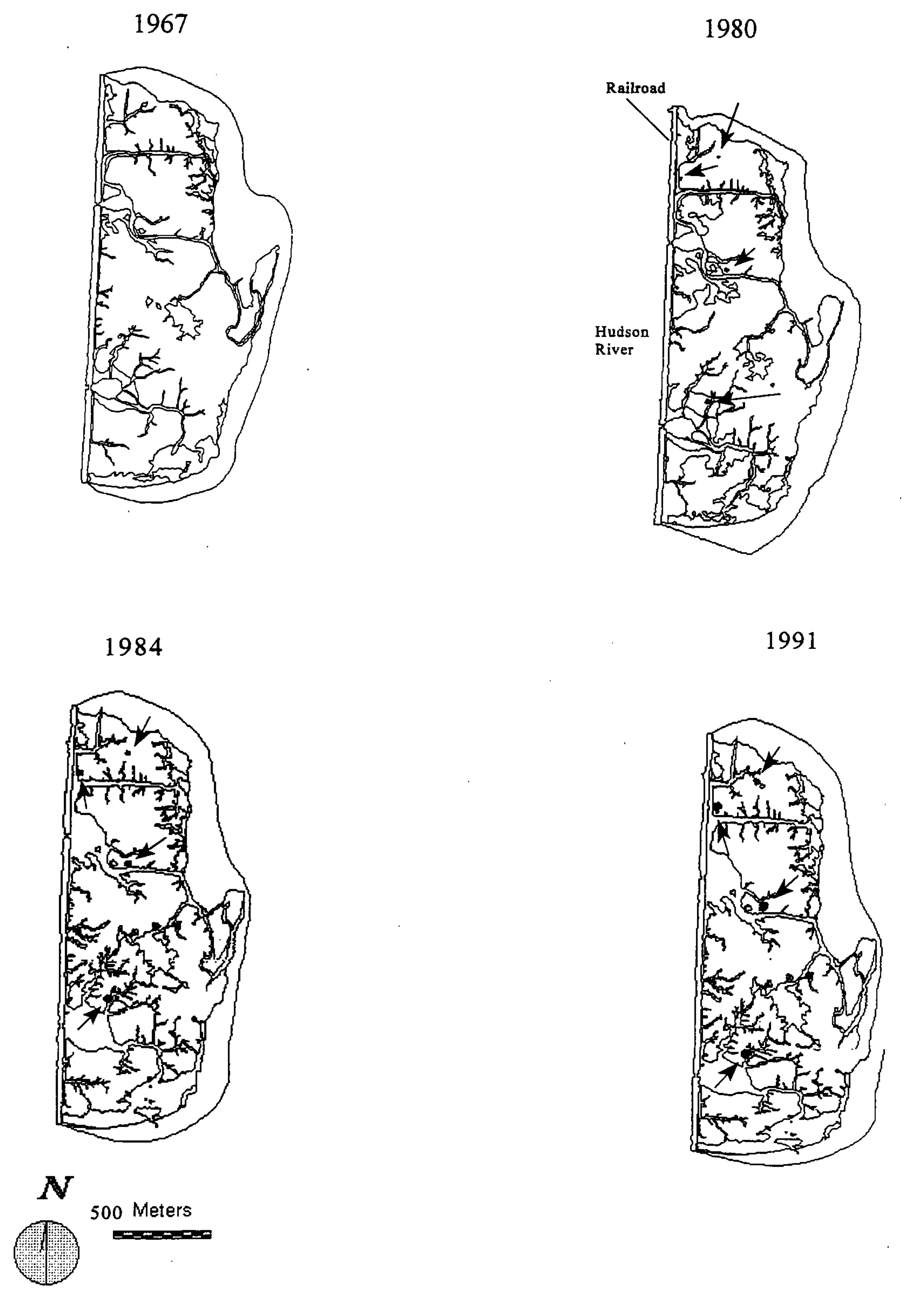

Figure 3B. Phragmites coverage at Tivoli North Bay (No stands in 1967). Phragmites colonies indicated by arrows.

IONA ISLAND

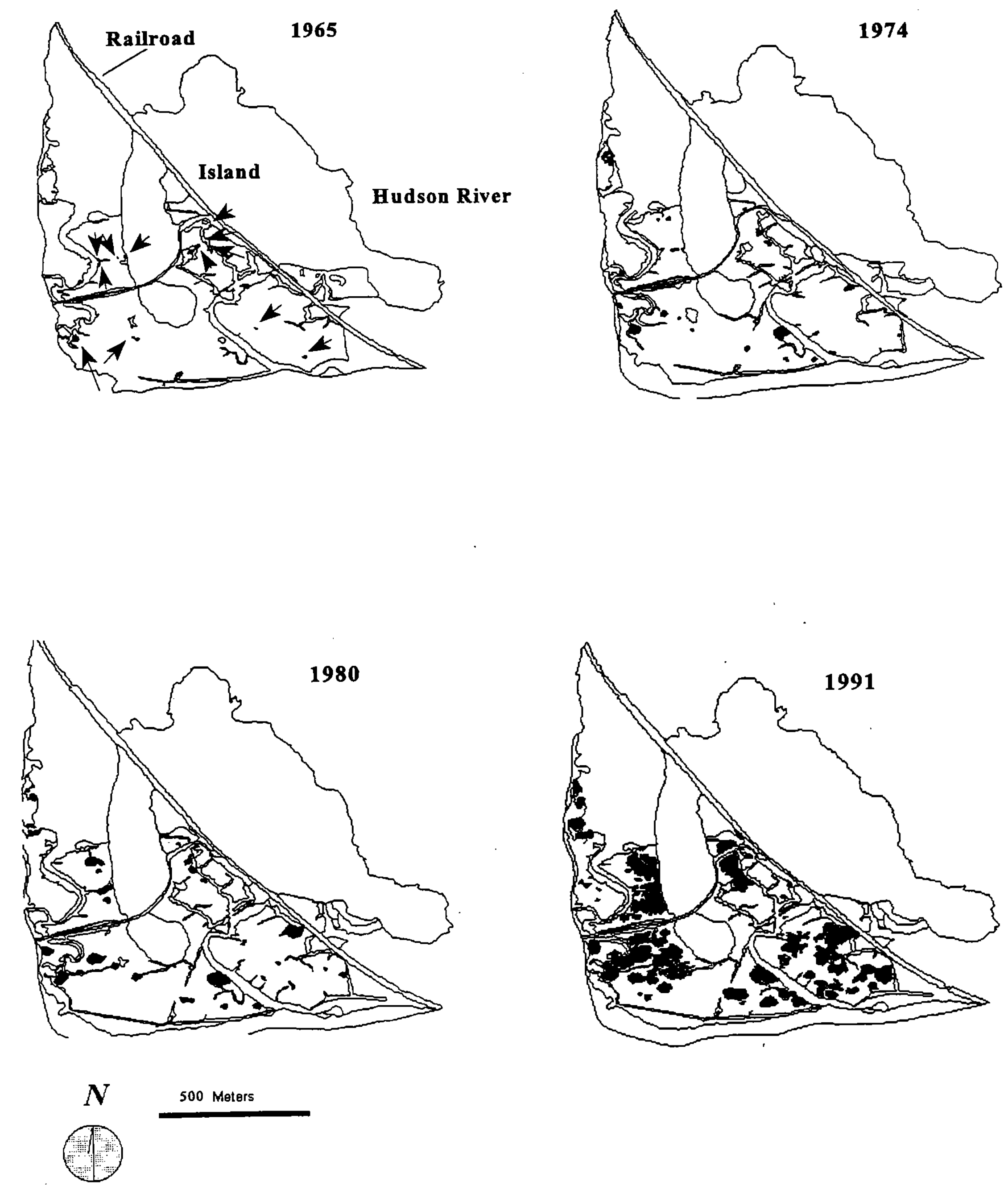

Figure 3C. Phragmites coverage at Iona Island. Phragmites colonies in black and indicated by arrows for 1965.

Piermont Marsh

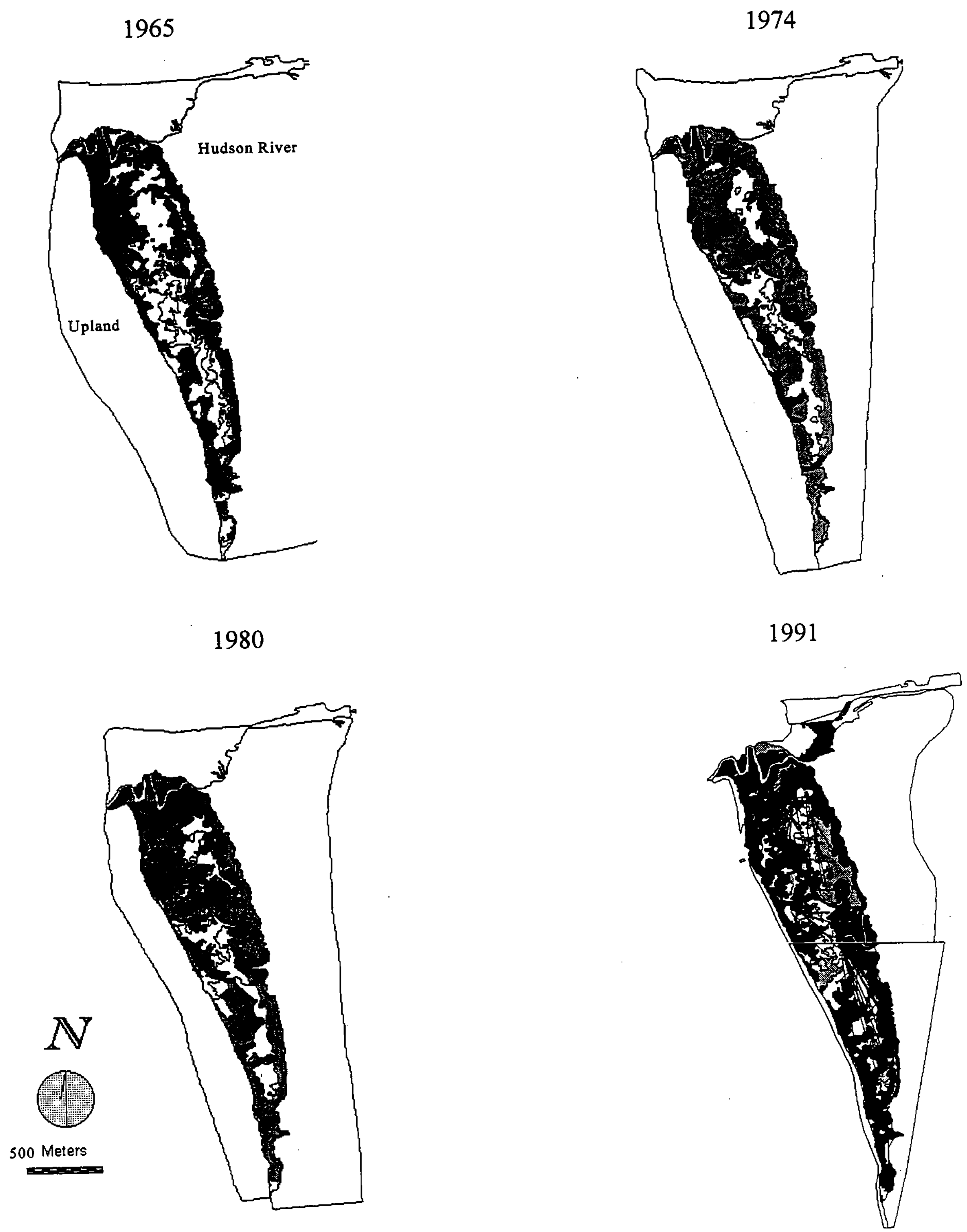

Figure 3D. Phragmites coverage at Piermont Marsh. Monotypic stands in black, phragmites mixed communities in grey.

Tivoli North Bay

Phragmites at Tivoli North Bay increased exponentially with time (Figure 2, $r^2=0.99$), expanding from 0 to 0.70 ha over 24 years (Table 2). The invasion rate increased from 0.01 $ha^{-1}yr^{-1}$ for the period 1967-1980 to 0.05 $ha^{-1}yr^{-1}$ for 1984-1991. Phragmites covered 0.48% of the marsh in 1991 (Table 2, Figure 3B).

Four of the five stands identified were located in cattail marsh, two of them adjacent to tidal creeks. The first four stands established between 1967 and 1974. A fifth stand established between 1974 and 1980 across the tidal creek from the largest stand in the marsh. Cattail showed a decrease in area due to a combination of factors, most notably invasion by purple loosestrife and, to a lesser degree, phragmites. Field observations indicated that areas where the aerial signatures were dominated by purple loosestrife could be as much as 50% cattail (Kiviat personal observations).

No phragmites was identified on the 1967 aerial photographs. If the invasion rate for 1967-1980 is extrapolated back to zero phragmites cover, the establishment date is 1965. Small stands that may have existed in 1967 may not have been visible on the aerial photographs. Four of the five extant stands, however, were not seen until after 1971 (Kiviat, personal observations).

Iona Island

From 1965 to 1980, there was a linear increase in the area of phragmites averaging 0.15 $ha^{-1}yr^{-1}$. From 1980 to 1991, expansion accelerated, averaging more than 1 $ha^{-1}yr^{-1}$ (Table 2). Phragmites increased from 4% to 27% of the marsh area in that 11 yr interval. The overall growth curve of phragmites at Iona Island was exponential (Figure 2, $r^2=0.995$).

Phragmites was 7 times as likely to establish on tidal creeks than not and 10 times as likely to establish in cattail dominated high marsh. Between 1980 and 1991 the number of stands within the cattail marsh began to increase faster than those on tidal creeks. In the field (September 1996), we identified approximately 5 new stands of phragmites at Iona Island that do not show on the 1991 photographs, and a visual estimate indicated as much as 50% of the marsh area may be phragmites.

The plant community replaced was overwhelmingly cattail (Figure 3C). From 1980 to 1991 the increase in phragmites area was 12.34 ha while cattail decreased 14.61 ha. Extrapolating the invasion rate for 1965-1974 back to zero phragmites cover gave an establishment date of 1962.

Piermont Marsh

Piermont marsh had large areas of cattail mixed with phragmites throughout the study period. The range of phragmites coverage within the mixed communities, visually estimated from the aerial photographs, was between 30 and 65%, depending on the year.

From 1965 to 1980, the areal coverage of both monotypic phragmites (12% of the marsh) and phragmites within mixed communities (20-37% of the marsh) increased little. From 1980 to 1991, monotypic phragmites stands increased to 64.57% of the total marsh area at a rate of 5.38 $ha^{-1}yr^{-1}$ (Table 2, Figure 3D), due to large areas of mixed cattail-phragmites (and some Olney threesquare - phragmites mixed communities) converting to phragmites monocultures. Piermont lost between 35 to 40% of the marsh area to phragmites during the study period. The overall invasion rate of phragmites at Piermont Marsh from 1980 to 1991 ranged from 2.66 to 3.70 $ha^{-1}yr^{-1}$, depending on which estimate of phragmites within the mixed plant communities is used. The expansion of phragmites at Piermont Marsh was represented equally well by exponential (r^2=0.87 to 0.74) and linear (r^2=0.84 to 0.72) regression lines (Figure 2).

The number of individual phragmites stands consistently decreased as they became part of larger stands, with the original 67 stands forming just 22 large stands by 1991. Phragmites stands were more than five times as likely to establish in cattail marsh immediately adjacent to tidal creeks than in all other locations and 27 times as likely to establish on tidal creeks overall. Phragmites colonies also replaced 8.50 ha of Olney threesquare mixed communities and 10.86 ha of salt meadow cordgrass mixed communities between 1965 and 1991.

If the earliest invasion rate for phragmites (1965-1974) is extrapolated back to zero phragmites cover, the establishment date ranges from 1790 to 1858, depending on which estimate of phragmites within the mixed communities is used.

DISCUSSION

Pattern of Invasion

Consistent with results for the Connecticut River (Warren and Fell 1996) phragmites stands at Iona Island were 7 times as likely to grow on creek banks than not and stands at Piermont were 27 times as likely to grow on creek banks than not. Creek bank stands in the Hudson River established first, were less likely to be mixed with other plant species, and displayed exponential invasion rates.

Creek banks experience physical disturbance from wave action, ice shear, muskrat burrowing and humans. This may provide an opportunity for phragmites seeds or rhizome fragments to establish and for established colonies to displace other plant communities. Stands at Iona Island and Piermont Marsh had a pattern of initial creek bank establishment with eventual spreading to the interior of the marsh. This is consistent with Warren's (1996) observation that phragmites stands are denser and older at creek banks, diminishing 20 to 50 m from the creek.

Salinity and Hudson River Distribution

Phragmites had the highest invasion rates and greatest areal coverage at Iona Island and Piermont Marsh. The average salinity at these sites is 3 and 6 ppt, respectively. Other authors have stated that phragmites does best at mesohaline (3-10 ppt) sites (Roman et al. 1984, McNabb and Batterson 1991, Marks et al. 1994, Warren and Fell 1996). Our results suggest that where marshes represent a range of salinities, such as the Hudson River, phragmites may be most invasive at mid salinity sites such as Piermont and Iona Island.

Colonization Dates

Extrapolating invasion rates gave initial colonization dates ranging from 1956 for Stockport Flats to 1965 for Tivoli North Bay. Although difficult to substantiate, phragmites establishment at Piermont was estimated to be between 1790 and 1858; Foley and Taber (1951) reported abundant phragmites at Piermont in 1951.

Connecticut River phragmites stands had inferred inception dates in the late 1960s to early 1970s with some extrapolating back to the 1920s (Warren and Fell 1996). Based on the research to date, large phragmites monocultures appear to be a recent phenomenon in northeastern tidal river marshes. The causes of the increased expansion rates are unknown. Changes in nutrient and sediment inputs, increase in marsh surface elevations above a threshold, increased human use of the marshes, and declines in muskrat populations could have facilitated phragmites expansion.

Plant Communities Invaded

Our results indicate that phragmites is expanding exponentially at Stockport Flats, Tivoli North Bay, Iona Island, and possibly Piermont Marsh (Figure 2). Piermont, with the highest percentage of phragmites, has lost 10.86 ha of the typically species - rich salt meadow cordgrass dominated community and 8.5 ha of Olney threesquare mixed areas. Our results at Piermont are similar to those on the Connecticut River where phragmites was found to invade and replace cattail, salt meadow cordgrass, salt grass, and black grass (Juncus gerardi) plant communities without preference (Warren and Fell 1996).

If phragmites continues to invade Hudson River marshes at the current rates, plant species diversity may eventually decrease as plant communities are replaced by phragmites. Although phragmites has invaded proportionally much larger areas of cattail marsh at all four sites the invasion of smaller areas with higher plant species diversity (e.g., Piermont) may pose a greater risk to the overall species diversity of the marsh.

In the freshwater tidal marshes at Stockport and Tivoli there is no immediate threat of large scale dominance by phragmites. Conversion of Iona Island and Piermont Marsh to phragmites monocultures, however, appears likely at the current rates of spread. The impacts of phragmites invasion on the marsh-estuarine ecosystem are difficult to estimate. Phragmites contribution to the detrital food web is comparable to cattail (Warren and Fell 1996); however, the quality of phragmites monocultures as habitat for birds and invertebrates is poorly understood. It is clear that phragmites monocultures change the structure of the marsh, but we have found no data documenting losses of plant species in phragmites dominated tidal marshes.

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Appendix 1. Aerial Photointerpretation Key for Identification of Phragmites Stands.

1. Texture (frequency of tonal change in the photographic image): Tight dense growth causing a "fine" appearance.

2. Tone (relative brightness of the image): Usually lighter appearance in winter and summer, darker in fall (September - November).

3. Monotypic appearance: Only one plant type represented, consistent height, texture, tone, etc. throughout.

4. True shadow: Judged by sun angle, caused by the tendency of phragmites to be much taller than other marsh plants.

5. Circular or rounded for at least part of the stand's perimeter.

6. Site: Present within a currently known stand area.

7. Shape: Consistent with known shape. As phragmites spreads it often maintains its original shape.

8. Habitat: Consistent with phragmites affinities, i.e., higher marsh elevations.

9. Size: Consistent with known rates of spread.

10. Stand has characteristic low point in its center.

REFERENCES

Adams, K.R. 1990. Prehistoric reedgrass (Phragmites) "cigarettes" with tobacco (Nicotiana) contents: a case study from Red Bow cliff dwelling, Arizona. Journal of Ethnobiology 10:123-139.

Avery, T.E. 1977. Interpretation of aerial photographs. Burgess Publishing Co. Minneapolis.

Bernard, J.M. 1995. Some observations on Phragmites stolons. NYFA Newsletter 6:2.

Blair, E.A., and W.C. Nieder 1993. Mapping of the Hudson River NERR: Creating tools for tidal wetland research, management and education. Final report to the Hudson River Foundation. New York, NY.

Boorman, L.A., and R.M. Fuller. 1981. The changing status of reedswamp in the Norfolk Broads. Journal of Applied Ecology 18:241-269.

Buck E.L. 1995. Selected environmental factors and the spread of Phragmites australis (common reed) on the lower Connecticut River. Master's thesis. Connecticut College, New London, Connecticut.

Cross, D.H. and K.L. Fleming. 1989. Control of phragmites or common reed. U.S. Fish and Wildlife leaflet 13.4.12. Ft. Collins, CO.

DeVries, C., and C. B. DeWitt. 1986. Freshwater tidal wetlands community description and relation of plant distribution to elevation and substrate. Pages IX-1 - 43 in E.A. Blair and J.C. Cooper, editors. Final reports of the T. Polgar Fellowship Program, 1985. Hudson River Foundation, New York, NY.

Eastman, R. J. 1992. IDRISI 4.1, user's guide. Clarke University. Worcester, MA.

Foley, D.D., and W.R. Taber. 1951. Lower Hudson waterfowl investigation. New York State Conservation Department. Pittman-Robertson project 47-R. Albany, NY.

Gallagher, J.L., and R.J. Reimold. 1973. Tidal marsh plant distribution and productivity patterns from the sea to fresh water - A challenge in resolution and discrimination. Pages 165-183 in Fourth Biennial Workshop, Color Aerial Photography in Plant Sciences and Related Fields, University of Maine at Orono.

Gleason, H.A. and A.C. Cronquist. 1991. Manual of vascular plants of northeastern United States and adjacent Canada. New York Botanical Garden, New York.

Haslam, S.M. 1973. Some aspects of the life history and autecology of Phragmites communis Trin. A review. Polskie Archiwum Hydrobiologii 20:79-100.

Jones, J. 1995. TOSCA reference guide. Clark University, Worcester, MA.

Kiviat E. 1991. Vegetation in the fresh-tidal habitats of Tivoli Bays, Hudson River. Hudson River National Estuarine Research Reserve Contract NA-83-AA-D-CZ061. Hudsonia Ltd., Annandale, NY.

Lillesand, T.M., and R.W. Kiefer. 1979. Remote sensing and image interpretation. John Wiley and Sons, New York.

Marks, M., B. Lapin, and J. Randall. 1994. Phragmites australis (P. communis): threats, management and monitoring. Natural Areas Journal 4:285-294.

McNabb, C.D., and R.R. Batterson. 1991. Occurrence of the common reed, Phragmites australis, along roadsides in lower Michigan. Michigan Academician 23:211-220.

Odum, W.E., T.J. Smith III, J.K. Hoover, and C.C. McIvor. 1984. The ecology of tidal freshwater marshes of the United States East Coast: a community profile. U.S. Fish and Wildlife Service, FWS/OBS-83/17.

Orson, R., R.S. Warren and W.A. Niering. 1987. Development of a southern New England drowned valley tidal marsh. Estuaries 10:6-27.

Reschke, C. 1990. Ecological communities of New York State. New York Natural Heritage Program. N.Y.S. Department of Environmental Conservation, Latham.

Rice, D., and J.C. Stevenson. 1996. The distribution and expansion rate of Phragmites australis in six Chesapeake Bay area marshes. Pages 467-76 in Hallam, C.A., J.M. Salisbury, K.J. Lanfear and W.A. Battaglin, editors. Proceedings of the AWRA Annual Symposium, GIS and Water Resources, 1996. American Water Resources Association, Herndon, Virginia, TPS-96-3.

Roman, C.T., W.A. Niering, and R.S. Warren. 1984. Salt marsh vegetation change in response to tidal restriction. Environmental Management 8:141-150.

Warren, R.S. 1994. Phragmites australis in the tidelands of the lower Connecticut River: patterns of invasion and spread. Report to The Nature Conservancy. New London, Connecticut.

Warren, R.S. and P.E. Fell. 1996. Phragmites australis on the lower Connecticut River: Impacts on emergent wetlands and estuarine waters. Contract #CWF 318R Long Island Sound Research Fund, State of Connecticut Department of Environmental Protection. Connecticut College, New London.