Belowground Biomass of *Phragmites australis* in Coastal Marshes

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Abstract - The distribution of belowground biomass within monotypic stands of invasive *Phragmites australis* (Common Reed) was documented from a series of oligo-, meso-, and polyhaline coastal marshes in New Hampshire. Soil profiles were described, and live biomass was documented growing to a maximum depth of 95 cm for roots and 85 cm for rhizomes. Our data show that invasive *P. australis* utilizes a greater depth range than native graminoids (90% within the top 70 cm and top 20 cm, respectively). We corroborate prior anecdotal observations and provide further evidence illustrating the potential for this invasive plant to access resources (i.e., water and nutrients) at depths greater than the native species with which it competes.

Introduction

Phragmites australis (Cav.) Trin. ex Steudel (Common Reed) is a perennial grass with a cosmopolitan distribution that can occur in a wide range of habitats (Chambers et al. 1999, Halsam 1972). Common Reed has become an aggressive invader of tidal and non-tidal wetlands, riparian areas, agricultural lands, and other natural areas throughout the eastern United States, including New Hampshire (Chambers et al. 1999, Fell et al. 2003, Saltonstall et al. 2004). Such rapid expansion appears to be due to a Eurasian variety of *Phragmites australis* (Saltonstall 2002), which has recently been distinguished from native varieties endemic to North America, *Phragmites australis* subsp. americanus Saltonstall, P.M. Peterson, & Soreng (Saltonstall et al. 2004). Exotic P. australis appears to be a better competitor than its native cousin especially in increasing eutrophic environments, exhibiting enhanced aboveground morphology (League et al. 2006, Saltonstall and Stevenson 2007), photosynthetic production (Mozdzer and Zieman 2010, Mozdzer et al. 2010), and salinity tolerances (Vasquez et al. 2005). Invasion by exotic P. australis (hereafter Phragmites) has led to the decline or loss of local populations of native marsh grasses, rushes, and sedges, particularly in tidal marshes of New England and the Mid-Atlantic (Keller 2000, Meyerson et al. 2000). In turn, critical structural and functional alterations (e.g., floral diversity, nutrient cycling, carbon storage, and wildlife usage) have occurred in invaded tidal marshes (Benoit and Askins 2002, Findlay et al.

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2003, Keller 2000, Windham and Lathrop 1999). Accordingly, much is known about the biology, physiology, and natural history of *Phragmites* (Haslam 1972), yet effective strategies to control this plant in the United States remain a challenge to the management community (Bart et al. 2006, Burdick and Konisky 2003, Marks et al. 1994).

It has been suggested that the tall shoots of *Phragmites* contribute to its success (Haslam 1972). Often densely spaced, its shoots are capable of extending 3–4 m in height, dwarfing most native species, which range from 0.2–0.8 m in height (Meyerson et al. 2000). The substantial discrepancy in plant height allows *Phragmites* to thrive and expand by easily shading out native competitors. However, *Phragmites*' competitive ability may also be facilitated by its extensive root system, which releases phytotoxins harmful to native plant root systems (Bains et al. 2009, Rudrappa et al. 2007) and is capable of altering the rhizosphere through enhanced gas diffusion (Armstrong and Armstrong 1988, Bart and Hartman 2000) and increased soil elevation (Rooth et al. 2003, Windham and Lathrop 1999). The latter two adaptations minimize physiological stresses associated with flooded, anaerobic conditions prevalent in tidal marsh habitats. These adaptive advantages of *Phragmites* are achieved by dense, finely branched, aerenchymous roots and resilient rhizomes.

Most reports suggest *Phragmites* roots are concentrated in the upper 50 cm of the soil column, while maximum rhizome depths are reported to occur from 40 to 100 cm (Bjork 1967, Kudo and Ito 1988, Ravit et al. 2003). Isolated reports have documented rhizomes penetrating as deep as 1.5 m below the marsh surface (Haslam 1970, Lissner and Schierup 1997). Throughout these accounts, Phragmites roots and rhizomes appear to vary in density and depth over a range of environmental conditions. For instance, Bjork (1967) reported the maximum rooting depth of *Phragmites* was restricted in deeper stagnant waters. Vretare et al. (2001) confirmed these results, and also found the depth of rhizomes were restricted by coarse soils. Although numerous studies have described lateral growth and aboveground expansion, few studies have examined the vertical distribution of Phragmites roots and rhizomes, which may aid in its overall success. Of the few studies reporting on Phragmites' maximum rooting depth (Haslam 1970, Lissner and Schierup 1997, Ravit et al. 2003, Vretare et al. 2001), most have been conducted in Europe and were largely anecdotal, lacking quantitative data, replication, or statistical analysis.

There is evidence that the ability of the exotic variety of *Phragmites* to produce roots and rhizomes extending considerable depths may have aided recent expansion. The historical range of native *Phragmites* was typically limited to the upland edge of tidal marshes (Orson 1999), but now *Phragmites* distribution includes creek banks and the interior of tidal marshes (Moore et al. 2011, Warren et al. 2001), even in polyhaline marshes (Amsberry et al. 2000). As *Phragmites* expands into higher salinity and lower elevation areas, it may be accessing freshwater at the lower marsh contact that flows from upland groundwater to tidal creeks (Adams and Bate 1999, Wieskel and Howes 1991). This deeper freshwater resource is largely unavailable for native graminoids of the high marsh, which typically root

to 20–30 cm (Gross et al. 1991, Steinke et al. 1996, Valiela et al. 1976) and allocate 90% of their belowground biomass in the upper 20 cm of soil (Gallagher and Plumley 1979, Valiela et al. 1976, Windham 2001). In New England salt marshes, Burdick et al. (2001) suggested *Phragmites* might be accessing deeper pore water that was measurably less saline than shallower depths in the soil profile. This finding was particularly evident during late summer months when freshwater flows and water-table elevations were at their minimum. While their study provided evidence of a salinity gradient with depth, it did not document the presence or distribution of belowground roots and rhizomes within the marsh profile.

Building upon prior studies, we examined soil cores collected from ten monotypic stands of invasive *Phragmites* and one stand of the native form in coastal marshes in New Hampshire, across oligohaline, mesohaline, and polyhaline conditions. Our research 1) quantitatively documents the presence, depth range, and biomass of live roots and rhizomes within the soil profile associated with monotypic stands of *Phragmites*, 2) evaluates the potential influence of salinity regime, soil type, and variety of *Phragmites* on belowground biomass and stand properties, and 3) suggests how knowledge of belowground biomass distribution can improve monitoring strategies.

Methods

Field collection

Soil cores were collected from monotypic stands of *P. australis* at eleven coastal marsh sites within New Hampshire (Fig. 1). All sites but one (Site 3) were located within tidal marshes. Of the 11 study sites, 10 contained the invasive form of *P. australis*, whereas 1 supported the native form (Site 8), *P. australis* subsp. americanus (Saltonstall et al. 2004). Cores were obtained using a gouge auger (I.D. 30 mm x 100 cm; Eijkelkamp model #04.01), allowing collection of intact profiles with minimal soil mixing or compaction to 100 cm. While this coring device gathered samples more narrow in diameter than other published methods, it was preferred because it allowed for consistent and successful extraction of deep cores regardless of soil type or texture (e.g., dense clay layers, cobble, or Phragmites rhizomes) that can hinder coring success. Cores were described in the field using standard methods for soil classification (USDA-NRCS 2010) and texture (Thien 1979), and then grouped into either of two simplified categories, "silt" versus "sand" soils, to facilitate comparison. Soils categorized as "silt" had smooth texture (not gritty) and included textures described as silt, silt loam, clay loam, and clay, while "sand" soils were gritty to the touch and included textures described as sand loam and sandy clay loam. Sandy clay soil types were not encountered at our study sites. After descriptions were completed, soil cores were labeled, wrapped in foil, and stored at 4 °C until laboratory analysis of biomass.

Paired cores (n = 2) were collected at 9 of the sites, whereas 4 cores were taken from haphazardly selected locations at 2 of the sites: Site 7 (an exotic population) and Site 8 (a native form in the same marsh) (Fig. 1). The only native stand of *Phragmites* in New Hampshire is located in the Great Bay National

Estuarine Research Reserve. Sites were grouped into 3 habitat types according to the classification of Odum (1988) following measurements of pore-water salinity at 3 locations in the stand at a depth of 40 cm. Pore water was obtained using a 1-mm-I.D. stainless steel tubing fitted with a 60-mL plastic syringe to draw

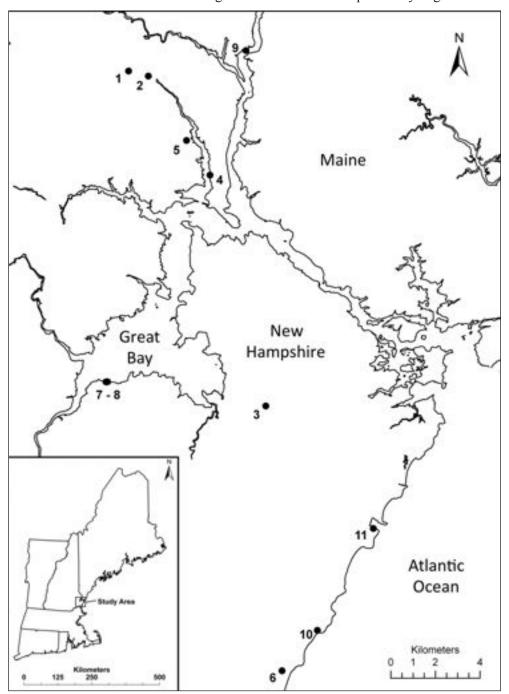


Figure 1. Study sites within Great Bay, NH and its tributaries. Black dots represent the 11 study sites.

water out of the saturated soil at the specified depth. Salinity was then measured in the field using a hand-held temperature-corrected optical refractometer that was calibrated with standard solutions (0 ppt and 15 ppt) daily. Three of the sites were determined to be fresh to oligohaline (0–5 ppt), 5 were mesohaline (5–18 ppt), and 3 were polyhaline (18–30 ppt). Collecting cores from monotypic stands insured that live root material from plants other than *Phragmites* would not be included in the sample, thus simplifying the subsequent sorting process. Two additional sets of 4 cores were collected in native marsh dominated by *Spartina patens* (Aiton) Muhl (Saltmeadow Cordgrass) (Sites 7 and 8) to provide comparable belowground biomass data. *Phragmites* stand properties were characterized at each site by counting live shoots and measuring stand height (mean of 3 tallest) within a 0.5-m² plot directly adjacent to each of the core sample locations.

Root and rhizome determinations

To determine the biomass contribution of live roots and rhizomes throughout the soil profile, the cores were divided into 5-cm sections from top to bottom (e.g., 0-5, 5-10, etc. to a depth of 100 cm). To facilitate sorting of organic material, sections were placed individually in shallow trays partially filled with water. Live roots and rhizomes from each core section were collected using forceps under a dissecting scope. The resulting live biomass was washed of sediment and dried at 65 °C for a minimum of 48 hours until it reached constant weight (Table 2).

Statistical analyses

One-way, fixed effects analysis of variance (ANOVA) models were used to compare belowground biomass components of entire cores, shoot density, and stem height for each salinity regime, soil type, and *Phragmites* variety. Since multiple cores (sub-samples) were taken at each site, data analysis for one-way ANOVAs were conducted by averaging sub-samples. Tests to determine the effect of *Phragmites* variety used the 4 cores from each population as replicates. Student's t post hoc test (α = 0.05) was run to determine differences among means for effects deemed significant in ANOVA models. To satisfy assumptions of normality, root data were inverse transformed and rhizome data were log transformed.

To identify the potential effects of depth, sub-samples were averaged and depth data were pooled together into 20-cm increments (0–20, 20–40, 60–80, 80–100) to reduce variability (e.g., improve homoscedasticity and normality of residuals). Root and rhizome data were log transformed. A three-way fixed effects ANOVA model (depth, salinity regime, soil type) was used to compare belowground biomass (root and rhizome) over depth. To show the effects of salinity regime by soil depth and soil type by soil depth, the data were analyzed using a one-way ANOVA for each category. A post hoc Student's *t* test was run to determine differences among depths.

Results

Live roots and rhizomes were documented to a maximum depth of 95 cm and 85 cm, respectively, among the sites sampled (Table 1). Belowground biomass

Table 1. Summary data of *Phragmites* (belowground biomass and stand properties) and site characteristics (soils and salinity). Site 8 was the native variety; only one core was assessed at Site 4.

	Max	Max	Total	Total						Phragmites	hragmites Phragmites
	root	rhizome	root	rhizome	Total	Mean				average	average
	depth	depth	biomass	biomass	biomass	rhizome :	Salinity	Soil	Salinity	density	height
Site	(cm)	(cm)	(g m ⁻²)	$(g \text{ m}^{-2})$	(g m ₋₂)	root	category	type	(ppt)	(# m ⁻²)	(cm)
1	52.5	37.5	140	2320	2460	16.4	Oligohaline	Sand	0	82	378
7	67.5	67.5	170	1850	2020	10.5	Oligohaline	Sand	0	110	349
33	42.5	40.0	130	3030	3160	15.4	Oligohaline	Silt	0	142	345
4	70.0	75.0	420	5830	6250	13.9	Mesohaline	Sand	10	174	461
5	70.0	82.5	470	2200	2680	4.8	Mesohaline	Silt	15	06	366
9	65.0	25.0	1080	4250	5320	3.5	Mesohaline	Sand	15	174	253
7	8.65	22.5	230	430	099	2.4	Mesohaline	Sand	12	87	295
∞	76.3	25.0	380	250	640	6.0	Mesohaline	Sand	17	129	234
6	65.0	47.5	120	1250	1370	10.6	Polyhaline	Silt	20	72	247
10	87.5	25.0	430	1070	1500	1.9	Polyhaline	Sand	24	220	362
11	0.09	0.09	450	2980	3430	0.9	Polyhaline	Silt	24	224	330

was observed throughout the majority of the soil profile across all pore-water salinity regimes and soil types. Root biomass ranged almost 10-fold from 120 to 1080 g m⁻². Rhizome biomass ranged from 250 to 5830 g m⁻² and generally was 2- to 20-fold greater than root biomass, with one exception: the native stand (Site 8; Table 1).

Although the total live biomass (root and rhizome) was similar among the 3 salinity regimes, mean root biomass of mesohaline stands was significantly greater than that of oligohaline stands, with polyhaline sites intermediate (Table 2). Though not significant, mean rhizome biomass followed the inverse pattern. As a result, rhizome divided by root biomass produced a ratio that was significantly greater in oligohaline compared with mesohaline or polyhaline marshes. Aboveground shoot density and height also appeared to be affected by salinity, although the differences were not statistically significant (Table 2). Oligohaline stands exhibited the lowest shoot density and tallest plants, but these differences were not statistically significant (Table 2).

A comparison of native and invasive stands (n = 4) occurring at Sandy Point Marsh showed no significant difference in belowground biomass, though the native averaged 65% more roots and 42% less rhizomes than the invasive stand (Table 2). The invasive variety grew significantly taller than the native variety (P = 0.016) and apparently had lower stem densities (P = 0.058).

Both roots and rhizomes showed a pronounced decreasing trend in biomass when pooled into 20-cm depth increments (Fig. 2). Overall root biomass was greatest in the top 40 cm of the core and significantly declined thereafter. Similarly, rhizome biomass was greatest in the upper depth categories, with about two thirds of the biomass in the upper 40 cm of sediment.

When the root biomass data were analyzed by salinity regime, a decreasing trend with depth was most apparent within mesohaline sites, which demonstrated a sharp, decrease in live root biomass with depth (Fig. 3a). Oligohaline

Table 2. Comparison of *Phragmites* belowground biomass and stand properties by salinity regime, *Phragmites* variety, and soil type. Values are means ± 1 standard error; letters indicate differences among the means using a post-hoc Students *t*-test.

	Root biomass (g m ⁻²)	Rhizome biomass (g m ⁻²)	Rhizome : root	Stem density (# m ⁻²)	Stem height (cm)
Salinity category					
Oligohaline	150 ± 10 a	2400 ± 340	$16.8 \pm 3.3 \text{ a}$	111 ± 17	357 ± 10
Mesohaline	520 ± 150 b	2590 ± 1080	$5.0 \pm 2.3 \text{ b}$	131 ± 19	322 ± 42
Polyhaline	$330 \pm 110 \text{ ab}$	1770 ± 610	$6.4 \pm 2.2 \text{ b}$	172 ± 50	313 ± 34
<i>P</i> -value	0.043	0.803	0.032	0.420	0.731
Phragmites Variety					
Native	380 ± 100	250 ± 170	0.9 ± 0.6	129 ± 14	$234 \pm 14 a$
Invasive	230 ± 80	430 ± 260	2.4 ± 1.9	87 ± 11	$295 \pm 12 b$
P-value	0.148	0.904	0.476	0.058	0.016
Soil Type					
Sand	410 ± 120	2280 ± 780	7.2 ± 2.5	139 ± 19	333 ± 30
Silt	290 ± 100	2370 ± 420	11.0 ± 4.0	132 ± 34	322 ± 36

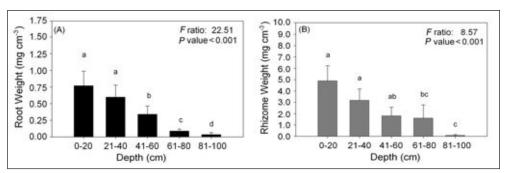
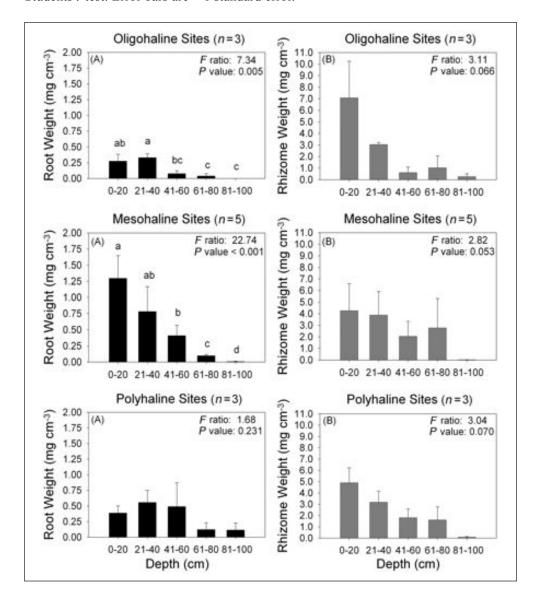


Figure 2. Average live root (A) and rhizome (B) biomass by 20-cm depth groupings in soil profile. Lowercase letters indicate differences among the means using a post-hoc Students t-test. Error bars are ± 1 standard error.



and polyhaline roots, however, exhibited relatively high biomass at mid-depths, peaking at the 20- to 40-cm depth range. In contrast, the biomass of live rhizomes declined sharply with depth in oligohaline sites, but was more gradual in polyhaline sites and consistent in mesohaline sites to a depth of 80 cm (Fig. 3b). When the data were sorted by soil type, live root biomass was similar in abundance in the top 60 cm for both sand and silt sites. Deeper than 60 cm, root biomass sharply declined, more so in silt sites (Fig. 4). Live rhizome biomass showed a gradual decline with depth for both soil textures.

Discussion

Several authors have noted that *Phragmites* has the ability to develop extensive roots and rhizomes that can grow rapidly (summarized in Engloner 2009, Haslam 1971, Soukup et al. 2002), reach considerable lateral length (Haslam 1972, Orson 1999, Rice et al. 2000), and penetrate deep within marsh soils (Bjork

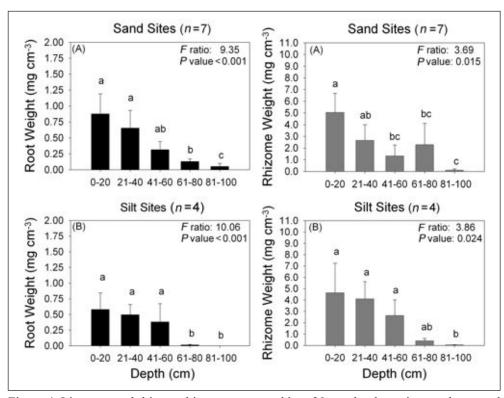


Figure 4. Live root and rhizome biomass averaged into 20-cm depth sections and grouped by (A) sand and (B) silt soil types. Lowercase letters indicate differences among the means using a post-hoc Students t-test. Error bars are ± 1 standard error.

Figure 3 (opposite page, lower figure). Live (A) root and (B) rhizome biomass averaged into 20-cm depth sections and grouped by pore-water salinity regime (oligohaline, mesohaline and polyhaline). Lowercase letters indicate differences among the means using a post-hoc Students t-test. Error bars are ± 1 standard error.

1967, Haslam 1970, Lissner and Schierup 1997, Ravit et al. 2003). All of these qualities potentially afford *Phragmites* an adaptive advantage over most native plants sharing tidal wetland habitats. In all sites sampled in this study, live roots of *Phragmites* were documented at depths greater than 40 cm and reached a maximum of 95 cm, exceeding the depth range of native graminoids (Table 3). Our study provides quantitative support for observations of *Phragmites* rooting depths noted in the literature by showing that this ability is in fact common for this species in New Hampshire and was consistently exhibited over a wide range of environmental conditions (e.g., salinity and soil texture).

In contrast, rhizomes exhibited greater variability, with rhizomes in one stand limited to soil depths as shallow as 22.0 cm, while another stand had rhizomes

Table 3. Observations of belowground biomass distribution and depth limits of *Phragmites australis* and other graminoids inhabiting tidal marsh. Percentages shown indicate proportion of total biomass contained within the denoted depth range. *observations include non-tidal sites; ** grown in experimental setting.

		Depth of maximum biomass Maximum		num
C	Consider			Maximum
Source	Species	(cm)	(%)	depth (cm)
Bjork 1967	Phragmites australis*	30		100–130 (soft substrate)
	P. australis			30 (hard/coarse substrate)
Haslam 1970	P. australis*			50–80** up to 200
Gallagher and Plumbley 1979		10-20		
Lissner and Schierup 1997	P. australis			35–85**
Rice et al. 2000	P. australis			100+
Vretare et al. 2001	P. australis			110**
Lynch and Saltonstall 2002	P. australis (var. americanus)			100+
Ravit et al. 2003	P. australis			70+
Moore et al. (this study)	P. australis	0–20	42	95 (roots); 85 (rhizomes)
Valiela et al. 1976	Spartina patens	0-15		20 (roots); 15(rhizomes)
	S. alterniflora Loisel.	0-15		20 (roots); 20 (rhizomes)
Gallagher and Plumbley 1979	S. patens	0 - 10		
Gross et al. 1991	S. alterniflora	0 - 10		30
	S. alterniflora			30
Steinke et al. 1996	Agropyron repens (L.) P. Beauv.	2–4		20
Windham 2001	S. patens			30
Saunders et al. 2006	S. patens/ Schoenoplect americanus (Pers.) Volkart ex Schinz & R. Keller	us 0–15		65 (roots); <15 (rhizomes)
Elsey-Quirk et al. 2011	S. alterniflora	0-15	86	
	S. patens	0-15	97	
	Juncus roemerianus Scheele	0–15	99	
	Distichlis spicata (L.) Greene	0–15	100	
Moore et al. (this study)	S. patens	0-20	92	70 (roots); 30 (rhizomes)

over 80 cm deep (Table 1). We suspect that this variability may have been due, at least in part, to the soil type, as sandy, mineral soils have been noted to inhibit deep penetration by rhizomes (Bjork 1967, Haslam 1970, Kudo and Ito 1988, Vretare et al. 2001). Additionally, the relatively narrow diameter coring device used in this study, while able to successfully obtain cores to depth, may be less likely to capture large, unevenly distributed rhizomes than more abundant roots. Nevertheless, the documentation of rhizomes across this depth range (22 to 83 cm) is consistent with less systematic observations of *Phragmites* depth in the literature (Table 3).

The distribution of belowground biomass is equally important as maximum penetration depth. We found root and rhizome biomass distributed over a greater depth range than most native plant halophytes, with 90% of the biomass occurring within the top 70 cm, versus the top 20 cm for *Spartina patens* (Fig. 2; Table 3), which has been noted co-occurring with *Phragmites* at coastal sites in New Hampshire and Massachusetts (Burdick et al. 2001, Moore et al. 2011). Windham (2001) documented similar results for *Phragmites*, finding considerable belowground biomass up to a depth 50 cm. Deep penetration of belowground biomass may allow *Phragmites* to access resources at soil depths affected less by tidal influences, thereby alleviating salinity stress and allowing it to expand its habitat range into more saline marshes.

Phragmites belowground biomass distribution may also be affected by environmental factors. Overall, a shallower depth range and significantly less biomass were found for roots in oligohaline sites compared with more saline sites (Fig. 3a), suggesting that *Phragmites* may allocate more of its resources to belowground growth to sustain itself in more physiologically taxing environments. Our findings are very similar to those documented by Soetaert et al. (2004) in Belgium and the Netherlands, who reported a total root biomass of 164 g m⁻² in an oligohaline marsh and 414 g m⁻² in a mesohaline marsh. Our study presents an average of 150 ± 10 g m⁻² in 3 oligohaline marshes and 520 ± 150 g m⁻² in 5 mesohaline marshes. The majority of rhizome biomass was also found at shallow depths for oligohaline sites, while rhizome biomass was more evenly distributed over depth in mesohaline and polyhaline regimes (Fig. 3b).

Phragmites aboveground morphology also appeared to be affected by porewater salinity, where stands tended to be taller with less dense shoots at sites lower in salinity (Table 2). This trend was shown in previous studies (Adams and Bate 1999, Chambers 1997, Hellings and Gallagher 1992, Soetaert et al. 2004), and coupled with belowground root biomass data, these trends suggest Phragmites may be altering its aboveground-to-root-biomass ratio based on salinity. In the more physically benign oligohaline marshes, Phragmites may be allocating a larger proportion of resources toward its aboveground structure to better compete for light. In more saline environments, Phragmites appears to commit greater resource allocation to roots. As marshes become more physically stressful (e.g., salinity, waterlogging, etc.) resource competition shifts from light to nutrients (Bertness 1991, Crain et al. 2004). The morphological plasticity of Phragmites

allows it to compete for belowground resources by increasing both its root biomass and depth range to potentially access fresher waters and nutrients beyond the reach of native marsh plants (Adams and Bate 1999, Burdick et al. 2001). *Phragmites* is capable of overcoming the stresses associated with greater depths (e.g., anoxia and toxic organic compounds) by developing thick hypodermal layers around its roots and rhizomes, which serve to minimize oxygen loss and promote diffusion of oxygen to more susceptible root tips (Armstrong and Armstrong 1988, Soukup et al. 2002).

While our sample size was not sufficient to make statistically robust conclusions regarding comparison of root and rhizome biomass between native and invasive forms of *Phragmites*, our data suggest native plants may invest more biomass in roots and less in rhizomes than the invasive form. A common garden experiment, using rhizomes collected from the same two stands in New Hampshire, found that native plants produced more roots than exotic plants (Holdredge et al. 2010). In other studies, League et al. (2006) found similar total belowground biomass among varieties, whereas Vasquez et al. (2005) found greater rhizome biomass associated with the invasive variety. Our results agree with Holdredge et al.'s (2010) that native stands produce more roots and fewer rhizomes, and these differences in belowground biomass allocation could help explain success of the invasive over the native variety.

Together with restoration of hydrology, increased salinity is critical in promoting re-establishment of native plant communities in tidal restoration efforts, particularly when these efforts are aimed at eliminating *Phragmites* (Bart et al. 2006, Rozsa 1995). The potential of *Phragmites* to obtain resources at soil depths beyond the reach of native marsh plants is very important in understanding competitive dynamics and especially important within a context of wetland restoration and vegetation management. Accordingly, measurement of pore-water salinity is recommended by salt marsh monitoring protocols (Drociak and Bottitta 2003, Neckles et al. 2002, Niedowski 2000, Steyer and Stewart 1992). However, none of the protocols suggest monitoring pore-water salinity throughout the range of live *Phragmites* roots documented in this study. Our findings suggest pore-water monitoring at greater depths is warranted to evaluate potential water resources available to Phragmites (sensu Burdick et al. 2001). Additional data can be directly obtained at greater depths or through the use of new field approaches such as electromagnetic induction that rapidly integrates pore-water salinity over a depth range of up to 150 cm (Moore et al. 2011).

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