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ORIGINAL PAPER

PhragNet: crowdsourcing to investigate ecology and management of invasive *Phragmites australis* (common reed) in North America

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Abstract Invasion biology research, often performed by scientists at relatively small spatial scales, provides experimental precision but may be limited in generalizability. Conversely, large-scale invasive species management represents a largely untapped wealth of information on invasion ecology and management, but such data are difficult to capture and synthesize. We developed a network ("PhragNet") of individuals managing wetlands occupied by native and non-native lineages of the invasive wetland grass *Phragmites australis* (common reed). This network collected environmental and genetic samples, habitat data, and management information to identify environmental and plant community associations of *Phragmites* invasion and patterns of management responses. Fifty managers overseeing 209 *Phragmites* stands in 16 US states and ON, Canada participated. Participants represented federal agencies (26%), municipalities (20%), NGOs (20%), academia (14%), state agencies (12%), and private landowners (8%). Relative to the native lineage, non-native *Phragmites* occurred in areas with higher nitrate/nitrite and ammonium than non-native *Phragmites*. Stand interiors had higher soil electrical conductivity than nearby uninvaded areas, consistent with use of road salt promoting spread of *Phragmites*. Non-native *Phragmites* co-occurred with fewer plant species than native *Phragmites* and was actively targeted for management. Herbicide was applied to 51% of non-native stands; surprisingly, 11% of native stands were also treated with herbicide. This project demonstrates the utility of crowdsourcing standardized data from resource managers. We conclude by describing how this approach could be expanded into an adaptive management framework, strengthening connections between wetland management and research.

Keywords Habitat management · Herbicide · Invasive species · Nutrients · Salinity · Wetlands

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Introduction

Invasive species collectively represent the second most common driver of recent extinctions after habitat loss (Bellard et al. 2016). There is a great deal of ongoing management to control invasive species. For example, the US Federal Government spent $2.3 billion on invasive species management in 2014 (The National Invasive Species Council 2014). Ongoing control efforts represent a tremendous, but thus far largely untapped, opportunity to learn about the ecology of invasive species and more effectively manage impacted habitats.

Technological advances in recent decades have facilitated an increase in the use of "crowdsourcing" in scientific research (Theobald et al. 2015). Crowdsourcing entails soliciting information from a large pool of individuals, typically through the internet, to answer targeted questions or perform tasks. Applied in a research context, crowdsourcing can narrow the divide between academics and practitioners in efforts to improve natural resource management and conservation outcomes (Conrad and Hilchey 2011). Crowdsourcing also enables ecological problems to be investigated at large spatial scales, which are often relevant to management but not tractable to traditionally small teams of researchers. Broad-scale, collaborative natural resource management and conservation efforts can use crowdsourced data to identify key drivers of ecological phenomena, such as species invasions. When natural resource managers share common challenges, improved conservation outcomes can be achieved by learning from one another (Wondolleck and Yaffee 2000). Projects that employ crowdsourcing facilitate such collaboration.

Phragmites australis (Cav.) Trin. ex Steud. (common reed; hereafter *Phragmites*) is a promising candidate for study via crowdsourcing. Non-native *Phragmites* is a high-priority challenge for wetland and wildlife managers because it can cause major disruptions to wetland diversity, structure, and function (Able and Hagan 2000; Benoit and Askins 1999; Ehrenfeld 2003; Gratton and Denno 2006). Despite being one of the most scientifically studied invasive species, there remain substantial areas of uncertainty regarding management of *Phragmites*. Best practices for controlling *Phragmites* and restoring impacted habitats are still not resolved despite 40 years of management efforts (Martin and Blossey 2013; Hazelton et al. 2014). Part of the problem is that *Phragmites* management is performed by many different types of organizations working across jurisdictional boundaries over large geographic areas. There are few mechanisms by which these disparate groups can efficiently share findings to support collective learning about management efficacy (Martin and Blossey 2013).

An additional source of uncertainty in *Phragmites* management arises from non-native *Phragmites* being a "cryptic" invader, with introduced European genotypes and a native subspecies having overlapping ranges (Saltonstall 2002; Saltonstall et al. 2004). In general, non-native *Phragmites* exhibits more traits associated with invasiveness, e.g., early emergence, rapid growth, high biomass, and displacement of native plant species (League et al. 2006; Price et al. 2014). However, the native subspecies can also exhibit rapid spread under conducive conditions (Lynch and Saltonstall 2002) and managers are not always able to confidently differentiate native and non-native lineages (Saltonstall 2003). This is an especially critical area of uncertainty because the native subspecies has declined across large portions of its range (Saltonstall 2011).

The extent to which environmental conditions determine the likelihood and magnitude of *Phragmites* invasion is also uncertain (Martin and Blossey 2013; Hazelton et al. 2014). Non-native *Phragmites* benefits from anthropogenic disturbance (Jodoin et al. 2008; Brisson et al. 2010; Eallonardo and Leopold 2014) and elevated nitrogen is associated with *Phragmites* invasion of New England salt marshes (Bertness et al. 2002). Increased availability of soil nutrients appears to provide a competitive advantage to non-native *Phragmites* over the native subspecies (Mozdzer et al. 2010; Holdredge et al. 2010). However, the expectation that eutrophication drives *Phragmites* invasion is largely based on research in Atlantic coastal systems, where nitrogen limitation may generally be greater than is found in inland systems (Caraco et al. 1987). Recent studies from the Midwest/Great Lakes region have found no differences in inorganic nitrogen or reactive phosphorus availability between plots with and without *Phragmites* (Tulbure and Johnston 2010) or in plots with native versus non-native *Phragmites* (Price et al. 2014).

We addressed the aforementioned areas of uncertainty for *Phragmites* management using a crowdsourcing approach. Our goals were to: (1) develop a cooperative learning network, "PhragNet," for studying *Phragmites* invasion and control; (2) provide native versus non-native genetic identifications for managers; and (3) investigate *Phragmites* invasion ecology using a continental-scale, highly replicated sampling framework. We hypothesized that non-native *Phragmites* would occur in areas with elevated soil nutrient concentrations and salinity (electrical conductivity) relative to areas with native or no *Phragmites*, achieve higher community dominance (relative cover) than native *Phragmites*, and would be associate with decreased plant diversity. We describe the groups of managers that participated in the network, our sampling protocol, and how this approach could be expanded into a long-term adaptive management framework.

Methods

Crowdsourcing

To recruit participants, we created a simple, informative website, which described our project and served as a document hub for our protocol and data forms. The website was maintained by the project coordinator on a free web hosting service to minimize project cost. The project coordinator and web-site administrator answered queries from individuals interested in the project, maintained up-to-date information on the website, performed web-based outreach to recruit new project participants, and ultimately sent participants sampling supplies and data forms.

We advertised introductory webinars through email listservs for the Great Lakes *Phragmites* Collaborative (greatlakesphragmites.net), Plant Conservation Alliance (nps.gov/plants), Northeast Illinois Invasive Plant Partnership (niipp.net), Invasive Plants Association of Wisconsin (ipaw.org), and the Midwest Invasive Plant Network (mipn.org). These list-servs targeted managers actively involved in weed and invasive species management. Several people forwarded the invitation to other relevant networks, such as the Colorado Weed Managers network, which expanded our outreach efforts via word-of-mouth. We conducted online webinars on 14 September 2012 and 20 September 2013. In the webinars, we described our research objectives, the activities that participants would perform, and how managers could benefit from participating, namely by receiving free *Phragmites* genotyping services and by contributing to a broader effort to improve *Phragmites* management. Many people followed up with questions, or emailed the project coordinator directly to ask questions; such personal communications facilitated participation in the project and were possible because we were targeting a relatively small group to join the network for this pilot.

Following a pilot year in 2012, we sought to expand our network in 2013 by creating a more user-friendly experience for participants. We sent interested managers packages containing all of the materials they would need to perform monitoring and to submit their data and samples. The packages contained data-entry forms, simple written and visual protocols for data and sample collection, pre-labeled sample bags, answers to frequently asked questions, and pre-paid flat-rate shipping boxes for sending samples to us for analysis. The project coordinator was available for questions by phone and email throughout the process.

For each *Phragmites* stand, participants reported management actions that were underway or planned, including use of herbicide, mowing, prescribed fire, seeding, other activities, or no action. While our outreach efforts focused on *Phragmites* populations undergoing management, intended for management, or being considered for management, inclusion of the “no action” category was important in the case of stands for which management was contingent on genetic lineage identification.

Monitoring protocol

Managers monitored wetlands and other habitats containing *Phragmites* using a transect-based protocol. The scalable protocol was designed so that it could be adapted to *Phragmites* stands of different sizes and would be accessible to managers with limited technical training and experience. The number of transects used to sample each stand depended on its area: one transect for stands $\leq$1 ha, two for stands of 1–2 ha, and three for stands of 2–5 ha. For stands >5 ha, we consulted with participants to determine how many transects would be feasible given stand size and the logistical challenges associated with sampling larger areas.

The sampling protocol entailed the following steps: the manager selected an arbitrary point on the edge of the stand, recorded the latitude and longitude using a GPS-enabled device, collected leaves (as fresh as possible) from three *Phragmites* stems spaced several paces apart, placed the leaves into a labeled zippered plastic storage bag and sealed the bag closed; these comprised the "edge" samples. The manager then walked in a straight line approximately 15 m into the stand and collected coordinates and leaves in this "interior" location (referred to as the interior transect-position). In addition, soil samples were collected from the interior of the stand; these comprised three ~45-ml, 10-cm deep samples collected several paces apart, which were then composited into a labeled plastic bag. Samples were collected using a plastic spoon (provided), or another soil sampling implement available to the manager, e.g., a metal spoon or trowel. Once samples were composited into the plastic bag, the bag was sealed to prevent loss of soil moisture.

To assess plant community composition, the manager performed a visual assessment of vegetation cover within their visual field in the interior of the stand. For *Phragmites* stands <1 ha in area, one visual assessment of cover represented the percent cover of the entire stand. For stands larger than 1 ha, which entailed data collection along multiple transects, one visual assessment of percent cover was recorded for each transect. Percent cover for *Phragmites*, other invasive species, and native species were recorded using five cover classes: none (0%), low (>0% and ≤10%), medium–low (>10% and ≤50%), medium–high (>50% and ≤90%), or high (>90%). The manager also visually assessed soil moisture in the stand interior, categorizing soils as dry, moist, or wet (standing water).

The manager then sampled a paired uninvaded area. This involved returning to the location on the stand's edge where sampling began and continuing to walk in a straight line 15 m outside of the *Phragmites* stand into an adjacent uninvaded area of a roughly comparable habitat type, e.g., paired invaded and uninvaded shallow marsh, stream bank, etc. At this location (exterior transect-position) the manager repeated the sampling performed in the interior, collecting GPS coordinates and soil samples and visually assessing vegetation and soil moisture (but not collecting leaves for genetic analysis).

Soil and genetic analyses

Data sheets, soil samples (in sealed plastic bags), and *Phragmites* leaf samples (also in sealed plastic bags) were shipped to the Chicago Botanic Garden. Soil samples were homogenized and subsampled for analysis of nutrient concentrations (ammonium [NH_4], nitrate/nitrite [NO_x], and orthophosphate [PO_4]) and soil moisture and electrical conductivity (as an indicator of soil salinity from road salt or coastal sources). These soil properties were analyzed because they have been implicated in prior studies of *Phragmites* invasion (Bertness et al. 2002; Mozdzer et al. 2010; Holdredge et al. 2010).

Gravimetric soil moisture and electrical conductivity were measured using standard protocols (APHA 2005). Additional subsamples were extracted using a potassium chloride (KCl) solution and ammonium (NH_4), nitrate/nitrite (NO_x), and orthophosphate (PO_4) concentrations were measured using a SEAL AQ2+ Discrete Analyzer (Seal Analytical, Inc., Mequon, WI, USA) following standard EPA methods. DNA was extracted from *Phragmites* leaf samples and native versus non-native haplotype identifications were performed using the Saltonstall (2003) PCR–RFLP technique for *Phragmites* chloroplast DNA. More detailed descriptions of soil and genetic methods are provided in Price et al. (2014) and Fant et al. (2016).

Much of the data we collected in this study relied on the judgement of resource managers and citizen volunteers, most of whom were not trained as scientists. Performing laboratory assessment of soil samples collected by participants adds objective measurements to what would otherwise be a relatively subjective process of conducting visual assessments, and answering survey questions. Although soil sample chemistry may be affected by storage and transport, we contend that including soil sample analysis and leaf sample genetic analysis in this study contributed valuable objective measurements that render the results of this study more scientifically defensible.

Data analyses

We constructed linear mixed effects models using the 'lmer' function in the lme4 package in R (R Development Core Team 2009; Bates et al. 2015) to evaluate soil attributes as a function of *Phragmites* lineage (native vs. non-native) and transect position (interior vs. exterior). Stand was included as a random error term to account for non-independence among multiple transect positions nested within the same stand. Soil attributes analyzed were percent soil moisture, electrical conductivity, and concentrations of ammonium, nitrate/nitrite, and orthophosphate. Other analyses consisted of summary statistics describing participants, response rates, and frequencies of management activities.

Results

Crowdsourcing

In the pilot year (2012), 6 managers participated in PhragNet; 44 participated in 2013. In 2013, we sent out 56 sampling packages upon request, of which 45 were completed and returned for an 80% response rate; one return package was lost in the mail in-route. The response rate could not be determined for 2012 because we did not send sampling packages that year. Total area of *Phragmites* stands sampled by participants was approximately 310 ha (this is a conservative estimate that excludes stands of unknown area), comprising 209 *Phragmites* stands. Stands were sampled in 16 US states and ON, Canada (Table 1). The 209 stands were sampled using a total of 249 transects. Each participant contributed data for 1–15 stands, mean 4.2 ± 3.3 (SD). The area of each sampled stand ranged from <0.001 to 40.5 ha (mean 1.5 ± 4.7 ha). The Midwestern U.S., where we were based and initially focused our outreach efforts, was well-represented, with 19 stands sampled in Illinois, 17 in Michigan, and 35 in Wisconsin (Fig. 1). The highest number of stands for a single state came from Colorado ($n = 39$).

Participants included landowners, volunteer stewards, professional natural resource managers from a variety of agencies, and academics. Sampled stands were located on private, municipal, state, federal, and military lands. Federal lands contained the largest stands (mean 3.2 ± 7.9 ha) and comprised the majority of total stand area (56%). Federal agencies comprised 26% of participants, followed by municipalities (20%), non-profit organizations (20%), colleges and universities (14%), state agencies (12%) and private landowners or consultants (8%) (Table 2).

Genetic identifications and environmental conditions

Phragmites leaf samples of sufficient quality (freshness) for genetic analysis came from 166 transects across 140 stands. Of these stands, 85 were determined to be the non-native lineage (61%) and 55 were native (39%). Relative to the native lineage, non-native *Phragmites* occurred in areas with higher ammonium and nitrate/nitrite than native *Phragmites*. Stand interiors (irrespective of lineage) had higher electrical conductivity than uninvaded surrounding areas (Fig. 2; Table 3). Differences in soil moisture and orthophosphate were not significant (Table 3).

In non-native stands, *Phragmites* was the dominant plant species (Fig. 3). In 56% of the non-native stands for which vegetation cover was recorded ($n = 75$), the cover class for *Phragmites* was >90%. In contrast, 30% of native stands had >90% *Phragmites* cover ($n = 53$). In addition, 48% of non-native stands contained no native species, as was true for 30% of native stands. Excluding stands of unknown area, non-native stands and native stands were similar in size and the difference was not significant (non-native: mean 1.9 ± 5.2 ha, $n = 78$; native: mean 2.6 ± 8.1 ha, $n = 54$; $p = 0.54$).

Management actions

A total of eight techniques for *Phragmites* control were reported for 67 non-native stands, 55 native stands, and 62 stands of unknown genotype. "No action" was reported most frequently (57% of stands, $n = 106$), followed by herbicide application (34%, $n = 63$). Infrequently applied actions included mowing (7%, $n = 12$), fire (4%, $n = 8$), grazing (4%, $n = 8$), and hand pulling or cutting of stems (1%, $n = 3$). Seeding and disking (use of a tractor-driven disc harrow) were applied on one stand each. The percentage of stands where no action, herbicide, or other treatments were applied varied by manager affiliation and *Phragmites* lineage (Fig. 4). For example, state governments applied herbicide to 100% of the non-native stands they managed. Most native stands (84%, $n = 55$) were not actively managed, compared to 34% of non-native stands ($n = 29$). 51% of non-native stands ($n = 34$) were treated with herbicide, compared to 11% of native stands ($n = 11$).

Discussion

We developed a network of land managers to crowdsource information on ecology and management of

Table 1 Number of *Phragmites* stands and spatial area by location

State or province	Stands (*n*)	Stands of known area[a] (*n*)	Area (mean ha ± SD)	Total area (ha)
CA: California	5	5	2.2 ± 1.6	10.9
CO: Colorado	39	37	0.9 ± 1.3	34.2
FL: Florida	8	7	0.6 ± 0.7	3.9
IL: Illinois	19	16	1.4 ± 2.1	22.1
IN: Indiana	4	4	20.4 ± 23.1	81.7
MA: Massachusetts	5	3	3.7 ± 2.5	0.1
MD: Maryland	14	13	1.4 ± 3.6	18.8
MI: Michigan	17	14	0.3 ± 0.2	4.3
MT: Montana	14	12	1.3 ± 2.0	16.5
NE: Nebraska	8	8	0.9 ± 0.3	7.1
NJ: New Jersey	1	0	–	–
NY: New York	2	2	0.2 ± 0.0	0.4
OH: Ohio	6	6	6.6 ± 8.1	39.6
SD: South Dakota	11	11	0.6 ± 0.5	6.1
VA: Virginia	12	12	3.9 ± 3.9	46.4
WI: Wisconsin	35	32	0.4 ± 0.4	12.5
ON, Canada	9	9	0.6 ± 0.5	5.6

[a] Stands where area was recorded as approximations (e.g., <1 ha), are included in this analysis

habitats occupied by native and non-native *Phragmites.* Fifty managers overseeing 209 *Phragmites* stands in diverse management contexts across 16 US states and ON, Canada participated. High interest in participating in this project underscores the potential for professional and citizen scientist involvement in invasive species research.

Crowdsourcing

Crowdsourcing data and environmental and biological materials allowed us to sample geographically widespread *Phragmites* populations that were actively managed or under consideration for future management. Often management was contingent on genetic identification of lineages, which motivated managers to participate. Outcomes from this crowdsourcing effort provide insights into factors associated with *Phragmites* invasion, prevailing management efforts, and the diverse types of organizations and individuals engaged in this work.

The 80% response rate we observed comprised individuals that were effectively pre-screened through a series of email or telephone exchanges with the project coordinator. To receive a sampling package, the manager first had to answer several questions via email, including how many stands they intended to sample and the areas of those stands, so that we could provide adequate data sheets and pre-labeled sample bags. Fifty-one individuals expressed interest in the project in 2012, and 105 individuals expressed interest in 2013. Most individuals that expressed interest did not ultimately follow-up with the information necessary to receive sampling packages, possibly because they recognized that participating would take a greater time commitment than they had initially anticipated. We found that using conversations to screen potential participants and sending pre-packaged sampling materials greatly increased participation rates, evident in the increase in participation from 2013 to 2014.

Many managers that participated in this research communicated to us that genetic analysis of *Phragmites* leaf samples, i.e., testing of whether they had native or non-native *Phragmites*, which was provided free of charge, was their primary motivation for participating. Thus, offering genotyping or other technical services could be an effective incentive for projects attempting to collect data and samples via crowdsourcing. However, we caution that managers should be carefully advised about how to collect viable samples. We requested that managers collect green leaf samples to facilitate genetic analysis, but in many

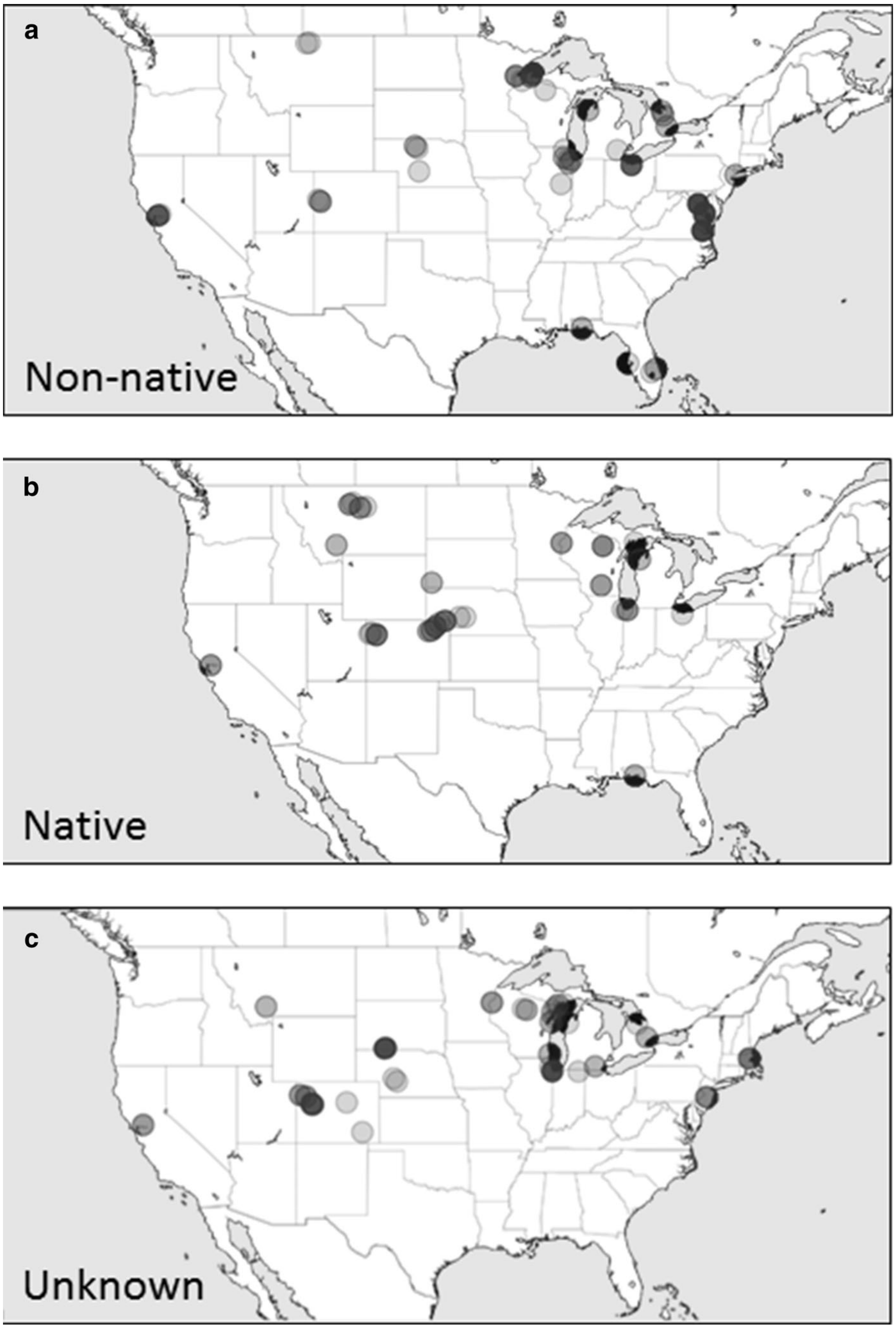

Fig. 1 Maps of sampled *Phragmites* stands by genotype; **a** non-native, **b** native and **c** unknown genotype. Darker circles on the surface of the land indicate more spatially overlapping samples

cases this was not possible. We were unable to determine the genotype of numerous leaf samples that were excessively dry and brittle. As the leaves were sent in sealed zippered plastic bags, and dry samples were primarily from areas with drier climates (e.g., the Great Plains region in fall), there is evidence to suggest that samples were dry at the time of collection, and did not dry out in transit. Some mucky and wet leaf samples could also not be genotyped. These limitations led to a 74% success rate in DNA extraction and lineage identification. We also received a large enough number of samples that it took over a year for our primarily volunteer laboratory technicians to process and analyze all of the samples. In a few instances,

Table 2 Number of *Phragmites* stands and spatial area by manager affiliation category

Org. type	Number agencies (n = 209 stands)	Stands (n = 209)	Stands of known area (n = 119)	Total area (ha) (n = 119 stands)	Area (mean ha ± SD) (n = 119 stands)
Academic	7	40	39	37.8	1.0 ± 1.4
Fed. Gov.	13	62	54	173.4	3.2 ± 7.9
Municipality	10	29	27	23.1	0.9 ± 0.9
Non-profit	10	41	37	15.1	0.4 ± 1.2
Private	4	9	6	1.5	0.2 ± 0.3
State Gov.	6	28	28	60.0	2.1 ± 4.3

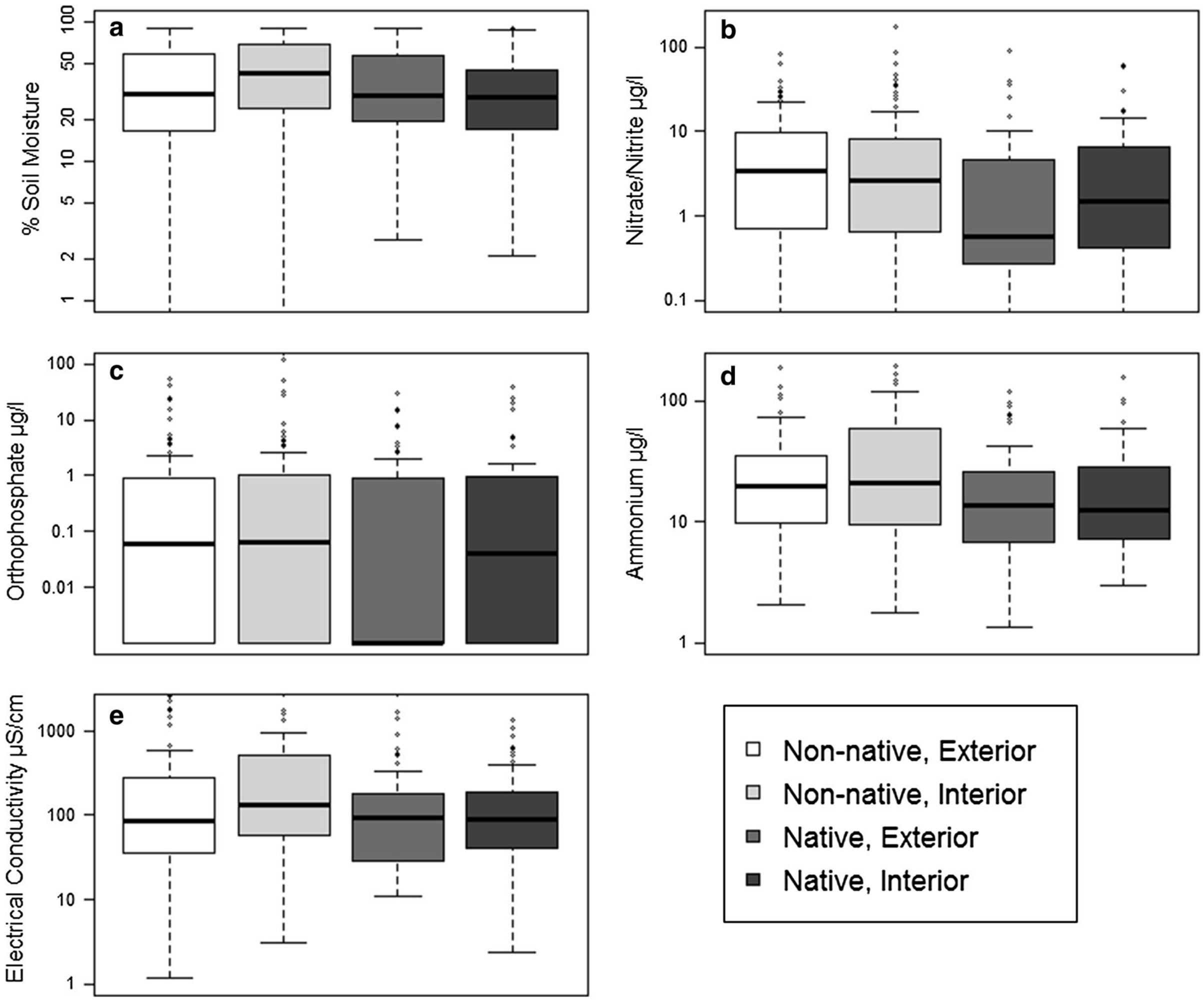

Fig. 2 Box plots showing associations of *Phragmites* genotype (native vs. non-native) and transect-position (interior of stand vs. exterior) with five soil attributes: **a** percent soil moisture, concentrations of **b** nitrate/nitrite, **c** orthophosphate, and **d** ammonium, and **e** soil electrical conductivity (as an indicator of salinity)

Table 3 Means and standard errors for soil attributes of *Phragmites* stands, grouped by lineage and transect position

	Phragmites lineage			Transect-position			Lineage and transect-position interaction
	Native (mean ± SD)	Non-native (mean ± SD)	*P*	Exterior (mean ± SD)	Interior (mean ± SD)	*P*	*P*
Soil moisture %	37.7 ± 24.2	40.7 ± 26.4	0.92	37.4 ± 25.0	41.7 ± 26.1	0.34	0.14
Orthophosphate (μg/l)	2.3 ± 6.4	3.3 ± 11.1	0.43	2.4 ± 6.9	3.5 ± 11.6	0.84	0.85
Nitrate/nitrite (μg/l)	7.3 ± 16.7	8.9 ± 17.9	**0.02**	8.1 ± 15.3	8.6 ± 19.3	0.74	0.10
Ammonium (μg/l)	23.0 ± 24.6	38.2 ± 51.8	**0.02**	27.2 ± 29.4	37.7 ± 54.6	0.09	0.18
EC reading (μS/cm)	211 ± 302	521 ± 1266	0.30	331 ± 814	485 ± 1216	**0.01**	0.08

P values are from linear mixed effects (lmer) models for lineage, transect position and the interaction of lineage and transect position, with *bold* indicating significant results ($P \leq 0.05$). To meet assumptions of normality for linear mixed effects models, soil moisture was logit-transformed and electrical conductivity and concentrations of orthophosphate, nitrate/nitrite, and ammonium were log-transformed

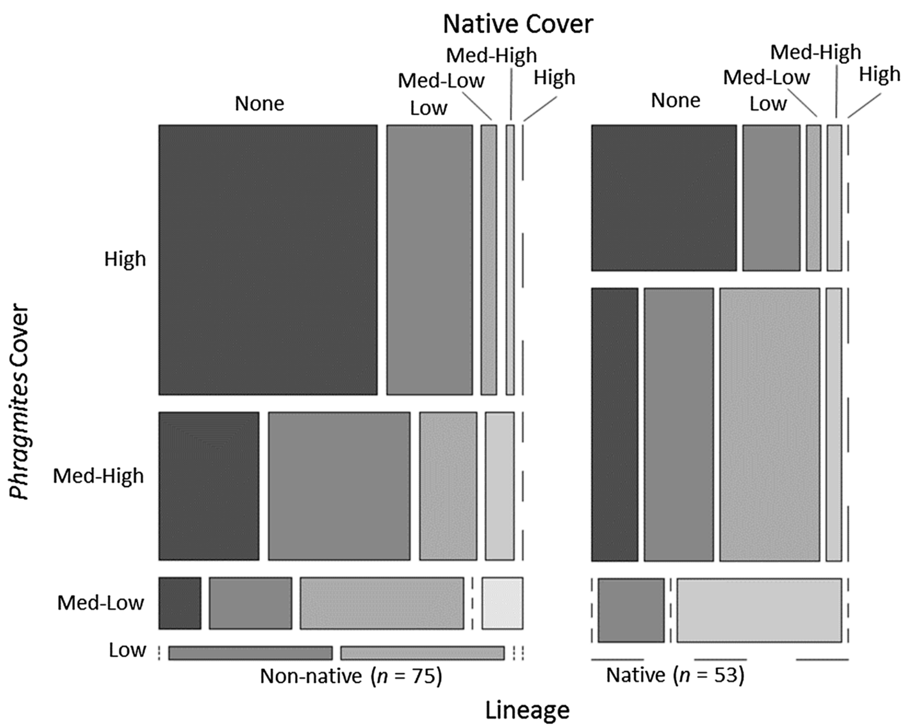

Fig. 3 Mosaic plot of community composition of non-native and native stands of *Phragmites.* On the *vertical axis*, percent cover for *Phragmites* was recorded as one of 5% cover classes: none (0%), low (>0 and ≤10%), medium–low (>10 and ≤50%), medium–high (>50 and ≤90%), and high (>90%). On the *horizontal axis*, percent cover of native species (excluding native *Phragmites*), was recorded using the same five cover classes. For each stand where multiple transects were sampled, the midpoints of the recorded cover classes were averaged to determine the overall cover class of the stand

managers requested that their samples be processed within a specific time-frame so that they could incorporate that information into management, in which case those samples were prioritized. In most instances, and because we were not issuing management recommendations based on results of laboratory analysis, the delay in sample processing did not directly affect management. A limited budget and high reliance on laboratory volunteers challenged our ability to serve a large network of participants,

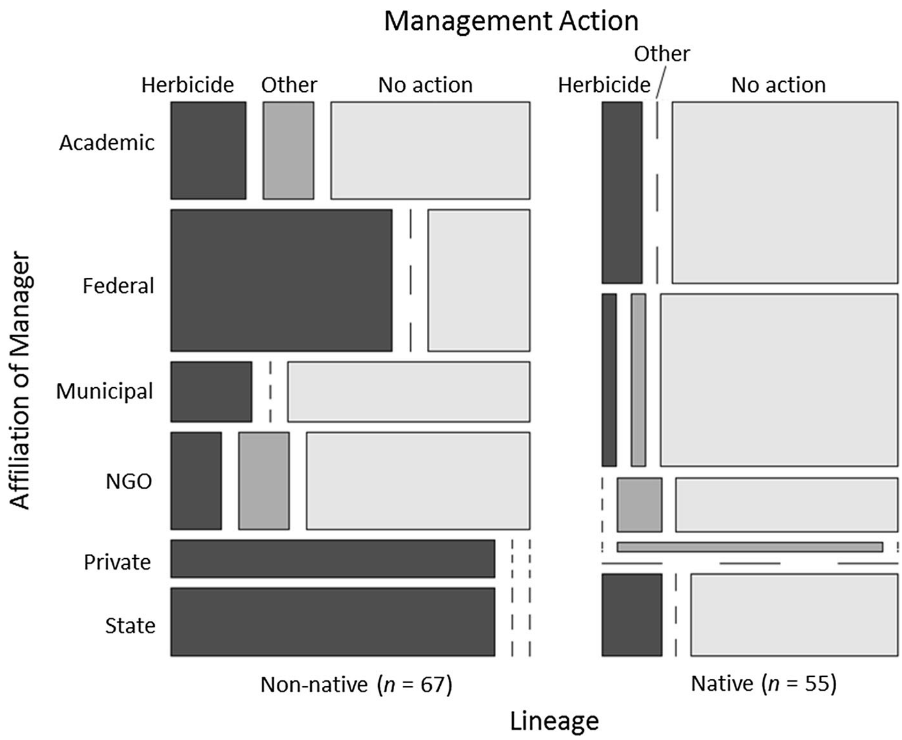

Fig. 4 Mosaic plot showing the frequency of three mutually exclusive categories of *Phragmites* management treatment methods (no action, herbicide, and other) for non-native and native *Phragmites* stands, grouped by manager affiliation category

providing a note of caution for efforts using crowdsourcing to investigate invasive species ecology and management. Those considering similar efforts should consider funding/workforce capacities, and the potential need to limit submissions of samples.

The data we collected is clearly a nonrandom sample; only participants that were reached by our recruitment efforts via list-servs and our website, chose to participate, and followed through with submission of all necessary information and samples ultimately contributed to our dataset. Some biases were unanticipated, e.g., we had unexpectedly high representation from Colorado due to secondary distribution of our contact information to weed managers throughout that state. Another potential bias in our data stems from allowing managers to establish transects at a starting point of their choosing on the edges of *Phragmites* stands. This made the protocol easier to follow than if we had required a randomized starting point. However, participants may have selected areas of stands that were easier to access and avoided very wet areas or areas with thick vegetation.

Environmental conditions

The likelihood of a wetland becoming invaded by *Phragmites* is far too complex to be assessed using a single variable (Ramseur 2012). We found mixed evidence that invasion by non-native *Phragmites* was associated with eutrophication. There were not significant differences in soil concentrations of orthophosphate between non-native stands and paired uninvaded areas. Orthophosphate concentrations were also not significantly different in non-native *Phragmites* stands than in native *Phragmites* stands. However, we determined that there were significant differences in ammonium and nitrate/nitrite concentration depending on lineage, in support of the hypothesis that non-native *Phragmites* is better able to exploit eutrophic habitats than native *Phragmites* (Mozdzer et al. 2010). We caution that, in observational studies such as ours, the response of an invasive plant species to soil attributes versus the potential influence of invasion on soil attributes can be indistinguishable and/or co-occurring phenomena (Price et al. 2014). In addition to responding to soil nutrients, *Phragmites* may itself alter nutrient concentrations (Windham and Meyerson 2003). We also found that interiors of *Phragmites* stands had higher electrical conductivity than surrounding uninvaded areas, reinforcing the role of road salt in facilitating inland spread of *Phragmites* (Burdick and Konisky 2003; Jodoin et al. 2008).

Management actions

As expected, we found that non-native *Phragmites* is actively targeted for management to a much greater degree than native *Phragmites*. The majority of sampled stands were non-native, likely because the behavior of non-native *Phragmites* is problematic compared to that of the native genotype (Price et al. 2014), attracting the interest of study participants. Our analysis of community composition in *Phragmites* stands of non-native and native genotypes are in agreement with Minchinton and Bertness (2003) and others who have found that non-native *Phragmites* necessitates management because it outcompetes native species and grows in monocultures. These findings reinforce those of Price et al. (2014) that these physically similar appearing and closely related lineages have very different ecologies, with the non-native lineage associating with lower native plant diversity.

The finding that 34% of native stands were targeted for active management warrants further consideration. Managers reported to us that genetic identification, of which they were often uncertain, was a major motivation for participating in this research. Therefore, our dataset contains many stands for which managers were unsure of the lineage. If our sample had included more stands of certain native lineage, perhaps these stands would not have been targeted for active management with the same seemingly high frequency. In any case, our sample demonstrates that some native stands are being managed. As native *Phragmites* is declining (Saltonstall 2002), and as it does not have the same detrimental effects on associated plant communities as the non-native lineage (Price et al. 2014), management of native *Phragmites* is concerning. Wider availability of genetic identification services is an area of need for targeting non-native stands and reducing risk to native populations.

Partnerships between the public and scientists have flourished in recent decades, in part due to citizen science efforts that make use of new web-based technologies that facilitate massive collaborations (Theobald et al. 2015). However, many projects that use a crowdsourcing approach to data and sample collection do not ultimately contribute to peer-reviewed literature. For example, only 12% of biodiversity-focused citizen science projects contributed to scientific peer-reviewed articles (Theobald et al. 2015), indicating that incorporating such approaches into research efforts can be challenging.

Development of a network is a critical first step in harnessing the power of ongoing management to accelerate learning regarding how to most effectively control *Phragmites* and restore impacted habitats. We developed a low-cost method for implementing such a network, utilizing relevant listservs, a low maintenance website hosted on a free web-hosting service, and free online informational webinars. Ultimately, we envision expanding this approach to strengthen the collective learning process over time by involving more managers. For this pilot study, data were transcribed from paper data sheets into a local copy of a database maintained by the project coordinator; however, the long-term, sustainable success of such a project would be facilitated by development of a centralized online database, which could be maintained by a series of project coordinators over time, or even by the managers themselves.

We sought to develop a long-term monitoring protocol and network that could serve as a platform for future adaptive management efforts to improve management outcomes for *Phragmites* control. Adaptive management would entail repeated standardized monitoring over time, to assess effectiveness of a suite of standardized management actions (Williams et al. 2009). Such long-term monitoring is necessary to characterize the efficacy of treatment techniques over meaningful timeframes.

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