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ABSTRACT

Grassland habitat is declining in the northeastern United States, leading to a decline in associated native species. Consequently, there is considerable interest by land managers in conserving and restoring grassland habitats in the Northeast. However, unlike the Great Plains and Europe, quantitative monitoring of restoration sites is uncommon, making it difficult to improve new restoration projects. Here we evaluate a grassland restoration in Waterford, Connecticut to determine if mechanical clearing of woody vegetation combined with sowing 23 native grasses and forbs led to successful establishment of these species. We also compared cover, diversity, and colonization by exotic and woody species in planted and unplanted areas over time. In the third and fifth growing seasons after planting in 2006, we sampled the vegetation in the planted site, an unplanted zone within the planted grassland, and an adjacent unplanted grassland. Twenty of the 23 sown species established by 2010, and sown species dominated the planted area (70% of total cover). Despite the successful establishment of most sown species, species richness and diversity were no higher in the sown grassland than in adjacent unseeded areas.

However, the sown grassland contained lower cover of non-native and invasive species. Big bluestem (*Andropogon gerardii* Vitman) established aggressively, potentially reducing both exotic colonization and native diversity. This study shows that sowing native grassland species can lead to the successful development of native-dominated grasslands. Results can inform future grassland restoration efforts in the Northeast and show that seeding with aggressive grass species may greatly impact restored plant communities.

*Index terms***:** monitoring, exotic species, species diversity, early successional habitat, New England grassland restoration

INTRODUCTION

Grassland habitats have declined over the last century throughout the northeastern United States due to agricultural abandonment, suburban development and fire suppression (Vickery et al. 1994). This decrease has led to considerable interest in conserving and restoring these open habitats throughout the region.

It is uncertain how prevalent grassland habitats were in the northeastern United States prior to European colonization (Askins 1997; Foster and Motzkin 2003). However, some areas dominated by native grassland species were present in the region, and the recent loss of grasslands has clearly led to the decline of native grassland plants, insects, and birds (Marks 1983; Askins 1997). The importance of grasslands in preserving biodiversity in human dominated landscapes has been recognized for decades in Europe (Török et al. 2010; Piqueray et al. 2011). As in Europe, conservation and restoration of native plant dominated grasslands in the northeastern United States has been acknowledged as an important component of the conservation of biodiversity in the region, even at specific sites that were not grasslands prior to European settlement (Foster and Motzkin 2003).

In areas where grasslands have converted to forest, mechanical removal of the woody species is necessary to restore grassland habitat (Lezberg et al. 2006; Dzwonko and Loster 2007). Even after removal of woody vegetation, however, recolonization by grassland species is necessary because these species usually do not persist in the seed bank in forested areas (Bisteau and Mahy 2005). If existing grasslands are adjacent to the restoration site, natural colonization may be sufficient (Pärtel et al. 1998). However, the majority of evidence shows that, for isolated sites and for many grassland species, sowing may be necessary to restore species rich grassland habitats (Dzwonko and Loster 2007; Piqueray et al. 2011). Because seed mixes of native plants, especially those using regional ecotypes, can be both difficult and costly to obtain (Jongepierová et al. 2007), it is important to understand if seed sowing improves restoration outcomes. If not, then limited resources may be better used in other aspects of restoration.

Numerous studies have examined the effectiveness of seed sowing in grassland restoration and have uncovered several critical themes. First, establishment success of sown species can vary greatly among sites (Lepš et al. 2007) and among species (Pakeman et al. 2002; Hellstrom et al. 2009). The degree of initial disturbance can influence establishment success, with greater disturbance (e.g. tilling or clearing) usually increasing establishment (Pywell et al. 2007). Second, sowing with more diverse seed mixes has been shown to increase species richness compared to natural regeneration or less diverse seed mixes (Pywell et al. 2002; Foster et al. 2007), especially when natural seed sources are distant. Thus, seed sowing is often used as a tool to increase the grassland diversity. Third, sowing native seed can help to prevent the establishment and spread of exotic or invasive species (Lawson et al. 2004; Sheley and Half

2006; Foster et al. 2007; Török et al. 2010). Invasive species are a major cause of restoration failure (Berger 1993; Kettenring and Adams 2011), so preventing invasions is a major goal of grassland restoration efforts.

Although grassland restoration has been well documented in Europe and the Midwest United States, there is little published information about clearing or seed sowing in restoration efforts in the northeastern United States. Because there can be large regional variation in species establishment (Lepš et al. 2007), it is unclear whether results from other regions can be applied to grassland restoration in the Northeast.

Restoring grassland and shrubland habitat is a conservation priority in the Northeast, and funding is available for landowners through federal programs and the Connecticut Department of Energy and Environmental Protection (DEEP). The DEEP has worked to restore or enhance 524 ha of grassland habitat on state land between 1998 and 2008, with 422 ha involving mechanical clearing of woody vegetation and 133 ha involving sowing seeds. (Paul Rothbart, DEEP, personal communication). In addition, land trusts and private landowners have been restoring grassland habitat.

Despite these efforts, it is unclear how much monitoring is occurring. The only published example with quantitative monitoring that we could find focused on the effects of clearing rather than on the effects of sowing seeds (Lezberg et al. 2006). Results from quantitative monitoring are necessary to inform future grassland restoration efforts in the Northeast.

In this study, we assessed the results of a project in Waterford, CT to recreate grassland habitat by mechanically clearing woody vegetation and planting seeds of species native to local grasslands. We compared vegetation change over five growing seasons in an area seeded with 23 species of native grassland herbs with two adjacent unseeded areas. We asked the following questions: 1) Does seed sowing lead to establishment of native grassland species? 2) Are species richness, diversity, grass cover and total plant cover changing over time in these grasslands? 3) Are the abundances of exotic, invasive, and woody species increasing over time?

This project is similar to those commonly carried out by land managers in New England. We recognize that this study only represents a single site, and is not a replicated test of the effect of seed sowing in New England. Nevertheless, thus study provides quantitative monitoring of grassland restoration that is lacking in this region and can thereby help inform future grassland restoration efforts.

METHODS

The study site was part of a small complex of grassland and savannah in the Connecticut College Arboretum, Waterford, Connecticut. The overall project goal was to reclaim grassland habitat from encroaching forest vegetation and to expand the total open area to approximately 4.2 ha. The site slopes gently to the northeast and adjoins a field to the east that has been kept in predominantly herbaceous vegetation by mowing since cultivation ended approximately 60 years ago. The soil is mapped as Sutton very stony fine sandy loam (NRCS 2011).

Approximately 2 ha of woody vegetation was mechanically cleared during 2004 (Fig. 1), stumps were ground down to below the soil surface and larger woody debris was removed with a York rake. Prior to clearing, the site was covered by young forest of *Prunus serotina* Ehrh., *Acer rubrum* L., *Pinus strobus*, and *Quercus velutina* Lam. The understory was dominated by invasive exotic shrubs and vines (e.g. *Celastrus orbiculatus* Thunb. and *Berberis thunbergii* DC.). Native shrubs were uncommon and there was very little herbaceous vegetation.

Three separate treatments were applied to parts of the cleared area. A 1.5 ha area (hereafter “planted”) was seeded on June 22, 2006 with a mixture of native grass and forb species supplied by New England Wetland Plants, Amherst MA (Table 1) using a tractor-pulled Truax Flex II seed drill. Seeds were applied at ~30 kg/ha based on recommendations from the seed supplier. Approximately 6 cm of rain fell during the next three days, allowing rapid germination. No supplemental irrigation or mulch was applied. A 0.07 ha area (hereafter “cleared”) within this field was cleared of all vegetation, but not planted due to some large boulders that prevented access by the seed drill (Fig. 1). Approximately 0.5 ha of the adjacent field to the east was cleared of encroaching woody vegetation, but existing ground layer vegetation, mainly grasses and forbs persisting from the old agricultural fields, remained intact (hereafter “existing”). The herbicides Crossbow® and Garlon® 3A were selectively applied to regrowing woody and invasive plants in all grasslands every summer since 2005. All grassland areas were mowed once each year in late winter.

Sampling

In July 2008, a permanently marked, 100 m long, east-west transect was established through the middle of the “planted” grassland and into the “cleared” grassland (Fig. 1). Thirty 1 m^2 sample plots were placed every 3 m on the north side of this line with 23 plots in the planted and 7 in the cleared grasslands.

A second permanent transect was established in the adjacent “existing” grassland (Fig 1). Fifteen plots were placed every 3 m on the east side of this 50 m north-south transect.

The percent cover of each species in each plot was estimated between August 20 and September 1 in both 2008 and 2010. Percent cover was measured by visual estimates of areal projection allowing for overlapping canopies, hence plot totals exceeded 100 %. Visual estimates were made by at least two of the three authors for each plot. Species nomenclature follows the Integrated Taxonomic Information System (http://www.itis.gov). Voucher specimens are contained in the Charles Graves Herbarium at Connecticut College (CCNL). We classified species as native or exotic using Tucker (1995) and as invasive based on the official list of Connecticut invasive species (http://www.hort.uconn.edu/cipwg/list.html). *Artemisia vulgaris* L., an aggressively spreading exotic species, was included as an invasive species.

Data Analysis

The abundance of species in the seed mixture (percent of total seeds by weight) was compared with the percent cover of those species in the planted grassland in 2008 and 2010 using two-tailed Pearson correlation. Species richness and diversity (Shannon-Weiner H`) were calculated for each plot.

We used paired t-tests to compare relative cover of sown species, total cover, species richness, diversity (question 2), exotic cover, invasive cover, and woody cover (question 3) between sample dates for each of the three grasslands.

RESULTS

Nineteen of the 23 sown species occurred within plots in at least one year (Table 1) and one more (*Penstemon digitalis* Nutt. ex Sims) was seen in the grassland but was not sampled. Establishment success was highly variable, with some sown species becoming abundant while others remained rare in the grassland. Four species occurred on the transect for the first time in

2010 (Table 1), suggesting that germination and establishment of these species may take several years.

The proportion of sown species increased in the planted grassland between years, reaching ~70% of cover by 2010 (t=5.62, p<0.001, Fig. 2a). Sown species had much lower cover in both unsown grasslands and did not change over time (t<1.2, p>0.25). These species may have naturally dispersed into these grasslands from surrounding areas. Graminoids were more common in the sown grassland than in the other two sites (Fig. 2b).

Species that were more abundant in the seed mixture tended to be more common in the planted grassland in 2008 (r=0.53, p=0.009). This relationship weakened to marginal significance by 2010 (r=0.39, p=0.063) largely due to increased dominance by a few of the sown species.

Total cover increased overall between 2008 and 2010 in the planted (t=5.03, p<0.001) and cleared grasslands (t=4.24, p=0.005) but not in the existing grassland (t=0.05, p=0.96). By 2010 total cover was similar among all three sites (Fig. 3a).

Species richness per plot did not change significantly over time in the planted or cleared meadow for either total richness or native species richness (t<1.08, p>0.32; Fig. 3b.). In the existing meadow, native richness declined slightly (t=2.06, p=0.058). Despite planting 23 native species, there was no indication that richness was higher in the planted grassland than either of the other grasslands. The Shannon-Weiner diversity index varied little among sites or years.

Cover of exotic species and invasive species did not increase between 2008 and 2010 in any grassland (t<1.27, p>0.18; Fig 4a). Exotic species cover in the planted grassland was very low (<3%) compared to the other two grasslands. Cover of invasive exotic species showed a similar pattern, with lower cover in the planted than in the existing grassland. However, invasive cover was <6.5% of the total cover in all sites. The cover of woody species increased over time in both the planted (t=2.26, p=0.034) and the cleared meadow (t=3.11, p=0.021) despite targeted herbicide application (Fig. 4b). The majority of woody cover consisted of native species (Table 2) including several species of blackberry (*Rubus* spp.) and winged sumac (*Rhus copallina* L.).

DISCUSSION

After five growing seasons, native herbaceous vegetation dominated both planted and non-planted restored areas, regardless of whether the site was initially cleared of ground layer vegetation. The abundance of woody species did increase over time, suggesting that continued management is needed to prevent the site from returning to dominance by woody species.

As seen in grassland restoration in other regions (Lawson et al. 2004; Foster et al. 2009), the majority of sown species established on the site. The sown site had greater grass dominance than unsown sites and nine species established in the planted grassland that were not present in unplanted grasslands in 2008. Sowing with grass dominated seed mixtures has also successfully increased grass dominance in other regions (Bakker and Wilson 2004).

The abundance of the species in the seed mix corresponded to its abundance in the vegetation although this relationship declined over time. Thus, in the short term, the proportion of seed of each species can be important, while over time factors such as environmental tolerances and competition become more important.

While most species established successfully, there was considerable variability among species that is not explained by abundance in the seed mix alone. Results from grassland restoration in Europe have also shown considerable variability (Pakeman et al. 2002), but that grasses and generalist species establish better than forbs and specialists (Pywell et al. 2002;

Lawson et al. 2004). Grasses established better than forbs overall at this site, but there was considerable variation among grass species.

Species establishment in grassland restoration can vary among regions so it is important to document species establishment in the Northeast. For example, some species (e.g., *Schizachyrium scoparium* (Michx.) Nash and *Lespedeza capitata* Michx.) established successfully both in this study and a restoration site in Kansas (Foster et al. 2009). However, *Andropogon gerardii* Vitman was more successful and *Sorghastrum nutans* (L.) Nash and *Andropogon virginicus* L. much less successful in Connecticut than in Kansas. *Asclepias tuberosa* L. established successfully in more than a third of the plots in Kansas and did not establish at all in Connecticut. Establishment can also be greatly impacted by climate and weather conditions or site-specific factors (Hellstrom et al. 2009), so this study is not a definitive evaluation of establishment success in the Northeast. Documentation of species establishment at multiple sites is necessary to understand which species will be generally effective for grassland restoration in the Northeast.

Despite successful establishment of the majority of the 23 sown species, native richness and diversity were no higher in the planted grassland than non-planted areas. The effects of seed sowing on grassland richness have been mixed, with some studies finding clear increases (Foster et al. 2007; Foster et al. 2009), and others finding no effect (Piper et al. 2007; Rydgren et al. 2010) or even decreases (Lepš et al. 2007). While sowing clearly added species to the grassland system in this study, these species may have simply replaced other species that might have naturally colonized.

Although the planted grassland did not display increased richness, it did have the lowest level of invasion by exotic and invasive species. Several studies have found that seed sowing can reduce invasion by exotic species, but that native colonization by unsown species is also often reduced (Lawson et al. 2004; Lepš et al. 2007; Török et al. 2010). Reduced natural colonization may explain the similarity in species richness among grasslands in this study.

Large or fast growing grass species are often particularly effective at reducing invasions of exotic species in grassland restoration, but they can also lead to reduced diversity and low colonization by native forbs (Fagan et al. 2008; Török et al. 2010). Because forb species provide most of the diversity in many grasslands (McCain et al.), strong dominance by grasses may reduce diversity. Even if diverse seed mixes are used, diversity may be low if aggressive sown grasses come to dominate the site (Lawson et al. 2004). *Andropogon gerardii* is becoming dominant and is more abundant at this site than in other local grasslands, and thus may be reducing potential diversity. Competitive dominance by large grasses may be more pronounced when using commercial varieties of these species rather than local ecotypes. For example, available ecotypes of *Panicum virgatum* L. have been aggressive in previous plantings (Dreyer, *personal observation*) and were not included in the seed mix for the current study. The use of widely available and inexpensive varieties of large-statured grasses in grassland restoration in the Northeast must be carefully considered.

Because seed sowing can reduce both invasion of exotics and native diversity, it is important to consider if it is a necessary or desirable management approach in restoring grasslands in the Northeast. If existing grasslands with native species are in close proximity to the restoration site, natural colonization will likely occur and seed sowing may not be necessary (Pärtel et al. 1998; Fagan et al. 2008). At our site, common species such as *Schizachyrium scoparium* and *Solidago* spp. colonized unplanted areas rapidly. However, rare and locally uncommon species will not establish without being sown. Sowing seed may also reduce the need for exotic invasive species control. Thus the landscape context of the restoration site needs to be considered (Ruprecht 2006).

We recognize that this study is not a formal scientific comparison of replicated sown and unsown plots. Thus differences among grasslands may reflect underlying site differences in addition to management differences. However, this study imitated what a land manager might do in restoring grassland habitat and documented the results. Results from this study indicate a successful pathway towards grassland development dominated by native species. Additionally, the restored sites appear to benefit open-site animal species, proving habitat for winter-resident sparrows and helping sustain local populations of blue-winged warbler (*Vermivora cyanoptera*), eastern towhee (*Pipilo erythropthalmus*) and eastern bluebird (*Sialia sialis*; R. Askins, personal communication). Given the scarcity of monitoring grassland restoration in Northeastern North America, these results will provide a baseline for comparison and a source of information for land managers who continue to restore early successional habitat in the Northeast.

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Table 1. Establishment success of species included in the seed mixture in the planted grassland.

Sown Species	Percent in seed mixture (by weight)	2008 Cover	2010 Cover
Forbs			
Asclepias tuberosa L.	0.52	0	0
Desmodium canadense (L.) DC.	2	0.87	1.57
Eupatorium hyssopifolium L.	1	0	0.22
Eutrochium maculatum (L.) E.E. Lamont	0.52	0.17	0.17
Eutrochium purpureum (L.) E.E. Lamont	0.52	0	0
Euthamia graminifolia (L.) Nutt.	0.9	0.17	1.35
Lespedeza capitata Michx.	2	1.61	3.65
Penstemon digitalis Nutt. ex Sims	0.5	0	0
Pycnanthemum virginianum (L.) Rob. & Fernald	2	0.04	0.04
Rudbeckia hirta L. var. *pulcherrima* Farw.	3	1.96	0
Rudbeckia triloba L.	2.5	0	0.04
Solidago nemoralis Aiton	1	3.91	5.00
Solidago juncea Aiton	0.5	0.35	3.61
Solidago speciosa Nutt.	1	0.22	0.74
Symphyotrichum laeve (L.) Á. Löve & D. Löve	0.53	0	0.13
Symphyotrichum novae-angliae (L.) G.L. Nesom	2	0.13	0.35
Symphyotrichum pilosum (Willd.) G.L. Nesom	0.52	0.96	0.48
Grasses			
Andropogon gerardii Vitman	10	20.57	53.52
Andropogon virginicus L.	8	0	0
Elymus canadensis L.	21	1.48	0.30
Schizachyrium scoparium (Michx.) Nash	20	14.09	18.96

Sorghastrum nutans (L.) Nash	10	3.74	10.09
Tridens flavus (L.) Hitchc.	10	0	0.17

Table 2. Percent cover of plant species with at least 1% cover in at least one of the three sites. Species in bold were included in the planted seed mixture.

	2008			2010		
Species	planted	cleared	existing	planted	cleared	existing
Forbs						
Conyza canadensis (L.) Cronquist	0.00	0.29	1.93	0.00	0.00	0.00
***Desmodium canadense* (L.) DC.**	0.87	0.14	0.00	1.57	0.00	0.00
***Euthamia graminifolia*(L.) Nutt.**	0.17	1.14	10.00	1.35	2.86	16.20
Fallopia convolvulus (L.) Á. Löve[E]	0.00	0.00	0.20	0.00	0.00	1.20
Hypericum perforatum L.[E]	0.00	0.57	2.60	0.00	0.00	0.00
***Lespedeza capitata* Michx.**	1.61	0.00	0.00	3.65	0.00	0.00
Oxalis stricta L.	0.00	0.00	2.27	0.04	0.00	0.40
Potentilla canadensis L.	11.39	19.71	10.47	3.04	25.57	6.07
Pteridium aquilinum (L.) Kuhn	0.00	0.00	19.40	0.00	0.00	10.73
***Rudbeckia hirta* L. var. *pulcherima* Farw.**	1.96	0.29	0.00	0.00	0.00	0.07
Rumex acetosella L.[I]	0.00	0.57	3.73	0.00	0.00	0.00
***Soldiago nemoralis* Aiton**	3.91	9.43	0.00	5.00	3.29	0.00
***Solidago juncea* Aiton**	0.57	1.71	0.07	3.61	1.29	0.00
Solidago rugosa Mill.	0.13	0.43	8.73	2.74	3.57	27.73
Graminoids						
Agrostis gigantea Roth [E]	0.70	4.43	13.53	0.52	5.86	11.67
***Andropogon gerardii* Vitman**	20.57	1.14	0.00	53.52	7.29	0.67
Carex sp.	1.65	1.14	0.00	5.17	3.86	0.27
Carex cephalophora Muhl. ex Willd.	0.13	0.29	5.33	0.09	0.14	5.67
Carex swanii (Fernald) Mack.	1.52	0.86	1.20	0.57	0.71	1.80
Dactylis glomerata L.[E]	0.00	0.00	0.13	0.00	0.00	1.73
Danthonia spicata (L.) P. Beauv. ex Roem.	0.00	0.00	1.80	0.00	0.00	0.07

& Schult.						
Dichanthelium acuminatum (Sw.) Gould & C.A. Clark *var. acuminatum*	5.04	1.29	2.47	0.22	0.00	0.00
Dichanthelium clandestinum (L.) Gould	0.04	1.00	1.33	0.52	0.00	5.47
Dichanthelium sphaerocarpon (Elliott) Gould	5.04	1.29	7.47	0.61	0.57	1.07
Digitaria ischaemum (Schreb.) Muhl.[E]	1.74	0.29	0.00	0.00	0.00	0.00
***Elymus canadensis* L.**	1.48	0.71	0.73	0.30	0.00	1.33
Elymus repens (L.) Gould [E]	0.00	0.00	2.07	0.00	0.00	0.00
Juncus tenuis Willd.	0.43	0.57	1.60	0.13	0.14	1.07
***Schizachirium scoparium* (Michx.) Nash**	14.09	5.29	15.20	18.96	18.57	16.47
***Sorghastrum nutans* (L.) Nash**	3.74	0.57	0.00	10.09	6.43	0.00
***Tridens flavus* (L.) Hitchc.**	0.00	0.00	0.00	0.17	1.14	1.47
Woody Plants						
Celastrus orbiculatus Thunb.[I]	0.09	0.57	1.13	0.09	0.71	1.00
Parthenocissus quinquefolia (L.) Planch.	0.26	0.00	0.33	0.17	0.00	1.07
Rhus copallina L.	1.96	0.43	0.00	6.22	5.29	1.07
Rosa multiflora Thunb.[I]	0.00	0.00	1.07	0.13	0.00	0.07
Rubus alleghaniensis Porter	9.78	13.43	3.07	6.17	14.14	1.33
Rubus flagellaris Willd.	5.61	5.29	4.13	17.96	20.29	11.73
Rubus hispidus L.	0.00	0.71	0.00	0.00	14.14	0.13
Rubus occidentalis L.[E]	0.00	1.43	0.80	0.17	2.14	0.93
Smilax rotundifolia L.	0.26	0.29	0.07	0.39	1.00	0.13
Toxicodendron radicans (L.) Kuntze	0.35	0.00	6.00	0.61	0.00	1.47

[E]Non-invasive exotic species

[I]Invasive exotic species

Fig 1. Aerial photo of site in 2001 (A) prior to restoration and in 2006 (B) following restoration. White lines indicate the location of transects (1 – seeded, 2 – unseeded). The dashed white line indicates the cleared grassland (unseeded portion of seeded grassland)

Fig. 2. (A) Proportion of the total cover that consists of species that were sown into the planted grassland. (B) Proportion of total vegetation that is grasses and related species (graminoids). Error bars indicate SE.

Fig. 3 Vegetation characteristics of the three grasslands. Total cover (A) can add to more than 100 because species are overlapping. (B) Number of species per 1 m^2 plots. Error bars indicate SE.

Fig. 4. Cover of all exotic species (A) and woody species (B) in the three grasslands. Error bars indicate SE.

Fig 1.

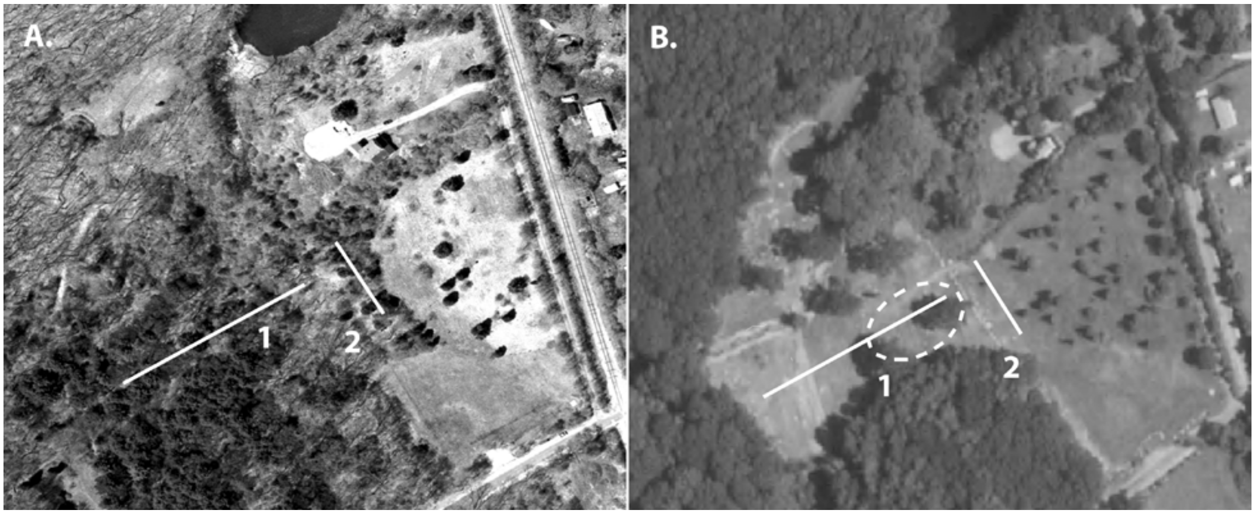
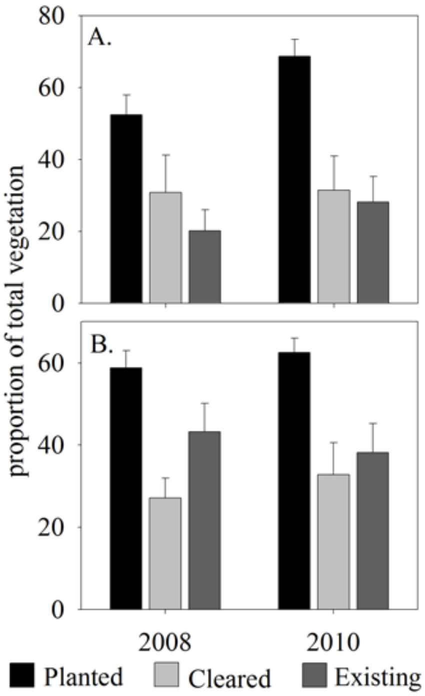
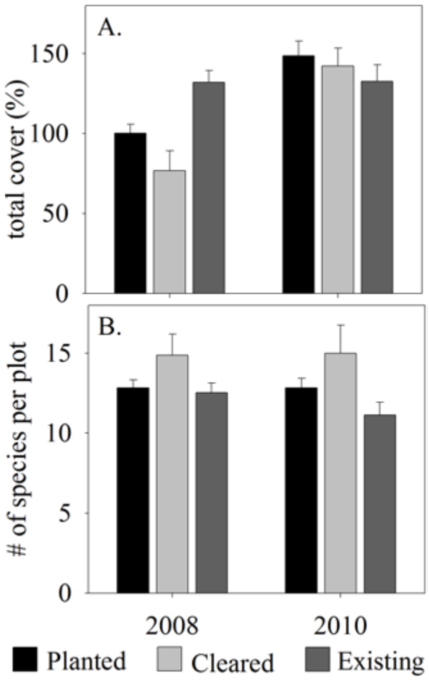


Fig 2.



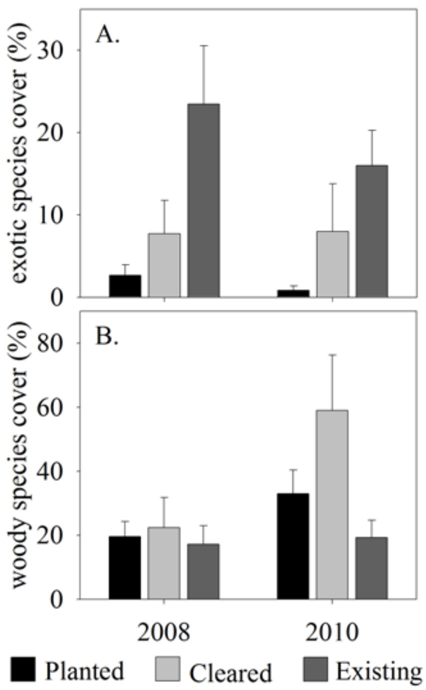
80
A.
60
40
20
0
B.
60
40
20
0
proportion of total vegetation
2008
2010
Planted
Cleared
Existing

Fig 3



A.
total cover (%)
0
50
100
150
B.
# of species per plot
0
5
10
15
2008
2010
Planted
Cleared
Existing

Fig.4



A.
exotic species cover (%)
30
20
10
0
B.
woody species cover (%)
80
60
40
20
0
2008
2010
Planted
Cleared
Existing