Evaluation of a large-scale invasive plant species herbicide control program in the Berkshire Taconic Plateau, Massachusetts, USA

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SUMMARY

In the late 1990's, The Nature Conservancy (TNC) documented a rise in five invasive plant species, barberry *Berberis thunbergii*, bittersweet *Celastrus orbiculatus*, garlic mustard *Alliaria petiolata*, buckthorn *Frangula alnus*, and honeysuckle *Lonicera morrowii* on the periphery of the relatively intact and uninvaded 14,600 ha Berkshire Taconic Plateau in Massachusetts (USA). The Plateau comprises an ecologically significant block of forest. In response, TNC began a large-scale herbicide-based control program on approximately 3,600 ha of land with the goal of reducing invasive cover to less than 10%. Our objective was to evaluate the efficacy of this effort, but this was hampered by a dearth of untreated control sites and pretreatment data on invasive species cover. Four sites (three treated, one untreated) on the plateau periphery similar in understory vegetation, overstory cover, slope, and proximity to a hiking trail were surveyed and compared. Across each site, native and invasive plant percent cover within 44, 1m² plots was measured, and native and invasive presence absence recorded on an additional 2,000m² area. All five target invasives were present at all four sites 5-years post-treatment. In two of the treated sites, invasive percent cover significantly exceeded the 10% goal, largely due to the abundance of garlic mustard. Without garlic mustard, all the sites (including the untreated one) had < 10% invasive cover. Surprisingly, the high level of invasive cover did not have a significant negative impact on native cover (native species richness was not quantified), although a hypothesized negative relationship was invoked as justification for the herbicide treatment. Given the difficulty in finding comparable treated and untreated sites after herbicide application, we suggest 1) that quantitative data on invasive abundance be gathered prior to a control program and 2) that treated and untreated plots be allocated to monitor outcomes. Without this, determination of effectiveness is difficult and likely to be inconclusive.

BACKGROUND

Plant invasions can be both detrimental to ecosystems and the services they provide (Mack 2000). Even if eradication of an invasive plant is desirable, it is often not physically or economically feasible once an invasion has grown to cover a large area (Mack 2000, Leung 2002). Nevertheless, myriad federal, state, and non-governmental organizations work to eliminate and control the spread of invasive plant species, which cumulatively cost tens of billions of US dollars in damage to agriculture and industry within the USA alone, and may be detrimental to native wildlife and natural ecosystems (Mack 2000, Pimentel 2005). While there is an abundant literature on what makes a species invasive (e.g. Rejmanek 1996, Daehler 2003, Callaway *et al*. 2004) and what systems are susceptible to invasion (Burke & Grime

1996), considerably less attention has been paid to the practical question of how successful interventions are at reducing invasive species (Sutherland 2000). The evaluation of one such program is the focus of this paper.

It is not surprising that more money is spent on invasive removal than on post-treatment monitoring. However, lack of resources to undertake monitoring can make outcome evaluation problematic. Invasive plant species removal techniques include physical removal, herbicide treatment, and biocontrol, all of which have been employed to reduce the cover of a wide variety of invasive plant species (Barnes 2004, Reinartz 2002, Wilson 1995). Eradication of widespread invasives is rarely, if ever, successful, but eradication is not the only objective of conservation programs. Where invasions occur on the periphery of relatively intact systems, physical removal and/or herbicide are potentially viable alternatives to keep well-established and widespread invaders out of particularly valuable native-dominated landscapes.

The Berkshire Taconic Plateau is one of the most ecologically significant intact blocks of forest in the northeastern USA. The Nature Conservancy (TNC) has been working to preserve it since 1993. The region supports a wide range of birds and mammals, and includes several ecologically rare habitats such as calciferous wetlands, dwarf pitch pine-scrub oak ridge tops, limey rock ledges, and talus slopes (Marx 2008). TNC researchers have concluded that one of the greatest threats to the integrity of the forest block is the alteration of species composition and structure as a result of plant invasions (Marx 2008). At present the core region (about 11,000 ha) is relatively free of invasive plants, but peripheral lands (around 3,600 ha) are relatively invaded, particularly near year-round open roads (Sadighi & Cooperman 2000).

ACTION

In 2002, TNC, funded by the U.S. Congress, hired private contractors to spray glyphosate-based herbicide on all observed invasive plants within about 3,600 ha of TNC, state, and private land peripheral to the 11,000 ha forest core. Each year (2002-2004), treatment consisted of two sprayings, one in autumn and another in spring. Contractors traversed the designated treatment sites, and spot treated invasive plants with herbicide. The goal was to protect the forest core from encroachment of five non-native invasive species found on the forest periphery: barberry *Berberis thunbergii*, bittersweet *Celastrus orbiculatus*, buckthorn *Frangula alnus*, garlic mustard *Alliaria petiolata*, and honeysuckle *Lonicera morrowii*. TNC's stated goal was to reduce invasive species cover to less that 10%, and ideally 5%, of the forest core in order to promote native seedling regeneration. Although the herbicide was very effective in killing invasive plants (Batcher 2004), preliminary data on regional invader percent cover were not collected prior to treatment, and untreated controls were not set aside for future analysis.

The lack of comparable treated/untreated pairs of sites made a statistical analysis of the efficacy of the control program impossible. Instead, we asked whether invasive plant abundance in what had been, prior to treatment, a highly invaded forest periphery now met the percent cover goals set by TNC. Second, we asked whether the presence of invasives had a measurable effect on native seedling regeneration and native vegetation abundance. We focused on four sites in the forest periphery that were qualitatively described as highly invaded prior to the start of the removal program: the one comparable untreated (site 1) and treated (site 2) pair and two additional treated sites (sites 3 and 4) nearby (Fig. 1). Sites 3 and 4 had no comparable untreated area with similar slope, aspect, and proximity from roads. TNC's initial survey found high invasion levels at all four sites, based on a total of 13, 5 x 5 m plots in which invasive abundance (from 1-5 invaders) was noted (Sadighi & Cooperman 2000). Sites 2 and 3 were treated in 2002-2004, and site 4 was treated from 2003-2004. These sites host mixed hardwood forests dominated by sugar maple *Acer saccharum* and striped maple *A.pensylvanicum*, with pockets of Eastern hemlock *Tsuga canadensis* mostly on slopes. The understory community in the hardwood regions is sparse, and virtually absent in hemlock-dominated areas. The soils at all four sites are fine sandy loams (Typic Haplorthod, USDA). Sites 1-3 are about 2 km from a major road; site 4 is directly adjacent to it.

We randomly located 10 transects at each site. Most transects were on flat ground (0-4% slope), though four (of 40 total) were steeper (approx.

9%). Each transect started on a walking trail, and ran 100 m perpendicular to that trail. On each transect, frequency and percent cover was recorded. For the former, we noted the presence or absence of each invader species as well as the number of native trees and native tree seedlings for every 1 m^2 on either side of the transect tape (total 2,000 m^2/site). Because these data are presence/absence, it could not be used to differentiate between a location that had, for example, one or three garlic mustard plants in a given m^2. At 11 evenly spaced sites along each transect, we used a gridded 1m^2 quadrat to estimate percent cover of bare ground, native ferns, native tree seedlings, native herbs, native trees, and invasive plant (by species). For statistical analyses, plants were grouped into three categories: invaders, native seedlings, and native understory plants. All statistical tests were performed using STATA v.10 (StataCorp, College Station, Texas).

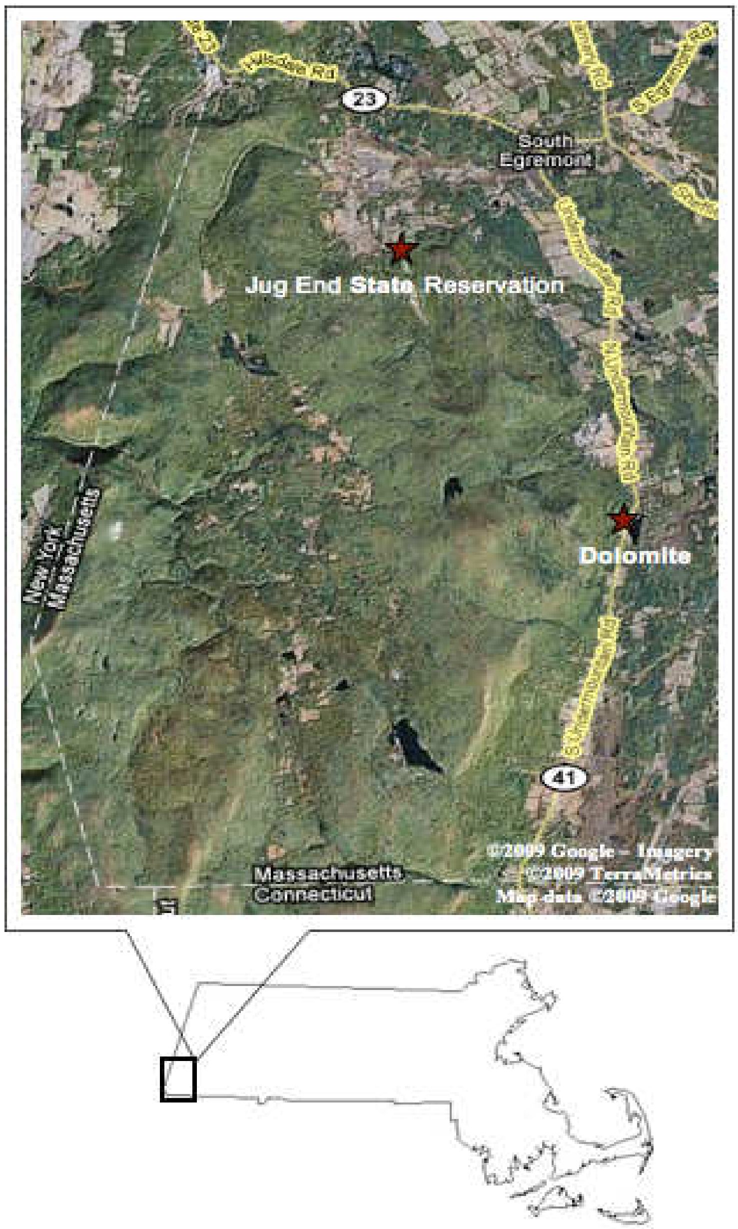

Figure 1. Satellite image of the Berkshire Taconic Plateau core forest block, southwest Massachusetts. Dotted whites lines indicate state borders and bolded lines all-season roads. The stars represent the location of the four study plots.

CONSEQUENCES

Invasive species cover was below the 10% threshold goal (t-test p<0.001) at both the treated and untreated sites 1 and 2. There was no significant difference in invasive cover between this treated and untreated pair (3 ± 2% and 4 ± 1%, respectively, t-test p = 0.81) (Fig. 2). Sites 3 and 4 had invasive cover well above the 10% threshold (20 ± 4% and 30 ± 6%, respectively). The frequency of invasives did differ between sites 1 and 2, with higher frequency in the treated site (8 ±3 % vs. 20 ± 7%, t-test p=0.33). The frequency of invasives was not significantly different from 10% at either site 1 or 2 (t-test p=0.57 and 0.33). The frequency of invasives at sites 3 and 4 was 60 ± 10%, and 70 ± 10%, both significantly above the 10% goal.

Since garlic mustard is a relatively recent invader, and TNC has since stopped basing treatment on its presence alone, we explored the cover of the four other invasive species. Removing garlic mustard from the percent cover data set does not significantly change the cover on untreated site 1 (t-test p=0.32), but it does significantly reduce invasive species cover on treated site 2 to around 1% (t-test p=0.003). Sites 3 and 4 were heavily invaded by garlic mustard, which accounted for about 9 and 27% of the cover, respectively. Thus removing garlic mustard from the percent cover data set reduces invasive cover at sites 3 and 4 to below 10%, although only site 4 is significantly below (t-test p=0.0001). Removing garlic mustard from the frequency dataset does not significantly affect invader frequency at sites 1 and 2. Sites 3 and 4 were heavily invaded by garlic mustard, and removing it significantly reduces the frequency of invasives (p<0.0001); however, not significantly below the 10% threshold (p=0.37).

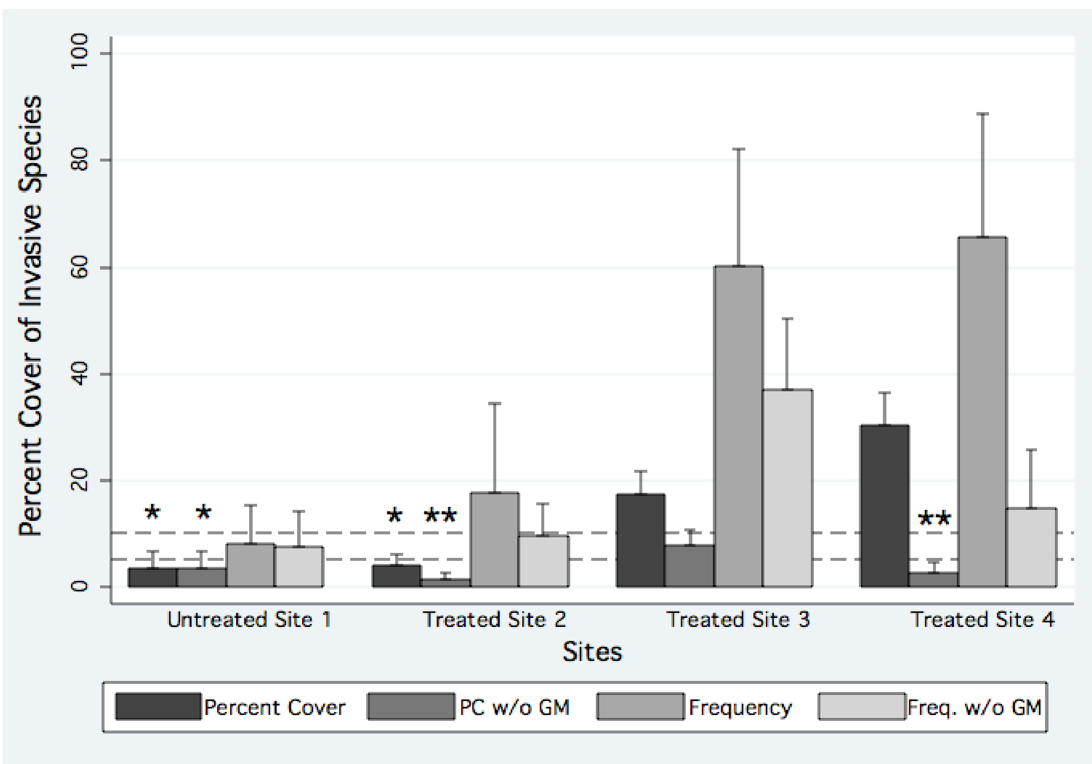

Figure 2. Percent cover (PC) and frequency of invasive species on each site with and without (w/o) garlic mustard (GM). Error bars represent standard error. One asterisk above a column = significantly below the 10% threshold, and two asterisks = significantly below the 5% threshold.

A common justification for invasive species removal is to alleviate their deleterious impacts on native species. Because native and invasive percent cover are not independent (they must sum to ≤ 100% within a quadrat), we explored the correlation between invasive species cover and native cover in the remaining space. Across all sites, we found no relationship between invasive species cover and the fraction of the remaining space occupied by natives (Fig. 3). Surprisingly, the frequency of invasive species was slightly positively correlated with native tree seedling abundance across all sites ($r= 0.094$, $p<0.001$; Fig. 4). Invasive effects on seedling regeneration are often of particular concern (Stinson 2007, TNC), but we found that the percent cover of native seedlings was not significantly correlated with the percent cover of invaders across all quadrats ($n=440$, linear regression $p=0.51$, data not shown).

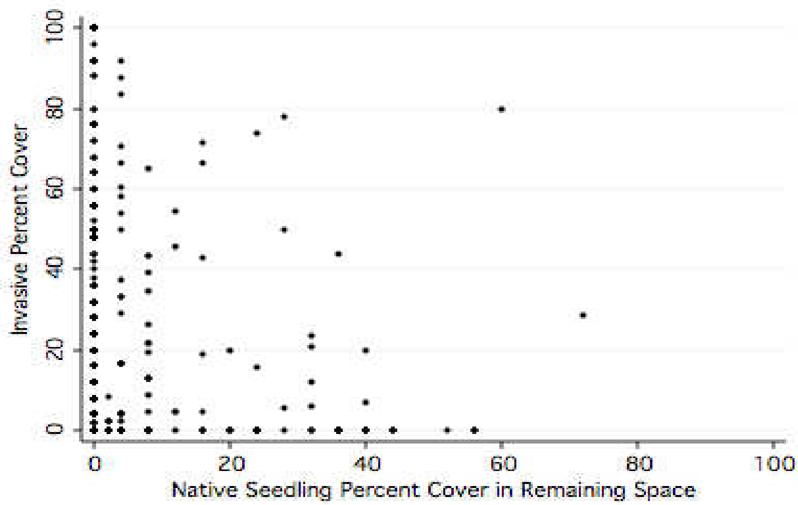

Figure 3. Percent invasive cover plotted against percent of remaining space occupied by natives (all 440 quadrats across the four sites). No significant relationship present.

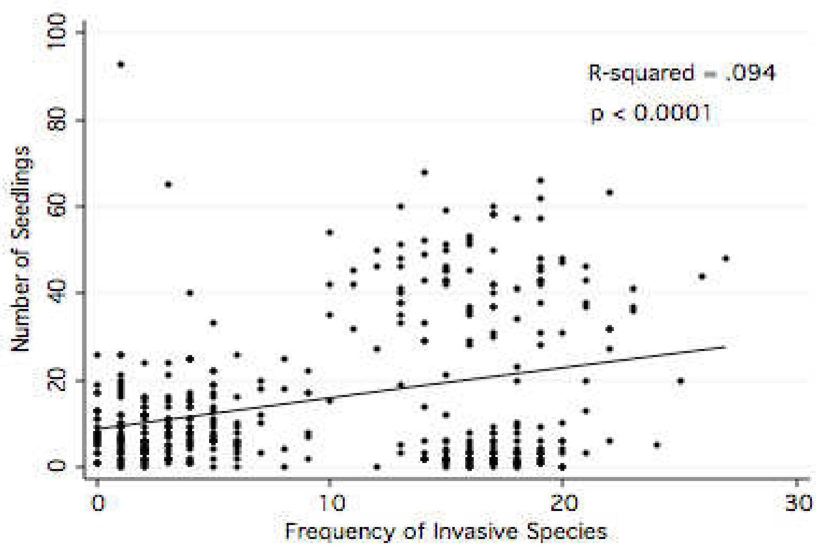

Figure 4. Frequency of invasive and native seedling abundance from every 1 m square sampled on all 40 transects.

Conclusions: In many ways, TNC's efforts to eradicate invasive plants are indicative of the conundrum that invasive species pose for land managers. The Berkshire Taconic Plateau has been a conservation area since the early 20th century and is the focus of TNC's forest conservation efforts in the region. The rapid penetration of non-native organisms into this relatively intact, high diversity landscape is a cause for concern. Similar concerns across the world make the management of invasive plants a multi-million dollar enterprise (Mack 2000), but, as in this case, extensive evaluation of success is rare. Though our post hoc tests are admittedly hampered by lack of replication, we found little suggestion that the herbicide treatment was effective across the Plateau.

Of all the invaders, garlic mustard may be the most likely to negatively affect natives; its rapid dispersal and effects on both native seedling regeneration and biogeochemical cycling have been well documented (Stinson 2007). Garlic mustard reached the Berkshires Taconic Plateau in the late 1990's only shortly before treatment began. Yet, its abundance in all treated sites highlights that an herbicide-based approach is unlikely to be successful in reducing its cover. In the face of continued new invasions, it is worth asking whether and how the success of invasive removal programs should be evaluated. At the least, invasive species removal programs should be designed *a priori* to allow post-treatment testing of program efficacy.

Furthermore, our data offer some insight into one of the common justifications for invasive species removal - that invaders have deleterious effect on native seedling regeneration. Our data suggest that while invasive species may take up space native species could potentially occupy, they do not negatively impact the abundance of native understory plants and seedlings at these sites, at least over the timescale of this study. It is important to note, however, that native species diversity may be adversely affected by invasion even if abundance is not (Hejda *et al*. 2009). It is not our intention to suggest that the lack of impact on native abundance should be taken as evidence that these plant invasions are benign. Rather, we suggest that targeting species that have demonstrable negative effects on ecosystems, rather than targeting those that are merely abundant, may be an approach worth considering.

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REFERENCES

Barnes T.G. (2004) Strategies to convert exotic grass pastures to tall grass prarie communities. *Weed Technology*, **18**, 1364-1370.

Batcher M. (2004) *Monitoring results for WIN barberry treatment areas at Jug End State Reservation, Berkshire County, MA and Edgar Masters Farm, Columbia County, NY.* Unpublished summary report.

Burke M.J.W. & Grime J.P. (1996) An experiment study of plant community invasibility. *Ecology*, **77**, 776-790.

Callaway R.M. & Ridenour W.M. (2004) Novel weapons: invasive success and the evolution of increase competitive ability. *Frontiers in Ecology and the Environment*, **2**, 436-443.

Daehler C.C. (2003) Performance comparisons of co-occurring native and alien invasive plants: implications for conservation and restoration. *Annual Review of Ecology, Evolution, and Systematics*, **34**, 183-211.

Hedja M., Pysek P. & Jarosik V. (2009) Impact of invasive plants on the species richness,diversity, and composition of invaded communities. *Journal of Ecology*, **97**, 393-403.

Leung B., Lodge D.M., Finnoff D., Shogren J.F., Lewis M.A. & Lamberti G. (2002) An ounce of prevention or a poung of cure: bioeconomic risk analysis of invasive species. *Proceeding Royal Society London*, **269**, 2407-2413.

Mack R.N., Simberloff D., Lonsdale W.M., Evans H., Clout M. & Bazzaz F.A. (2000) Biotic invasions: causes, epidemiology, global consequences, and control. *Ecological Applications*, **10**, 689-710.

Marx L. & Lombard K. (2008) *Has regeneration of native forest trees increased in areas treated through TNC's Weed It Now invasives removal* *program?* Unpublished report.

Pimentel D., Zuniga R. & Morrison D. (2005) Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics*, **52**, 273-288.

Reinartz J.A. (2002) Winter season offers many advantages for treating invasive buckthorns and honeysuckles. *Ecological Restoration Notes*, **4**, 237.

Rejmanek M. & Richardson D. M. (1996) What attributes make some plant species more invasive? *Ecology*, **77**, 1655-1661.

Sadighi K. & Cooperman D. (2000) *Protocol for Berkshire Taconic Landscape non-natives survey*. Unpublished data.

Stinson K., Kaufman S., Durbin L. & F. Lowenstein (2007) Impacts of garlic mustard invasion on a forest understory community. *Northeastern Naturalist*, **14**, 73-88.

Sutherland W.J. (2000) *The conservation handbook: techniques in research, management and policy*. Blackwell Science, Oxford, UK.

Wilson S.D. & Pärtel M. (2003) Extirpation or coexistence? Management of a persistent introduced grass in a prairie restoration. *Restoration Ecology*, **1**, 410-416.