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Legacy Effects Of Different Long-Term Non-Native Plant Removal Methods On Herbaceous Communities

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Abstract

Non-native invasive species are a threat to the diversity and success of native species. There have been many attempts to eradicate non-native invasive species and prevent re-invasion by restoring the habitat, but no method has been completely successful. Reinvasion is expected, unless all of the invasive plants are eradicated from the site and surrounding area. Successful restoration of the habitat after non-native invasive eradication involves restoring the overall diversity of the habitat as closely to the composition of the original habitat as possible. A long-term study began at the University of North Carolina at Asheville (UNCA) in 2008 to determine the effectiveness of three methods (mechanical, chemical, and a combination) for removing introduced and invasive species and for promoting native recovery. The treatments ended in 2013, and in 2014 the current study began to determine community assemblage after the cessation of the annual treatments. The original study was done with three 25 x 50 m blocks in both sites on the UNCA campus containing four 16.7 x 25 m plots for each treatment and a control. A nested design was used in this study to sample the herbaceous layer in the summers of 2014-15, where eight 4 m^2 subplots were sampled within each larger 16.7 x 25 m treatment plot. A nested mixed models analysis was used to test the effect of treatment on the percent cover of both non-native and native species. Results suggest that some form of mechanical treatment is the most effective at reducing reinvasion of non-native species. The chemical treatment alone was not effective at the Pisgah Forest site, and was less effective at the Chestnut Ridge site than the mechanical and combination treatments. Mechanical treatments may be the most effective treatment of non-native invasive species in urban forests.

1. Introduction

Non-native invasive species are a growing threat to the diversity and success of native species, which motivates control programs due to habitat disruption and domination by non-native species[1,2]. Some habitats are more susceptible to invasion than others, particularly ones that have experienced high levels of disturbance, have low species richness, are near a potential source of propagules, or are similar to the non-native species source habitat[3,4]. Many non-native species rely on disturbances, forest edges and gaps in the habitats to invade[3,5]. Old-field communities are quite susceptible to non-native invasions because they are successional ecosystems transitioning from abandoned agricultural land into woody forests[6]. A successful invasion depends on the habitat characteristics, including the soil moisture, light cover, plant cover and litter density, and the interaction between the habitat and the species attributes[3]. Invasive species take advantage of any increased availability of a limiting factor, like those habitat characteristics[7]. The invasibility of a habitat is not static, but depends on the conditions at the time, allowing fluctuations[7].

Extinction and immigration are two processes that affect the diversity and invasibility of a habitat. Extinction processes remove or limit species through competition, extreme disturbances, and chronic environmental stress. Extinction-driven communities with higher species diversity are less easily invaded[8]. Immigration processes facilitate entry of new species into the community through propagule pressure, and high resource availibility[7, 10]. Resources become available through either a decline in the existing vegetation, or an increase in the supply of resources at a faster rate than the existing vegetation can capture[7]. Invasive species in an immigration-driven community can produce large persistent seed banks, increasing species density and abundance resulting in greater seed production[9]. Diversity does not decrease invasibility in immigration-driven communities[7, 8, 10]. Instead, the timing between an increase in resource availability and the capture of these resources by existing vegetation determines invasibility[7].

Attempts to restore invaded areas by eradicating non-native species and preventing their reestablishment have not been completely successful[1]. Non-native invasive species are most commonly eradicated manually, chemically, or a combination of both. Manual eradication by cutting is the least effective method because re-sprouting can occur[11]. Combining manual and chemical removal of non-native species is effective, as well as chemical injection into the stem of woody plants[11]. Native revegetation along with non-native invasive eradication helps restore the native habitat and may act as a natural barrier to recolonization and expansion of non-native invasive species[1]. Habitat restoration does not always prevent non-native reinvasion and a significant gain in native abundance does not always occur, likely because of propagule limitation[1]. Successful restoration requires reestablishment of the overall native diversity as close as possible to the original composition, which may require seeding or planting of native species[11].

Removal of non-native species in urban forests is difficult because these species are isolated from mature native forests and are surrounded by developed land that is often the source of non-native propagules[12, 13]. Mature forests are a source for native seed regeneration, so the isolation of urban forests leads to a decrease in the seed rain and seed bank of native species[12]. Non-native species often have a long distance seed dispersal, and long term persistence in the seed bank[12]. Birds disperse non-native species occurring in residential gardens causing the buffers surrounded by high canopy cover to become the most invaded urban landscape due to high bird abundance[4].

Reinvasion is expected, unless all of the invasive plants are eradicated from the site and surrounding area[11]. Favorable conditions for invasive reestablishment can be a consequence of habitat restoration methods[11]. One example is seen with the reinvasion of *Acer platanoides* (Norway maple). When *A. platanoides* was removed a significant increase of new *A. platanoides* recruitment occurred, which led to rapid recolonization. The *Acer platanoides* results may apply to other non-native invasive, but the treatment effectiveness is generally specific to the habitat being treated[1]. Because reinvasion is expected, treatment effectiveness, legacy effects after invasive species removal, and the impact of the invasive species to the ecosystem during its residence are three factors that should be evaluated post-treatment[15].

A long-term removal study from 2008-2013 at the University of North Carolina at Asheville was conducted to determine the effectiveness of three methods (chemical, mechanical and a combination of both) of non-native species removal to promote native recovery. The goal of this research was to determine how community composition changed after these annual treatments ceased and if the legacy of non-native removal differed among treatments.

2. Methods

2.1. Study Sites

This study was conducted in two urban forest sites in the Blue Ridge region of the Appalachian Mountains on the University of North Carolina at Asheville campus: Chestnut Ridge (CR), and Pisgah Forest (PF). Both study sites are reforested areas with heavily invaded understories. Chestnut Ridge is a 24-hectare *Quercus-Carya* (oak-hickory) dominated forest. It was previously a pastureland, and now is the last forested ridge in Asheville with less recent disturbance than Pisgah Forest. Pisgah Forest is a 20-hectare *Pinus strobus* (Eastern white pine) and hardwood dominated forest. Around 100 years ago the area served as a dairy farm and was replanted with *P. strobus* in the 1930s.

2.2. Vegetation Surveys

In 2008, three 25 x 50 m blocks were established in each site. Each block is subdivided into 16.7 x 25 m treatment plots. Each plot received one the following randomly selected treatments: a mechanical treatment consisting of uprooting the invasive plants, a chemical treatment from the application of a 5% glyphosate with a non-ionic surfactant via foliar spot spray, or a combination of the two treatments. The treatment plots have been surveyed since 2008, while the control was added in 2009. The treatments were applied each summer from 2008 until 2012, excluding chemical treatment in 2011. All non-native species, and the native *Toxicodendron radicans* (poison ivy) were treated. Through 2013, the treatment plots were surveyed each summer using sixteen randomly placed 0.5 m^2 quadrats in each plot excluding a 3 m buffer at the edges.

This research randomly placed eight permanent 4 m^2 non-overlapping subplots within the sampling area of each plot. The herbaceous layer of each permanent subplot was sampled in the summer of 2014 using eight 0.5 m^2 quadrants and counting the number of squares each species occupied in the subplot to quantify the percent of the plot the species covered (percent cover). This was repeated in the summer/fall of 2015. The herbaceous layer includes all non-woody plants and any woody plant under 25 cm in height with tissue inside the quadrats. The percent cover of each species was estimated by comparing the number of squares in which tissue occurred divided by the total number of sampling squares (n = 400).

2.3. Data Analysis

A mixed model ANOVA with the subplots nested within plots (SAS Institute, Cary, NC) was used to test the treatment effects on both native and non-native herbaceous cover and richness. A post-hoc Tukey's test compared the differences among plots at a significance level of $p < 0.05$. Analyses were run annually for each site separately. To determine which individual species were driving these community responses, we summarized the cover of the most abundant species.

3. Results

3.1. Chestnut Ridge

3.1.1. species richness

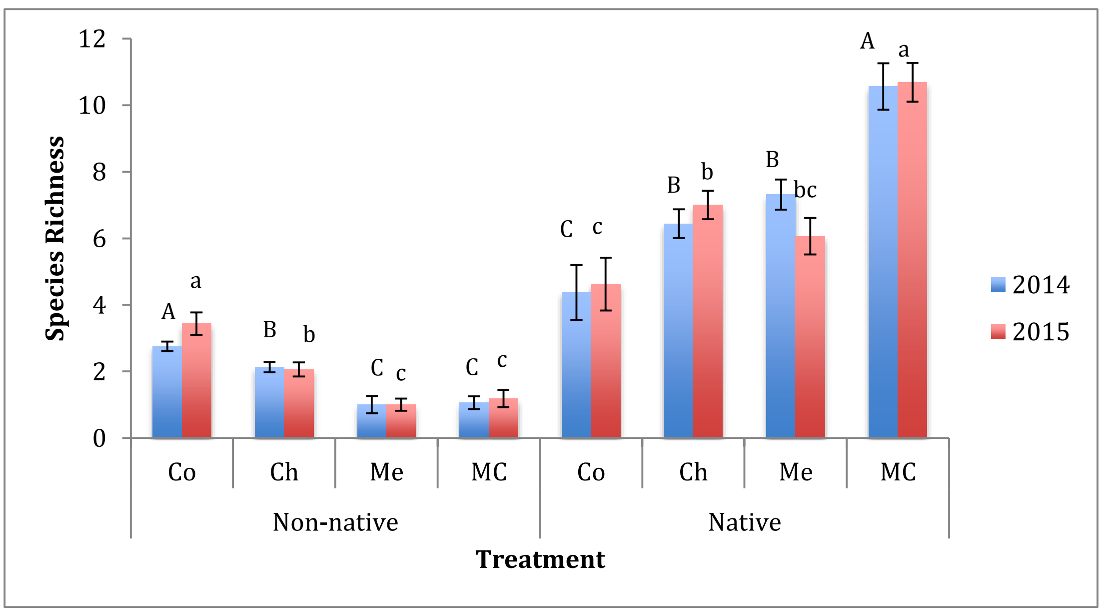

Figure 1. Mean (± 1 SE) species richness in Chestnut Ridge (CR) for non-native and native species.

Figure 1. The mean (± SE) native and non-native species richness in each treatment at the Chestnut Ridge in 2014 and 2015. The mean includes all 4 m^2 subplots within a treatment. The treatments are control (Co), chemical (Ch), mechanical (Me), and the combination (MC). Treatments within each year and species type with different letters differed significantly ($p < 0.05$). Capital letters are for 2014 and lowercase are for 2015.

In 2014 the Chestnut Ridge non-native species richness differed significantly among treatments (F = 19.50, df = 3,60; p < 0.0001). The control had the highest richness, while the mechanical and combination treatments had the lowest richness and did not differ significantly (Figure 1). The non-native species richness differed significantly among treatments in 2015 (F = 18.73, df = 3,60; p < 0.0001). The results from 2015 followed the same trend found in 2014 (Figure 1).

In 2014 the Chestnut Ridge native species richness differed significantly among treatments (F = 23.64, df = 3,60; p < 0.0001). The richness was highest in the combination treatment, while the control had the lowest richness (Figure 1). The mechanical and chemical treatments did not differ significantly. The native species richness in 2015 differed significantly among treatments (F = 13.73, df = 3,60; p < 0.0001). The combination treatment maintained the highest richness (Figure 1). The chemical and mechanical treatments were not significantly different, and the control was not significantly different from the mechanical treatment (Figure 1). The native species richness of the combination treatment was significantly higher than all other treatments in 2014 and 2015.

3.1.2. herbaceous cover

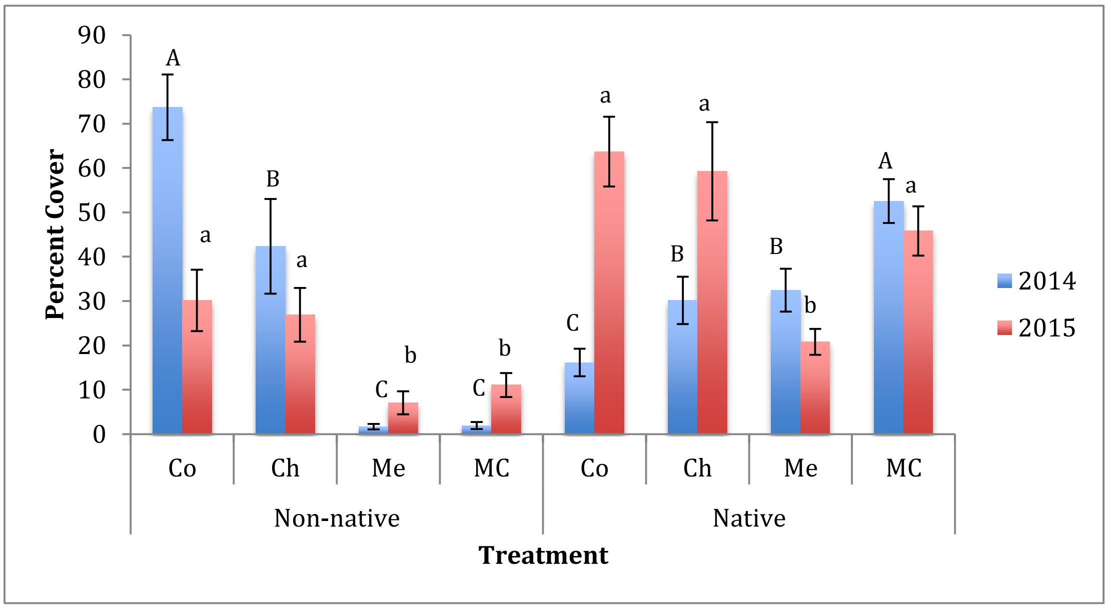

Figure 3. Mean (± SE) percent cover in Chestnut Ridge (CR) for non-native and native species

Figure 2. The mean (± SE) native and non-native species percent cover in each treatment at the Chestnut Ridge site in 2014 and 2015. The mean includes all 4 m^2 subplots within a treatment. The treatments are control (Co), chemical (Ch), mechanical (Me), and the combination (MC). Treatments within each year and species type with different letters differed significantly (p < 0.05). Capital letters are for 2014 and lowercase are for 2015.

In 2014 the Chestnut Ridge non-native species cover differed significantly among treatments (F = 28.70, df = 3,60; p < 0.0001). The control had the highest non-native cover. The combination and mechanical treatments did not differ significantly (Figure 2). The non-native species cover differed significantly among treatment in 2015 F = 5.28, df = 3,60; p = 0.0027). The control did not differ significantly from the chemical treatment, and the combination and mechanical treatments did not differ significantly (Figure 2).

In 2014 the Chestnut Ridge native species cover differed significantly among treatments (F = 10.48, df = 3,60; p < 0.0001). Native cover was highest in the combination treatment, and lowest in the control. The mechanical and chemical treatments did not differ significantly (Figure 2). The 2015 native species cover was significantly different among treatments (F = 6.66, df = 3,60; p = 0.0006). The control, chemical and combination treatments did not differ significantly (Figure 2). The mechanical treatment was significantly lower than all other treatments. The control shifted from the lowest native cover in 2014, to the highest in 2015 (Figure 2).

3.1.2. species abundance

Table 1. Most abundant species in the Chestnut Ridge herbaceous cover survey by year and treatment. Abundance is measured by the sum of a species percent cover within a treatment. Species marked with * represents species that were treated in the study. The data from the control treatment labeled 2008 are from 2009.

Treatment	**2008**	**Total % cover**	**2014**	**Total % cover**	**2015**	**Total % cover**
Control	*Lonicera japonica**	35.10	*Lonicera japonica**	1037.75	*Lonicera japonica**	1048.00
	*Celastrus orbiculatus**	1.64	*Parthenocissus quinquefolia*	94.25	*Toxicodendron radicans**	86.75
	Parthenocissus quinquefolia	1.34	*Celastrus orbiculatus**	86.75	*Rosa multiflora**	85.00
Chemical	*Lonicera japonica**	17.41	*Hedera helix**	697.00	*Hedera helix**	743.50
	*Hedera helix**	16.00	*Parthenocissus quinquefolia*	172.50	*Parthenocissus quinquefolia*	216.25
	Smilacina racemosa	4.40	*Smilacina racemosa*	119.50	*Smilacina racemosa*	131.50
Mechanical	*Lonicera japonica**	28.08	*Rubus allegheniensis*	135.75	*Smilacina racemosa*	115.75
	Smilacina racemosa	4.32	*Smilacina racemosa*	121.25	*Actaea racemosa*	100.75
	*Celastrus orbiculatus**	4.08	*Actaea racemosa*	88.50	*Rubus allegheniensis*	61.50
Combination	*Lonicera japonica**	19.80	*Smilacina racemosa*	276.75	*Smilacina racemosa*	233.00
	*Hedera helix**	11.06	*Actaea racemosa*	179.50	*Actaea racemosa*	159.25
	*Celastrus orbiculatus**	5.36	*Parthenocissus quinquefolia*	118.25	*Parthenocissus quinquefolia*	111.25

There was not much change in species abundance in Chestnut Ridge between 2014 and 2015. There was a large change in the species abundance between the 2008 pre-treatment data and the post-treatment data in all treated plots. *Lonicera japonica* (Japanese honeysuckle), a non-native invasive species, was the most abundant species pre-treatment throughout all of the treatment plots (Table 1). Along with *L. japonica*, *Celastrus orbiculatus* (oriental bittersweet), and *Hedera helix* (English ivy), were the most abundant non-native invasive species pre-treatment. *Parthenocissus quinquefolia* and *Smilacina racemosa* were the most abundant native species pre-treatment. The most abundant species present in the control were the same from the 2008 and 2014 data. *Parthenocissus quinquefolia* was replaced by the native *T. radicans* in the control in 2015, which was the only native species that was treated with the non-native species. *Celastrus orbiculatus* was replaced by the non-native *Rosa multiflora* (multiflora rose) in the control in 2015. *Lonicera japonica* maintained the most abundant species in the control from 2008 into 2015 with increasing abundance. The mechanical and combination treatments most abundant species included only native species in the 2014 and 2015 post-treatment data. The most abundant species post-treatment in the chemical treatment was *H. helix* both years, increasing in abundance from the 2008 pre-treatment data.

3.2. Pisgah Forest

3.2.1. species richness

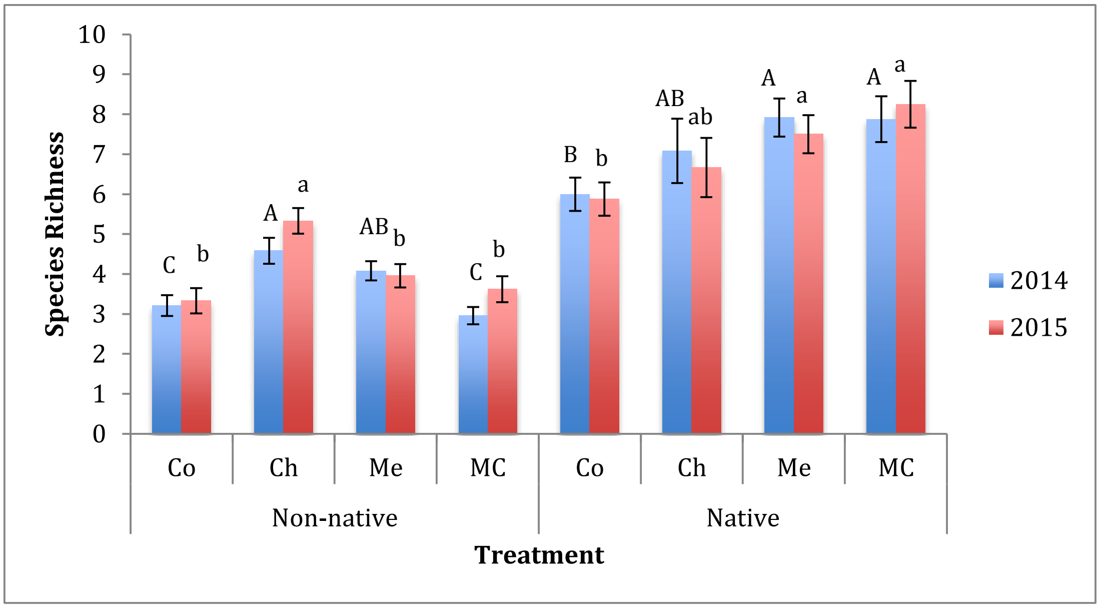

Figure 3. Mean (± SE) species richness in Pisgah Forest (PF) for non-native and native species.

Figure 3. The mean (± SE) native and non-native species richness in each treatment at the Pisgah Forest site in 2014 and 2015. The mean includes all 4 m^2 subplots within a treatment. The treatments are control (Co), chemical (Ch), mechanical (Me), and the combination (MC). Treatments within each year and species type with different letters differed significantly ($p < 0.05$). Capital letters are for 2014 and lowercase are for 2015.

In 2014 the Pisgah Forest non-native species richness differed significantly among treatments ($F = 8.29$, df = 3,92; $p < 0.0001$). Species richness did not differ significantly in the chemical and mechanical treatment. The mechanical treatment did differ significantly from the control, though the control and combination treatments did not differ significantly (Figure 3). The 2015 non-native species richness differed significantly among treatments ($F = 9.62$, df = 3,60; $p < 0.0001$). The chemical treatment species richness was significantly higher than all other treatments. The mechanical, combination, and control treatments did not differ significantly (Figure 3).

In 2014 the Pisgah Forest native species richness did not differ significantly among treatments ($F = 2.34$, df = 3,92; $p = 0.0781$). The mechanical, combination, and chemical treatments did not differ significantly (Figure 3). The chemical and control treatments did not differ significantly. The 2015 native species richness differed significantly among treatments ($F = 3.28$, df = 3,92; $p = 0.0244$). The 2015 native species richness followed the same trend as the 2014 native species richness (Figure 3).

3.2.2. herbaceous cover

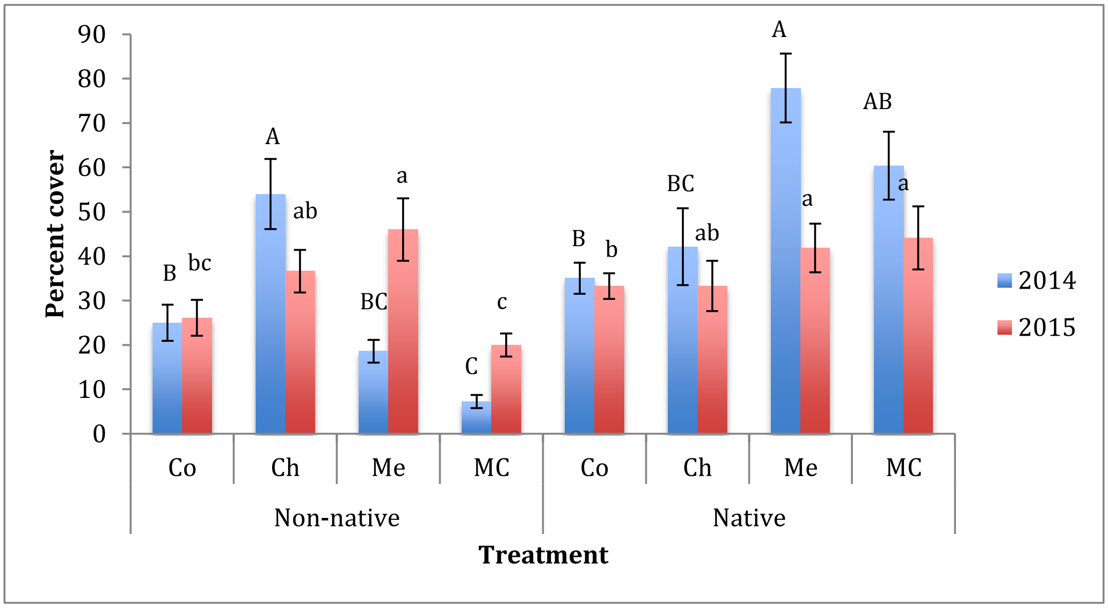

Figure 4. Mean (± SE) percent cover in Pisgah Forest (PF) for non-native and native species

Figure 4. The mean (± SE) native and non-native species percent cover presented in each treatment at the Pisgah Forest site in 2014 and 2015. The mean includes all 4 m^2 subplots within a treatment. The treatments are control (Co), chemical (Ch), mechanical (Me), and the combination (MC). Treatments within each year and species type with different letters differed significantly ($p < 0.05$). Capital letters are for 2014 and lowercase are for 2015.

In 2014 the Pisgah Forest non-native species cover differed significantly among treatments ($F = 18.12$, df = 3,92; $p < 0.0001$). Non-native cover was significantly higher in the chemical treatment than the other treatments. There was no significant difference between the control and mechanical treatments, and no significant difference between the mechanical and combination treatments (Figure 4). In 2015 the non-native cover differed significantly among treatments ($F = 5.54$, df = 3,92; $p = 0.0015$). There was no significant difference between the mechanical and chemical treatments, while there was no significant difference between the chemical and control treatments, and no significant difference between the control and combination treatments (Figure 4).

In 2014 the Pisgah Forest native species cover differed significantly among treatments ($F = 7.19$, df = 3,92; $p < 0.0001$). There was no significant difference between the mechanical and combination treatments, no significant difference between the combination and chemical treatments, and no significant difference between the chemical and control treatments (Figure 4). The 2015 native species cover did not differ significantly among treatments ($F = 2.30$, df = 3,92; $p = 0.0828$). There was no significant difference between the combination, mechanical, and chemical treatments (Figure 4). There was no significant difference between the chemical and control treatments.

3.2.3. species abundance

Table 2. Most abundant species in the Pisgah Forest herbaceous cover survey by year and treatment. Abundance is measured by the sum of a species percent cover within a treatment. Species marked with * represents species that were treated in the study. The data from the control treatment labeled 2008 are from 2009.

Treatment	**2008**	**Total % cover**	**2014**	**Total % cover**	**2015**	**Total % cover**
Control	*Lonicera japonica**	12.42	*Toxicodendron radicans**	337.50	*Lonicera japonica**	388.50
	*Celastrus orbiculatus**	1.92	*Lonicera japonica**	304.25	*Toxicodendron radicans**	328.25
	*Toxicodendron radicans**	1.49	*Parthenocissus quinquefolia*	160.50	*Celastrus orbiculatus**	186.75
Chemical	*Ligustrum sinense**	8.18	*Hedera helix**	371.75	*Hedera helix**	407.75
	*Lonicera japonica**	4.82	*Celastrus orbiculatus**	308.50	*Lonicera japonica**	193.75
	Parthenocissus quinquefolia	4.74	*Alliaria petiolata**	263.75	*Parthenocissus quinquefolia*	192.50
			Parthenocissus quinquefolia	260.25	*Celastrus orbiculatus**	181.00
Mechanical	*Lonicera japonica**	9.35	*Parthenocissus quinquefolia*	456.25	*Parthenocissus quinquefolia*	359.25
	*Celastrus orbiculatus**	4.62	*Senecio aureus*	311.00	*Senecio aureus*	196.25
	Parthenocissus quinquefolia	4.38	*Rubus allegheniensis*	273.75	*Galium aparine*	178.75
Combination	*Hedera helix**	7.00	*Parthenocissus quinquefolia*	749.50	*Parthenocissus quinquefolia*	852.25
	*Ligustrum sinense**	4.31	*Prunus serotina*	153.50	*Prunus serotina*	92.00
	*Celastrus orbiculatus**	4.10	*Rubus allegheniensis*	138.75	*Rubus allegheniensis*	114.00

At Pisgah Forest there was a large change in the species abundance between the pre-treatment and post-treatment data among all plots, including the control. *Ligustrum sinense* was one of the most abundant non-native invasive species pre-treatment in Pisgah Forest, along with *L. japonica*, *H. helix*, and *C. orbiculatus* (Table 2). *Parthenocissus quinquefolia* and *T. radicans* were the most abundant native species. The most abundant species in the control changed from *L. japonica* in the pre-treatment to the native *T. radicans* in 2014, back to *L. japonica* in 2015. The non-native species *Celastrus orbiculatus* replaced the native *Parthenocissus quinquefolia* in the control in 2015. *Hedera helix* was the most abundant post-treatment species in the chemical treatment both years (Table 2). The most abundant species in the chemical treatment were mostly non-native pre-treatment and post-treatment, excluding *P. quinquefolia*. *Parthenocissus quinquefolia* was the most abundant post-treatment native species in the mechanical and combination treatments both years. The most abundant species in the mechanical and combination treatments were all native species post-treatment.

4. Discussion

4.1. Chestnut Ridge

The removal of non-native species likely was one of the main reasons the treated plots had significantly lower non-native species richness than the control plots. The non-native species richness and percent cover in the mechanical and combination treatments were significantly lower than the control both years suggesting that some form of mechanical removal kept the non-native cover low. Some have found that mechanical treatments are effective at treating invasive species, especially under the correct conditions[16]. For example, mechanical removal of *Lonicera maackii*, which was a shrub species found in the herbaceous cover survey for this study, can be effective in moist soil but resprouting will likely occur if any root remains[16]. However, rapid reestablishment of *L. maackii* after large shrubs are removed has been found[16]. The non-native cover did increase in both the mechanical and combination treatment between 2014 and 2015 (Figure 3). This may support other findings that show mechanical removal causes recolonization of invasive species as a result the disturbance[5].

Interestingly, the non-native cover in the control dropped dramatically from the highest among treatments in 2014 to the lowest in 2015 (Figure 3). The native cover in the control followed the opposite trend, increasing from the lowest among treatments in 2014 to the highest in 2015 (Figure 3). The native species *T. radicans* increased in abundance substantially from 2014 to 2015, which contributed to the steep increase of native species (Table 1). An increase in carbon dioxide in the atmosphere may have contributed to these results[17]. Mohan et al[17] found that under elevated carbon dioxide conditions, *T. radicans* growth increased 149% annually, compared to the ambient carbon dioxide condition. Woody plants receiving 25% more carbon dioxide only grew 31% in biomass[17].

A slight decrease of native species cover in the mechanical and combination treatments between 2014 and 2015 may indicate that the mechanical treatments have a negative effect on the native species over time. For Biggerstaff and Beck[18] mechanical removal of *Hedera helix* (English ivy) increased the emergence of native seedlings, the number of native species, and the native species diversity more than chemical removal. Other studies found similar results suggesting native species are more positively impacted by mechanical removal than by chemical removal[1, 19]. Soil disruptions caused by the mechanical removal of invasive species may have contributed to the decrease in native cover. Human disruption within the treatment plots between the summers when vegetation surveying was done may have caused a decrease in the native cover as well.

The native species richness of the mechanical treatment in 2015 did not differ from the control, but the native cover was significantly lower than in the control, suggesting mechanical treatments may help reduce the non-native species richness and cover, but negatively affect the native species richness and cover. Native species remained the most abundant both years in the mechanical and combination treatments, but the abundance did decrease in 2015 among all species except *Actatea racemosa* in the mechanical treatment (Table 1). Flory and Clay[19] found that native tree seedling density was lower in the mechanically treated plots of *Microstegium vimineum* and highest in the post-emergent herbicide treatment. The pulling of *Microstegium* in their experiment may have disturbed native tree seedlings. That explanation does not seem fitting for this study because treatment had not been done since Summer 2012, but the trend may be a result from the increase of non-native species cover in those treatments from 2014 to 2015.

The subplots that were resampled in Fall 2015 were primarily within the mechanical treatment. Some of the species that were present in mid-summer may have senesced by the fall, or other fall species may have been more abundant. This may have altered results, but with the nested design the difference should not have been substantial enough to omit the data.

4.2. Pisgah Forest

The non-native species results in Pisgah Forest did not follow a predictable trend. The control in Chestnut Ridge had the highest non-native species richness both years (Figure 1), but in Pisgah Forest the chemical treatment had the highest non-native richness (Figure 2). The Pisgah Forest chemical treatment had a high non-native cover as well, though it did not differ significantly from the control in 2015 (Figure 4). The results suggest the chemical treatment was not effective at controlling non-native species, or the control began with a low non-native species richness and the chemical treatments began with a high non-native species richness.

Some have found that chemical treatments can inhibit a habitat from becoming more similar to uninvaded habitats[1]. The species abundance results are consistent with this finding (Table 2). The results could be revealing a side effect of chemical treatment where a removed non-native plant is replaced with a different one[1]. The highest species abundance in the chemical treatment maintained three non-native species both years, but *C. orbiculatus* was replaced with *L. japonica,* and *A. petiolata* was replaced with *C. orbiculatus* (Table 2). Biggerstaff and Beck[18] found that chemical treatment can been effective at removing *Hedera helix,* but the species abundance results from this study do not support their finding (Table 2). *Hedera helix* had the highest species abundance in the chemical treatment both years, and increased in 2015.

The mechanical treatment and chemical treatment did not maintain a low non-native percent cover. The combination treatment was most effective because the lowest non-native cover was maintained both years and was significantly lower than the chemical treatment (Figure 4). The non-native species richness in the combination treatment did not differ from the control both years, further indicating that there may have been issues with the control. The control was dominated by the native *T. radican* in 2014, which may have contributed to the low non-native species cover. The low non-native species richness may be a result of the high cover and abundance associated with *T. radicans*, and *L. japonica* both years.

The native species richness and percent cover trends correspond almost exactly, which is ideal. In a heavily invaded habitat like Pisgah Forest the native species cover in the control is expected to be the low because the non-native species would dominate the habitat. The native species richness and percent cover in the mechanical and combination treatments were significantly higher than the control both years, suggesting that at least some form of mechanical treatment was effective. Chemical treatments alone appeared to have little effect on controlling non-native invasive species. The native species cover dropped most dramatically in the mechanical treatment (Figure 4) between years. The most abundant species in the mechanical treatment were native species both years, indicating the efficacy of the treatment, but those species did experience a decrease in abundance. The trend is likely from inter-annual variation, but may represent a negative effect of mechanical treatment on native species over time and explain the subsequent increase in non-native species. Many others have found that mechanical treatments cause a disruption that allows invasive species to reestablish and invade[1, 5, 15, 20] .

4.3. Conclusion and Applications

Mechanical treatments were the most effective for removing non-native species in southern Appalachian urban forests. There may have been negative effects of the mechanical treatments on the native species after treatment, despite the effect on non-native species. The chemical treatment alone did have an effect in Chestnut Ridge, but the chemical treatment was not effective in preventing the reinvasion of non-native species at either site.

Both sites were old fields and have gone through successional changes to become urban forests. A non-native species invasion during succession could have been a factor in the high levels of invasion at the start of the removal study in 2008 invasion level present today. The ratio of herbaceous to woody cover shifts from herbaceous dominated to woody dominated when an old field transitions into a young forest[6]. Non-native invasion may have altered the interactions between the native species and the community, decreasing the herbaceous:woody foliar ratio[6]. The old-field dynamics may have had an effect on the success of the treatments. A study in Tennessee, USA found the non-native species *L. japonica* and *M. vimineum* to be of concern in old-field succession[6]. In New Jersey, USA non-native species were found in the post-removal surveys that had not been previously documented in the study site, including *Ailanthus altissima, L. japonica, A. petiolata,* and *Rubus phoenicolasius*[5]. These species were all present in this experiment's herbaceous survey, and *L. japonica* and *A. petiolata* were among the most abundant species. *Lonicera japonica* had the highest species abundance in the control for both sites, and will likely require continued treatment because invasive species have a higher survival rate, and grow faster than native species[20].

Non-native species treatment has not been found to result in long-term outcomes[2]. Long-term control programs alone are likely to negatively affect the native species, which may have happened in this study[1]. Invasive species are treated to increase the success of the native species, but many studies fail to increase the native species as a response[1]. Native restoration may be necessary in urban forests, like forests in this study, to increase the native diversity and resist reinvasion[13]. On an experimental scale invasion rate and native plant diversity are negatively correlated, but native restoration may not be effective on the large scale because invasion rate is positively correlated with native plant diversity[21]. This response is likely caused by the delay between an increase in the supply of resources, and the capture of these resources by native species[7, 21]. More research needs to be done on the underlying mechanisms driving the non-native reinvasions of these urban forest. A long-term herbaceous survey with seed bank and seed rain analysis may better determine the most effective treatment. Soil analysis may shed light on what type of habitats are welcoming to non-native species, and how the non-native species change the habitat once invaded.

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6. References

1 . Kettenring KM, Adams CR. 2011. Lessons learned from invasive plant control experiments: a systematic review and meta-analysis. Journal of Applied Ecology. 48(1): 970–979.

2. Skurski TC, Maxwell BD, Rew LJ. 2013. Ecological tradeoffs in non-native plant management. Biological Conservation. 159(1): 292-302.

3. Meekins JF, McCarthy BC. 2001. Effect of Environmental Variation on the Invasive Success of a Nonindigenous Forest. Ecological Applications. 11(5): 1336-1348.

4. Seabloom EW , Borer ET, Boucher VL, Burton RS, Cottingham KL, Goldwasser L, Gram WK, Kendall BE, Michele F. 2003. Competition, seed limitation, disturbance, and reestablishment of California native annual forbs. Ecological Applications. 13(3): 575-592.

5. Webb SL, Pendergast IV TH, Dwyer ME. 2001. Response of native and exotic maple seedling banks to removal of the exotic, invasive Norway maple (*Acer platanoides*). Journal of the Torrey Botanical Society. 128(2): 141-149.

6. Keubbing SE, Souza L, Sanders NL. 2014. Effects of co-occurring non-native invasive plant species on an old-field succession. Forest and Ecology Management. 324(1): 196-204.

7. Davis MA, Grime JP, Thompson K. 2000. Fluctuating resources in plant communities: a general theory of invasibility. Journal of Ecology. 88(1): 528-534.

8. Brown RL, Peet RK. 2003, Diversity and Invasibility of Southern Appalachian Plant Communities. Ecology. 84(1): 32-39.

9. Robertson SG, Hickman KR. 2012. Aboveground plant community and seed bank composition along an invasion gradient. Plant Ecology. 213(1): 1461-1475.

10. Vila M, Gimeno I. 2007. Does invasion by an alien plant species affect the soil seed bank?. Journal of Vegetation Science. 18(1): 423-430.

11. Hartman KM, McCarthy BC. 2004. Restoration of a Forest Understory After the Removal of an Invasive Shrub, Amur Honeysuckle (*Lonicera maackii*). Restoration Ecology. 12(2): 154-165.

12. Overdyck E, Clarkson BD. 2012. Seed rain and soil seed banks limit native regeneration within urban forest restoration plantings in Hamilton City, New Zealand. New Zealand Journal of Ecology. 36(2): 177-190.

13. Loeb RE, Germeraad J, Treece T, Wakefield D, Ward S. 2010. Effects of 1-Year vs. Annual Treatment of Amur Honeysuckle (*Lonicera maackii*) in Forests. Invasive Plant Science and Management. 3(3):334-339.

14. Vidra RL, Shear TH. 2008. Thinking Locally for Urban Forest Restoration: A Simple Method Links Exotic Species Invasion to Local Landscape Structure. Restoration Ecology. 16(2): 217-220.

15. Abella SR, Chiquoine LP, Backer DM. 2013. Soil, Vegetation, and Seed BAnk of a Sonoran Desert Ecosystem Along an Exotic Plant (*Pennisetum ciliare)* Treatment Gradient. Environmental Management. 51(1): 946-957.

16. Gayek A. 2000. Effect of Habitat Variation on Rate and Success of Colonization of Two Invasive Shrubs, Lonicera Maackii and Ligustrum Vulgare, in a Forested Glen. (Electronic Thesis or Dissertation). Retrieved from https://etd.ohiolink.edu/

17. Mohan JE, Ziska LH, Schlesinger WH, Thomas RB, Sicher RB, George K, Clarke JS. 2006. Biomass and toxicity responses of poison ivy (*Toxicodendron radicans*) to elevated atmospheric CO_2. PNAS. 103(24): 9086-9089.

18. Biggerstaff MS, Beck W. 2007. Effects of Method of English Ivy Removal and Seed Addition of Regeneration of Vegetation in a Southeastern Piedmont Forest. The American Midland Naturalist. 158(1): 206-220.

19. Flory SL, Clay K. 2009. Invasive plant removal method determines native plant community responses. Journal of Applied Ecology. 46(1): 434-442.

20. Heleno R, Lacerda I, Ramos JA, Memmott J. 2010. Evaluation of resoration effectiveness: community response to the removal of alien plants. Ecological Applications. 20(5): 1191-1203.
21. Questad EJ, Thaxton JM, Cordell S. 2011. Patterns and consequences of re-invasion into a Hawaiian dry forest restoration. Biological Invasions.