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RESEARCH NOTE

Does Removal of the Invasive Shrub *Lonicera maackii* Alter Arthropod Abundance and Diversity?

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ABSTRACT: To evaluate the effects of Amur honeysuckle (*Lonicera maackii*) removal on arthropod abundance and taxon richness, we sampled arthropods in seven removal plots and seven control plots in urban parkland in Louisville, Kentucky, in the first and third years after removal. We found no differences in overall abundance between invaded and removal plots in the first year after management, although removal plots had 12%–16% higher taxon diversity than invaded plots. Three years after management, invaded plots had 46% higher ground-dwelling arthropod abundance and 31% higher taxon richness, partly explained by other shrubs in managed plots. Herbivores were 91% more abundant in removal plots. Our results suggest that honeysuckle removal can have small effects on the entire arthropod community, but an increase in herbivore abundance should be expected following removal of this unpalatable invasive species.

Index terms: Amur honeysuckle, arthropods, herbivores, *Ligustrum sinense*

INTRODUCTION

Invasive plant species can disrupt ecosystems by reducing biodiversity at multiple trophic levels (Levine et al. 2003; Gaertner et al. 2009; Hejda et al. 2009; van Hengstum et al. 2014). Despite the importance of understanding whole-community responses to invasive species management, only a small number of studies have evaluated impacts of invasive plant removal on any group besides native plants (Reid et al. 2009; van Hengstum et al. 2014). Studies on arthropod response to invasive species removal often have conflicting results. For example, arthropod species assemblages quickly recovered to pre-invasion states following removal of *Phragmites australis* (Cav.) Trin. ex Steud. in southern New Jersey salt marshes (Gratton and Denno 2005). Removal of *Ligustrum sinense* Lour. from southeastern forests increased butterfly abundance and diversity, indicating recovery within two years (Hanula and Horn 2011). However, removal of *Gypsophila paniculata* L. from Michigan sand dunes decreased arthropod abundance and diversity in a three-year study (Emery and Doran 2013). With these considerations, managers should address the effects of invasive species removal on a case by case basis.

Lonicera maackii Rupr. (Amur honeysuckle) is an invasive shrub introduced into the United States for erosion control and landscaping (Luken and Thieret 1996). It forms dense stands that negatively impact native arthropod species by altering the plant community (McKinney and Goodell 2010; Loomis and Cameron 2014). In addition, its leaves contain phenolic compounds making it unpalatable for many herbivores (Cipollini et al. 2008; Lieurance and Cipollini 2012). Removal of *L. maackii* may affect arthropod communities directly by altering habitat and food resources, or indirectly by altering plant communities. Direct effects are likely to be found immediately after *L. maackii* management, while indirect effects may take several years to appear (Runkle et al. 2007). This study addressed the following question: Does *L. maackii* removal alter arthropod abundance and diversity? We expected that *L. maackii* removal would have direct positive effects on arthropods, especially herbivores, as *L. maackii* leaves are unpalatable to herbivores in its introduced range (McEwan et al. 2009; Lieurance and Cipollini 2013). We also expected that *L. maackii* removal would have longer-term indirect positive effects on arthropods as the native plant community returned (Runkle et al. 2007). To test these predictions, we examined responses of arthropod communities one and three years after *L. maackii* removal in an urban deciduous forest in Kentucky.

METHODS

Study Site

We conducted this study in two parks managed by the Olmsted Parks Conservancy (Cherokee: 38.241°N, −85.696°W; and Seneca: 38.235°N, −85.668°W) in Louisville, Kentucky, USA. These parks have been managed as urban forests since 1890 and 1928, respectively. Our study sites were located along the Middle Fork of Beargrass Creek, a third-order stream that is urbanized and strongly channelized (Beargrass Creek Watershed Council 2005). The dominant trees in these woodlands were *Acer saccharum* Marsh. and *Fraxinus americana* L. The unmanaged understory was mostly *Lonicera* shrubs, with the exotic shrub *Ligustrum sinense* L. (Chinese privet) being co-dominant in some locations.

Honeysuckle Removal and Arthropod Sampling

We established seven 10 m × 10 m paired plots (3-m buffer between pairs) within a 166-ha heavily invaded area of the parks (100% understory cover; >72 live stems plot^{-1}). This area is representative of typical honeysuckle densities in unmanaged urban parks. In January 2009, all *L. maackii* was removed from one plot in each pair. Stems were cut at the base of the shrub and an herbicide solution (25% glyphosate) was applied to the cut stems. Cut biomass was removed from the plots. Over the three years of our study, stem height and density did not return to pre-removal levels (mean = 47 live stems plot^{-1}, range = 11–139 live stems plot^{-1} with all stems <1 meter in 2011, compared to mean = 145 live stems plot^{-1}, range = 72–279 live stems plot^{-1} before removal). Other invasive plants, such as Chinese privet, were not removed in order to evaluate plant community responses as part of another study in this system.

To sample arthropod abundance and diversity, we divided all plots into sixteen 2.5 m × 2.5 m quadrats, and buried one pitfall trap (an empty 0.24 L plastic cup) flush with ground surface in each of the four central quadrats. Pitfall traps were left empty (no alcohol or other liquid to trap arthropods) to avoid poisoning wildlife or pets that frequent the parks. A yellow sticky trap (21 cm × 10 cm) was positioned approximately 8 cm above the soil in two diagonally opposite, center quadrats in each plot to capture flying insects under the shrub canopy. We chose these sampling methods because shrub density in many plots was too high to manage active sampling methods such as sweep nets or a vacuum. Sampling was conducted in April, July, and October of 2009 (the year immediately following removal), and in May, July, and November of 2011 (third year after removal). These sampling dates corresponded to seasonal differences between *L. maackii* and the associated tree canopy. Its leaves emerge earlier than native species and leaf senescence occurs later than most native species (McEwan et al. 2009; Fridley 2012), providing potential forage and refuge for arthropods early in spring and late into fall. Traps were left out for 48 hr, and transported in coolers back to the lab where they were stored at −20 °C until processing, where they were counted and identified, most often to the family level (Marshall 2006). We did not calculate any community diversity indices because taxa classifications to species level were not possible.

In late spring 2009 and 2011, we quantified vegetation responses to management by visually estimating other shrub stem density (stems >2 m high), % cover of herbs + vines, % bare soil, and herb species richness for each quadrat (n = 16) in each plot.

Analysis

To simplify vegetation data and identify key variables that could be responsible for indirect effects of *L. maackii* removal on arthropods, we used principal components analysis (PCA). In both years, PCA results indicated that the number of non–honeysuckle shrub stems (mostly the co-dominant *Ligustrum sinense*) described most of the differences in vegetation across plots (PC1 explaining 86%–92% of the variation in the data; with non–honeysuckle shrub stems loadings >0.99). The number of non–honeysuckle shrub stems (>2 m high) was added as a random covariate in our full statistical models to account for indirect effects on arthropods mediated through changes in vegetation.

We used the data from individual traps within plots to calculate average total arthropod abundance, herbivore abundance, total taxon richness, and herbivore taxon richness per plot and used mixed linear models (Kuehl 2000) to test for differences in these variables between removal and invaded plots with honeysuckle treatment and season as fixed effects, and block (each plot pair) and shrub density as random covariates. All analyses were conducted with SYSTAT v.12 (SYSTAT 2007). Abundance data were log(x+1) transformed to meet test assumptions. We analyzed data from each trap type separately, as the traps specialized in capturing different groups of arthropods. Different personnel processed the data for each year, so we also examined results from each year separately in order to avoid sampler bias, which could artificially create differences between years. Large climate differences between the sampling years could also confound treatment effects.

RESULTS

We collected 5396 individuals representing 114 taxa from removal plots, and 6607 individuals (115 taxa) from invaded plots, over the two sampling years. Sticky traps caught a large number of flying herbivores, mostly the leaf hopper *Graphocephala coccinea* (Family Cicadellidae), and aphids (Family Aphidae). Pitfall traps caught almost no herbivores. Summed across both years, we collected a total of 1364 individual herbivores from invaded plots and 1570 individual herbivores from removal plots.

We found no differences between removal and invaded plots in overall arthropod abundance one year after removal (Tables 1–3). However, overall taxon richness and herbivore richness from sticky traps were 12%–16% higher in removal plots (Tables 1 and 2).

Three years after removal, we found no differences in arthropod abundance measured with sticky traps, but we did find 46% higher arthropod abundance in invaded plots measured with pitfall traps. Pitfall taxon richness in the third year was also higher (31%) in invaded plots (Tables 1 and 2). In contrast, herbivore abundances were 91% higher in removal plots in the third year after removal. Herbivore taxon richness showed no differences across treatments (Tables 1 and 3).

The number of shrub stems (other than honeysuckle) occurring in plots, which ranged from 0 to 408 per 100 m^2, had a negative effect on total arthropod abundance and taxon richness as measured with pitfall traps in the third year. There were

Table 1. Per plot mean and standard error for overall and herbivore abundance and richness as measured with pitfall (PT) and sticky traps (ST) in 2009 and 2011. Asterisks denote a statistically significant difference between invaded and removal plots at $p \leq 0.05$.

Variable measured	Invaded		Removal	
	Mean	SE	Mean	SE
2009 PT overall abundance	3.401	0.426	3.976	0.717
2009 PT overall taxon richness	2.008	0.171	2.004	0.216
2009 ST overall abundance	107.548	23.915	92.500	15.994
2009 ST overall taxon richness*	18.619	1.312	20.825	1.241
2009 herbivore abundance	21.786	5.336	24.050	7.102
2009 herbivore taxon richness*	5.714	0.720	6.600	0.597
2011 PT overall abundance*	7.024	1.943	4.806	1.295
2011 PT overall taxon richness*	2.310	0.277	1.762	0.274
2011 ST overall abundance	24.333	2.249	29.429	3.496
2011 ST overall taxon richness	9.571	0.438	9.833	0.799
2011 herbivore abundance*	9.595	1.164	18.357	3.000
2011 herbivore taxon richness	2.857	0.232	4.452	1.096

also significant sampling date and block effects (Table 2).

DISCUSSION

Our results indicate that Amur honeysuckle removal has a small but significant impact on arthropod communities both immediately and three years after management. The initial increase of taxon richness one year after management may be due to a reduction in the physical barriers presented by thick *L. maackii* growth, making sticky traps more visible to more species of flying insects. Immediately after removal, the structural complexity in removal plots was low compared to invaded plots. By the third year, annual understory plants had established, increasing the physical structural complexity of the understory and possibly obscuring sticky traps.

Three years after management, invaded plots had higher ground-dwelling arthropod abundances and diversity. Removal of *L. maackii* may have indirectly reduced ground-dwelling arthropod numbers due to an associated increase in non–honeysuckle shrub abundance, mostly consisting of *Ligustrum sinense*. Removal of *L. sinense* can increase ground-dwelling beetles (Ulyshen et al. 2010) and likely affects other terrestrial arthropods. In our study,

Table 2. Linear mixed model analysis for effects of honeysuckle removal on total arthropod abundance and taxon richness as measured with pitfall and sticky traps. Statistically significant results ($p \leq 0.05$) are bolded.

	2009 pitfall			2009 sticky			2011 pitfall			2011 sticky		
Source	df	*F*	*p*	df	*F*	*p*	df	*F*	*p*	df	*F*	*p*
Total arthropod abundance												
Removal	1	0.405	0.530	1	0.956	0.337	1	8.053	**0.008**	1	2.363	0.135
Season	2	7.819	**0.002**	2	119.277	**< 0.001**	2	55.827	**< 0.001**	2	8.067	**0.002**
Removal × Season	2	0.466	0.632	2	3.234	0.055	2	0.624	0.543	2	1.408	0.261
Block	6	1.466	0.225	6	5.807	**< 0.001**	6	5.254	**0.001**	6	1.959	0.105
Other shrub stems	1	1.210	0.280	1	1.092	0.305	1	5.414	**0.027**	1	0.620	0.437
Taxon richness												
Removal	1	0.003	0.955	1	5.921	**0.022**	1	8.515	**0.007**	1	0.408	0.528
Season	2	7.245	**0.003**	2	48.67	**< 0.001**	2	25.068	**< 0.001**	2	0.580	**0.009**
Removal × Season	2	1.397	0.263	2	0.278	0.759	2	0.439	0.649	2	1.035	0.368
Block	6	1.655	0.168	6	2.397	0.054	6	1.194	0.337	6	0.734	0.626
Other shrub stems	1	0.027	0.869	1	0.045	0.834	1	4.974	**0.034**	1	0.548	0.465

Table 3. **Mixed linear model analysis for effects of honeysuckle removal on herbivore abundance and taxon richness as measured with pitfall and sticky traps. Statistically significant results ($p \leq 0.05$) are bolded.**

Source	2009 pitfall df	2009 pitfall *F*	2009 pitfall *p*	2009 sticky df	2009 sticky *F*	2009 sticky *p*	2011 pitfall df	2011 pitfall *F*	2011 pitfall *p*	2011 sticky df	2011 sticky *F*	2011 sticky *p*
Herbivore abundance												
Removal	1	0.049	0.827	1	1.651	0.209	1	0.106	0.747	1	12.291	**0.002**
Season	2	0.922	0.409	2	75.740	**0.000**	2	1.839	0.177	2	4.326	**0.023**
Removal × Season	2	0.922	0.409	2	1.767	0.189	2	0.154	0.858	2	0.980	0.387
Block	6	1.509	0.210	6	6.250	**0.000**	6	1.103	0.384	6	3.033	**0.020**
Other shrub stems	1	0.007	0.935	1	0.091	0.766	1	0.001	0.975	1	0.149	0.703
Herbivore taxon richness												
Removal	1	0.003	0.957	1	3.469	0.073	1	0.089	0.768	1	2.102	0.158
Season	2	0.473	0.628	2	50.071	**0.000**	2	1.804	0.183	2	0.379	0.688
Removal × Season	2	1.314	0.284	2	0.907	0.415	2	0.139	0.871	2	1.475	0.245
Block	6	1.934	0.109	6	2.528	**0.044**	6	1.125	0.373	6	1.006	0.441
Other shrub stems	1	0.124	0.727	1	0.014	0.905	1	0.003	0.958	1	0.201	0.657

the presence of other shrubs (mostly *L. sinese*) negatively impacted ground-dwelling arthropods (Table 2).

Herbivores showed no response immediately after removal, but were almost twice as abundant in removal plots three years after management (Table 3). Unpalatable invasive plants can deter phytophagous insects (Burghardt et al. 2010; Tallamy et al. 2010; Fickenscher et al. 2014), and Amur honeysuckle contains phenolic compounds known to decrease herbivory (Cipollini et al. 2008; Lieurance and Cipollini 2012). While total herbivore abundance and diversity was likely underestimated in our study due to the passive collection methods, and while sticky traps and dry pitfall traps do not always fully sample the arthropod community, we found evidence that the removal of *L. maackii* directly increases herbivores over time.

Despite the strong herbivore response, our results should be viewed with some caution. These woodlands are surrounded by urban land use and had been colonized densely by honeysuckle for approximately 35 years before this study began (Carreiro and Zipperer 2011). As a consequence, the opportunity for diversity to rebound greatly after shrub removal may be constrained by a species-depauperate urban matrix and by honeysuckle suppression of a diverse plant community for decades. It is also possible that our results from one year and three years after removal did not capture the recovery time needed to gauge long-term recovery. Habitats degraded by *L. maackii* can take as long as seven years after removal to recover plant species richness and cover (Runkle et al. 2007). Scale may be another complicating factor. Our study plots were 10 m × 10 m placed within large invaded areas several hectares in size, so the relatively small scale of the removal may have had little effect relative to the arthropods' foraging and dispersal flight distances, which can range to several kilometers (Pasquet et al. 2008; Kissling 2015). We expect larger-scale removals may have even larger effects on arthropods, and so our results represent the most conservative consequences of management. A final consideration is that our results may be a consequence of the significant removal of plant biomass, regardless of invasive status. However, our treatments reflect realistic conditions following management and, while we detected little response in overall arthropod abundance, there was a large increase in herbivores as more palatable shrubs and herbaceous plants established in the removal plots. This suggests that the response has some specificity to honeysuckle removal.

CONCLUSION

Studies on the impacts of invasive plant species management on multiple trophic levels can help direct restoration efforts (Reid et al. 2009; Heleno et al. 2010). Contrary to our predictions, *L. maackii* removal had minor overall effects on arthropod abundance and diversity. However, as predicted, management greatly increased herbivore abundances over time. Time since removal, scale of the removal, and consequences for native plants should be important considerations for future research.

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Margaret Carreiro focuses most of her research on understanding how urban environments (the built environment, people) interact with the natural and semi-natural components of cities and suburbs. Her expertise is centered on the responses of vegetation, soils, and ecosystem processes to urban and suburban landscapes, and research in invasive species ecology that informs adaptive woodlands management.

Sarah Emery is an associate professor at the University of Louisville and broadly interested in biodiversity and the dynamics of terrestrial plant communities. Her current work focuses on plant–fungus interactions in Great Lakes sand dunes and agronomic systems. Other related interests include the role of dominant species in ecosystems, prairie and savanna restoration, and the management and population dynamics of exotic invasive species.

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