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N O T E

Diversity and Seasonal Occurrence of Native and Nonnative Ants (Hymenoptera: Formicidae) in Long-Term Experimental Chinese Privet (Lamiales: Oleaceae) Plots in Georgia, USA[1]

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Chinese privet (*Ligustrum sinense* Loureiro) (Oleaceae) is a shade-tolerant invasive shrub first introduced from China into the US in the mid-19th Century as an ornamental (Wyman 1973, Shrubs and Vines for American Gardens, Macmillan, NY). Chinese privet is an aggressive invader across the southeastern United States and is now found in 27 U.S. states, including Hawaii (EDDMapS, http://www.eddmaps.org/; 20 May 2021), resulting in loss of native species richness across much of its invaded range (Hanula et al. 2009, Invas. Plant Sci. Manag. 2: 292–300; Hudson et al. 2014, Forest Ecol. Manag. 324: 101–108; Merriam and Feil 2003, Biol. Invasions 4: 369–373; Wilcox and Beck 2007, Southeast. Nat. 6: 535–550). Ward (2002, Southeast Geogr. 1: 29–48) documented an 8% increase in Chinese privet cover in the Upper Oconee River floodplain in northern Georgia between 1951 and 1999.

Where Chinese privet establishes, it can dominate as an understory monoculture (e.g., Wilcox and Beck 2007), reducing flowering plant richness needed to support pollinators and, over the long term, likely reducing woody debris diversity necessary as harborage and food for a number of arthropods. Several studies have investigated these impacts of Chinese privet infestation on various taxa, including arthropod communities, with most reporting similarly negative results. A more abundant and diverse bee fauna was found on Chinese privet removal plots compared to control (infested) plots 1 and 2 yr after treatment, and again 5 yr after treatment (Hanula and Horn 2011a, Insect. Conserv. Divers. 4: 275–283; Hudson et al. 2013, Biol. Conserv. 167: 355–362). In a later study on bees at the same study

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site, Ulyshen et al. (2020, Forest Sci. 66: 416–423) placed traps at 0.5, 5, and 15 m above the forest floor. Bee abundance and diversity were higher near the forest floor in plots where Chinese privet was removed, but similar among plots in the elevated traps. Likewise, beetle richness was increased near ground level after Chinese privet removal in the same experimental plots (Ulyshen et al. 2010, Biol. Invasions 12:1573–1579). In another study, butterfly abundance increased after Chinese privet removal, although richness and evenness did not differ between treatments (Hanula and Horn 2011b, For. Ecol. Manage. 262: 674–680).

Ants (Hymenoptera: Formicidae) are abundant and ecologically important arthropods—turning and aerating soil, dispersing seeds, playing a major role in food webs, and serving as environmental indicators and ecosystem engineers (Jones et al. 1994, Oikos 69: 373–386; Folgarait 1998, Biodivers. Conserv. 7: 1221–1244). As such, understanding the effects of Chinese privet and other invasive plants on ant communities is an imperative area of invasion biology research. Many ants are highly successful invasive species, transported around the globe via commerce and other human activity (McGlynn 2002, J. Biogeo. 26: 535–548). Both native and nonnative ants inhabit Georgia forests where Chinese privet occurs. In this paper, we present data on ant diversity and seasonal occurrence in experimental plots with and without Chinese privet, as well as in areas with no history of extensive Chinese privet infestation, reporting on native and nonnative ants in our study sites in northern Georgia.

Experimental Chinese privet removal plots were established in four locations in northern Georgia within the Oconee River watershed in October–November 2005 as detailed in Hanula et al. (2009). Sites included Sandy Creek Nature Center north of Athens, GA (Sandy Creek); the Georgia State Botanical Gardens south of Athens (Botanical Garden); the Scull Shoals Experimental Forest in the Oconee National Forest (Scull Shoals); and the University of Georgia Warnell School of Forest Resources Watson Springs Forest (Watson Springs). Briefly, treatments consisted of hand-felling, mechanical removal (mulching with a Gyrotrac® mulching machine) (Klepac et al. 2007, USDA. For. Serv. Southern Res. Sta. Res. Paper SRS43), and no treatment (control). Hand-felling and mechanical removal treatments were followed by herbicide application to stumps and, in 2006, to sprouts, seedlings, and saplings. By 2007, virtually all privet had been removed from the hand-felling and mechanical removal plots, and in 2012 reinfestation of treated plots was minimal (3% and 7% in hand-felling and mechanical removal plots, respectively) (Hudson 2013, Effects of removing Chinese privet (*Ligustrum sinense*) on plant communities, pollinator communities, and tree growth in riparian forests five years after removal with mechanisms of reinvasion. MS Thesis, Univ. Georgia, Athens). Three additional "desired future condition" plots (riparian hardwood forest with little or no Chinese privet) were established in the Oconee National Forest: one near the Apalachee River (Apalachee) (Greene Co., GA); one near Harris Creek (Harris) (Greene Co., GA), and one near Falling Creek (Falling) (Oglethorpe Co., GA).

Ground-dwelling arthropods were sampled using pitfall traps operated for 7-d periods seven times (March, April, May, June, July, August, and October) during 2006, 2007, and 2011. The pitfall traps consisted of a 480-ml plastic cup buried to ground level. A small funnel (8.4-cm diameter) was inserted into the cup and directed crawling insects into a 120-ml specimen cup below. The cup was placed at the intersection of two, 1-m long drift fences and the specimen cup filled with a soap and NaCl-formaldehyde solution (New and Hanula 1998, South. J. Appl. For. 22: 175–183) as a preservative. We used five pitfall traps per plot, each being placed within a subplot. Subplots were located at the plot center and half the distance from the center to each plot corner. Trap samples for each plot were combined into one collective sample per plot and stored in 70% alcohol until they were sorted and identified. Ants were identified using published keys. For the 2006 and 2007 samples, ants were sorted and identified to genus only. Those samples subsequently degraded and were eventually lost. Ants from the 2011 samples were identified to species, and vouchers deposited at the Mississippi Entomological Museum, Mississippi State, MS.

We tested for possible treatment effects on ant richness (for ant genera in 2006 and 2007 samples and for species in 2011 samples) using rarefaction and extrapolation with Hill numbers (Chao et al. 2014, Ecol. Monogr. 84: 45–67) using iNEXT Online (Chao et al. 2016, iNEXT (iNterpolation and EXTrapolation, http://chao.stat.nthu.edu.tw/wordpress/software_download/, 1 June 2021]). Because ants are colonial organisms and pitfall catch can be heavily influenced by proximity to nests, we used sampling-unit-based incidence data rather than abundance data (Gotelli et al. 2011, Myrmecol. News 15: 13–19). We set $q = 0$ to yield species richness, specified an endpoint of 206, and accepted default values for number of knots (40), bootstraps (50), and confidence interval (95%). For species-level 2011 data, we also set $q = 1$ to yield Shannon diversity using the same parameters.

To compare ant communities among the three treatments and the desired condition plots, using species-level data from 2011 we performed nonmetric multidimensional scaling (NMS) using PC-ORD (McCune and Mefford 2010, PC-ORD v. 6.0. MjM Software, Gleneden Beach, OR). We used the Jaccard distance measure on presence–absence data for this analysis. We used the same presence–absence matrix and distance measure to perform a multiresponse permutation procedure (MRPP) to test for differences between treatments. Finally, to test for associations between ant taxa and one or more treatments, we performed indicator species analysis in R using the package "indicspecies" (De Cáceres et al. 2010, Oikos 119: 1674–1684). We used the function multipatt (multilevel pattern analysis) to conduct this analysis, using 9,999 permutations to calculate *P*-values for each combination. The resulting indicator values range from 0 to 1 (no association to complete association).

Lastly, we subjected the four most abundant species to analysis of variance using log-transformed data ($\log X + 1$) to test for treatment effects on those species. Site was used as a blocking factor, and we tested for effects of treatment and date using the *F*-statistic.

We collected and identified 50 species of ants from the pitfalls (Table 1), including the invasive Asian needle ant, *Brachyponera chinensis* (Emery). While only present at five of the seven sites, Asian needle ant was greater than 4× more abundant than the next-most commonly collected species, *Lasius americanus* Emery. Asian needle ant was most abundant in the Botanical Gardens control plot, where it was captured in increasing numbers throughout the season (2, 15, 12, 125, 511, 1,000+, and 1,000+ for March, April, May, June, July, August, and October, respectively). When Asian needle ant numbers exceeded 1,000 in a sample, counting of individual ants was stopped. Zungoli and Benson (2008, Pp. 51–57, *In* Robinson and Bajomi [eds.], Proc. 6th Intern. Conf. Urban Pests, Budapest,

Table 1. Checklist of ants, in order of abundance, collected in experimental Chinese privet plots in northern Georgia, 2011.

Species*	Subfamily	Total Collected	Months Collected	Sites Collected
Brachyponera chinensis (Emery) (nn)	Ponerinae	2691**	Mar, Apr, May, Jun, Jul, Aug, Oct	Botanical Garden, Falling, Sandy Creek, Scull Shoals, Watson Springs
Lasius americanus Emery	Formicinae	759	Mar, Apr, May, Jun, Jul, Aug, Oct	Apalachee, Botanical Garden, Falling, Harris, Sandy Creek, Scull Shoals, Watson Springs
Crematogaster ashmeadi Mayr	Myrmicinae	396	Mar, Apr, May, Jun, Jul, Aug, Oct	Apalachee, Botanical Garden, Falling, Harris, Sandy Creek, Scull Shoals, Watson Springs
Aphaenogaster carolinensis Wheeler	Myrmicinae	385	Mar, Apr, May, Jun, Jul, Aug, Oct	Apalachee, Botanical Garden, Falling, Harris, Sandy Creek, Scull Shoals, Watson Springs
Crematogaster vermiculata Emery	Myrmicinae	254	Mar, Apr, May, Jun, Jul, Aug, Oct	Apalachee, Botanical Garden, Harris, Sandy Creek, Watson Springs
Prenolepis imparis (Say)	Formicinae	222	Mar, Apr, May, Oct	Apalachee, Botanical Garden, Falling, Harris, Sandy Creek, Scull Shoals, Watson Springs
Tapinoma sessile (Say)	Dolichoderinae	157	Mar, Apr, May, Jun, Jul, Aug	Apalachee, Botanical Garden, Harris, Sandy Creek, Scull Shoals, Watson Springs
Solenopsis carolinensis Forel	Myrmicinae	156	Jun, Jul, Aug	Apalachee, Botanical Garden, Falling, Harris, Sandy Creek
Myrmecina americana Emery	Myrmicinae	152	Mar, Apr, May, Jun, Jul, Aug, Oct	Apalachee, Botanical Garden, Sandy Creek, Scull Shoals, Watson Springs
Pheidole dentata Mayr	Myrmicinae	128	Apr, May, Jun, Jul, Aug, Oct	Apalachee, Botanical Garden, Falling, Harris, Sandy Creek, Scull Shoals, Watson Springs

Table 1. Continued.

Species*	Subfamily	Total Collected	Months Collected	Sites Collected
Camponotus chromaiodes Bolton	Formicinae	104	Mar, Apr, May, Jun, Jul, Aug, Oct	Apalachee, Botanical Garden, Harris, Sandy Creek, Scull Shoals, Watson Springs
Camponotus pennsylvanicus (DeGeer)	Formicinae	104	Mar, Apr, May, Jun, Jul, Aug, Oct	Apalachee, Botanical Garden, Harris, Sandy Creek, Scull Shoals, Watson Springs
Stenamma impar Forel	Myrmicinae	56	Mar, Apr, May, Jul	Apalachee, Botanical Garden, Falling, Harris, Sandy Creek
Aphaenogaster fulva Roger	Myrmicinae	45	Apr, May, Jun, Jul, Aug, Oct	Apalachee, Botanical Garden, Falling, Harris, Sandy Creek, Watson Springs
Ponera pennsylvanica Buckley	Ponerinae	45	Mar, Apr, May, Jun, Jul, Aug	Apalachee, Botanical Garden, Falling, Harris, Sandy Creek, Scull Shoals, Watson Springs
Camponotus castaneus (Latreille)	Formicinae	38	Mar, Apr, May, Jun, Jul, Aug, Oct	Apalachee, Botanical Garden, Sandy Creek, Watson Springs
Pheidole dentigula Smith	Myrmicinae	36	Mar, May, Jun, Jul, Aug, Oct	Apalachee, Botanical Garden, Falling, Sandy Creek
Nylanderia vividula (Nylander) (nn)	Formicinae	33	Mar, Apr, May, Jun, Jul, Aug	Apalachee, Botanical Garden, Harris, Sandy Creek, Scull Shoals
Nylanderia faisonensis (Forel)	Formicinae	24	Apr, May, Jun, Jul, Aug	Botanical Gardens, Falling, Sandy Creek
Formica pallidefulva Latreille	Formicinae	20	Apr, May, Jun, Jul, Aug	Apalachee, Botanical Garden, Sandy Creek

Table 1. Continued.

Species*	Subfamily	Total Collected	Months Collected	Sites Collected
Strumigenys louisianae Roger	Myrmicinae	12	Apr, May, Jun, Jul, Aug	Apalachee, Falling, Harris
Camponotus nearcticus Emery	Formicinae	11	Apr, May, Jun, Jul, Aug	Apalachee, Botanical Garden, Harris, Sandy Creek, Scull Shoals, Watson Springs
Camponotus subbarbatus Emery	Formicinae	11	Apr, Jun, Jul, Aug	Sandy Creek, Scull Shoals, Watson Springs
Hypoponera opacior Forel	Ponerinae	9	Mar, Apr, Jun, Jul, Aug	Botanical Garden, Falling
Stigmatomma pallipes (Haldeman)	Amblyoponinae	8	May, Jun, Jul, Aug	Apalachee, Botanical Garden, Falling, Sandy Creek, Watson Springs
Solenopsis invicta Buren (nn)	Myrmicinae	6	Mar, May, Jun	Apalachee, Botanical Garden, Harris, Sandy Creek
Camponotus snellingi Bolton	Formicinae	5	Apr, May, Jun	Botanical Garden, Sandy Creek, Scull Shoals
Temnothorax schaumii (Roger)	Myrmicinae	5	Apr, May, Jul, Aug	Apalachee, Botanical Garden, Sandy Springs
Myrmica punctiventris Roger	Myrmicinae	4	Jun, Jul, Aug, Oct	Sandy Creek, Watson Springs
Proceratium chickasaw deAndrade	Proceratiinae	4	May, Jun, Aug	Apalachee, Botanical Garden, Sandy Creek

Table 1. Continued.

Species*	Subfamily	Total Collected	Months Collected	Sites Collected
Strumigenys rostrata Emery	Myrmicinae	4	May, Oct	Botanical Garden, Harris
Crematogaster pilosa Emery	Myrmicinae	3	May, Aug	Botanical Garden, Harris
Proceratium pergandei (Emery)	Proceratiinae	3	Jun, Jul	Botanical Garden, Watson Springs
Temnothorax curvispinosus (Mayr)	Myrmicinae	3	Jun, Jul, Oct	Sandy Creek, Scull Shoals
Brachymyrmex depilis Emery	Formicinae	2	May, Jul	Watson Springs
Colobopsis impressa Roger	Formicinae	2	Jun	Falling, Scull Shoals
Lasius claviger Roger	Formicinae	2	May	Watson Springs
Lasius interjectus Mayr	Formicinae	2	May	Watson Springs
Pseudomyrmex ejectus (Smith)	Pseudomyrmicinae	2	May, Jul	Apalachee, Harris
Strumigenys pilinasis Forel	Myrmicinae	2	May	Harris
Aphaenogaster mariae Forel	Myrmicinae	1	Jun	Harris

Table 1. Continued.

Species*	Subfamily	Total Collected	Months Collected	Sites Collected
Aphaenogaster miamiana Wheeler	Myrmicinae	1	Jun	Harris
Camponotus caryae (Fitch)	Formicinae	1	May	Botanical Garden
Colobopsis mississippiensis (Smith)	Formicinae	1	Jun	Scull Shoals
Colobopsis obliqua (Smith)	Formicinae	1	Jun	Apalachee
Lasius aphidicola (Walsh)	Formicinae	1	Jul	Falling
Neivamyrmex opacithorax (Emery)	Pseudomyrmicinae	1	Aug	Sandy Creek
Nylanderia concinna (Trager)	Formicinae	1	May	Sandy Creek
Pheidole tetra Creighton	Myrmicinae	1	Jun	Sandy Creek

* Nonnative species are indicated with (nn).
** Counting was stopped at 1000 for two samples with excessive numbers of individual ants.

Hungary) observed peak worker activity in August, followed by a decline in September and inconsistent activity in October. We do not have exact numbers for August and October, but clearly foraging activity and/or the number of available foragers in colonies increases in this species later in the season.

For ant genera identified in 2006 and 2007 (1 and 2 yr after treatment, respectively) there were no significant differences in ant diversity among the treatments. The 95% confidence intervals for extrapolated species richness data ($q = 0$) from 2011 overlapped among treatments, but 95% confidence intervals for desired future condition plots diverged from control and mulched plots using extrapolated Shannon diversity ($q = 1$) (Fig. 1). There was an overall trend toward increased ant diversity in desired condition plots in 2007 and 2011. Mean species richness for all years and treatments is presented in Table 2.

Our NMS analysis yielded a three-dimensional solution with a final stress of 8.29. The desired plots form a distinct cluster within the ordination space, suggesting a relatively distinct ant community, while there is considerable overlap among the three other treatments (Fig. 2). Based on MRPP, there was a marginally significant difference in community composition among treatments ($T = -1.38$, $P = 0.09$). Pairwise comparisons reveal that the ant communities in the desired plots differed significantly from those in the control ($T = -2.26$, $P = 0.03$) and chainsaw ($T = -1.57$, $P = 0.05$) plots. No other pairwise comparison was significant. Indicator species analysis found four ant species to be significantly associated with the desired plots, with one of them also associated with the control plots (Table 3). The first species, *Nylanderia vividula* Nylander ("Nylander's crazy ant") is an indoor pest in many situations, widely distributed throughout the U.S. Gulf Coast states. *Pseudomyrmex ejectus* (Smith) nests in dead twigs and stalks of herbaceous plants. *Solenopsis carolinensis* Forel is a common thief ant in forests in the southeastern United States and is known to nest in the bark of pine trees (J.A.M., pers. obs.). *Strumigenys louisianae* Roger is widespread and is a specialized predator on collembola (Wilson 1953, Ann. Entomol. Soc. Am. 46: 479–495). It is thought to be the only native species in the genus. It cannot be determined from our data if these species-level patterns were driven by differences in privet invasion history or by other factors affecting ant distribution across our sampling area.

Analysis of variance results for the four most abundant species varied. *Brachyponera chinensis* catches were related to site, and site × date × treatment ($F = 4.75$; df = 4, 79; $P = 0.002$; and $F = 7.52$, df = 2, 70, $P = 0.001$, respectively), with more being captured late in the season and a single control plot at the Botanical Gardens yielding thousands of individuals compared to 0–13 in all other plots. For *Crematogaster ashmeadi*, site, site × date, and site × date × treatment were all significant ($F = 3.12$, df = 4, 79, $P = 0.021$; $F = 2.56$, df = 7, 72, $P = 0.021$; $F = 18.8$, df = 2, 70, and $P < 0.001$, respectively). Fewer *C. ashmeadi* were collected at the Botanical Gardens site than the other sites, and seasonal activity was highest June–August, although they were collected on all sampling dates. More *C. ashmeadi* were collected in mulched (7.4 ±1.9) ($\bar{x} \pm$ SE) and chainsaw (2.29 ± 0.65) plots than in controls (1.25 ± 0.36). There were no significant treatment effects noted for *L. americanus* or *Aphaenogaster carolinensis* Wheeler.

Although a few species with specialized nesting habits were collected in this study (e.g., arboreal species, twig and cavity nesting species), the majority of ant species collected are known to nest in soil, under debris, and/or in decaying wood.

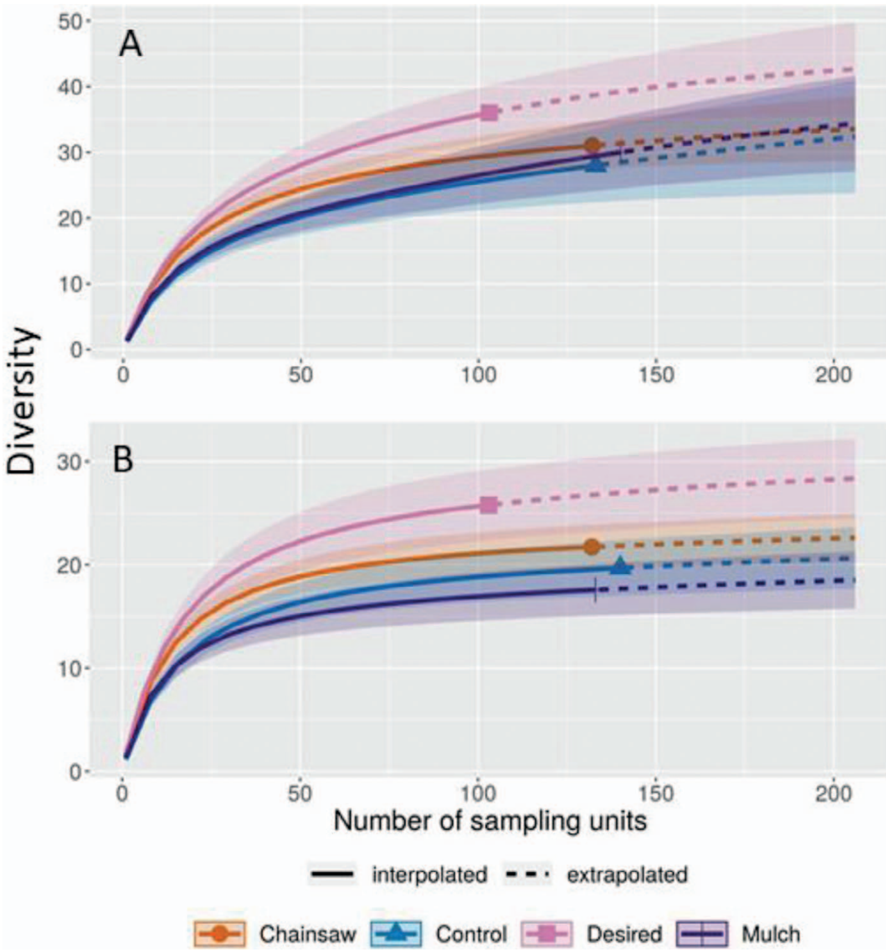

Fig. 1. Rarefaction and extrapolation-based diversity from 2011 pitfall trap catches in control (Chinese privet-infested), mulch and chainsaw (Chinese privet removed via mulching machine and chainsaw felling, respectively), and "desired condition" (no history of privet infestation) plots in the Oconee River floodplain, north Georgia. Curves are bounded by 95% confidence interval. Curves represent (A) species richness ($q = 0$) and (B) Shannon diversity ($q = 1$).

Plots where Chinese privet was hand-felled may have offered more nesting sites for some ant species for a limited time after treatment. Differences in pitfall catches for individual species suggest that dense populations of Chinese privet may favor (*B. chinensis*) or suppress (*C. ashmeadi*) some ants; however, these results should be interpreted cautiously given the potential local variation in pitfall traps with respect to nest proximity. Regardless, presence of Chinese privet did not appear to impact our measures of ant diversity relative to the removal treatments. Species contributing to

Table 2. Ant richness in experimental Chinese privet plots in northern Georgia.

Year and Treatment	$\bar{x}$ Richness ± SE*	n
2006		
Control	4.50 ± 0.29	4
Chainsaw	6.25 ± 1.03	4
Mulch	5.50 ± 0.87	4
Desired	6.00 ± 0.00	3
2007		
Control	6.25 ± 0.48	4
Chainsaw	6.75 ± 0.63	4
Mulch	6.50 ± 0.29	4
Desired	8.67 ± 1.76	3
2011		
Control	15.00 ± 1.83	4
Chainsaw	17.50 ± 2.87	4
Mulch	16.50 ± 1.85	4
Desired	22.00 ± 2.65	3

* Genus-level data for 2006 and 2007, species-level data for 2011.

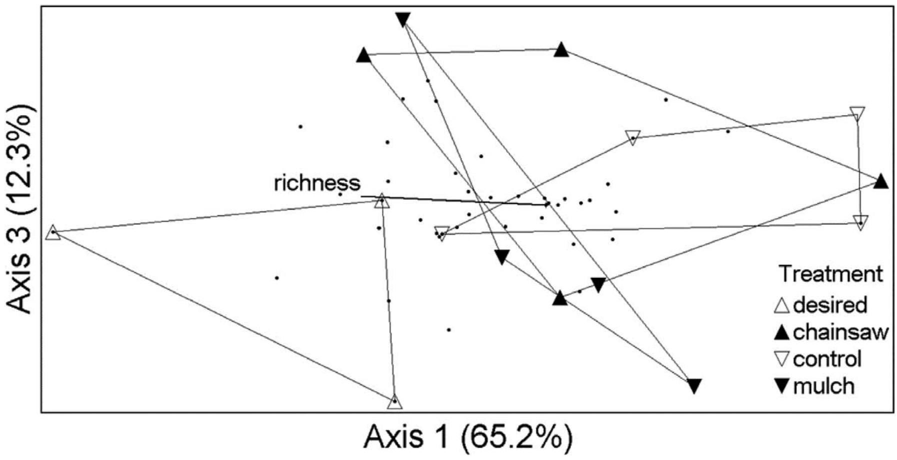

Fig. 2. Ordination from NMS showing differences in ant community composition among the four treatments.

Table 3. Results from indicspecies analysis showing significant associations between ant taxa and one or more treatments.

Taxa	Desired	Chainsaw	Control	Mulch	Statistic
Nylanderia vividula	×		×		$IV = 0.845$, $P = 0.023$
Pseudomyrmex ejectus	×				$IV = 0.816$, $P = 0.033$
Solenopsis carolinensis	×				$IV = 0.816$, $P = 0.05$
Strumigenys louisianae	×				$IV = 1$, $P = 0.005$

increased diversity in desired condition plots included myrmicine species in the specialized predator genus *Strumigenys* and the uncommonly collected myrmicine *Aphaenogaster mariae* Forel, an arboreal species that has usually been collected from the trunks of live trees using bait (DeMarco 2015, Phylogeny of North American *Aphaenogaster* species [Hymenoptera: Formicidae] reconstructed with morphological and DNA data. PhD Dissertation. Michigan State Univ., East Lansing).

Ant sampling is biased by sampling method, with pitfall traps generally collecting fewer species than more-targeted methods such as hand-collecting in quadrats (Gotelli et al. 2011, Myrmecol. News 15: 13–19; Salata et al. 2020, Biodiv. Conserv. 29: 3031–3050 and references therein). Collections at the Sandy Creek site in 2011–2012 using a modified Winkler litter extraction method captured >47 ant species (D. Booher, pers. comm.), whereas we collected and identified 31 species at Sandy Creek in this study; our results are somewhat limited in contrast to more-exhaustive collecting methods. Long-term studies with multiple collection methods would be informative in terms of ant communities in restored areas where Chinese privet has been removed versus similar, undisturbed areas with no or little history of Chinese privet infestation, and in Chinese privet-infested controls. Understory plant cover in both privet removal treatments and desired condition plots was similar (~40–60%) 2 yr after treatment, but the plant communities in desired condition plots were highly dissimilar to both controls and privet removal treatments (Hanula et al. 2009) with early successional species abundant in the treated plots. Plants may provide ants with vegetative matter for foraging, food bodies, nesting sites, nectar, and eliasomes (Beattie and Hughes 2002, Pp. 211–235. *In* Herrera and Pellmyr [eds.], Plant-Animal Interactions: An Evolutionary Approach, Blackwell Science, Oxford, U.K.), and higher diversity of plants in desired condition plots may support a more diverse ant population. As pointed out by Hanula et al. (2009), it is likely that Chinese privet suppression may be required for long periods of time, or that active understory restoration may be necessary, to realize understory and forest conditions similar to areas with no history of Chinese privet. The same is likely true for arthropod groups such as ants that interact with shrubs and forbs in the understory.

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