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Removing an exotic shrub from riparian forests increases butterfly abundance and diversity

James L. Hanula *, Scott Horn

USDA Forest Service, Southern Research Station, 320 Green Street, Athens, GA 30602, USA

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ABSTRACT

Invasive plants are one of the greatest threats to endangered insect species and a major threat to Lepidoptera in eastern North America. We investigated the effects of the invasive shrub Chinese privet (*Ligustrum sinense*) and two methods (mulching or hand-felling) of removing it from riparian forests on butterfly communities and compared them to untreated, heavily invaded control plots and to "desired future condition" forests that never had extensive privet cover. Privet mulching resulted in nearly twice as many butterflies as privet felling and both treatments had more butterflies two years after privet removal than untreated control plots. Butterfly communities on control plots differed from those on the two treatments and the desired future condition forests. A number of forest characteristics were evaluated but only herbaceous plant cover (excluding privet) was positively correlated with butterfly abundance, diversity and evenness. The Carolina satyr, *Hermeuptychia sosybius*, was the best indicator of forests where privet had never invaded. Removing Chinese privet from riparian forests in the southeastern United States greatly improved forest habitats for butterflies and evidence suggests that butterfly communities in other temperate forests could benefit from removal of extensive shrub layers dominated by a single species.

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1. Introduction

Butterflies represent one of the most beloved and recognized insect groups among entomologists and the lay public. New et al. (1995) refers to them as the flagship taxa for invertebrate conservation and the plight of butterflies has been a focus of entomologists for over a century. Nevertheless, focused conservation efforts in North America did not begin until formation of the Xerces Society in 1971 (Pyle, 1976). More recently, the Butterfly Conservation Initiative (BFCI), consisting of 43 accredited zoos and aquariums linked with seven partner organizations, was formed in 2001 to conserve threatened, endangered and vulnerable butterflies and their habitats (Sanchez and Daniels, 2007). Currently, the US Fish and Wildlife Service lists 19 endangered and 3 threatened butterflies or skippers in the United States (http://ecos.fws.gov/tess_public/pub/SpeciesReport.do?kingdom=I&listingType=L&mapstatus=1, last accessed 5/03/2010). The establishment of the Xerces Society and the BFCI, and the large number of listed butterfly species are indications of the interest in and concern for this insect group among conservation organizations and the general public.

Factors contributing to butterfly declines include a wide variety of human activities such as, use of pesticides, urbanization, intensive forestry, agriculture, and exotic species (New, 1997; Wagner and VanDriesche, 2010). Among the many factors affecting butterflies, invasive species (including invasive insects, diseases and plants) are increasingly being recognized as a serious threat. Of these, Wagner and VanDriesche (2010) consider invasive plants to be the single greatest invasive threat to federally listed insect species and a major threat to Lepidoptera in eastern North America.

Chinese privet, *Ligustrum sinense*, is an exotic invasive shrub introduced to North America in the 1850s. Since then it has escaped cultivation and spread to dominate the shrub layer of over 1 million hectares of forest land (Miller et al., 2008). This estimate is based on forest interior plots and does not include forest edges or urban forest settings where privet is often the most severe. However, forest edges may be particularly important to butterflies that otherwise would be excluded from modern, dense forest plantings (Robertson et al., 1995), so the thick growth of Chinese privet evident along roadside, stream and field to forest edges may be especially harmful to butterflies.

We investigated the effects of Chinese privet and two methods of removing it from riparian forests on a variety of organisms including plants (Hanula et al., 2009), beetles (Ulyshen et al., 2010), and bees (Hanula and Horn, 2011). Only a few studies have examined the effects of removing invasive species on butterflies. Pfitsch and Williams (2008) removed white pine (*Pinus strobus*) a native tree invading open sandy areas, and found greater butterfly usage of those areas after removal. Severns (2008) removed tall oat

* Corresponding author. Tel.: +1 706 559 4253; fax: +1 706 559 4287.
E-mail address: jhanula@fs.fed.us (J.L. Hanula).

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grass, *Arrhenatherum elatius*, invading short grass prairies in Oregon and found oviposition by the Fender's blue butterfly, *Icaricia icarioides fenderi*, increased 2.5–5 times. Removal of tamarisk trees (*Tamarix ramosissima* Deneb) from riparian areas along a river in Colorado improved butterfly habitat but not all species responded to removal (Nelson and Wydoski, 2008). Florens et al. (2010) studied the effect of removing invasive plants from an island forest and found that forests with invasives removed had much greater butterfly abundance and richness than unweeded forests. Here we report the effects of removing privet on butterfly communities and compare them to untreated, heavily invaded control plots and to "desired future condition" plots that never had extensive privet cover. We also examined forest and plant community characteristics associated with changes in the butterfly community and whether any butterfly species were indicators of the desired forest condition.

2. Methods

2.1. Study site

Four study sites within the Oconee River watershed in northeast Georgia were selected based on their extensive privet infestations, access for machinery, and potential for public visitation and use in education and outreach programs (see Hanula et al., 2009 for map; http://www.srs.fs.usda.gov/pubs/ja/ja_hanula018.pdf). The sites were the Sandy Creek Nature Center on the North Oconee River north of Athens; the Georgia State Botanical Gardens on the Middle Oconee River south of Athens; the Scull Shoals Experimental Forest on the Oconee River in the Oconee National Forest; and the University of Georgia's, Watson Springs Forest that is also along the Oconee River. Overstory tree species included ash (*Fraxinus* spp.), willow oak (*Quercus phellos*), sugarberry (*Celtis laevigata*), sycamore (*Plantanus occidentalis*) and loblolly pine (*Pinus taeda*). At each site we selected three homogeneous plots, approximately 2 ha in size, in areas with the heaviest privet infestation. All plots had 10 m buffers of untreated area between the plot boundary and the stream edge to minimize potential soil movement into the streams resulting from soil disturbance by heavy machinery.

We also selected three "desired future condition" plots on the Oconee National Forest near the Scull Shoals and Watson Springs treatment sites. These plots were areas of mature riparian hardwood forest with little or no privet or history of privet invasion. The plots were used for comparison and as representatives of the forest type in the absence of privet. The plots were located along Harris Creek and the Apalachee River in Greene County, and Falling Creek in Oglethorpe County, Georgia. All three were located at least 10 m from rivers or streams. Only the Falling Creek plot had detectable levels of privet with 1.4 percent privet shrub cover and 0.35 percent privet cover in the herbaceous layer (Hanula et al., 2009).

2.2. Privet removal

Initial treatments were applied in October and November, 2005 and consisted of mechanical removal of privet, hand-felling of privet, or no treatment. Specifics of the mechanical removal can be found elsewhere (Klepac et al., 2007; Hanula et al., 2009). Briefly, mechanical removal was done with a Gyrotrac® mulching machine mounted on rubber tracks. The contractor was asked to remove all privet possible but to avoid removing non-privet trees 10 cm or larger. The surfaces of cut stumps were treated with 30% triclopyr (Garlon® 4) or 30% glyphosate (Foresters'®) herbicide to reduce sprouting.

Hand-felling was done with chainsaws, brush saws or machetes depending on the size of the stem. All stems 1.5 cm diameter or larger near ground level were cut and left in place. Large shrubs were cut up further so that brush was 1 m or less above ground. Stumps were treated with herbicide as described above.

In December 2006 mulched and hand-fell plots were treated with a foliar spray of 2 percent glyphosate using backpack sprayers or Solo backpack mistblowers to rid the plots of the abundant seedlings and root and stump sprouts. Treatment in the winter effectively targets privet without harming dormant native species (Harrington and Miller, 2005). By the summer of 2007 privet removal plots contained less than 1 percent privet in the shrub or herbaceous plant layers (Hanula et al., 2009).

2.3. Butterfly sampling

Butterflies were sampled using pan traps during the growing season of 2007. Blue pan traps are as effective for capturing butterflies and skippers in forests as malaise traps with color panels added (Campbell and Hanula, 2007) and yellow pan traps have been used effectively in other areas (Benes̑ et al., 2000; Cizek et al., 2003). To increase the probability of catching a large representative sample we used both blue and yellow pan traps consisting of Solo® bowls (530 ml capacity) supported approximately 30 cm above the ground by a wire loop (Campbell and Hanula, 2007). Bowls were filled with water containing Ajax® dishwashing detergent to reduce surface tension. Ten traps were used per plot with two traps (one of each color) placed in each of five subplots which were located at the center and half the distance from the center to each plot corner. Pan traps were operated for seven day periods seven times (March, April, May, June, July, August and October). Samples from each plot were combined into one sample per plot and stored in 70% alcohol until they were sorted, pinned and identified. Trap catches were standardized to account for occasional disturbance by animals by dividing the number of butterflies of each species caught per plot on each sample date by the number of traps collected and then multiplying by ten (the number of traps at the beginning of each sample date).

2.4. Plant sampling

The understory herbaceous plant community and shrub layer was surveyed on all plots in late June 2007. Herbaceous plant and shrub community surveys were completed at the same time using the line-point intercept method (Godinez-Alvarez et al., 2009). Trees were surveyed in September 2007. Desired future condition plots were only sampled once in June 2006 since they were used as an example of what the composition of these forests should be, so we were not interested in how the plant community changed. Details of plant survey techniques and results were provided by Hanula et al. (2009).

2.5. Statistical analyses

The general linear models procedure of SAS (SAS Institute, 2000) was used to analyze the data on treatment effects on butterfly abundance, species richness and diversity. We analyzed the data as a randomized complete block experiment with sites as blocks although plots were not randomized because not all plots were accessible to the mulching machinery. Plots within sites were selected to be homogeneous so randomization was not deemed to be essential. The REGWQ multiple comparison procedure (Day and Quinn, 1989; SAS, 1982) was used for means separation. We also examined treatment effects on several other measures of the butterfly community including Shannon diversity (H') and evenness (J).

Simple linear regression analysis (PROC GLM; SAS, 2000) was used to examine the relationships of butterfly abundance, richness, diversity and evenness with plot characteristics that included basal area of trees/ha, number of trees/ha, percent non-privet shrub cover, percent herbaceous plant cover, herbaceous plant diversity (H′), herbaceous plant richness and evenness (J). Measures of the herbaceous plant community did not include privet.

Analyses of similarity in the butterfly communities among treatments and desired future condition plots were conducted with the PAST program (Hammer et al., 2001) to perform ANOSIM analyses using the Bray-Curtis distance measure (with 10,000 permutations) on a dataset with all butterflies included. ANOSIM provides a method for determining if communities within the various treatments are significantly dissimilar.

Non-metric multidimensional scaling (NMS) analysis of trends in butterfly abundance in the plots was used to further analyze community level responses (PC-ORD; McCune and Mefford, 1999; McCune and Grace, 2002). Analyses were conducted using the "slow and steady" autopilot feature. Butterfly species that had less than three individuals per plot during the year were excluded from analysis. Vector analysis was used to examine the response of the butterfly community to plant community variables (Gaiser et al., 1998). We included basal area of trees/ha, number of trees/ha, percent non-privet shrub cover, percent herbaceous plant cover, herbaceous plant diversity (H′), herbaceous plant richness and plant evenness (J). An R^2 of 0.3 was used as the cutoff for vector scaling of joint plots.

Indicator species analysis (PC-ORD; McCune and Mefford, 1999) using treatments as the grouping variable was used to determine if any butterfly species were indicative of forests that never experienced privet invasion. Since several species were useful indicators, we conducted indicator species analyses on the herbaceous plant data to determine if their host plants were also indicators of the habitat.

3. Results

We caught 1496 butterflies from 6 families, 28 genera and 35 species (Table 1). The most common were the skippers *Lerema accius* (646) and *Poanes zabulon* (322), the nymphalid *Chlosyne nycteis* (122), the papilionid *Papilio glaucus* (86) and the satyrid *Hermeuptychia sosbius* (58).

Mulching privet had the greatest immediate benefit in terms of butterfly abundance (Table 2). Two years after treatment mulched plots had significantly more butterflies than either the privet felling plots or the controls. Although fewer butterflies were captured on the privet felling plots compared to mulched plots, they had more butterflies than the controls which averaged only 23 butterflies captured per plot during the growing season. Mulched plots also had higher species richness than control plots but not privet felling plots. Species richness on felling and control plots was not significantly different even though felling plots had twice as many species. Removing privet did not affect butterfly diversity or evenness. Desired future condition plots were not compared directly to treatment plots but they had similar numbers of species and overall butterfly abundance to the mulched plots.

Butterfly communities on control plots were dissimilar from privet felling, mulched, and desired future condition plots based on analysis of similarity of all butterflies (Table 3). Felling and mulched plots had similar butterfly community composition and both were similar to the desired future condition using $P < 0.05$ as the cutoff. However, the felling plots were dissimilar from the desired future condition at $P < 0.06$.

NMS ordination (Fig. 1) showed that a two-dimensional solution was optimal (final stress = 2.41). Although butterfly communities in the desired future condition forests were not dissimilar from those where privet was removed based on analysis of similarity, the desired plots were still grouped somewhat apart from the mulched or felled plots in the NMS ordination confirming the

Table 1
Total number of butterflies of each species captured on all plots in riparian forests during 2007. Numbers in species column represent unidentified morphospecies.

Family	Genus	Species	Total No.
Hesperidae	*Amblyscirtes*	*aesculapius*	41
		hegon	1
	Ancyloxypha	*numitor*	1
	Epargyreus	*clarus*	2
	Erynnis	*brizo*	2
		horatius	6
		juvenalis	19
	Euphyes	*vestris*	15
	Hylephila	*phyleus*	2
	Lerema	*accius*	646
	Oligoria	*maculata*	5
	Poanes	*zabulon*	322
	Polites	*vibex*	2
	Pompeius	*verna*	55
	Wallengrenia	*egeremet*	9
		L2003	1
		L2026	2
Lycaenidae	*Calycopis*	*cecrops*	23
	Celastrina	*ladon*	2
Nymphalidae	*Chlosyne*	*nycteis*	122
	Libytheana	*carinenta*	1
	Phyciodes	*tharos*	30
	Polygonia	*interrogationis*	4
	Vanessa	*atalanta*	3
		virginiensis	1
Papilionidae	*Battus*	*philenor*	2
	Eurytides	*marcellus*	1
	Papilio	*glaucus*	86
		troilus	13
Pieridae	*Anthocharis*	*midea*	6
	Ascia	*monuste*	3
	Eurema	*daira*	1
	Abaeis	*nicippe*	8
Satyridae	*Hermeuptychia*	*sosybius*	58
	Megisto	*cymela*	1

Table 2
Butterfly species richness, abundance, diversity (H′) and evenness (J) in riparian forests in 2007 where Chinese privet was left intact or removed by mulching or felling in 2005. Desired future condition plots were similar forests with no history of privet invasion. Data from those plots were not included in the analyses but are provided for comparison.

Treatment	*N*	Butterflies (mean ± SE)[a]			
		Species/plot	Butterflies/plot	(H′)	(J)
Control	4	4.5 ± 1.2 a	22.6 ± 4.6 a	1.0 ± 0.2 a	0.7 ± 0.08 a
Mulch	4	14.8 ± 3.9 b	156.9 ± 29.0 b	1.6 ± 0.3 a	0.6 ± 0.04 a
Felling	4	10.3 ± 1.6 ab	92.2 ± 16.0 c	1.3 ± 0.1 a	0.6 ± 0.01 a
Desired	3	15 ± 1.0	178.5 ± 22.7	1.8 ± 0.1	0.7 ± 0.03

[a] Means followed by the same letter within a column are not significantly different according to the Ryan–Einot–Gabriel–Welch multiple range test ($p < 0.05$).

Table 3
Results of ANOSIM analysis of similarity of butterfly communities in privet removal treatment plots.

	ANOSIM pairwise comparison *p*-values[a]		
	Control	Felling	Mulch
Felling	0.030	–	–
Mulch	0.029	0.322	–
Desired	0.030	0.056	0.171

[a] ANOSIM analyses were conducted using PAST – Palaeontological Statistics, Version 1.89 (Hammer et al., 2001). Numbers <0.05 indicate butterfly communities are significantly dissimilar.

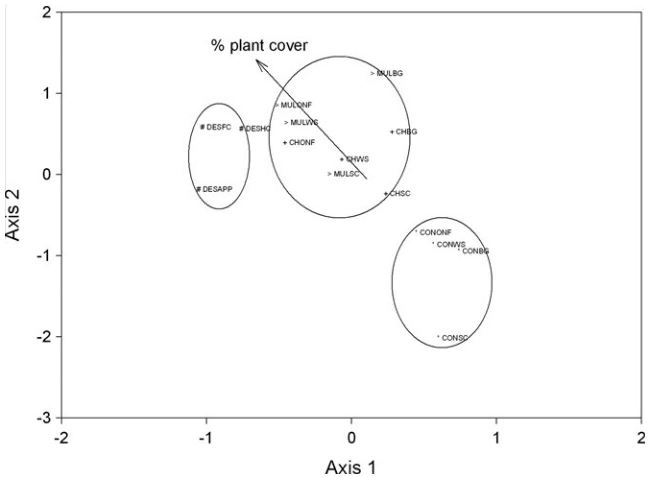

Fig. 1. NMS ordination graph of the butterfly communities in 2007 on plots receiving privet removal (Oct. 2005) by hand-felling or mulching and subsequent herbicide treatment of privet in the herbaceous layer (Dec. 2006). Plot abbreviations starting with DES, desired future condition; CON, control; MUL, mulched; and CH, chainsaw or hand-felling.

low level of similarity suggested by the ANOSIM analysis. Non-privet herbaceous plant cover was correlated with both ordination axes (Axis 1, $R^2 = 0.39$; Axis 2, $R^2 = 0.76$). Herbaceous plant cover was the only plant community attribute we measured correlated with either axis.

Butterfly abundance, richness and diversity were positively correlated with percent non-privet herbaceous plant cover (Fig. 2). No other plant, tree or shrub attributes were correlated with butterfly community characteristics. Approximately 76% of the variation in butterfly abundance was explained by its relationship with non-privet herbaceous plant cover. Likewise, 43% and 37% of the variation in butterfly richness and diversity can be explained by their relationship with herbaceous plant cover, respectively.

Based on indicator species analyses the Carolina satyr, *Hermeuptychia sosybius*, had the highest indicator value (IV = 82.8 out of 100 possible, $p = 0.009$) for the desired future condition forests. Three species of Hesperiidae, *Amblyscirtes aesculapius* (IV = 75.1, $p = 0.02$), *Euphyes vestris* (IV = 66.7, $p = 0.03$) and *P. zabulon* (IV = 55.5; $p = 0.003$) were also significant indicators of the desired future condition forests. Among plants in the herbaceous layer, Carolina silverbell (*Halesia carolina*) and crossvine (*Bignonia capreolata*) both had indicator values of 100 ($p = 0.002$) for the desired future condition. Panic grasses (*Dichanthelium* spp.; IV = 93.9, $p = 0.007$), blackberry, (*Rubus* spp.; IV = 69.4, $p = 0.02$), sedges (*Carex* spp.; IV = 66.7, $p = 0.03$), River oats (*Chasmanthium latifolium*; IV = 66.7, $p = 0.03$) and spicebush (*Lindera benzoin*; IV = 66.7, $p = 0.03$) were other species with significant value as indicators of the desired forest condition. Conversely, American burnweed (*Erechtites hieracifolia*; IV = 65.9, $p = 0.003$), stinging nettle (*Urtica dioica*; IV = 60.7, $p = 0.01$) and sweetgum seedlings (*Liquidambar styraciflua*; IV = 73.0, $p = 0.0006$) were indicators of the mulching treatment. While violets (Viola spp.; IV = 63.6, $p = 0.02$) were indicators of the felling treatment and Chinese privet (IV = 94, $p = 0.0002$) was the only indicator species for untreated control plots.

4. Discussion

Removing Chinese privet had a major impact on butterfly abundance and community composition. Wagner and VanDriesche (2010) suggested that the primary impact of invasive plants on native butterflies was through shading and competition with larval host plants and adult nectar resources. Two years after removing Chinese privet from riparian forests they had much more diverse, abundant and distinctly different plant communities than untreated control plots (Hanula et al., 2009). However, plant communities where privet was removed were also distinctly different from the communities in desired future condition forests. Plant communities resulting from the two methods of removal were similar but plots where privet was mulched had almost 70% herbaceous cover compared to approximately 40% on privet felled plots. Butterfly abundance was lower on felled plots than on mulched plots, which reflected the lower overall plant cover even though they had similar plant species (Hanula et al., 2009). This trend was also evident in the strong positive linear relationship between butterfly abundance and non-privet herbaceous plant cover. Butterfly species richness and diversity also were correlated with herbaceous plant cover.

These results are similar to those of Campbell et al. (2007) who found that butterfly abundance was positively correlated with herbaceous plant cover in a deciduous forest in North Carolina. Mac Nally et al. (2004) reported that availability of nectar sources had the greatest explanatory power for butterfly species richness and Koh (2008) found percent ground cover by weeds was the best predictor of butterfly richness.

It is unclear whether the relationship between non-privet herbaceous plant cover and butterfly community characteristics was directly related to greater availability of host plants or nectar sources or if greater plant cover is a reflection of the more open forest canopy and greater sunlight reaching the forest floor. Most likely it is a combination of these factors. However, herbaceous plant cover was the only plot attribute correlated with any of the butterfly community characteristics. Tree density, measured as either basal area or number of trees per hectare, was not correlated with butterfly community attributes even though increasing privet cover was associated with fewer trees in the research area (Hanula et al., 2009). On the other hand, desired future condition plots were in relatively closed canopy forests with a nearly 50 percent non-privet shrub cover, so the forest floor was more shaded than the privet removal plots. Nevertheless, they also had over 60% non-privet herbaceous plant cover (Hanula et al., 2009) and they had almost the same number of butterfly species, total butterflies, and butterfly diversity and evenness as the privet mulched plots. Based on these results, greater non-privet herbaceous plant cover was the most likely reason for increased butterfly abundance and diversity and not the more open forest canopy and greater sunlight reaching the forest floor. The increased plant cover most likely resulted in more nectar and possibly larval host plants for butterflies compared to privet infested controls.

The mulching machine caused more soil disturbance since the cutting head regularly contacted the soil when grinding stumps down to the soil surface. Increased soil disturbance has been suggested as a management tool to improve grasslands for butterflies in England (Oates, 1995), and in our study it was most likely the reason for greater plant cover on mulched plots which also had more butterflies than privet felling plots.

Plant communities resulting from both methods of privet removal consisted primarily of early colonizers of disturbed areas and were highly dissimilar from plant communities in desired future condition forests, with no history of privet, or control plots that still had extensive privet cover (Hanula et al., 2009). Despite very different plant communities, butterfly communities in desired future condition forests were not dissimilar from privet mulched plots based on ANOSIM analyses, but NMS ordination suggested some separation in butterfly communities in the two areas was still evident two years after removal. In contrast, bee communities on desired future condition plots were very similar to the privet re-

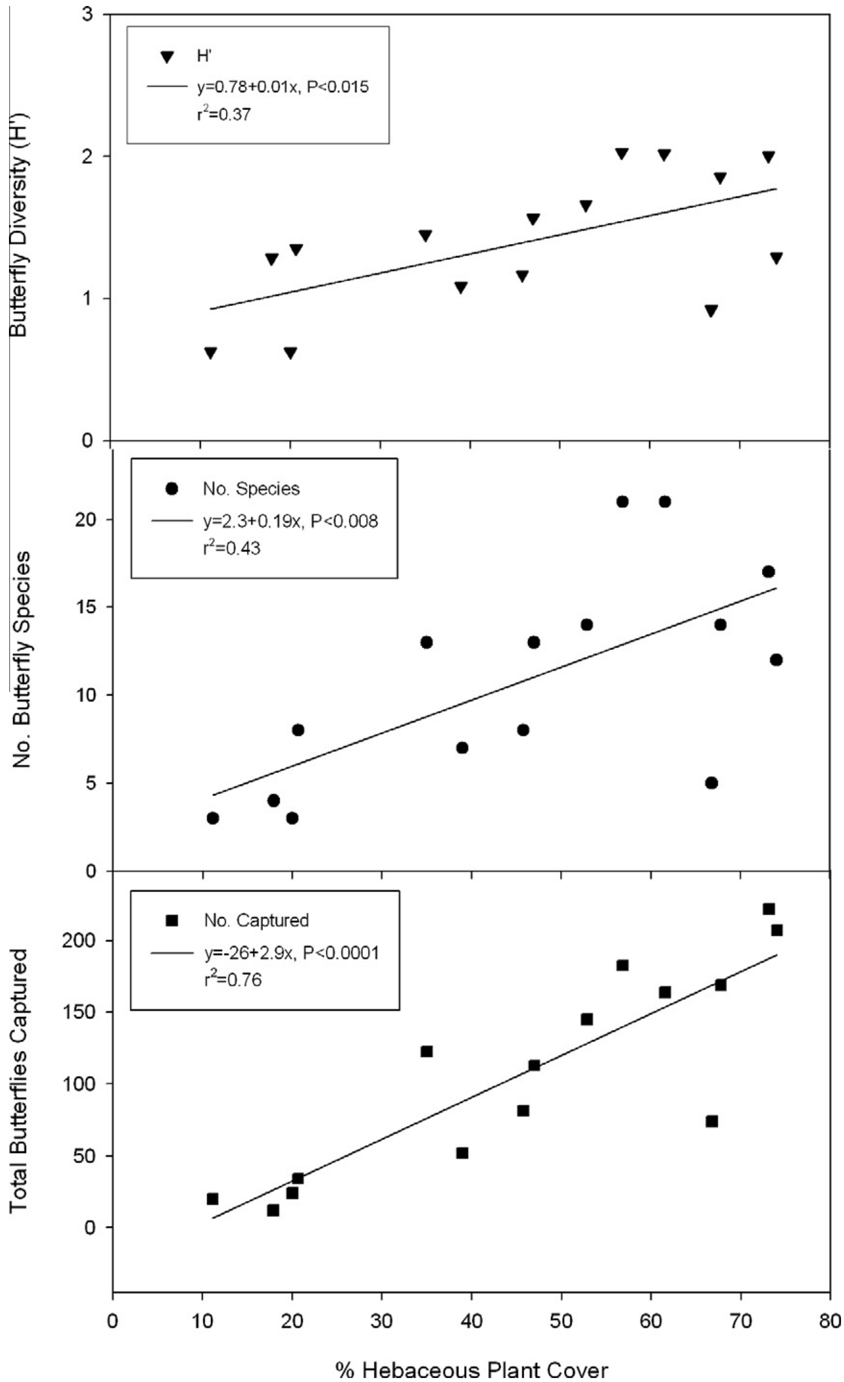

Fig. 2. Linear regression analyses of percent non-privet herbaceous plant cover with butterfly abundance, diversity (H′) and evenness (J).

moval plots regardless of removal method (Hanula and Horn, 2011).

Robertson et al. (1995) suggested that woodland butterflies are slow to recolonize forested areas after restoration efforts. In our study recolonization was rapid although, unlike bees (Hanula and Horn, 2011), the community of butterflies did not reach a high level of similarity to mature, uninvaded forest butterfly communities. One reason for the rapid reestablishment of butterflies in our plots may have been the proximity to forest roads, power line right-of-ways and river edges. Corridors have been shown to enhance butterfly dispersal (Haddad and Tewksbury, 2005; Haddad and Baum, 1999) as well as plants (Brudvig et al., 2009) and a variety of other organisms (Haddad et al., 2003). Nevertheless, even relatively dense pine forests are not a complete barrier to butterfly movement between habitat patches (Haddad, 1999). Likewise, we caught some butterflies in forests with dense privet so these forests were not totally impermeable to butterflies either. Therefore, a variety of mechanisms were likely responsible for the rapid movement of butterflies into forests once privet was removed.

Some butterflies are capable of utilizing exotic species as host plants or nectar sources (Bowers et al., 1992; Thompson, 1993; Graves and Shapiro, 2003; Tallamy and Shropshire, 2009) but in most cases these plants have a negative effect on butterflies. For example, exotic species serve as population sinks where some butterflies oviposit but the larvae die (New and Sands, 2002; Graves and Shapiro, 2003; Cassagrande and Dacey, 2007). Nevertheless, the greatest effect of invasive species on butterflies is through crowding out or shading of the native hosts (e.g., Valtonen et al., 2006; Pfitsch and Williams, 2008; Severns, 2008; Moron et al., 2009).

Four butterfly species were significant indicators of riparian hardwood forests that had never been invaded by privet, while none were indicative of the other treatments. Larvae of all four species feed on grasses or sedges (http://www.butterfliesandmoths.org/checklists) and three grass or sedge genera or species were among the six herbaceous plants that were also indicators of uninvaded riparian forests. These results suggest that privet shading and displacement of their native host plants has resulted in these woodland butterflies being displaced as well.

5. Conclusions

Our study shows the benefit of removing an invasive shrub from riparian forests in the southeastern US on butterfly communities. Clearly butterflies and bees (Hanula and Horn, 2011) would benefit from the removal of Chinese privet from the more than 1 million hectares of forest land (Miller et al., 2008) currently invaded by this exotic shrub. However, privet is not the only shrub to affect plant communities. For example, shrub honeysuckles, *Lonicera* spp., are common invasive shrubs in the northeastern US that diminish plant richness and abundance (Woods, 1993; Collier et al., 2002) and pollination services to native herbaceous plants (McKinney and Goodell, 2010) much like Chinese privet. Even native shrubs that increase in abundance due to changes in land use or forest management practices can have the same negative effect on plant communities (Baker and Van Lear, 1998; Phillips et al., 2010) and their removal can benefit pollinators (Campbell et al., 2007). Thus, elimination of heavy shrub layers resulting from invasion by exotics or expanding domination by native species due to changes in forest management practices would benefit butterflies and likely other flower visiting insects as well.

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