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Effects of Crofton weed *Ageratina adenophora* on assemblages of Carabidae (Coleoptera) in the Yunnan Province, South China

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Abstract

Crofton weed (*Ageratina adenophora*) is a highly invasive weed that has spread into several provinces of southern China. This study compares carabid assemblages originating from native pastures with assemblages in Crofton weed dominated communities in the Lancang County, Yunnan Province, to assess how the invasion of this neophyte impacts the community structure of ground-dwelling arthropods.

Over a period of 16 months, a total of 1574 carabid beetles representing 28 species were collected at two types of pasture, and 679 carabid beetles representing 34 species at stands of Crofton weed. The most common carabid species, *Tetragonoderus arcuatus* and *Harpalus indicus*, were mostly found in the pastures, while four of the five rarest species were present exclusively under Crofton weed.

Alpha-diversity and evenness of carabid assemblages were greater under Crofton weed. Three distinct groups of carabid species were separated according to indicator values and a characterization of habitats: habitat generalists, Crofton weed specialists and native pasture specialists. The distribution of carabid species was related to environmental parameters such as depth of litter layer, total phosphorus, height of vegetation, amount of fresh biomass and pH of the soil. According to this study, the invasion of Crofton weed will alter the structure of carabid communities, but will not necessarily reduce the alpha-diversity of carabid assemblages.

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1. Introduction

Biotic invasions are regarded as an important cause of biodiversity losses (Drake et al., 1989; Williamson, 1996; Shigesada and Kawasaki, 1997). They potentially modify ecosystem structure and functioning, thus creating cascading effects for resident biota by altering system-level flows, physical resources, or the availability and quality of nutrients and food (Mack et al., 2000; Crooks, 2002). Plant invasions often greatly diminish the abundance of native plant species or even threaten their survival (Mack et al., 2000). Although the impacts of plant invasions on native

plants have been well documented (Steenkamp and Chown, 1996; Sousa et al., 2000; Angelica and Dudley, 2003), the impacts on ground-dwelling insect assemblages are more complex and less-well known. Previous studies investigating such impacts have reached differing conclusions. While most studies discovered a decrease in arthropod diversity following plant invasions due to a decreasing plant species richness and habitat heterogeneity (Beerling and Dawah, 1993; Steenkamp and Chown, 1996; Greenwood et al., 2004), results from other studies indicated an increase in density and diversity of arthropods (O'Hare and Dalrymple, 1997; Philippa et al., 1998; Hedge and Kriwoken, 2000). Hence, the question of how plant invasions affect invertebrate assemblages is still open for debate.

Originating from Mexico, Crofton weed (*Ageratina adenophora* R.M. King & H. Rob) is a highly invasive and

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noxious weed reaching pest status in many tropical and sub-tropical areas (Auld, 1969; Qiang, 1998). It has also expanded rapidly in South China (Liu et al., 1985; Xie et al., 2001). This resulted in alterations of many native ecosystems because of the fast growth rate and allelopathic properties of this invader (Liu et al., 1989; Qiang, 1998). Although many studies have been conducted to evaluate its potential damage to plant community composition (Liu et al., 1985), its ecological characteristics and eradication methods (Alan, 1961), information on how Crofton weed affects arthropod diversity in Southern China is widely lacking.

To study this question, carabid assemblages under Crofton weed were compared to assemblages under pastures, with a detailed investigation on species abundance and composition and their spatial distribution.

2. Materials and methods

This study was carried out at a pasture research station (22°33'N, 100°0.5'E) in the Lancang County of the Yunnan Province, South China. The area is characterized by a sub-tropical monsoon climate with a mean annual temperature of 18.6 °C, varying between mean temperatures of 12.5 °C in January and 23.1 °C in June. Annual precipitation amounts to 1600 mm, 89% of which occurs between July and September.

The vegetation in this region is dominated by secondary forests and grasslands, which have replaced the natural forests after their destruction by the local residents. In the middle of the last century, Crofton weed invaded the native grasslands in this region and formed monodominant plant communities. In 1996, this neophyte was widely eradicated using herbicides, and native pastures were restored. Nevertheless, some areas were reinvaded by Crofton weed.

In this study, eight Crofton weed dominated and eight native grassland sites were chosen, with four of the native grassland sites being dominated by *Setaria* sp. and the four remaining sites by *Echinochloa* sp. Each site was 1 ha in size and had an inclination of less than 20°. In Crofton weed dominated sites, Crofton weed reached coverage of up to 80%. The native grasslands (*Echinochloa* sp. and *Setaria* sp.) were sown for seed production. There were no cutting and fertilizer applications in Crofton weed, while the native weed was cut once a year to harvest seeds, and fertilizer

applications were 750 kg (N:P:K = 1:1:1) per ha. The main characteristics of the three vegetation types are listed in Table 1. All sites were located within a radius of 50 km at altitudes between 1600 and 1800 m. The distance between any two plots was larger than 1 km.

Eight groups of pitfall traps were placed on each study site. Each of these groups consisted of five traps, with four traps located at the corners and one in the center of a 1 m² quadrat. The quadrats were placed 20 m apart in a straight line crossing the site center. At each pitfall trap, a PVC pipe with a diameter of 10 cm and a length of 20 cm was used to support the trap in the ground, minimizing the interference with the surrounding vegetation during sampling. A disposable cup with a diameter of 9 cm and a depth of 10 cm containing 75% alcohol was placed inside each pipe to collect the beetles so that the upper edge was level with the soil surface. Traps were protected from water by circular polyethylene covers of 15 cm diameter positioned approximately 6 cm above the ground surface.

The carabid beetles were collected each month for a 16-month period from October 2003 to January 2005, with sampling occurring during a 5-day period each month. Most carabid beetles caught in pitfall traps could be identified to species level, while some were identified only to the genus level due to a lack of detailed references.

Environmental conditions of the sampling sites were examined to explore whether any of these conditions could be used to predict the abundance of the dominant carabids and the species richness of carabid assemblages. The depth of the leaf litter layer and the coverage and average height of the vegetation were measured within each of the 1 m × 1 m quadrats. Fresh weight of the above-ground biomass was also measured. Soils were sampled to a depth of 10 cm and their pH, organic matter, total nitrogen, phosphorus and potassium contents were measured using standard methods (Liu, 1996).

Various indices were used in the statistical analysis, including the Berger–Parker index to demonstrate differences in the dominance structure, the Simpson index to emphasize differences in the evenness of the distribution, and *Chao* 1 to further evaluate changes in alpha-diversity between communities. Simpson's Reciprocal index and *Chao* 1 were calculated using the software package *EstimateS* (Colwell, 2005). The Bray–Curtis index was used to determine the similarity of carabid assemblages in any two plots within or between *Echinochloa* and *Setaria* pastures. To investigate differences in carabid assemblages

Table 1

Mean values and standard deviation of vegetation height, vegetation coverage, fresh weight of the above-ground biomass and depth of the leaf litter layer of the three vegetation types investigated in this study

Vegetation type	<i>Echinochloa</i> pasture	<i>Setaria</i> pasture	Crofton weed
Mean vegetation height (m)	0.40 ± 0.27	1.01 ± 0.10	1.00 ± 0.30
Vegetation coverage (%)	69 ± 16	89 ± 6	90 ± 7
Fresh weight of above-ground biomass (kg/m ²)	0.98 ± 0.57	2.48 ± 0.55	2.79 ± 0.70
Depth of leaf litter layer (cm)	0.15 ± 0.06	0.40 ± 0.14	2.36 ± 0.87

between vegetation types, one-way ANOVA was carried out using the SPSS for Windows software (version 13.00). Responses of carabid beetle assemblages to habitat variables were examined, and a CCA biplot representing the relationships between carabid assemblage and site habitat variables was constructed using the program CANOCO for Windows 4.5 (Ter Braak and Šmilauer, 1998). The statistical significance of the canonical axes was tested using Monte Carlo permutations (499 permutations). The Indicator value (IndVal) approach (Dufrière and Legendre, 1997) was used to identify carabid indicator species and species assemblages for the Crofton weed and native grassland habitats.

3. Results

A total of 2253 carabid beetles representing 35 species were collected in the course of this study; 1574 beetles representing 28 species were sampled from the pasture sites, and the remaining 679 specimen representing 34 species from Crofton weed-dominated plots (Table 2). The ANOVA results indicated that carabid assemblages did not differ significantly between the *Setaria* and *Echinochloa* pastures. Comparisons of Bray–Curtis indices within and between groups implied that carabid assemblages of the two pasture types could be considered to originate from one collectivity ($F = 0.24$, d.f. = 1, 26, $p = 0.63$). Therefore, the data of

Table 2
Table showing the carabid species indicator value and the abundance of the carabid species in different habitat types

Species	IndVal (%)	Crofton weed	<i>Setaria</i> pasture	<i>Echinochloa</i> pasture
All habitats				
<i>Anisodactylus karennius</i> Bates	100 ns	92/8	93/4	62/4
<i>Agonum</i> sp.	93.75 ns	46/7	17/4	37/4
<i>Carabus vogtae</i> Beheim & Breuning	93.75 ns	22/7	11/4	14/4
<i>Harpalus pseudotinctulus</i> Schaubberger	87.5 ns	64/8	11/3	38/3
<i>Stenolophus</i> sp.	75 ns	30/6	9/4	10/2
<i>Trigonotoma lewisii</i> Bates	75 ns	10/6	7/3	9/3
<i>Galeritula feae</i> Bates	68.75 ns	16/5	6/2	9/4
<i>Trigonognatha yunnana</i> Straneo	68.75 ns	24/6	3/2	8/3
<i>Lesticus magnus</i> Motschulsky	62.5 ns	14/7	2/1	13/2
<i>Parophonus hauseri</i> Schaubberger	50 ns	8/4	2/2	3/2
<i>Chlaenius montivagus</i> Andrewes	18.75 ns	2/2	1/1	0/0
<i>Macrochilus trimaculatus</i> Olivier	18.75 ns	4/2	2/1	0/0
<i>Oxycendrus</i> sp1	18.75 ns	2/2	2/1	0/0
<i>Pristosia</i> sp.	18.75 ns	2/2	0/0	1/1
Crofton weed				
<i>Hyphaereon masumotoi</i> Ito	87.5*	101/8	7/3	8/3
<i>Cosmodiscus</i> sp.	62.5*	10/6	1/1	1/1
<i>Orthogonius yunnanensis</i> Tian & Deuve	55.56 ns	8/5	1/1	0/0
<i>Oxycendrus</i> sp2	50 ns	4/4	0/0	0/0
<i>Taridius vietnamensis</i> Kirschenhofer	48.61 ns	7/5	1/1	1/1
<i>Chlaenius</i> sp1	30 ns	4/3	0/0	1/1
<i>Nanodiodes piceus</i> Nietner▲	25 ns	2/2	0/0	0/0
<i>Oodes</i> sp.	25 ns	4/2	0/0	0/0
<i>Calathus</i> sp.▲	12.5 ns	1/1	0/0	0/0
<i>Craspedophorus philippinus</i> Jedlicka	12.5 ns	3/1	0/0	0/0
<i>Pheropsophus beckeri</i> Jedlicka▲	12.5 ns	1/1	0/0	0/0
<i>Trichotichus</i> sp.▲	12.5 ns	1/1	0/0	0/0
<i>Setaria</i> and <i>Echinochloa</i> pasture				
<i>Aepnidius adelioides</i> Jedlicka	100*	56/8	46/4	57/4
<i>Tetragonoderus arcuatus</i> Dejean	100*	105/8	246/4	450/4
<i>Harpalus indicus</i> Bates	93.75*	23/7	213/4	13/4
<i>Harpaliscus birmanicus</i> Bates	82.07*	8/5	24/3	97/4
<i>Chlaenius cambodiensis</i> Bates	71.59*	1/1	10/3	11/3
<i>Pterostichus</i> sp.	52.08 ns	1/1	2/2	3/3
<i>Setaria</i> pasture				
<i>Callistomimus vitalisi</i> Andrewes▲	25 ns	0/0	1/1	0/0
<i>Echinochloa</i> pasture				
<i>Chlaenius bioculatus</i> Chaudoir	65.63*	2/2	0/0	7/3
<i>Chlaenius</i> sp2	28.57 ns	1/1	1/1	2/2

The “IndVal”-column shows the species indicator value for the habitat clustering hierarchy, ns: not significant. In the other columns, the first number indicates the number of specimens, and the second number corresponds with the number of plots where the species was sampled.

* $p < 0.05$.

carabid assemblages in the two pasture sites were pooled for later analysis.

On the pasture sites, the Berger–Parker index reached 0.44, with the two most abundant species *Harpalus indicus* and *Tetragonoderus arcuatus* comprising 59% of the total number of beetles trapped; whereas under the Crofton weed, the Berger–Parker index was 0.15, and the five most common species, *Aepnidius adelioides*, *Anisodactylus karennius*, *Harpalus pseudotinctulus*, *Hyphaereon masumotoi* and *T. arcuatus*, each contributed between 8% and 17% of the total catch, jointly accounting for about 62% of the total beetles collected at the eight sites. As a whole, the most numerous species were *T. arcuatus*, *H. indicus* and *A. karennius*, each contributing over 10% of the overall catch. *T. arcuatus* was significantly more abundant in pastures than under the Crofton weed, while *H. masumotoi* showed an opposite response.

Five species marked with a black triangle in Table 2 were considered rare because their overall contribution to the catches reached less than 0.1%. Among these species, *Callistomimus vitalisi* was only caught on the pastures, while the other four species, *Calathus* sp., *Pheropsophus beckeri*, *Nanodiodes piceus* and *Trichotichnus* sp., were found only at sites dominated by Crofton weed.

Not only was the number of species trapped under Crofton weed dominated vegetation greater than at the pasture sites, but this reflected also in higher alpha-diversity values ($F = 25.44$, d.f. = 1.14, $p = 0.0002$) and a higher evenness in the distribution ($F = 10.47$, d.f. = 1.14, $p = 0.006$) of the beetle assemblages in Crofton weed compared to pastures.

A classification of the carabid beetles according to the different habitats allowed the identification of three groups according to their indicator values (Fig. 1, species listed in Table 2). These groups were (1) habitat generalists that commonly occurred in both Crofton weed and native grassland; (2) Crofton weed specialists that were exclusively or mostly present only in invaded habitats; (3) native grassland specialists, which were captured exclusively or most abundantly in native grassland, either dominated by *Setaria* sp. or *Echinochloa* sp.

A canonical correspondence analysis was performed in order to examine the relationship between the distribution of abundant carabid species as dependent variables and environmental parameters; namely the height of vegetation, depth of the litter layer and amount of fresh biomass, organic matter content, total phosphorus, total Nitrogen, Potassium and the pH of the soil as independent variables. The eigenvalues of the first two axes were 0.19 and 0.09, respectively, and these two axes explained a proportion of 19.5 and 10.3% of the total variance in the dataset. The first canonical axis strongly correlated with depth of the litter layer, total phosphorus, height of vegetation, amount of fresh biomass and pH of the soil, while the second canonical axis mainly represented total Potassium in the soil. *Parophonus hauseri* and *Trigonognatha yunnana* both had high scores on

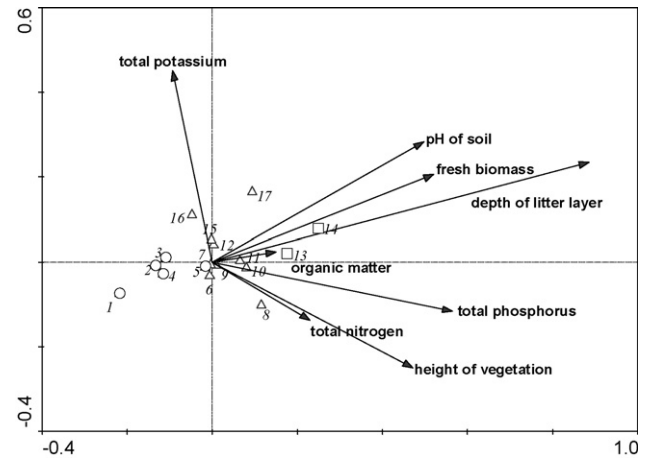


Fig. 1. Ordination plot of the canonical correspondence analysis of the 35 carabid species as dependent variables. Species with a total catch of less than 10 individuals are not shown in the diagram, but were included in the original calculations. The other numbers (1–17) indicate the species (1, *Chlaenius cambodiensis*; 2, *Harpalus indicus*; 3, *Tetragonoderus arcuatus*; 4, *Harpaliscus birmanicus*; 5, *Aepnidius adelioides*; 6, *Agonum* sp.; 7, *Stenolophus* sp.; 8, *Lesticus magnus*; 9, *Anisodactylus karennius*; 10, *Harpalus pseudotinctulus*; 11, *Galeritula feae*; 12, *Carabus vogtae*; 13, *Hyphaereon masumotoi*; 14, *Cosmodiscus* sp.; 15, *Trigonotoma lewisii*; 16, *Parophonus hauseri*; 17, *Trigonognatha yunnana*). The three carabid species groups, habitat generalists (triangle), *Setaria* and *Echinochloa* specialist (circle) and Crofton weed specialist (square), are forming distinct groups in the ordination diagram.

the second axis; hence these species tend to occur at sites with high potassium levels in the soil.

From the species and site points in the CCA ordination diagram (Fig. 1), it may be inferred that *H. masumotoi* and *Cosmodiscus* sp. reached highest scores on the first axis and hence mostly occur at sites with a deep litter layer, which corresponds to the occurrence of Crofton weed-dominated vegetation, and that *H. indicus*, *Chlaenius cambodiensis*, *T. arcuatus* and *Harpaliscus birmanicus* with lowest scores on the first axis reached a maximum abundance at sites with little litter and small amounts of fresh biomass on the ground, conditions represented by the pasture habitats. The three aforementioned groups of carabids were widely separated along the first canonical axis, with habitat generalists located in the center of the ordination plot.

4. Discussion

This study demonstrates that distinct carabid assemblages inhabit plots dominated by invasive Crofton weed and native pastures. Fewer individuals, but more species of carabid beetles were captured under Crofton weed than in the native pastures. This reflects in a higher alpha-diversity and higher value of the species estimator *Chao* 1 at plots dominated by Crofton weed, where species were also distributed more evenly as compared to the pastures. These results differ from most previous studies investigating changes in arthropod species assemblages following the

invasion of neophytes (Steenkamp and Chown, 1996; Sousa et al., 2000; Greenwood et al., 2004). However, studies by O'Hare and Dalrymple (1997) and Philippa (1998) emphasized that vegetation structure and environmental factors appear to be of greater importance in influencing arthropod assemblages than whether dominant plants were exotic or native.

Several common species, such as *T. arcuatus*, *H. indicus* and *H. birmanicus*, preferred pastures to Crofton weed, which resulted in a greater overall abundance of carabids captured in pastures. *Harpalus* sp. and *Harpaliscus* sp. are very small seed feeders relying strongly on the seed supply from different weeds, which may explain the very high abundance of these species in the pastures with their higher plant species diversity, which also results in a more constant seed production (Lövei, 1996). The invasion of Crofton weed altered the structure of plant communities and environmental conditions for ground-dwelling carabid communities, which led to the pronounced differences in alpha-diversity observed. The apparent importance of the litter layer depth in relation to carabid assemblages was also recorded by other studies (e.g. Jukes et al., 2001; Molnár et al., 2001).

While evaluating diversity indices, three groups of carabid species could be distinguished, with many species occurring in all three habitat types, but a number of habitat specialists being exclusively present only in either Crofton weed vegetation or at native pastures. Hence, a total loss of native pasture will potentially have a detrimental effect on the species specialized on these habitats.

It has finally to be noted that many carabids species, for example *A. adelioides*, *T. arcuatus*, *H. indicus* or *H. birmanicus*, were captured in both the *Echinochloa* and *Setaria* pasture, with only *Chlaenius bioculatus* being restricted to *Echinochloa* pasture. Hence, although these two native pastures differed greatly in several habitat characteristics, they were inhabited by similar carabid assemblages. The recent creation of these pastures and similarities in their land use history may partly be responsible for these results (Thiele, 1977), which means that further species may invade in the future, which could be further aided by a pasture management aimed at the creation of more heterogeneous habitats.

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