Tropical Ecology **51**(2): 255-263, 2010 ISSN 0564-3295

www.tropecol.com

Lac-production, arthropod biodiversity and abundance, and pesticide use in Yunnan Province, China

YOUQING CHEN[1*], QIAO LI[2], YANLIN CHEN[2], SIMING WANG[1] & YUANCHENG YANG[1]

[1]*Research Institute of Resources Insects, CAF, Kunming, 650224, Yunnan, China*

[2]*School of Conservation Biology, Southwest Forestry University, Kunming, 650224, Yunnan, China*

Abstract: The current prosperity in the lac market provides an incentive for farmers to increase lac production. In Yunnan Province of southwest China, lac was traditionally produced on the upper part of the mountain slopes, from 900-1500 m in altitude, where farmers were living and farming. Lac-production and farming were integrated into an agroforest system. Farmers there enjoyed both cash income and non-cash benefits from these multipurpose lac plants, especially the increased soil fertility and soil retention, with limited labor input, in that fragile environment. Perhaps most importantly, this agroecosystem provided an arthropod bank to ensure the crops growing next to the lac plants were largely free of pest damage. Under a diverse and thin canopy of lac plants with lac insects, the compounded system harbored a high biodiversity of associated organisms. Because of the synchronism and accessibility of these natural enemies to crops pests, farmers rarely sprayed pesticides to control pests. The recent trend of reducing the complexity of this system so as to increase lac production and crops yield raises concerns about the potential loss of biodiversity in this organic agriculture model. Here, we illustrate the ecological and economical importance of these agroecosystems, and hope to attract more attention to this valuable agroecosystem.

Resumen: La prosperidad actual en el mercado de la laca ofrece un incentivo para que los agricultores incrementen la producción de laca. En la provincia Yunnan del suroeste de China, la laca se producía tradicionalmente en la partes altas de las laderas de las montañas, entre 900 y 1500 m de altitud, donde los campesinos vivían y cultivaban sus tierras. La producción de laca y la agricultura fueron integradas en un sistema agroforestal. Allí, los campesinos disfrutaron un ingreso en efectivo y recibieron beneficios no monetarios de estas plantas de laca multipropósito, especialmente un aumento en la fertilidad del suelo y en la retención del suelo, con una inversión limitada de trabajo, en ese ambiente frágil. Quizá sea más importante aún que este agroecosistema proporcionó un banco de artrópodos para asegurar que los cultivos que crecen cerca de las plantas de laca estuvieran libres en gran medida de daños por plagas. Bajo un dosel diverso y delgado de plantas de laca con insectos de laca, el sistema compuesto albergó una biodiversidad alta de organismos asociados. Debido al sincronismo y la accesibilidad de estos enemigos naturales de las plagas de los cultivos, los campesinos raramente rocían pesticidas para controlar a las plagas. La tendencia reciente de reducir la complejidad de este sistema con el fin de incrementar la producción de laca y el rendimiento de las cosechas acarrea preocupaciones sobre la pérdida potencial de biodiversidad en este modelo de agricultura orgánica. Aquí ilustramos la importancia ecológica y económica de estos agroecosistemas y esperamos atraer más atención hacia este valioso agroecosistema.

Resumo: A actual prosperidade no mercado da laca providencia um incentivo para os agricultores aumentarem a sua produção. Na província de Yunnan, sudoeste da China, a laca era tradicionalmente produzida na parte superior das encostas da montanha, entre as altitudes

* *Corresponding Author*; e-mail: cyqcaf@yahoo.com.cn

de 900-1500 m, onde os agricultores viviam e agricultavam. A produção de laca e a agricultura estavam integradas num sistema agroflorestal. Aí, os agricultores beneficiavam tanto de um rendimento monetário, como de benefícios não pecuniários a partir destas plantas multi-uso produtoras de laca, especialmente do aumento da fertilidade e conservação do solo, com um input limitado de mão-de-obra, num ambiente frágil. Talvez, e mais importante, este agro-ecossistema servia de abrigo a um banco de artrópodes que asseguravam que o cultivo próximo às plantas produtoras de laca estivessem amplamente livre de danos causados por pragas. Sob um dossel diverso e fino de plantas produtoras de laca com os respectivos insectos, o sistema composto abrigou uma grande biodiversidade de organismos associados. Devido ao sincronismo e acessibilidade destes inimigos naturais das pragas da agricultura, os agricultores raramente pulverizavam pesticidas para controlar as pragas. A recente tendência de reduzir a complexidade deste sistema de modo a aumentar a produção de laca e o rendimento das culturas, levanta preocupações sobre a perda potencial de biodiversidade neste modelo de agricultura orgânica. Aqui ilustrámos a importância ecológica e económica desses agro-ecossistemas, e esperamos atrair mais atenção para este valioso agro-ecossistema.

Key words: Agroecosystem; biodiversity; lac insects; lac-production; organic agriculture.

Introduction

Anthropogenic modification of habitats, largely due to agricultural conversion, is a global threat to biodiversity (Gaston *et al.* 2003; Tilman *et al.* 2002). Much previous attention has focused on the use of set-aside areas for conservation; however, there is increasing recognition that protected areas are not sufficient to slow the biodiversity decline, and attention is now turning towards the potential utility of managed land for conservation (Bengtsson *et al.* 2003; Novacek & Cleland 2001; Tscharntke *et al.* 2005). No where is this need more imperative than in the tropics, where the greatest diversity of species occurs (Myers *et al.* 2000), but conservation funding is often low, which increases the reliance of these regions on managed land for biodiversity maintenance (Perfecto *et al.* 1996).

The lac insects (*Kerria* spp., Hemiptera: Kerriidae) are scale insects which occur naturally as parasites on various host plants. They produce lac, a layer of red resin on branches of host-trees on which they settle. Lac resin is natural, biodegradable and non-toxic, and thus widely used in food, textiles and pharmaceutical industries in addition to surface coating, electrical component manufacturing, and other fields. Lac insects naturally distributed in tropical and subtropical areas of south and south-east Asia, and most of the lac-producing systems have traditionally been integrated with farming systems as agroecosystems.

During the past fifty years, this traditional farming system has been replaced by independent intensified food crop agricultural systems and monoculture lac tree forests. Lac insect agro-ecosystems have been highlighted for their conservation potential, but management to intensify lac production reduces biodiversity and may restrict ecosystem services (Chen *et al.* 2008). Farming systems which include lac production have seldom been described in the previous literature (especially in English), except for descriptions of the population ecology of lac insects and the relationship between lac insects and their host trees (Bhagat 1988; Chen & Wang 2007a; Chen *et al.* 2003; Chen *et al.* 2004a, b; Chen *et al.* 2005a, b; Chen *et al.* 2006a, b; Kher & Lakra 1988; Mishra *et al.* 2000; Saha & Jaipuriar 2000; Subbarayudu & Ram 1997; Varshney & Srivastava 1989).

The lac system in China

Yunnan Province, located in the southwest of China, is the major lac producing area in the country (Chen & Yao 2007). Labor is the basic limiting factor in farming systems in Yunnan Province. Lac-production allows both cash and non-cash income with little input of labor. Especially in traditional lac-production schemes, lac production synchronizes with corn production. In summer, farmers sow corn seeds in fallow lands. At the same time, they increase the population of lac insects by tying up bundles of small branches covered with live larvae from the winter generation to branches of trees inside the fallow lands or kept close to houses and paths which are easily accessible. In autumn, when corn is harvested, it is also the time to gather lac, and the winter generation begins. It takes 10 to 20 days extra labor to manage 900 lac-host trees and produce lac on them. Growing trees for lac is much less labor-intensive compared to planting, maintaining, and harvesting corn, rubber-tree or tea trees. A major advantage of lac host-trees is that they are naturally dispersed and germinated multipurpose trees, whereas planting tree seedlings is labor-intensive, expensive and uncertain because of the long dry season (MacDichen & Raintree 1991). Experienced farmers never plant any lac trees because lac trees in their villages grew by themselves.

Before 1960s, lac host-trees naturally distributed along the valley slope, especially the area was farmed and settled by human. Lac insects spread along the valley with the help of wind and other animals (including human) (Chen & Wang 2007c). The village territories featured areas with distinct agroecological condition. Soil water during the long dry season was the major variable, but orientation, degree of slope and altitude were important factors. Village territories were organized in successive belts. Forest belts, which surrounded the houses, were themselves surrounded by permanent fields. Most fallow lands were located lower than the houses between 900 - 1200 m in altitude, and paddy field were situated in the valley at 800 - 1100 m in altitude. Trees were only found in the forest belts and in the fallow lands, where spontaneous trees grew in both cultivated and fallowed fields. Many of them were lac host-plants, such as *Dalbergia szemaoensis*, *Ficus altissima*, *F. racemosa* and *D. obtusifolia*. Host-plants in upland fields were closely associated with fallowing cultivation (Hou *et al.* 1985). Fires at the beginning of cultivation cycle temporarily eliminated herbaceous competitors of young tree sprouts. During cultivation, weeding reduced such competition, and farmers preserved some of more vigorous sprouts by avoiding them when plowing and hoeing. Farmers protected both crops and trees from cattle.

In 1980s, more lac host-plants were planted by farmers, and most of these plant species are native plant species. Lac insects were raised on trees from the fifth year on and a lac production cycle equaled two crop-cultivation cycles. The density of trees was limited to 150 - 200 per hectare in upland fields in order to preserve grain yield. Families with more land available kept a high density of 300 - 450 trees per hectare, but the fields were further from the houses.

In the 2000s, more lac-forests were planted, but most of these lac-forests consisted of few tree species or only one tree species. Half of these plant species were introduced from other provinces and the density of trees was up to 900 - 1500 per hectare. Farmers cultivated crops next to these lac trees just when these trees were young, and gave up cultivation completely when these trees were matured, for the thick crown of lac trees intercepted most sunlight the crops needed.

The land utilization was gradually strengthened to gain more lac production during the last fifty years. In 1960s, the areas which can produce lac reached 5,82,000 hectare, and lac-trees numbered 80 million, but the lac production was low, and lac was used as barter by various highland ethnic groups (Ou & Hong 1984). After the foundation of the Lac Research Institute (Chen 1998), lac production increased sharply, and more wild lac trees were used. At the same time, lac-producing was introduced to the neighbouring provinces of south China. In the 1980s, lac-production in Yunnan Province reached its peak, and the largest production was more than 3400t per year. But lac-production declined gradually after its peak, and it was only 150 t per year at the end of the twentieth century. About half of lac-trees were felled. In 21st century, attempts by researchers and governors to develop cultivation of important lac host-plants have met with great interest on the part of farmers, and subsequently about 40,000 hectare lac-forests were developed. The lac-production recovered to 3000 t per year.

The intensified land utilization activity to gain more lac was not successful in Yunnan Province during the past fifty years. The natural lac-plant resources are abundant in Yunnan Province. The lac-production correlated with the number of used lac-trees, the stand conditions where lac insects were cultivated (Chen & Wang 2007b), and other factors such as demand and prices, but not tree density in certain area. If all existing lac-trees were used, the lac-production of Yunnan Province could reach as high as 10,000 t annually.

The purposes of this report are to illustrate the economical and ecological importance of this system and determine if the recent steps to increase food and lac yield are having negative effects on biodiversity and ecosystem services such as biological control.

Materials and methods

Study systems

The research was carried out at four sites in Niukong region of Lüchun County, Yunnan Province, China (22° 53´ N, 101° 56´ W). Plant sampling and runoff measurements were conducted in 2002, while other observations were conducted from 2006-2007. All sites were between 1000 - 1300 m above sea level in elevation and receive ca.1500 mm of rain per year. The sites represented different land use patterns, including natural forest with lac production (I), natural forest without lac production (II), dry land (III), and paddy field (IV). The area of each site ranged from 0.75 to 1.0 ha with a minimum distance of 300 m between sites.

In lac agroecosystems, lac insect host-plants were local trees such as *Ficus semicordata*, *Dalbergia obtusifolia* and *D. szemaoensis*. Lac insects (*Kerria yunnanensis*) were raised on trees from the fifth year on. The density of trees was limited to 150 - 200 per hectare in upland fields (sites I and II) in order to preserve grain yield. In intensified-use land (sites III and IV), dry land was converted to cultivate rice from March to August. In natural sites, after several years of afforestation (from 1999), the degree of canopy closure reached 0.6.

Economic importance of lac and chemical pesticide usage investigation

Economic importance of lac and chemical usage were determined by questioning 50 families that engaged in lac production. All selected families produced lac from 1980s till the present and had approximately the same number of lac host plants per person. The frequency and timing of chemical pesticide usage were also recorded for each of the families between two decades, and one year was selected as representative of each decade. We recorded pesticide activity per family using an index, where, 0 = no pesticide was used, 1 = pesticide was used. Provided the pesticide was used, we recorded the number of pesticide applications per family at the same time.

Runoff sampling and analysis

Runoff investigation was conducted in four kinds of land use, including lac forest (site I), fell slash (site III), fallow lands (site III), and bench terrace in the slope (site IV, next to paddy fields). The effects on soil retention by lac host plants were surveyed through runoff observations for four months (from May to August). Runoff coefficient analysis is expressed as $Q = c \cdot i \cdot A$ (Haan *et al.* 1982), where "Q" is the peak runoff rate, "c" is the runoff coefficient, "i" is the rainfall intensity and "A" is the watershed area. Samples from the collectors were combined for analyses. Runoff samples were oven-dried at 110 °C and weighed. Exchangeable cations were extracted with 1 M ammonium acetate (Thomas 1982) and measured by atomic absorption spectrometer. Nitrogen was analyzed using the Kjeldahl procedure involving digestion with sulphuric acid (Jackson 1968). Phosphorus, calcium, potassium, iron, copper, manganese, zinc, boron and magnesium were determined by atomic absorption spectrometer with sulphuric and perchloric acid digestions (Murphy & Riley 1962; Olsen & Sommers 1982).

The effect of lac producing on graminaceous weeds

Plant species abundance and biomass sampling was conducted in four kinds of land-use including mature forests (site I), young forests (site II, planted in 2000), fallow lands (site III) and fell (site III, next to fallow lands). The abundance and biomass of graminaceous weeds was measured in a total of thirty 1m × 1m samples at each site, 120 plots were selected totally.

Arthropod sampling

At each site, two 100 m transects were created for arthropod collection. The ground-dwelling arthropods were collected in pitfall traps, which were placed along transects at 10 m intervals at ground level. Pitfall traps were made from plastic containers, 8.0 cm in diameter and 15 cm in deep, covered by a stone plate to protect the trap from rain. Arthropods falling into the trap were killed by a solution of ethylene glycol or a mixture of sugar, vinegar and alcohol. Traps were left out for five days and nights. Equal effort sweep net sampling (100 swings of a 38 cm diameter muslin net that was swung with each pace while walking) was undertaken in the morning from 8 00 to 10 00, when the vegetation was dry. The contents of each transect were placed separately in plastic bottles and stored in 75 % alcohol.

Data analysis

The effects of land use/agricultural management on graminaceous weeds were assessed by comparing the total abundance and total biomass of weeds. The effects of land use/agricultural management on soil retention and soil fertilization were assessed by comparing the means of observed chemical data. The effect of land use on arthropods was assessed by comparing species richness and abundance of parasite and predator arthropods in four sites, using a combined data set from pitfall traps and sweep-netting. Results from both trapping methods deviated from a normal distribution; after square root transformation of individuals, and logarithm transformation of species richness. We performed one-way ANOVA followed by Tukey's multiple comparison tests on the difference of richness and abundance of arthropods among land use types (SPSS 16.0).

Results and discussion

The economic and ecological importance of lac in Yunnan Province

Lac has been the most important source of cash in the mountainous regions in south Yunnan Province, until recently. An average family which farms two hectares of lac host plants could harvest 300 kg lac every year, with a value of approximately 4500 RMB (~$ 675 in U.S. dollars in 2008). This is a significant sum, often fifty percent of the whole family's yearly income.

Fuel-wood and timber with a small or a medium diameter are also available after lac is harvested. An average family which can harvest 300 kg lac every insect generation can gain 3000 kg fuel-wood. This fuel-wood can be for approximately 1500 RMB if sold, or can be used as fuel by the family to avoid felling more trees. All of the lac host-trees have strong regeneration of woody stems. The new sprouts can reach 2 to 4 m high after the fallow period of three lac insect generations, and can be used to produce lac again, which ensures sustainable lac production.

Besides the economic value, lac host-trees no doubt affect adjacent crops. Trees do reduce the amount of sunlight available to crops, but the effect is likely minimal for several reasons. First, one third of the trees are used to produce lac every half year, and the other two third of the trees don't have big crowns during their fallow period. Secondly, trees are regularly trimmed for harvesting lac, so that the radius of the crown and the vigor of the trees are reduced. Thirdly, lac insects prefer an environment with sunlight penetrating and wind ventilating to live in, so that the density of the trees is thin generally (Chen & Wang 2007a). Shade provided by trees may explain the limited growth of graminaceous weeds also (Table 1). The total abundance of weeds in mature lac forest was 22.7 % of that in fell, and 12.9 % of that in fallow lands; the total biomass in mature lac forest was 4.2 % of that in fell, and 4.9 % of that in fallow lands. Single individuals of seven plant species were not included in table 1, among them one moss species distributed only in mature forest, three fern species distributed only in the fallow land, and three straw species distributed only in fell. The distribution of these weeds may illustrate the difference of habitats, including light, humidity, the degree of soil rarefaction, and management intensity. Less weeds in lac forest likely reduces herbaceous plant competition for soil nutrients, benefitting crop yields.

The amount of runoff in lac forest from May to August was 58.8 %, 53.9 %, 47.6 %, and 31.7 % of that in fell slash, respectively (Table 2). The amount of washed-away nutrients in lac forest was less 40 % than that in fell (Table 3). The forest crown reduces the impact of rain-drops on the soil while the roots stabilize the soil on steep slopes. Besides these soil retention effects, the nitrogen-fixing nodules of *D. obtusifolia* and *D. fusca* are assumed to provide some nitrogen for the crops and probably have a positive effect on the re-growth of vegetation during the fallow period. Diverse multipurpose lac plants ensure sustainable cultivation of crops without fertilization.

Biodiversity in lac insect agroecosystems and organic agriculture

The lac-production agroecosystem hosted many arthropods including parasitic and predatory groups that are natural enemies of some agricultural pests (Table 4). The collected parasitic and predatory arthropods in natural lac agroecosystem were nominally the most diverse among the four land-use types, but there were only modest statistical differences; lac-production forests had more abundant and diverse parasitic arthropods than dry lands (Table 4).

Less pesticide spraying in traditional lac agroecosystem suggests the existence of natural enemies in this system, which makes organic agriculture more practical. Almost no pesticide was used in 1980s by farmers investigated, and were not widely available (Table 5). The farmers

Table 1. The main cover plant species and biomass in four land use types.

Plant species	Abundance			
	Mature forests (site I)	Young forests (site II)	Fallow lands (site III)	Fell (site III)
Eupatorium odoratum	0	4	41	83
Cynodon dactylon	0	0	294	73
Guizotia abyssinica	0	0	0	73
Panicum trypheron	0	0	9	29
Valeriana officinalis	0	207	98	29
Phragmites australis	0	0	0	20
Pueraria omeiensis	1	82	74	0
Cyperus spp.	6	12	23	1
Oplismenus compositus	63	0	0	0
Ceratopteris thalictroides	0	0	3	0
Total Abundance (number /30m^2)	70	305	542	308
Biomass (kg/m^2)	0.30	1.10	6.10	7.20

Observations of a single individual of a particular species were not included in the table (17 total plant species were observed).

Table 2. Runoff inside and outside lac agroforest in Lüchun, Yunnan (2002).

Month	Total Precipitation (mm)	The amount of runoff in mm and the coefficient of runoff (%)			
		Lac forest (site I)	Fell slash (site III)	Fallow lands (site III)	Bench terrace in the slope (site IV)
May	335.00	44.63 (13.32)	75.94 (22.67)	76.84 (22.94)	43.65 (13.03)
June	402.50	53.56 (13.31)	99.45 (24.71)	121.92 (30.29)	62.62 (15.56)
July	624.50	86.53 (13.86)	181.85 (29.12)	199.97 (32.02)	95.55 (15.30)
August	336.60	21.26 (6.32)	66.97 (19.90)	96.80 (28.76)	40.01 (11.89)

Table 3. The total amount of washed-away nutrients from May to August inside and outside lac agroforests in Lüchun, Yunnan (2002).

	Lac forest (site I)	Fell slash (site III)	Fallow lands (site III)	Bench terrace in the slope (site IV)
Organic matter (kg)	18.27	54.94	168.73	112.28
Total N (kg)	0.92	2.62	8.58	5.56
Total K (kg)	0.56	1.65	6.78	5.07
Total P (kg)	3.71	10.42	30.96	16.86
Effective N (g)	59.67	170.69	562.80	416.26
Effective K (g)	18.24	52.14	227.47	147.59
Effective P (g)	124.38	341.70	915.40	714.59
Effective Ca (g)	1907.11	5682.70	11895.76	7225.59
Effective Mg (g)	67.33	199.20	718.40	823.62
Effective Fe (g)	29.679	85.97	280.64	206.02
Effective B (g)	0.04	0.08	0.32	0.26
Effective Cu (g)	1.03	2.99	7.77	4.98
Effective Mn (g)	17.40	52.30	187.07	131.91
Effective Mo (g)	0.02	0.06	0.21	0.17
Effective Zn (g)	0.53	1.72	4.24	2.99

Table 4. The comparison of arthropod predator and parasite abundance and species richness among different land use patterns (mean ± 1 SE). Means prefixed with different letters are significantly different at $P < 0.05$.

Site	Predator abundance	Predator richness	Parasite abundance	Parasite richness
I-forest with lac-production	^{AB} 19.01 ± 1.96	^{A} 1.96 ± 0.05	^{A} 10.43 ± 0.33	^{A} 1.64 ± 0.01
II-forest without lac-production	^{B} 15.72 ± 1.19	^{A} 1.87 ± 0.03	^{AB} 9.02 ± 0.30	^{AB} 1.54 ± 0.01
III-dry land	^{B} 14.77 ± 0.48	^{A} 1.81 ± 0.03	^{B} 5.53 ± 1.01	^{B} 1.30 ± 0.06
IV-paddy	^{A} 22.84 ± 0.87	^{A} 1.83 ± 0.03	^{AB} 7.43 ± 1.37	^{AB} 1.40 ± 0.10

Table 5. Comparison of chemical pesticide applications between two time periods.

	The percentage of families using chemical pesticides per year (%)	The average (± 1SE) number of pesticide applications per year by families using pesticides
1980s	2	1
2000s	20	1.4 ± 0.16

said that the crops planted next to lac plants were not eaten by pests. In the 21st century, a few farmers began to use pesticide to control rice planthoppers in some years (Table 5). In 1980s, pesticides were not widely available and abundant for farmers in mountainous area, and many farmers did not appeal to pesticides to control pests as in 2000s. Perhaps there was not a difference in pest populations between two decades, but less pesticides was used in 1980s, which is helpful to the environment, and overall pesticides use is still rare in present.

Conclusions

Agroecosystem including lac-producing in Yunnan Province is a very special ecosystem in southern subtropical areas. These multipurpose lac tree species give farmers both a cash income and various non-monetary products such as fuel-wood and timber with limited labor inputs. Although lac-trees affect the growth of crops next to them, they do reduce the abundance of weeds, which is helpful to reduce herbaceous plant competition for soil nutrients and labor input (Table 1). Besides its economic importance, lac-agroecsystem has positive effects on soil retention and soil fertilization. The washed-away soil and nutrients in lac forest is less than that in other land-use type (Tables 2 & 3).

In the traditional agroforest, the forest strips provide an alternative habitat for arthropods, as well as birds and small mammals (Cuthbertson & McAdam 1996; Stamps & Linit 1998), which is vital in annual cropping systems to ensure crops free of pest damage (Phillips *et al.* 1994). Provided pesticides were used in some years, this habitat ensures the colonization persistence and continuity of natural enemies to deliver the ecosystem service of pest control. The neighbourhood of natural and managed ecosystems is often important for sustaining the agroecosystems.

Lac agroecosystems serve as an arthropod bank that is temporally synchronized and physically accessible to pest population when/ where the pests damage the crops. But there were not strong differences between lac forest and other type of land utilization for parasite and predator arthropods in this study, as expected from previous research. Smaller lac insect populations in the natural lac agroecosystem, since some trees that hosting lac insects were destroyed by some person, may partly explain the insignificantly statistical difference of arthropod biodiversity among land use-way in this experiment. This study was conducted in one area of lac agroecosystem, we can not generalize the results to other areas of this type arbitrarily, and additional field studies should be conducted to further determine the arthropod diversity along land management gradients. But simplifying elements of the habitat, such as planting a monoculture of lac tree and the separating of lac-producing and crop planting, may affect the arthropod biodiversity and associated ecosystem services such as pollination and biological control. Species loss does not affect all species similarly, which may result in the release of herbivores due to reduced control by natural enemies (Bruno & Connor 2005), ultimately impacting primary productivity. As the balance of agroecosystems and organic food become important issues in these areas, the major contribution of lac-production in the future might not be the cash income it allows, but its contribution to maintaining this ecological balance and ensuring organic food.

Acknowledgements

The data on which this paper is based were collected in various lac-producing farms in Yunnan Province, China. We wish to thank producers from the Lüchun County for giving permission to work on their farms. We thank Jeremy Wojdak for his hard work on the English language. Two anonymous reviewers gave valuable comments on earlier versions of the manuscript. This research was partially supported with a grant from the Chinese Forestry Academy Science Foundation (riricaf 200801z).

References

Bengtsson, J., P. Angelstam, T. Elmquvist, U. Emanuelsson, C. Forbes, M. Ihse, F. Moberg & M. Nyström. 2003. Reserves, resilience and dynamic landscapes. *Ambio* **32**: 389-396.

Bhagat, M.L. 1988. Field studies on the initial mortality of lac insect *Kerria lacca* Kerr. in relation to host plants. *Indian Forester* **114**: 339-341.

Bruno, J.F. & M.I. O'Connor. 2005. Cascading effects of predator diversity and omnivory in a marine food web. *Ecology Letters* **8**: 1048-1056.

Chen, X.M. 1998. The resource protection and utilization of genus *Kerrica* (Hemiptera: Kerriidae). *Biodiversity Science* **6**: 287-290. (in Chinese).

Chen, Y.L., Y.Q. Chen, Q. Li, Y. Zhang & X.Y. Zhou. 2008. Preliminary study on the spider community in *Kerria* spp. ecosystem. *Journal of Fujian College of Forestry* **28**: 179-183. (in Chinese).

Chen, Y.Q., X.M. Chen & K. Li. 2003. A probe into the mortality of lac insect population and improvement of mortality formula. *Forest Research* **16**: 135-140. (in Chinese).

Chen, Y.Q., X.M. Chen & K. Li. 2004a. A primarily study on relationship between amino acid content of host trees and *Kerria lacca*. *Forest Research* **17**: 362-367. (in Chinese).

Chen, Y.Q., X. M. Chen & K. Li. 2004b. Preference of lac insect to host branch in foraging. *Forest Research* **17**: 159-166. (in Chinese).

Chen, Y.Q., X.M. Chen, K. Li, L. Shi & Z.Y. Chen. 2005a. A primarily study on relationship between mineral salt contents of host trees and *Kerria lacca*. *Chinese Journal of Ecology* **24**: 523-527. (in Chinese).

Chen, Y.Q., X.M. Chen, K. Li, L. Shi & Z.Y. Chen. 2005b. A study on population dynamics of lac insect and its lac secreting. *Journal of Northwest Forestry University* **20**: 170-174. (in Chinese).

Chen, Y.Q. & S.Y. Wang. 2006a. Growth of *Schleichera oleosa* infested by *Kerria lacca*. *Entomological Knowledge* **43**: 549-552. (in Chinese).

Chen, Y.Q. & S.Y. Wang. 2006b. The influence on plants nutrient contents parasitized by *Kerria lacca*. *Entomological Knowledge* **43**: 691-695. (in Chinese).

Chen, Y.Q. & S.Y. Wang. 2007a. Effects of host plants on natural population of *Kerria yunnanensis* (Hemipterae: Kerridae). *Chinese Journal of Applied Ecology* 18(4): 761-765. (in Chinese).

Chen, Y.Q. & S.Y. Wang. 2007b. Geographic distribution of *Kerria yunnanensis* Ou *et* Hong (Hemiptera: Kerridae) and the role of ecological factors. *Acta Entomologica Sinica* **50**: 521-527. (in Chinese).

Chen, Y.Q. & S.Y. Wang. 2007c. Natural distribution, diffusion and geographical origin of the genus *Kerria* (Hemiptera: Kerriidae). *Entomotaxonomia* **29**: 107-115. (in Chinese).

Chen, Y.Q. & W.J. Yao. 2007. Lac Resources and Their Utilization in the World. *World Forestry Research* **20**: 61-65. (in Chinese).

Cuthbertson, A. & J. Mcadam. 1996. The effect of tree density and species on carabid beetles in a range of pasture-tree agroforestry systems on a lowland site. *Agroforestry Forum* **7**: 17-20.

Gaston, K.J., T.M. Blackburn & K.K. Goldewijk. 2003. Habitat conversion and global avian biodiversity loss. *Proceedings of the Royal Society of London B*. **270**: 1293-1300.

Haan, C.T., H.P. Johnson & D.L. Brakensiek. 1982. *Hydrologic Modeling of Small Watersheds*. American Society of Agricultural Engineers, St. Joseph, Michigan.

Hou, K.W., Y.D. Chen & Y.P. Chen. 1985. On the vegetation condition of the best growing region of lac insect in Yunnan. *Acta Botaniea Sinica* **7**: 17-24. (in Chinese).

Jackson, M.L. 1968. *Ana ´lisis Quı´ mico de Suelos*, 1st ed. Editorial Omega, Barcelona.

Kher, S. & P.K. Lakra. 1988. Preliminary observations on some recorded and unrecorded host plants and natural enemies of lac insect, *Kerria lacca* (Kerr.) in Haryana. *Haryana Agricultural University Journal of Research* **18**: 131-133.

Macdichen, K.G. & J.B. Raintree. 1991. An overview of multipurpose tree species. pp. 5-16. *In*: D.A. Taylor & K.G. MacDichen (eds.) *Research on multipurpose tree species in Asia*. Proceedings of an international workshop, Thailand.

Mishra, Y.D., S.N. Sushil, S. Kumar & A. Bhattacharaya. 2000. Variability in lac productivity and related attributes of *Kerria* spp. (Homoptera: Tachardiidae) on ber (*Zizyphus mauritiana*). *Journal of Entomological Research* **24**: 19-25.

Murphy, J. & J.P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. *Anal. Chim. Acta* **27**: 31–36.

Myers, N., R.A. Mittermeier, C.G. Mittermeier, G.A.B. Da Fonseca & J. Kent. 2000. Biodiversity hotspots for conservation priorities. *Nature* **403**: 853-858.

Novacek, M.J. & E.E. Cleland. 2001. The current biodiversity extinction event: Scenarios for mitigation and recovery. *Proceedings of the National Academy of Sciences, USA* **98**: 5466-5470.

Olsen, S.R. & L.E. Sommers. 1982. Chemical and Microbiological Properties. pp. 416-418. *In*: A.L. Page, R.H. Miller, D.R. Keeney (eds.) *Methods of Soil Analysis*, Part 2 2nd ed. American Society of Agronomy, Inc., SSSA, USA.

Ou, B.R. & G.J. Hong. 1984. Lac insect. *In:* Zhu, Guokai, Li Liying, Guo Fu, Huang Kexun (eds.) *Insects as natural resources*. Science Press, Beijing. (in Chinese).

Perfecto, I., R.A. Rice, R. Greenberg & M.E. Van Der Voort. 1996. Shade coffee: a disappearing refuge for biodiversity. *BioScience* **46**: 598-608.

Phillips, D.S., J. Griffiths, M. Naeem, S.G. Compton & L.D. Incoll. 1994. Responses of crop pest and their natural enemies to an agroforestry environment. *Agroforestry Forum* **5**: 14-20.

Saha, S.K. & S.K. Jaipuriar. 2000. Variability and interrelationship of biological parameters and resin-characteristics in lac insect, *Kerria lacca* (Kerr.). *Shashp*a **7**: 17-20.

Stamps, W.T. & M.J. Linit. 1998. Plant diversity and arthropod communities: implications for temperate agroforestry. *Agroforestry Systems* **39**: 73-89.

Subbarayudu, B. & R.L. Ram. 1997. Distribution of host plants of the lac insect, *Kerria lacca* (Kerr.). *Journal of Entomological Research* **21**: 187-192.

Thomas, G.W. 1982. Chemical and Microbiological Properties. pp. 159-165. *In*: A.L. Page, R.H. Miller, D.R. Keeney (eds.) *Exchangeable Cations*. *Methods of Soil Analysis*, Part 2 2nd ed. American Society of Agronomy, Inc., SSSA, USA.

Tilman, D., K.G. Cassman, P.A. Matson, R. Naylor & S. Polasky. 2002. Agricultural sustainability and intensive production practices. *Nature* **418**: 671-677.

Tscharntke, T., A.M. Klein, A. Kruess, I. Steffan-Dewenter & C. Thies. 2005. Landscape perspectives on agricultural intensification and biodiversity. ecosystem service management. *Ecology Letters* **8**: 857-874.

Varshney, R.K. & P.N. Srivastava. 1989. Amino acid and carbohydrate constituents of the India lac insect, *Kerria lacca* (Homoptera: Tachardiidae) at different stages of development. *Annales de la Societe Entomologique de France* **25**: 380-382.