生物多样性 BIODIVERSITY SCIENCE
2023, 31 (5): 23074, pages 1–11
doi: 10.17520/biods.2023074

•研究报告•

基于蛾类多样性研究人工林斑块的边缘效应

段曼微[1], 李香[2], 周阳[1], 赵敏欣[1], 孙秀玲[3], 韩冰[4], 张刚[5], 权子豪[1], 李凯[1*]

1. 北京林业大学生态与自然保护学院, 北京 100083; 2. 北京市绿地养护管理事务中心, 北京 102211; 3. 北京自然博物馆, 北京 100050; 4. 北京市十三陵林场, 北京 102200; 5. 北京市通州潞城集体林场, 北京 101100

摘要: 斑块状造林是当前国内营建人工林的主要方式之一, 在林内不同斑块间形成了大量的边缘环境。为探究人工林斑块间边缘效应的生物多样性特点, 本文基于北京平原造林中的毛白杨(*Populus tomentosa*)林–国槐(*Styphnolobium japonicum*)林、国槐林–栾树(*Koelreuteria paniculata*)林、栾树林–桧柏(*Juniperus chinensis*)林、旱柳(*Salix matsudana*)林–杜仲(*Eucommia ulmoides*)林4种树种组合, 选择与植物具有营养关系的蛾类为研究对象, 采用非度量多维尺度(NMDS)排序、Anosim分析、物种多样性指数等对蛾类数量、物种组成与多样性进行分析; 并基于林下植被特征因子调查, 使用Pearson相关性分析探讨了植被特征因子与蛾类群落特征的关系。结果表明: 本研究共采集到蛾类4,428只, 分属于24科144种。(1)斑块边缘的蛾类物种组成与斑块内存在差异, 边缘独有种比例占所在样地组合物种数的13.59%–18.32%。(2)边缘物种多样性指数多为相邻斑块中间值或略高于斑块内; 旱柳林–杜仲林边缘的Simpson指数显著高于杜仲林斑块, Shannon-Wiener多样性指数、Margalef丰富度指数显著高于旱柳林斑块, Pielou均匀度指数显著低于杜仲林斑块。(3)蛾类Simpson指数与植被的平均高度和平均盖度呈显著负相关关系; 而蛾类物种数与植被的平均高度和平均盖度呈显著正相关关系。(4) 4种边缘类型的边缘效应均呈正效应($I_{H'}$ >1), 其中旱柳林–杜仲林边缘的边缘效应强度最低(I_C = 0.915185808)。斑块状人工林的边缘中存在对生境变化产生响应的蛾类类群, 这是斑块状人工林生物多样性提高的基础。不同树种组合斑块的边缘效应所呈现的生物多样性特点不同, 可能存在优势物种暴发的风险。本研究可为后续造林及林分管理提供指导意见。

关键词: 蛾类; 边缘效应; 人工林; 生物多样性; 斑块

段曼微, 李香, 周阳, 赵敏欣, 孙秀玲, 韩冰, 张刚, 权子豪, 李凯 (2023) 基于蛾类多样性研究人工林斑块的边缘效应. 生物多样性, 31, 23074. doi: 10.17520/biods.2023074.
Duan MW, Li X, Zhou Y, Zhao MX, Sun XL, Han B, Zhang G, Quan ZH, Li K (2023) Edge effect in plantation patches based on moth diversity. Biodiversity Science, 31, 23074. doi: 10.17520/biods.2023074.

Edge effect in plantation patches based on moth diversity

Manwei Duan[1], Xiang Li[2], Yang Zhou[1], Minxin Zhao[1], Xiuling Sun[3], Bing Han[4], Gang Zhang[5], Zihao Quan[1], Kai Li[1*]

1 *School of Ecology and Nature Conservation, Beijing Forestry University, Beijing 100083*
2 *Beijing Municipal Forestry and Parks Bureau, Beijing 102211*
3 *Beijing Museum of Natural History, Beijing 100050*
4 *Beijing Ming Tombs Forest Centre, Beijing 102200*
5 *Lucheng Collective Forest Centre in Beijing Tongzhou District, Beijing 101100*

ABSTRACT

Aims: Afforestation though patch planting is one of the main ways of plantation construction in China. As a result, a large number of edge environments have emerged between different patches in the forest. The unique characteristics of these edge environments and their effects on biodiversity are worthy of attention. The purpose of this study is to explore its biodiversity performance characteristics.

Methods: This study was based on the four different combinations of tree species, specifically the patches of *Populus tomentosa* forest and *Styphnolobium japonicum* forest, *Styphnolobium japonicum* forest and *Koelreuteria paniculata* forest, *Juniperus chinensis* forest and *Styphnolobium japonicum* forest, *Salix matsudana* forest and *Eucommia ulmoides*

收稿日期: 2023-03-11; 接受日期: 2023-05-16
基金项目: 北京林业大学大学生创新创业训练项目(x202110022213)
* 通讯作者 Author for correspondence. E-mail: jiujiu@bjfu.edu.cn

forest in Beijing Plain. The research selected the moth population in these forests as study objects and analyzed the species number, species composition and diversity of moth using non-metric multidimensional scaling (NMDS), analysis of similarities (Anosim), and species diversity index. Based on the survey of vegetation characteristic factors, Pearson correlation analysis was used to investigate the relationship between vegetation factors and moth community characteristics.

Results: A total of 4,428 moths were collected, representing 144 species of 24 families. (1) The composition of moth species differed between the edges and the patches, with unique species in the edge accounted for 13.59%–18.32% of the total species in the sample plot. (2) The diversity index of edge species was generally found to be slightly higher than or between that pure forest patches. The dominance index of the edge of *Salix matsudana* forest and *Eucommia ulmoides* forest was significantly higher than that of *Eucommia ulmoides* forest patch, while the Shannon-Wiener diversity index and Margalef richness index were significantly higher than that of *Salix matsudana* forest patch. Moreover, the Pielou evenness index of the edge was significantly lower than that of *Eucommia ulmoides* forest patch. (3) The moth Simpson dominance index was found to be negatively correlated with the average height and coverage of vegetation and the number of moth species was positively correlated with the average height and coverage of vegetation. (4) The four types of edge effects were all positive ($I_{H'} > 1$), and the edge effect intensity of the edge of *Salix matsudana* forest and *Eucommia ulmoides* forest was the lowest ($I_C = 0.915185808$).

Conclusion: Some certain groups of moths inhabit marginal habitats, which contribute to the higher biodiversity found in patch plantations. The edge effects of paths composed of different tree species exhibit distinct biodiversity characteristics, and there is a possibility of dominant species outbreaks. This study can provide guidance for future subsequent afforestation and stand management.

Key words: moth; edge effect; plantation; biodiversity; patch

随着国内城市化进程的加快及人类对环境质量需求的提高，城市中开始出现大量的人工林(冯雪等, 2016)。而大面积营造纯林存在明显缺陷，例如生物多样性下降(尤文忠等, 2008)、病虫害发生几率高(Faccoli & Bernardinelli, 2014)等。因此，国内斑块状造林已逐渐替代大面积纯林造林(李利, 2020)，并形成了大量的人工林斑块间的边缘。

边缘是生态环境快速变化的区域，一般具有较高的生物多样性(田超等, 2011)。昆虫对环境的变化十分敏感(王义平等, 2008)，森林边缘会对昆虫的群落结构等产生影响(杨贵军等, 2016)。目前人工林边缘的研究大部分集中于相对明显的边缘如林草(Brigić et al, 2014)、林牧(Martínez-Falcon et al, 2018)、林缘地区(Chaundy-Smart et al, 2012)等，而针对斑块状人工林边缘的研究较少。在国内斑块状造林的大趋势下，人工林斑块间的边缘效应以及所产生的生物多样性特点是一个值得思考的问题。

蛾类种类繁多(Ober & Hayes, 2009)，对微环境敏感(Summerville, 2011)，在食物链中具有承上启下的地位(Holmes et al, 1979; Diaz et al, 2020)，经常作为监测森林生态效益的指示类群(Kitching et al, 2000)。当前人工林中的蛾类多样性研究大多基于整体环境(郭欣乐等, 2022)或单一林分(任雪毓等, 2022)。人工林内存在大量的边缘，但目前针对其生物多样性特点的研究则较少。蛾类作为生物多样性研究的常见类群，一定程度上可以反映人工林斑块边缘的生态效益。本研究以蛾类为研究对象，基于4种常见斑块树种组合，运用自制灯诱装置，通过比较蛾类群落与多样性特征，探究了人工林斑块边缘效应的生物多样性表现，以期为人工林的管理与后续平原造林计划提供依据。

1 研究方法

1.1 研究区概况

本研究地点位于北京市通州区潞城集体林场(39°48′–39°51′ N, 116°47′–116°53′ E)，地处北京市东南部。林场树种组成以华北地区常见造林树种为主，包括国槐(*Styphnolobium japonicum*)、毛白杨(*Populus tomentosa*)、栾树(*Koelreuteria paniculata*)、元宝枫(*Acer truncatum*)、桧柏(*Juniperus chinensis*)、旱柳(*Salix matsudana*)、杜仲(*Eucommia ulmoides*)等，不同纯林斑块呈现不规则镶嵌状排列。

1.2 样地设置

选取该地区常见的4类树种组合进行试验研究：毛白杨林–国槐林、国槐林–栾树林、旱柳林–杜仲林、国槐林–桧柏林，各树种斑块宽度均大于70 m,

表1　人工林斑块蛾类调查样地概况(平均值 ± SD)
Table 1　Plot overview of plantation patches moth survey (mean ± SD)

	平均树高 Average tree height (m)	平均胸径 Average diameter at breast height (cm)	株行距 Distance between trees (m)	林下植被高度 Height of understory vegetation (m)	林下植被盖度 Coverage of understory vegetation (%)
毛白杨林 *Populus tomentosa* forest (mby)	13.53 ± 1.05	20.00 ± 1.63	4 × 4	0.18 ± 0.11	3.00 ± 1.41^{b}
毛白杨林–国槐林1边缘 Edge of *Populus tomentosa* forest & *Styphnolobium japonicum* forest 1 (E_{yh})	–	–	–	0.28 ± 0.10	53.89 ± 20.65^{a}
国槐林1 *Styphnolobium japonicum* forest 1 (gh1)	9.17 ± 0.62	32.67 ± 2.05	4 × 4	0.31 ± 0.24	48.00 ± 21.02^{ab}
栾树林 *Koelreuteria paniculata* forest (ls)	6.83 ± 0.85	17.67 ± 2.05	3.5 × 3.5	0.18 ± 0.19	20.67 ± 24.99^{b}
栾树林–国槐林2边缘 Edge of *Koelreuteria paniculata* forest & *Styphnolobium japonicum* forest 2 (E_{lh})	–	–	–	0.28 ± 0.35	50.33 ± 27.19^{a}
国槐林2 *Styphnolobium japonicum* forest 2 (gh2)	8.67 ± 0.47	21.33 ± 2.62	4 × 4.5	0.16 ± 0.09	59.22 ± 32.26^{a}
桧柏林–国槐林2边缘 Edge of *Juniperus chinensis* forest & *Styphnolobium japonicum* forest 2 (E_{bh})	–	–	–	0.35 ± 0.20	48.78 ± 29.18^{a}
桧柏林 *Juniperus chinensis* forest (gb)	3.17 ± 0.24	13.00 ± 2.16	3 × 3	0.28 ± 0.13	64.44 ± 27.33^{a}
旱柳林 *Salix matsudana* forest (hl)	12.00 ± 0.82	22.67 ± 2.05	4 × 4	0.35 ± 0.15	61.11 ± 12.86^{a}
旱柳林–杜仲林边缘 Edge of *Salix matsudana* forest & *Eucommia ulmoides* forest (E_{hd})	–	–	–	0.19 ± 0.07	51.78 ± 24.89^{a}
杜仲林 *Eucommia ulmoides* forest (dz)	8.33 ± 0.47	25.00 ± 4.08	3.5 × 3.5	0.18 ± 0.06	24.22 ± 21.26^{b}

国槐林1和国槐林2为分开的两块不同样地, 间距300 m; 不同字母表示不同样地间差异显著。
Styphnolobium japonicum forest 1 and *Styphnolobium japonicum* forest 2 are two different plots; Different letters represent significant differences.

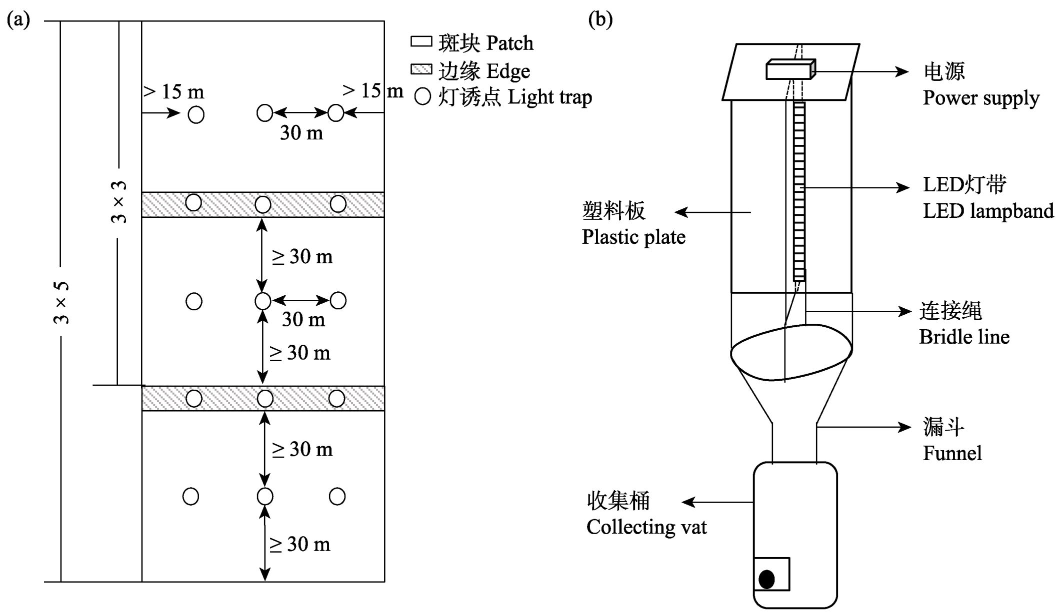

图1　人工林斑块蛾类调查灯诱点位(a)及灯诱装置(b)设置图
Fig. 1　Schematic diagram of the sample setting (a) and light trap (b) of the plantation patches moth survey

边缘长度在100 m以上。样地概况见表1。

1.3　样本采集

运用自制灯诱装置进行蛾类采集(图1; 图2b, c), 结构借鉴White等(2016)。灯源为6 w的LED紫光灯带, 该瓦数下灯诱有效直径为30 m (Truxa & Fiedler, 2012; Merckx & Slade, 2014)。使用12 v蓄电池进行

供电，设置漏斗进行引流，蛾类掉入放有乙酸乙酯的收集桶内进行毒杀。

本研究在2022年6–8月进行，每月调查1次，分别在每个树种组合的纯林斑块内及斑块边缘设置3个灯诱点。每组样地类型灯诱两晚，以保障采集数量。针对样地具体情况，采取3 × 3或3 × 5的排列方式，以间距30 m设置灯诱样点(图1a)。灯诱时间为每晚的19:30–22:30，采集到的蛾类样品于第2天进行分类整理。林下植被特征因子调查以灯诱点为中心设置1 m × 1 m的样方进行，主要调查植被的平均盖度(V_c)和平均高度(V_h)，并测量环境温度、湿度。

图2　毛白杨林–国槐林1样地情况(a)及灯诱装置实物图(b, c)
Fig. 2　Schematic representation of *Populus tomentosa* forest & *Styphnolobium japonicum* forest 1 and its edge (a) and diagram of light trap (b, c)

1.4　数据分析

(1)采集数量：统计不同斑块蛾类的个体数N和物种数S。(2)物种组成：Venn图可表示不同斑块的蛾类物种组成；使用非度量多维尺度(NMDS)排序，选择Bray-Curtis距离可视化物种组成，通过相似性分析(Anosim)比较组内及组间的群落物种组成差异。(3)物种多样性：优势度使用Simpson指数测度：$C = \sum P_i^2$ (i = 1，2，3，……，S)；多样性使用Shannon-Wiener多样性指数测度：$H' = -\sum P_i \ln P_i$ (i = 1, 2, 3, ……, S)；丰富度使用Margalef丰富度指数测度：$D = (S-1)/\ln N$；均匀度使用Pielou均匀度指数测度：$J = H'/\ln S$；其中$P_i = n_i/N$, n_i为物种i的个体数。(4)林下植被特征因子关联性分析：使用Pearson相关性分析检验植被特征因子与蛾类特征数据的相互关系。(5)边缘效应强度：使用边缘效应指数(王伯荪和彭少麟，1986)计算边缘效应强度：$I_{H'} = mH_{边}'/\sum H_{边i}'$，$I_C = mC_{边}/\sum C_{边i}$，$H_{边}'$为边缘群落的蛾类多样性指数，$H_{边i}'$为各个群落的蛾类多样性指数，$C_{边}$为边缘群落的蛾类优势度指数，$C_{边i}$为各个群落的蛾类优

表2　人工林斑块及边缘蛾类个体数量
Table 2　Individuals of moth in plantations patches and edges

科 Family	mby	E_{yh}	gh1	ls	E_{lh}	gh2	E_{bh}	gb	hl	E_{hd}	dz
夜蛾科 Noctuidae	181	109	122	298	239	117	99	203	240	361	204
尺蛾科 Geometridae	68	52	122	79	87	85	71	23	13	30	23
螟蛾科 Pyralidae	21	30	59	100	106	72	38	40	33	62	67
菜蛾科 Plutellidae	12	6	15	23	26	18	26	47	9	18	15
卷蛾科 Tortricidae	4	21	8	17	24	30	16	23	22	22	16
织蛾科 Oecophoridae	1	3	5	14	11	16	15	17	21	23	10
麦蛾科 Gelechiidae	7	5	10	18	13	2	5	6	28	13	10
草螟科 Crambidae	2	13	10	11	15	9	8	4	6	24	13
舟蛾科 Notodontidae	6	5	2	1	1	4	2	–	3	14	6
瘤蛾科 Nolidae	–	–	1	–	1	–	1	–	7	18	12
其他 Others	1	7	3	17	14	13	7	16	4	12	10
合计 Total	303	251	357	578	537	366	288	379	386	597	386

缩写含义见表1。The abbreviations see Table 1.

势度指数, m为组成边缘的群落数。$I_{H'}$值越大则边缘效应强度越强, 当$I_{H'}$值大于1时边缘效应呈正效应, 小于1则呈负效应; I_C值越低则边缘效应强度越高。

采用单因素方差分析(one-way ANOVA)比较不同纯林斑块及其边缘人工林内的昆虫群落的个体数量及多样性指数, 显著性水平为0.05。

所有数据分析在R 4.2.1、SPSS 26.0以及PAST (Hammer et al, 2001)软件中完成, 使用R 4.2.1和Origin 2023软件完成作图。

2 结果

2.1 蛾类物种数和个体数量

本研究共采集到蛾类4,428只, 分属于24科144种, 其中有77.1%的个体鉴定到种, 其余鉴定到科。物种数上, 夜蛾科、螟蛾科为优势类群, 共占总物种数的25.7%; 个体数量上, 夜蛾科为优势类群, 占总个体数的49.1%, 其次为尺蛾科, 占14.8% (表2)。

物种数上, 毛白杨林–国槐林1边缘、栾树林–国槐林2边缘、桧柏林–国槐林2边缘、旱柳林–杜仲林边缘的物种数均位于两种纯林斑块之间或略高于斑块内, 仅旱柳林–杜仲林边缘显著高于旱柳林斑块; 在个体数量上, 旱柳林–杜仲林边缘高于纯林斑块内且差异显著, 其余边缘均位于纯林斑块之间或略低于斑块内(图3)。在4种边缘类型中, 个体数量及物种数均表现为旱柳林–杜仲林边缘 > 栾树林–国槐林2边缘 > 桧柏林–国槐林2边缘 > 毛白杨林–国槐林1边缘, 旱柳林–杜仲林边缘的个体总数(199 ± 30)及物种数(45 ± 4)均大于其余边缘, 与桧柏林–国槐林2边缘和毛白杨林–国槐林1边缘存在显著差异($P < 0.05$)。

2.2 蛾类物种组成及群落结构

桧柏林–国槐林2斑块及其边缘中共采集蛾类96种, 有14种仅在边缘出现; 桧柏林–国槐林2边缘与国槐林和桧柏林共有的种类分别占相应斑块的61.5%和72.2%。栾树林–国槐林2斑块及其边缘中共采集蛾类101种, 有16种仅在边缘出现; 栾树林–国槐林2边缘与栾树林和国槐林共有的种类分别占相应斑块的73.1%和67.7%。毛白杨林–国槐林1斑块及其边缘共采集蛾类74种, 有13种仅在边缘出现, 毛白杨林–国槐林1边缘与毛白杨林和国槐林共有的种类分别占相应斑块的75.0%和68.6%。旱柳林–杜仲林斑块及其边缘共采集蛾类109种, 其中有16种仅在边缘出现; 旱柳林–杜仲林边缘与旱柳林和杜仲林共有的种类分别占相应斑块的77.6%和64.9% (图4)。

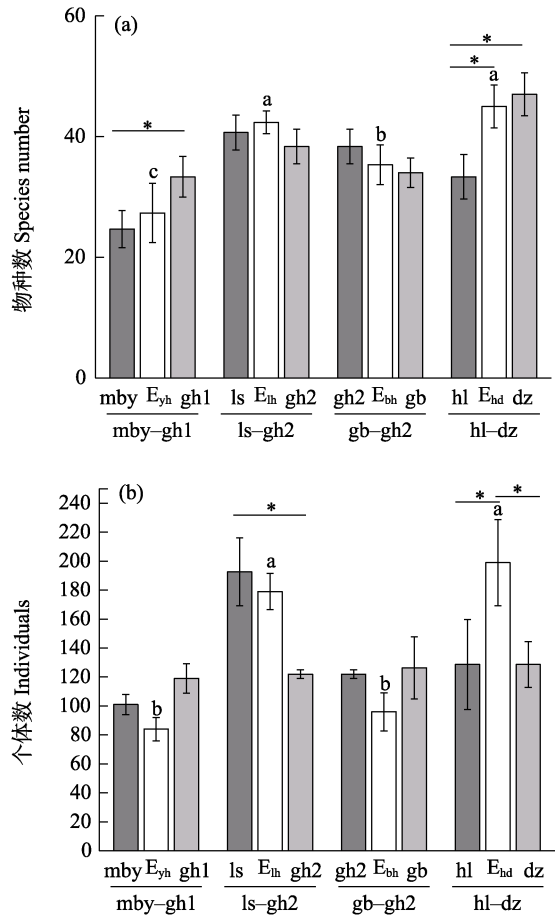

图3 人工林斑块及边缘蛾类物种数(a)和个体数(b) (平均值 ± SD)。*代表斑块与边缘间差异显著; 不同小写字母表示不同边缘间差异显著。缩写含义见表1。

Fig. 3 Moth species number (a) and individuals (b) of plantation patches and edges (mean ± SD). * represents significant difference, different lowercase letters represent significant differences between different edges. The abbreviations see Table 1.

NMDS分析结果表明不同边缘与斑块内的蛾类物种组成均存在差异, 且边缘蛾类群落样方投影均位于两个斑块之间并与斑块样方投影出现重叠, 显示出过渡状态(图5), Anosim分析显示仅旱柳林–杜仲林边缘与纯林斑块物种组成均存在显著差异($P < 0.05$; $R = 0.01$)。对边缘独有种的比较发现, 在4种边缘类型中, 独有种比例达到了所在样地组合物种数的13.6%–18.3% (图6), 且4种边缘类型不存在显著差异。

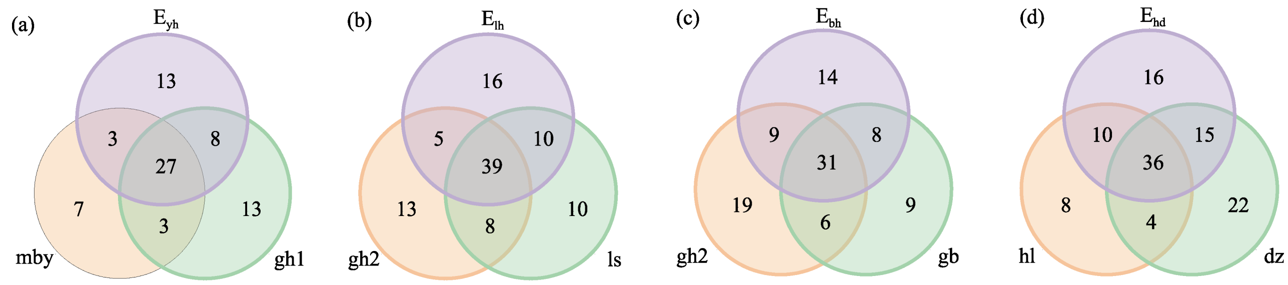

图4　人工林斑块及边缘蛾类物种数的Venn图。缩写含义见表1。
Fig. 4　Venn diagram of moth species numbers in plantation patches and edges. The abbreviations see Table 1.

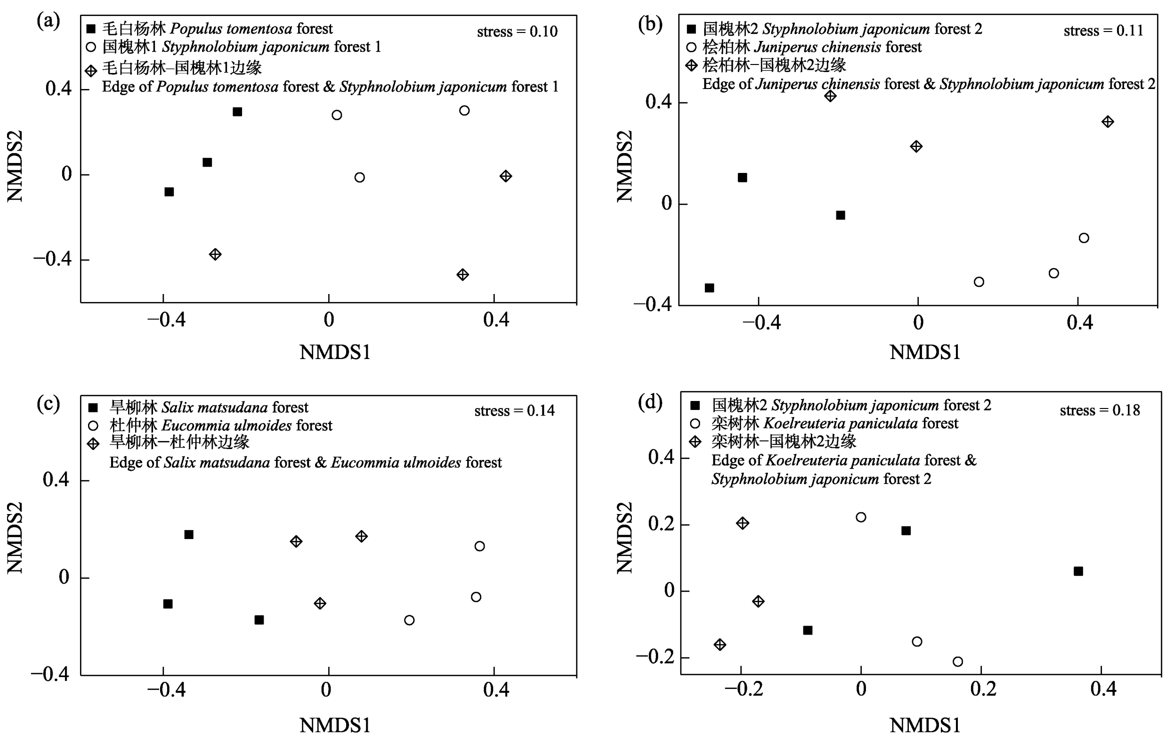

图5　人工林斑块及边缘的蛾类群落非度量多维尺度(NMDS)排序图
Fig. 5　Ordination plot of non-metric multidimensional scaling (NMDS) of moth communities in plantation patches and edge

2.3　蛾类多样性指数

4种边缘类型的Shannon-Wiener多样性指数、Margalef丰富度指数、Pielou均匀度指数均位于两种纯林斑块之间或略高于斑块内；Simpson指数除毛白杨林–国槐林1边缘均位于两种纯林斑块之间；桧柏林–国槐林2边缘及毛白杨林–国槐林1边缘的Pielou均匀度指数均高于斑块内。旱柳林–杜仲林边缘的Simpson指数显著高于杜仲林斑块；Shannon-Wiener多样性指数、Margalef丰富度指数显著高于旱柳林斑块；Pielou均匀度指数显著低于杜仲林斑块(图7)。

4种边缘类型中，旱柳林–杜仲林边缘的Margalef丰富度指数、Simpson指数最高，但Pielou均匀度指数和Shannon-Wiener多样性指数最低，表明旱柳林–杜仲林边缘的蛾类群落物种丰富度较大但优势类群较为集中，从而该群落呈现出了多样性降低的特点。旱柳林–杜仲林边缘与其余边缘相比存在优势物种较多的现象，本研究发现该物种为委夜蛾(*Athetis furvula*) (附录1)。

2.4　蛾类群落组成与植被特征因子关联性

不同斑块及边缘的温度不存在显著差异，且边缘温度的平均值均位于斑块之间或略高于斑块内

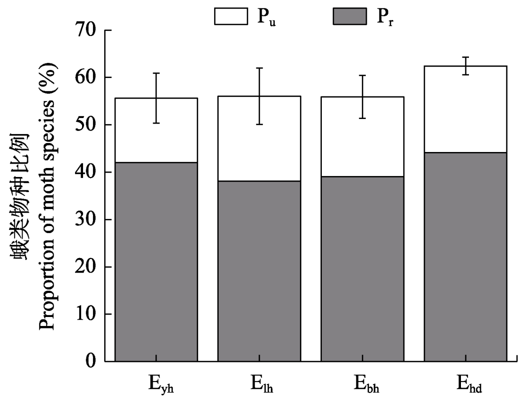

图6　人工林边缘类型蛾类物种占其所属样地物种数比例(平均值 ± SD)。P_u代表独有种比例; P_r为剩余物种比例。缩写含义见表1。

Fig. 6　Proportion of moth species of plantation edge types in the number of species in the plot (mean ± SD). P_u represents the proportion of unique species; P_r represents the proportion of the remaining species. The abbreviations see Table 1.

(图8a), 即边缘为蛾类提供了过渡温度(Pinksen et al, 2021)。边缘植被的平均高度均高于斑块内或位于中间, 但不同斑块内差异不显著; 在4种边缘类型中, 旱柳林–杜仲林边缘的植被平均高度(0.19 ± 0.07)最低, 但与其他边缘差异不显著。边缘的植被盖度大多位于斑块之间, 在不同斑块中差异显著; 在4种边缘类型中, 桧柏林–国槐林2边缘平均盖度最低(48.78 ± 29.18), 但与其他3类边缘均差异不显著(表1)。

蛾类Simpson指数与植被的平均高度和平均盖度呈显著负相关关系; 蛾类物种数与植被的平均高度和平均盖度呈显著正相关关系。除此之外, 蛾类Pielou均匀度指数与植被的平均高度呈显著正相关关系; Shannon-Wiener多样性指数、Margalef丰富度指数与植被的平均盖度呈显著正相关关系(图8c)。

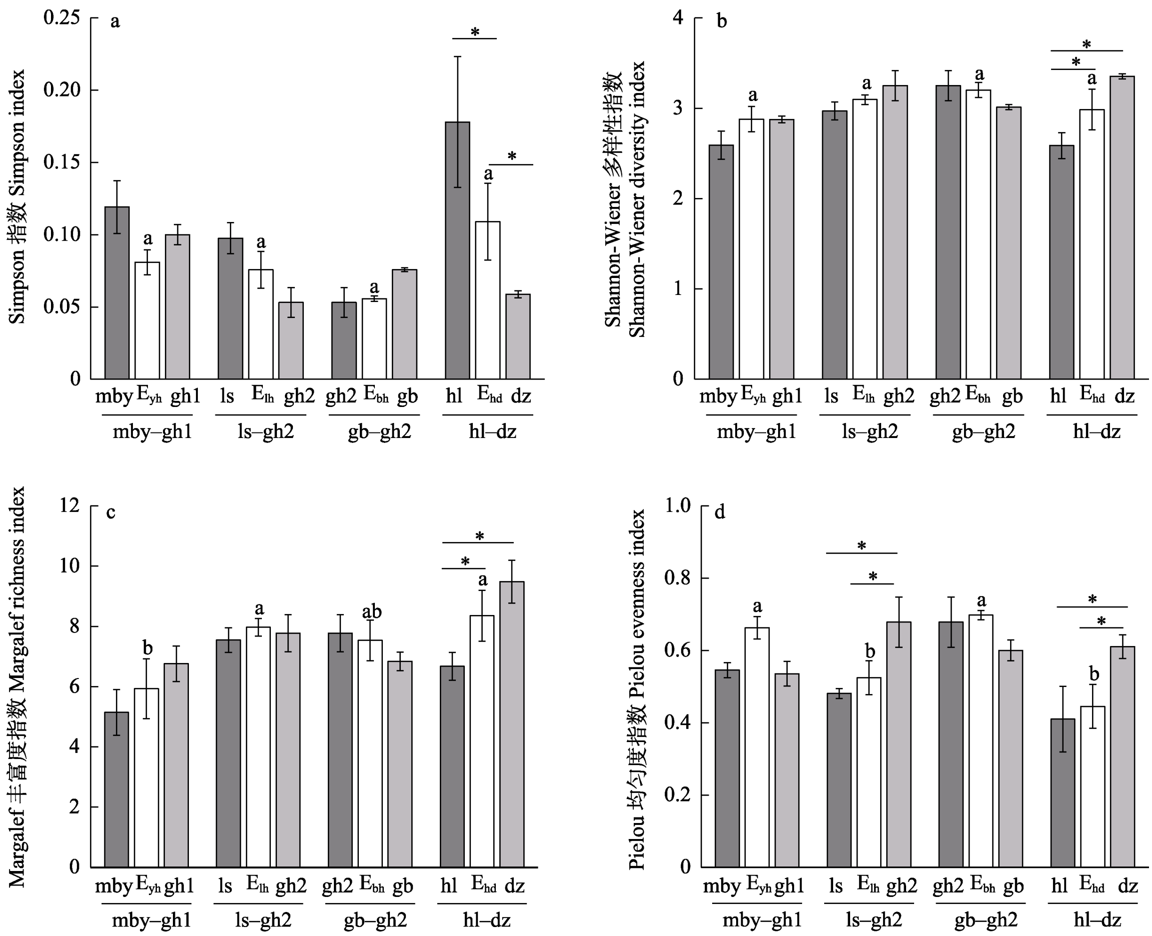

图7　人工林斑块及边缘物种多样性指数(平均值 ± SD)。*代表斑块与边缘间差异显著; 不同小写字母表示不同边缘间差异显著。缩写含义见表1。

Fig. 7　The species diversity index of plantation patches and edges (mean ± SD). * represents significant difference, different lowercase letters represent significant differences between different edges. The abbreviations see Table 1.

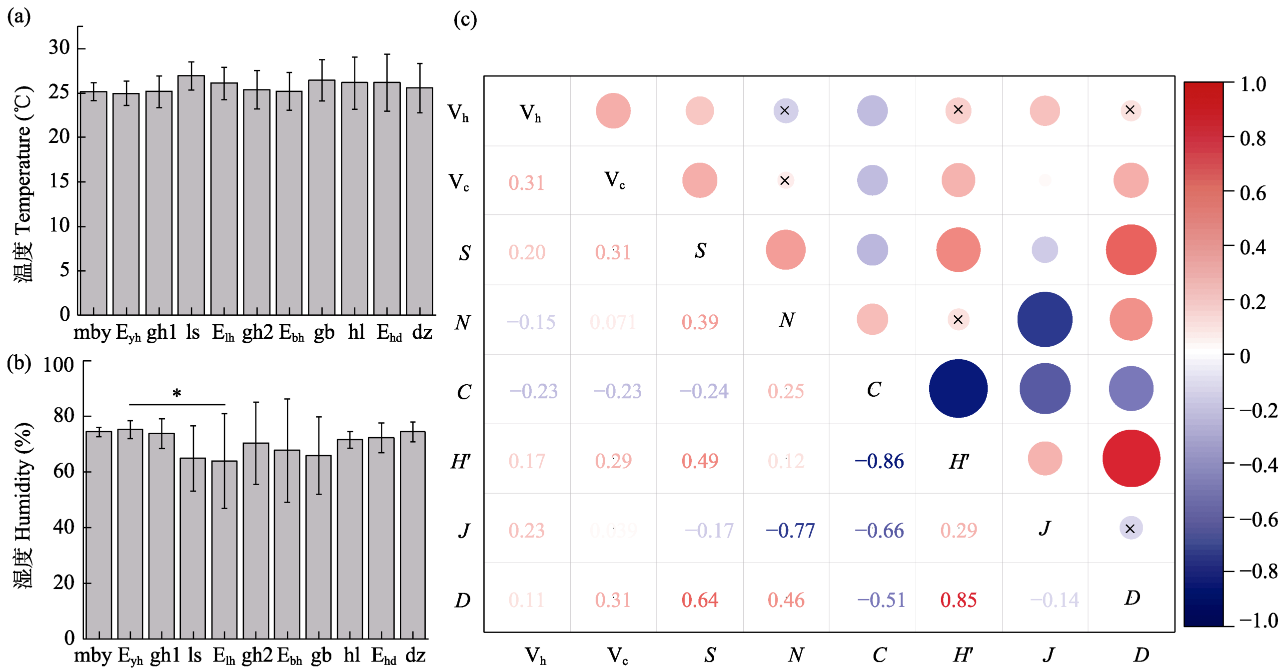

图8　蛾类特征指数与环境因子相关性分析。(a)温度(平均值 ± SD); (b)湿度(平均值 ± SD); (c)蛾类特征指数与植被特征因子相关性分析图，圆圈大小代表相关性强度，“×”表示不存在显著相关性。V_h: 林下植被平均高度; V_c: 林下植被平均盖度; *S*: 物种数; *N*: 个体数; *C*: Simpson指数; *H′*: Shannon-Wiener多样性指数; *J*: Pielou均匀度指数; *D*: Margalef丰富度指数。其余缩写含义见表1。

Fig. 8　Correlation analysis between moth characteristic index and environmental factors. (a) Temperature (mean ± SD); (b) Humidity (mean ± SD); (c) The plot of correlation analysis between moth characteristic index and vegetation characteristic factors. The circle size represents the correlation strength, “×” represents no significant correlation. V_h, Height of understory vegetation; V_c, Coverage of understory vegetation; *S*, Species numbers; *N*, Individuals; *C*, Simpson index; *H′*, Shannon-Wiener diversity index; *J*, Pielou evenness index; *D*, Margalef richness index. Other abbreviations see Table 1.

表3　不同人工林边缘类型的边缘效应指数

Table 3　Edge effect index of different plantation edge types. The abbreviations see Table 1.

边缘效应强度 Edge effect intensity	毛白杨林–国槐林1边缘 E_{yh}	栾树林–国槐林2边缘 E_{lh}	桧柏林–国槐林2边缘 E_{bh}	旱柳林–杜仲林边缘 E_{hd}
$I_{H'}$	1.102593793	1.078513732	1.105394079	1.080308277
Ic	0.862558656	0.854916806	0.771192529	0.915185808

2.5　边缘效应强度

不同边缘的边缘效应指数$I_{H'}$值均大于1，表明所选取的4种边缘类型均存在正向的边缘效应，即边缘的物种丰富度和多样性均大于相邻斑块。边缘效应指数I_C值的比较结果为旱柳林–杜仲林边缘 > 毛白杨林–国槐林1边缘 > 栾树林–国槐林2边缘 > 桧柏林–国槐林2边缘，表明旱柳林–杜仲林边缘效应强度最低(表3)。

3　讨论

边缘处于两种斑块的过渡地带，起到连通不同林分中生物的作用(Niemelä et al, 2007)。森林中存在部分主要植物物种，它们的出现会导致蛾类数量成倍的增加(Narango et al, 2020)，边缘会为这些植物提供生存地点，这可能与边缘存在一定的光照有关，该现象同样发生在纯林的林窗中(陈博等, 2021)。当前多数关于人工林多样性的研究发现，边缘植被多样性相对于林内更高(李新荣和Павлов, 1999; 于顺利等, 2000; 高俊峰和张芸香, 2005; 王德艺等, 2016)。边缘更加开阔多样的环境增加了植食性昆虫对植物的利用率，从而影响到昆虫群落(Altamirano et al, 2016)，例如访花昆虫(Korpela et al, 2015)以及刺吸式昆虫(de Araujo & do Espirito-Santo Filho, 2012)的增加。Pinksen等(2021)的研究发现，

在砍伐后的林地边缘蛾类的丰富度并没有显著增加，但出现了一定的独有种。本研究中采集到的大部分蛾类物种为人工林斑块与人工林斑块边缘共有，但边缘也存在一定的独有种，其个体数量、物种数量有时甚至大于斑块内，人工林斑块内的物种组成与边缘存在差异。边缘独有种占其斑块物种数的比例为16.7% ± 1.9%，且4种边缘类型之间差异不显著，表明不同的边缘类型虽独有种不同，但仍为其所属样地提供了新的多样性基础，在原有的斑块组成上，边缘的出现提高了其所属样地的生物多样性。

本研究中，不同类型的人工林斑块边缘的蛾类群落存在不同的特点。旱柳林–杜仲林边缘的蛾类物种数、个体数量均大于纯林斑块，且在4种边缘类型中最高；旱柳林–杜仲林边缘蛾类物种多样性指数和物种组成与纯林斑块内存在显著性差异，表明旱柳林–杜仲林边缘与其他3类边缘相比与纯林斑块的蛾类群落差异更大。4种边缘类型中，旱柳林–杜仲林边缘的Pielou均匀度指数最低但Simpson指数最高，与其他边缘相比其优势种更为集中，这表明旱柳林–杜仲林边缘造成了部分优势物种的增加从而导致其生物多样性降低。此外，旱柳林–杜仲林边缘的边缘效应强度最低，进一步表明其边缘的存在导致的生物多样性提升最低。人工林边缘的出现对昆虫多样性效益的提升及生态系统的稳定均起到了一定的正向作用，但同时也会带来优势物种暴发的风险。

影响蛾类物种组成的因素包括：寄主植物的密度(Luque et al, 2007)、冠层、林龄(Ober & Hayes, 2009)、植被密度(Highland et al, 2013)等。边缘环境与林分内部存在一定的差异，例如温度和光照的增加(Pinzon et al, 2021)等，且边缘的空旷性会导致蛾类更易被捕食者发现，这可能会给部分蛾类带来被捕食的危机(Zuk & Kolluru, 1998)，从而进一步影响蛾类群落分布。在本研究中，边缘的温度虽未与斑块内呈现明显的相关性，但大部分边缘温度仍处于相邻的纯林斑块之间，边缘在人工林生态系统中起到了一定的过渡作用。植被平均盖度在不同斑块内差异显著，且植被盖度与蛾类丰富度存在显著的正相关关系，相似的结论在甲虫类昆虫中也有体现(Magura, 2002; 刘继亮等, 2021)。本研究发现部分边缘的植被平均高度高于林地内部，表现出明显的边缘差异，且蛾类Simpson指数与植被高度呈显著的负相关关系，Pielou均匀度指数与植被高度存在显著的正相关关系，且旱柳林–杜仲林边缘的植被平均高度最低。部分研究发现某些寡食性蛾类幼虫的生长主要依赖寄主植物，与多食性蛾类相比，它们更喜欢高度较低的植被(Pöyry et al, 2006)。因此，在人工林林分管理上，适当减少林地杂草割除，保留一定的高植被，可防止寡食性蛾类的大幅度增加，这在一定程度上会提升其带来的生物多样性效益，更有利于当地生态系统的稳定。

边缘效应一直是生态学讨论研究的问题，本研究结果表明，斑块状人工林边缘的出现一定程度上提高了当地的蛾类物种多样性，但不同树种组合斑块的边缘效应所呈现的生物多样性特点不同，可能存在优势物种暴发的风险。在昆虫数量减少的大环境下(Hallmann et al, 2017)，如何恢复和提高人工林昆虫群落的多样性和稳定性成为一个值得考虑的问题。因此，选择适宜的块状组合林分，减少植被割除，保证一定的植被高度及盖度，避免单一物种的大量出现，从而进一步提高人工林生态系统的稳定性是以后森林管理中需要考虑的。

参考文献

Altamirano A, Valladares G, Kuzmanich N, Salvo A (2016) Galling insects in a fragmented forest: Incidence of habitat loss, edge effects and plant availability. Journal of Insect Conservation, 20, 119–127.

Brigić A, Starčević M, Hrašovec B, Elek Z (2014) Old forest edges may promote the distribution of forest species in carabid assemblages (Coleoptera: Carabidae) in Croatian forests. European Journal of Entomology, 111, 715–725.

Chaundy-Smart RFC, Smith SM, Malcolm JR, Bellocq MI (2012) Comparison of moth communities following clear-cutting and wildfire disturbance in the southern boreal forest. Forest Ecology and Management, 270, 273–281.

Chen B, Jiang L, Xie ZY, Li YD, Li JX, Li MJ, Wei CS, Xing C, Liu JF, He ZS (2021) Taxonomic and phylogenetic diversity of plants in a *Castanopsis kawakamii* natural forest. Biodiversity Science, 29, 439–448. (in Chinese with English abstract) [陈博, 江蓝, 谢子扬, 李阳娣, 李佳萱, 李梦佳, 魏晨思, 邢聪, 刘金福, 何中声 (2021) 格氏栲天然林林窗植物物种多样性与系统发育多样性. 生物多样性, 29, 439–448.]

de Araujo WS, do Espírito-Santo Filho K (2012) Edge effect benefits galling insects in the Brazilian Amazon.

Biodiversity and Conservation, 21, 2991–2997.

Diaz C, Maksuta D, Amarpuri G, Tanikawa A, Miyashita T, Dhinojwala A, Blackledge TA (2020) The moth specialist spider *Cyrtarachne akirai* uses prey scales to increase adhesion. Journal of the Royal Society Interface, 17, 20190792.

Faccoli M, Bernardinelli I (2014) Composition and elevation of spruce forests affect susceptibility to bark beetle attacks: Implications for forest management. Forests, 5, 88–102.

Feng X, Ma LY, Cai BJ, Duan J, Jia LM, Jia ZK, Wang JZ (2016) Effectiveness evaluation based on the afforestine construction in Beijing Plain. Journal of Northwest Forestry University, 31, 136–144. (in Chinese with English abstract) [冯雪, 马履一, 蔡宝军, 段劼, 贾黎明, 贾忠奎, 王金增 (2016) 北京平原百万亩造林工程建设效果评价研究. 西北林学院学报, 31, 136–144.]

Gao JF, Zhang YX (2005) Species diversity in overlapped zones of typical secondary forests in Guandishan Mountains. Acta Botanica Boreali-Occidentalia Sinica, 25, 2017–2023. (in Chinese with English abstract) [高俊峰, 张芸香 (2005) 关帝山次生林区典型森林交错带物种多样性研究. 西北植物学报, 25, 2017–2023.]

Guo XL, Zhang K, Zhou T, Hu Y, Sun XL, Li K (2022) Characteristics of moth community in different types of urban forest plantations in Beijing. Chinese Journal of Ecology, 41, 316–323. (in Chinese with English abstract) [郭欣乐, 张科, 周童, 胡阳, 孙秀玲, 李凯 (2022) 北京不同类型人工林中蛾类群落特征. 生态学杂志, 41, 316–323.]

Hallmann CA, Sorg M, Jongejans E, Siepel H, Hofland N, Schwan H, Stenmans W, Müller A, Sumser H, Hörren T, Goulson D, de Kroon H (2017) More than 75 percent decline over 27 years in total flying insect biomass in protected areas. PLoS ONE, 12, e0185809.

Hammer O, Harper DAT, Ryan PD (2001) PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica, 4, 1–9.

Highland SA, Miller JC, Jones JA (2013) Determinants of moth diversity and community in a temperate mountain landscape: Vegetation, topography, and seasonality. Ecosphere, 4, 1–22.

Holmes RT, Schultz JC, Nothnagle P (1979) Bird predation on forest insects: An exclosure experiment. Science, 206, 462–463.

Kitching RL, Orr AG, Thalib L, Mitchell H, Hopkins MS, Graham AW (2000) Moth assemblages as indicators of environmental quality in remnants of upland Australian rain forest. Journal of Applied Ecology, 37, 284–297.

Korpela EL, Hyvönen T, Kuussaari M (2015) Logging in boreal field-forest ecotones promotes flower-visiting insect diversity and modifies insect community composition. Insect Conservation and Diversity, 8, 152–162.

Li L (2020) Impacts of plain afforestation on forest landscape patterns in Beijing. Journal of Chinese Urban Forestry, 18(4), 5–10. (in Chinese with English abstract) [李利 (2020) 平原造林对北京森林景观格局的影响. 中国城市林业, 18(4), 5–10.]

Li XR, Павлов BH (1999) A study on composition structure and species diversity in ecotone of coniferous and broad-leaved forest in Russia plain. Chinese Biodiversity, 7, 291–296. (in Chinese with English abstract) [李新荣, Павлов BH (1999) 俄罗斯平原针-阔林过渡带森林群落组成结构与物种多样性的研究. 生物多样性, 7, 291–296.]

Liu JL, Ba YB, Niu RX, Li FR, Zhao WZ (2021) Ground beetle diversity and their value as bioindicators for desertification in a natural desert of the middle of the Hexi Corridor, Northwest China. Acta Ecologica Sinica, 41, 5435–5445. (in Chinese with English abstract) [刘继亮, 巴义彬, 牛瑞雪, 李锋瑞, 赵文智 (2021) 河西走廊天然固沙植被区地表甲虫多样性及其对沙漠化的指示作用. 生态学报, 41, 5435–5445.]

Luque C, Gers C, Lauga J, Mariano N, Wink M, Legal L (2007) Analysis of forestry impacts and biodiversity in two Pyrenean forests through a comparison of moth communities (Lepidoptera, Heterocera). Insect Science, 14, 323–338.

Magura T (2002) Carabids and forest edge: Spatial pattern and edge effect. Forest Ecology and Management, 157, 23–37.

Martínez-Falcon AP, Zurita GA, Ortega-Martínez IJ, Moreno CE (2018) Populations and assemblages living on the edge: Dung beetles responses to forests-pasture ecotones. PeerJ, 6, e6148.

Merckx T, Slade EM (2014) Macro-moth families differ in their attraction to light: Implications for light-trap monitoring programmes. Insect Conservation and Diversity, 7, 453–461.

Narango DL, Tallamy DW, Shropshire KJ (2020) Few keystone plant genera support the majority of Lepidoptera species. Nature Communications, 11, 5751.

Niemelä J, Koivula M, Kotze DJ (2007) The effects of forestry on carabid beetles (Coleoptera: Carabidae) in boreal forests. Journal of Insect Conservation, 11, 5–18.

Ober HK, Hayes JP (2010) Determinants of nocturnal Lepidopteran diversity and community structure in a conifer-dominated forest. Biodiversity and Conservation, 19, 761–774.

Pöyry J, Luoto M, Paukkunen J, Pykälä J, Raatikainen K, Kuussaari M (2006) Different responses of plants and herbivore insects to a gradient of vegetation height: An indicator of the vertebrate grazing intensity and successional age. Oikos, 115, 401–412.

Pinksen J, Moise ERD, Sircom J, Bowden JJ (2021) Living on the edge: Effects of clear-cut created ecotones on nocturnal macromoth assemblages in the eastern boreal forest, Canada. Forest Ecology and Management, 494, 119309.

Pinzon J, Dabros A, Riva F, Glasier JRN (2021) Short-term effects of wildfire in boreal peatlands: Does fire mitigate the linear footprint of oil and gas exploration? Ecological Applications, 31, e02281.

Ren XY, Pang Y, Wang M, Li GH, Wang YJ, Li JZ, Wang HB (2022) Analysis of moth diversity in oak forests, *Quercus variabilis* and *Q. mongolica* in northern China. Forest Research, 35(6), 143–150. (in Chinese with English abstract) [任雪毓, 庞岩, 王梅, 李国宏, 王艳军, 李建忠, 王鸿斌 (2022) 北方蒙古栎和栓皮栎林蛾类多样性比较分析. 林业科学研究, 35(6), 143–150.]

Summerville KS (2011) Managing the forest for more than the trees: Effects of experimental timber harvest on forest Lepidoptera. Ecological Applications, 21, 806–816.

Tian C, Yang XB, Liu Y (2011) Edge effect and its impacts on forest ecosystem: A review. Chinese Journal of Applied Ecology, 22, 2184–2192. (in Chinese with English abstract) [田超, 杨新兵, 刘阳 (2011) 边缘效应及其对森林生态系统影响的研究进展. 应用生态学报, 22, 2184–2192.]

Truxa C, Fiedler K (2012) Attraction to light—From how far do moths (Lepidoptera) return to weak artificial sources of light? European Journal of Entomology, 109, 77–84.

Wang BS, Peng SL (1986) Analysis on the forest communities of Dinghushan Guangdong. X. Communities edge effect. Acta Scientiarum Naturalium Universitatis Sunyatseni, 25(4), 31–38. (in Chinese with English abstract) [王伯荪, 彭少麟 (1986) 鼎湖山森林群落分析. X. 边缘效应. 中山大学学报(自然科学版), 25(4), 31–38.]

Wang DY, Hao JF, Li Y, Qi JQ, Pei ZL, Huang YJ, Jiang Q, Chen Y (2016) Examination of edge effects in a *Cryptomeria fortune* plantation in Zhougong Mountain, western Sichuan. Biodiversity Science, 24, 940–947. (in Chinese with English abstract) [王德艺, 郝建锋, 李艳, 齐锦秋, 裴曾莉, 黄雨佳, 蒋倩, 陈亚 (2016) 川西周公山柳杉人工林群落的边缘效应. 生物多样性, 24, 940–947.]

Wang YP, Wu H, Xu HC (2008) Biological and ecological bases of using insect as a bio-indicator to assess forest health. Chinese Journal of Applied Ecology, 19, 1625–1630. (in Chinese with English abstract) [王义平, 吴鸿, 徐华潮 (2008) 以昆虫作为指示生物评估森林健康的生物学与生态学基础. 应用生态学报, 19, 1625–1630.]

White PJT, Glover K, Stewart J, Rice A (2016) The technical and performance characteristics of a low-cost, simply constructed, black light moth trap. Journal of Insect Science, 16, iew011.

Yang GJ, Wang XP, Jia YX, Zhang DZ (2016) Diversity of darkling beetle community in the artificial cultivation *Caragana* intermedia shrub-desert grassland ecotone in Yanchi County, Ningxia, China. Acta Ecologica Sinica, 36, 608–619. (in Chinese with English abstract) [杨贵军, 王新谱, 贾彦霞, 张大治 (2016) 人工柠条-荒漠草地交错带拟步甲昆虫群落多样性. 生态学报, 36, 608–619.]

You WZ, Liu MG, Yun LL (2008) Analyse on soil improvement of different types of water and soil conservation forests mixed with *Pinus tabulaeformis* in semi-arid area of western Liaoning Province. Forestry Science & Technology, 33(5), 20–24. (in Chinese with English abstract) [尤文忠, 刘明国, 云丽丽 (2008) 辽西半干旱区不同类型油松水土保持林土壤改良效应分析. 林业科技, 33(5), 20–24.]

Yu SL, Liu CR, Ma KP (2000) A study on the ecotones between *Quercus mongolica* community and other communities. Chinese Biodiversity, 8, 277–283. (in Chinese with English abstract) [于顺利, 刘灿然, 马克平 (2000) 蒙古栎群落交错带(ecotone)的研究. 生物多样性, 8, 277–283.]

Zuk M, Kolluru GR (1998) Exploitation of sexual signals by predators and parasitoids. The Quarterly Review of Biology, 73, 415–438.

(责任编委: 朱朝东　责任编辑: 黄祥忠)

附录　Supplementary Material

附录1　人工林斑块及边缘蛾类物种原始采集记录表

Appendix 1　Table for original collection records of moth species in plantation patches and edges

https://www.biodiversity-science.net/fileup/PDF/2023074-1.pdf

段曼微，李香，周阳，赵敏欣，孙秀玲，韩冰，张刚，权子豪，李凯 (2023) 基于蛾类多样性研究人工林斑块的边缘效应. 生物多样性, 31, 23074. https://www.biodiversity-science.net/CN/10.17520/biods.2023074.

附录1　人工林斑块及边缘蛾类物种原始采集记录表

Appendix 1　Table for original collection records of moth species in plantation patches and edges

物种 Species	毛白杨林 *Populus tomentosa* forest	毛白杨林– 国槐林 1 边缘 Edge of *Populus tomentosa* forest & *Styphnolobium japonicum* forest 1	国槐林 1 *Styphnolobium japonicum* forest 1	栾树林 *Koelreuteria paniculata* forest	栾树林–国槐林 2 边缘 Edge of *Koelreuteria paniculata* forest & *Styphnolobium japonicum* forest 2	国槐林 2 *Styphnolobium japonicum* forest 2	桧柏林–国槐林 2 边缘 Edge of *Juniperus chinensis* forest & *Styphnolobium japonicum* forest 2	桧柏林 *Juniperus chinensis* forest	旱柳林 *Salix matsudana* forest	旱柳林–杜仲林边缘 Edge of *Salix matsudana* forest & *Eucommia ulmoides* forest	杜仲林 *Eucommia ulmoides* forest
小菜蛾 *Plutella xylostella*	12	6	15	23	26	18	26	47	9	18	15
含羞草雕蛾 *Homadaula anisocentra*	1	0	0	0	0	0	0	0	0	0	2
国槐尺蛾 *Semiothisa cinerearia*	15	16	23	32	31	38	25	12	7	22	12
丝绵木金星尺蛾 *Calospilos suspecta*	47	31	91	30	30	26	19	2	0	1	1
大造桥虫 *Ascotis selenaria*	1	2	3	5	8	12	16	3	1	3	1
刺槐外斑尺蛾 *ctropis excellens*	0	0	1	3	7	1	6	1	1	0	2
小红姬尺蛾 *Idaea muricata*	0	1	1	0	5	3	0	0	3	2	2
泛尺蛾 *Orthonama obstipata*	1	1	2	5	1	0	4	4	1	1	1
上海枝尺蛾 *Macaria shanghaisaria*	0	0	0	0	1	0	0	0	0	0	0
桑尺蛾 *Phthonandria atrilineata*	0	0	0	0	0	0	1	0	0	0	0
格庶尺蛾 *Semiothisa hebesata*	2	1	0	2	0	1	0	0	0	0	0
紫条尺蛾 *Timandra recompta*	0	0	1	2	1	3	0	1	0	0	0
曲紫线尺蛾 *Timandra comptaria*	2	0	0	0	1	0	0	0	0	0	0
黄双线尺蛾 *Syrrhodia perlutea*	0	0	0	0	2	0	0	0	0	1	0
小黑袋蛾 *Psyche* sp.	0	0	0	0	0	0	0	1	0	0	0
尖瓣灰纹卷蛾 *Cochylidia richteriana*	0	0	0	1	1	1	1	5	0	1	6
草小卷蛾 *Celypha flavipalpana*	1	3	2	5	5	6	3	0	1	1	0
杨柳小卷蛾 *Gypsonoma minutana*	1	13	1	2	8	6	3	6	16	16	1
植黑小卷蛾 *Endothenia gentiana*	1	4	3	0	9	1	2	1	2	0	2
白钩小卷蛾 *Epiblema foenella*	1	1	2	3	1	4	1	2	2	2	2
隐黄卷蛾 *Archips arcanus*	0	0	0	6	0	0	0	0	0	1	3
顶梢小卷蛾 *Laspeyresia pseudonectis*	0	0	0	0	0	3	0	0	0	0	0
棉双斜卷蛾 *Clepsis pallidana*	0	0	0	0	0	2	0	0	0	0	1
豌豆镰翅小卷蛾 *Ancylis badiana*	0	0	0	0	0	0	0	0	0	0	1
细尖蛾 *Cosmopterix gracilis*	0	0	0	0	0	0	0	0	0	0	1
黑白间蛾 *Labdia niphosticta*	0	0	0	5	4	9	4	6	0	2	0
四点绢蛾 *Scythris sinensis*	0	1	0	3	5	1	0	0	0	0	0
和列蛾 *Autosticha modicella*	0	1	0	2	0	1	0	0	1	1	0

物种 Species	毛白杨林 *Populus tomentosa* forest	毛白杨林– 国槐林 1 边缘 Edge of *Populus tomentosa* forest & *Styphnolobium japonicum* forest 1	国槐林 1 *Styphnolobium japonicum* forest 1	栾树林 *Koelreuteria paniculata* forest	栾树林–国槐林 2 边缘 Edge of *Koelreuteria paniculata* forest & *Styphnolobium japonicum* forest 2	国槐林 2 *Styphnolobium japonicum* forest 2	桧柏林–国槐林 2 边缘 Edge of *Juniperus chinensis* forest & *Styphnolobium japonicum* forest 2	桧柏林 *Juniperus chinensis* forest	旱柳林 *Salix matsudana* forest	旱柳林–杜仲林边缘 Edge of *Salix matsudana* forest & *Eucommia ulmoides* forest	杜仲林 *Eucommia ulmoides* forest
绣线菊麦蛾 *Athrips spiraeae*	7	5	8	13	10	2	2	5	22	4	4
麦蛾 *Sitotroga cerealella*	0	0	0	3	0	0	1	1	3	4	0
甘薯麦蛾 *Brachmia macroscopa*	0	0	1	1	1	0	2	0	3	5	6
鸡血藤棕麦蛾 *Dichomeris oceanis*	0	0	0	0	1	0	0	0	0	0	0
旋纹潜蛾 *Leucoptera scitella*	0	0	0	0	1	0	1	7	0	0	2
百花翼蛾 *Alucita baihua*	0	0	0	0	0	0	0	0	0	0	1
桃展足蛾 *Stathmopoda auriferella*	0	1	0	1	4	0	1	4	3	0	3
双线织蛾 *Promalactis* sp.	1	2	5	13	7	16	14	13	18	23	7
梅祝蛾 *Scythropiodes issikii*	0	1	0	1	0	1	0	0	0	0	0
四斑绢野螟 *Diaphania quadrimaculalis*	0	0	0	0	0	0	0	0	1	1	0
菜螟 *Hellula undalis*	2	10	7	5	11	5	5	4	5	17	9
台湾绢丝野螟 *Glyphodes formosanus*	0	0	3	3	0	1	2	0	0	2	0
稻筒水螟 *Parapoynx vittalis*	0	0	0	1	0	1	1	0	0	1	0
黄杨绢野螟 *Diaphania perspectalis*	0	1	0	0	0	0	0	0	0	0	0
长须曲角水螟 *Camptomastix hisbonalis*	0	2	0	0	2	2	0	0	0	0	2
乌苏里褶缘野螟 *Paratalanta ussurialis*	0	0	0	1	0	0	0	0	0	1	0
草地螟 *Margaritia sticticalis*	0	0	0	1	1	0	0	0	0	0	0
黄翅缀叶野螟 *Botyodes diniasalis*	0	0	0	0	1	0	0	0	0	1	0
桑绢野螟 *Diaphania pyloalis*	0	0	0	0	0	0	0	0	0	0	1
棉褐环野螟 *Haritalodes derogata*	0	0	0	0	0	0	0	0	0	0	1
玉米螟 *Ostrinia nubilalis*	1	0	0	0	0	0	0	0	6	2	0
款冬玉米螟 *Ostrinia scapulalis*	0	1	7	3	6	4	3	2	3	7	6
细条纹野螟 *Tabidia strigiferalis*	0	0	0	0	1	0	0	0	2	0	2
三角夜斑螟 *Nyctegretis triangulella*	0	0	0	3	5	0	0	2	5	7	10
二点织螟 *Aphomia zelleri*	2	15	15	8	16	6	7	5	3	1	4
蔗茎禾草螟 *Chilo sacchariphagus*	0	0	3	2	2	2	0	3	1	2	6
红云翅斑螟 *Oncocera semirubella*	0	0	0	1	0	1	0	1	0	3	4
元参棘趾野螟 *Anania verbascalis*	0	1	1	4	2	3	0	0	0	3	2
麦牧野螟 *Nomophila noctuella*	0	3	0	1	1	0	5	3	0	4	3
小瘿斑螟 *Pempelia ellenella*	5	0	2	3	0	5	1	1	0	4	2

段曼微，李香，周阳，赵敏欣，孙秀玲，韩冰，张刚，权子豪，李凯 (2023) 基于蛾类多样性研究人工林斑块的边缘效应. 生物多样性, 31, 23074. https://www.biodiversity-science.net/CN/10.17520/biods.2023074.

物种 Species	毛白杨林 *Populus tomentosa* forest	毛白杨林– 国槐林 1 边缘 Edge of *Populus tomentosa* forest & *Styphnolobium japonicum* forest 1	国槐林 1 *Styphnolobium japonicum* forest 1	栾树林 *Koelreuteria paniculata* forest	栾树林–国槐林 2 边缘 Edge of *Koelreuteria paniculata* forest & *Styphnolobium japonicum* forest 2	国槐林 2 *Styphnolobium japonicum* forest 2	桧柏林–国槐林 2 边缘 Edge of *Juniperus chinensis* forest & *Styphnolobium japonicum* forest 2	桧柏林 *Juniperus chinensis* forest	旱柳林 *Salix matsudana* forest	旱柳林–杜仲林边缘 Edge of *Salix matsudana* forest & *Eucommia ulmoides* forest	杜仲林 *Eucommia ulmoides* forest
库氏岐角螟 *Endotricha kuznetzovi*	4	4	12	51	55	32	9	3	1	3	9
揽绿岐角螟 *Endotricha olivacealis*	0	0	0	0	6	0	1	0	0	1	1
豆荚野螟 *Maruca vitrata*	1	0	0	0	1	0	1	0	1	1	0
拟紫斑谷螟 *Pyralis lienigialis*	0	0	0	0	0	2	0	0	0	0	0
巴塘暗斑螟 *Euzophera batangensis*	0	0	1	4	1	1	0	3	1	0	0
泰山簇斑螟 *Psorosa taishanella*	0	1	0	4	0	0	2	0	0	2	0
灰直纹螟 *Orthopygia glaucinalis*	2	1	5	0	1	0	0	0	0	0	1
白点暗野螟 *Bradina atopalis*	0	1	9	6	5	4	4	2	0	1	1
双线云斑螟 *Nephopterix bilineatella*	1	0	0	6	1	0	2	0	5	14	5
大豆网丛螟 *Teliphasa elegans*	0	1	0	0	0	0	0	0	0	0	0
微红梢斑螟 *Dioryctria rubella*	0	0	1	0	0	1	0	0	2	1	1
纯白草螟 *Pseudocatharylla simplex*	0	0	0	0	0	1	0	1	0	0	0
桃蛀螟 *Dichocrocis punctiferalis*	0	0	0	0	0	0	1	1	1	1	0
葡萄切叶野螟 *Herpetogramma luctuosalis*	0	0	2	0	1	0	0	0	0	0	1
黄纹髓草螟 *Calamotropha paludella*	0	1	1	3	1	2	1	11	0	1	1
胡枝子小羽蛾 *Fuscoptilia emarginata*	0	1	0	0	2	0	0	2	0	0	2
背斑长角蛾 *Nemophora dorsigutellus*	0	0	0	0	0	0	1	0	0	0	0
柳丽细蛾 *Caloptilia chrysolampra*	0	0	0	0	0	0	0	0	0	4	2
美国白蛾 *Hyphantria cunea*	0	2	2	2	0	1	1	0	2	1	0
戟盗毒蛾 *Porthesia kurosawai*	0	0	1	1	2	0	0	0	1	0	0
粉缘钻夜蛾 *Earias pudicana*	0	0	1	0	1	0	1	0	7	18	12
小地老虎 *Agrotis ipsilon*	4	6	8	3	9	10	12	42	2	12	9
八字地老虎 *Xestia cnigrum*	30	22	24	34	28	15	11	18	9	16	11
乏夜蛾 *Niphonyx segregata*	6	2	6	6	9	3	4	16	10	12	9
朽木夜蛾 *Axylia putris*	3	1	0	0	1	0	0	2	7	4	3
二点委夜蛾 *Athetis lepigone*	8	5	11	3	5	6	7	3	1	0	4
委夜蛾 *Athetis furvula*	76	42	22	148	94	30	23	26	151	167	62
甜菜夜蛾 *Spodoptera exigua*	1	0	3	13	7	2	1	0	3	11	5
谐夜蛾 *Emmelia trabealis*	0	0	0	0	0	0	0	1	0	1	2
栎光裳夜蛾 *Ephesia dissimilis*	2	5	3	6	3	2	4	7	4	11	3

物种 Species	毛白杨林 *Populus tomentosa* forest	毛白杨林– 国槐林 1 边缘 Edge of *Populus tomentosa* forest & *Styphnolobium japonicum* forest 1	国槐林 1 *Styphnolobium japonicum* forest 1	栾树林 *Koelreuteria paniculata* forest	栾树林–国槐林 2 边缘 Edge of *Koelreuteria paniculata* forest & *Styphnolobium japonicum* forest 2	国槐林 2 *Styphnolobium japonicum* forest 2	桧柏林–国槐林 2 边缘 Edge of *Juniperus chinensis* forest & *Styphnolobium japonicum* forest 2	桧柏林 *Juniperus chinensis* forest	旱柳林 *Salix matsudana* forest	旱柳林–杜仲林边缘 Edge of *Salix matsudana* forest & *Eucommia ulmoides* forest	杜仲林 *Eucommia ulmoides* forest
梨纹剑夜蛾 *Acronicta rumicis*	1	0	0	0	0	0	1	1	0	2	3
瘦银锭夜蛾 *Macdunnoughia confusa*	0	0	0	2	0	0	1	0	1	3	0
小文夜蛾 *Eustrotia noloides*	4	1	7	6	1	2	4	5	1	1	1
窄肾长须夜蛾 *Herminia satakei*	7	1	4	11	10	10	5	13	4	17	10
红粘夜蛾 *Mythimna rufipennis*	0	0	0	0	0	0	0	0	1	0	0
亚皮夜蛾 *Nycteola asiatica*	1	0	1	1	2	1	0	0	0	2	2
粘虫 *Mythimna separata*	4	1	0	1	1	1	1	1	0	0	1
棉铃虫 *Helicoverpa armigera*	0	0	1	0	1	1	1	0	0	0	1
标瑙夜蛾 *Maliattha signifera*	26	14	17	36	44	17	11	56	22	57	42
黑点贪夜蛾 *Simplicia rectalis*	0	0	0	1	0	0	0	0	1	0	0
白肾俚夜蛾 *Deltote martjanovi*	0	0	0	0	0	0	1	0	0	0	1
甘蓝夜蛾 *Mamestra brassicae*	5	4	3	2	4	1	0	3	5	10	1
隐金夜蛾 *Abrostola triplasia*	0	0	0	0	2	0	1	0	0	0	0
双带夜蛾 *Naranga aenescens*	0	0	0	0	0	0	0	3	0	1	0
波莽夜蛾 *Raphia peusteria*	0	0	0	0	0	0	2	0	0	3	2
淡剑贪夜蛾 *Spodoptera depravata*	3	3	10	9	8	6	6	5	10	16	20
兀鲁夜蛾 *Xestia ditrapezium*	0	0	0	0	0	0	0	0	0	0	1
涓夜蛾 *Rivula sericealis*	0	0	0	0	2	0	0	0	0	0	1
姬夜蛾 *Phyllophila obliterata*	0	1	1	0	0	1	0	0	0	0	0
角翅舟蛾 *Gonoclostera timoniorum*	0	0	0	0	0	1	0	0	1	1	0
杨扇舟蛾 *Clostera anachoreta*	0	2	0	1	1	3	1	0	2	12	6
杨小舟蛾 *Micromelalopha troglodyta*	6	3	1	0	0	0	1	0	0	1	0
榆白边舟蛾 *Nerice davidi*	0	0	1	0	0	0	0	0	0	0	0
尺蛾科未定种 1 Unknown Geometridae 1	0	0	0	0	0	0	0	0	0	0	4
尺蛾科未定种 2 Unknown Geometridae 2	0	0	0	0	0	1	0	0	0	0	0
夜蛾科未定种 1 Unknown Noctuidae 1	0	0	0	0	0	0	0	1	0	0	0
夜蛾科未定种 2 Unknown Noctuidae 2	0	0	0	8	7	0	0	0	4	3	6
夜蛾科未定种 3 Unknown Noctuidae 3	0	0	0	0	0	3	1	0	1	7	3
夜蛾科未定种 4 Unknown Noctuidae 4	0	0	0	0	0	0	0	0	1	0	0
夜蛾科未定种 5 Unknown Noctuidae 5	0	0	0	0	0	0	0	0	2	5	1

段曼微, 李香, 周阳, 赵敏欣, 孙秀玲, 韩冰, 张刚, 权子豪, 李凯 (2023) 基于蛾类多样性研究人工林斑块的边缘效应. 生物多样性, 31, 23074. https://www.biodiversity-science.net/CN/10.17520/biods.2023074.

物种 Species	毛白杨林 *Populus tomentosa* forest	毛白杨林– 国槐林 1 边缘 Edge of *Populus tomentosa* forest & *Styphnolobium japonicum* forest 1	国槐林 1 *Styphnolobium japonicum* forest 1	栾树林 *Koelreuteria paniculata* forest	栾树林–国槐林 2 边缘 Edge of *Koelreuteria paniculata* forest & *Styphnolobium japonicum* forest 2	国槐林 2 *Styphnolobium japonicum* forest 2	桧柏林–国槐林 2 边缘 Edge of *Juniperus chinensis* forest & *Styphnolobium japonicum* forest 2	桧柏林 *Juniperus chinensis* forest	旱柳林 *Salix matsudana* forest	旱柳林–杜仲林边缘 Edge of *Salix matsudana* forest & *Eucommia ulmoides* forest	杜仲林 *Eucommia ulmoides* forest
夜蛾科未定种 6 Unknown Noctuidae 6	0	0	0	0	0	1	0	0	0	0	0
夜蛾科未定种 7 Unknown Noctuidae 7	0	1	1	0	0	1	2	0	0	0	0
夜蛾科未定种 8 Unknown Noctuidae 8	0	0	0	6	1	4	0	0	0	0	0
夜蛾科未定种 9 Unknown Noctuidae 9	0	0	0	2	0	0	0	0	0	0	0
细蛾科未定种 1 Unknown Gracillariidae 1	0	0	0	1	0	0	0	0	0	3	0
细蛾科未定种 2 Unknown Gracillariidae 2	0	0	0	2	0	0	0	0	0	0	0
细蛾科未定种 3 Unknown Gracillariidae 3	0	0	0	0	0	0	0	0	0	1	0
螟蛾科未定种 1 Unknown Pyralidae 1	0	0	0	0	0	0	0	1	0	0	0
螟蛾科未定种 2 Unknown Pyralidae 2	0	0	0	1	0	0	0	0	0	0	1
螟蛾科未定种 3 Unknown Pyralidae 3	0	1	0	0	0	0	0	1	0	0	1
螟蛾科未定种 4 Unknown Pyralidae 4	5	0	0	0	0	0	1	0	0	0	0
螟蛾科未定种 5 Unknown Pyralidae 5	0	0	0	0	0	0	0	0	1	0	0
螟蛾科未定种 6 Unknown Pyralidae 6	0	0	0	0	0	0	0	0	1	0	0
螟蛾科未定种 7 Unknown Pyralidae 7	0	0	0	0	0	0	0	0	0	1	0
螟蛾科未定种 8 Unknown Pyralidae 8	0	0	0	0	0	0	0	0	0	0	2
螟蛾科未定种 9 Unknown Pyralidae 9	0	0	0	0	1	6	0	0	0	0	4
螟蛾科未定种 10 Unknown Pyralidae 10	0	0	0	0	0	2	0	0	0	0	0
螟蛾科未定种 11 Unknown Pyralidae 11	0	0	0	0	0	0	0	0	0	2	0
螟蛾科未定种 12 Unknown Pyralidae 12	0	0	0	0	0	0	0	0	0	1	0
微蛾科未定种 1 Unknown Nepticulidae 1	0	1	0	0	0	0	0	0	0	0	0
卷蛾科未定种 1 Unknown Tortricidae 1	0	0	0	0	0	0	0	0	0	1	0
卷蛾科未定种 2 Unknown Tortricidae 2	0	0	0	0	0	0	5	6	1	0	0
卷蛾科未定种 3 Unknown Tortricidae 3	0	0	0	0	0	7	1	3	0	0	0
草螟科未定种 1 Unknown Crambidae 1	0	0	0	0	0	0	0	0	0	1	0
麦蛾科未定种 1 Unknown Gelechiidae 1	0	0	0	1	1	0	0	0	0	0	0
麦蛾科未定种 2 Unknown Gelechiidae 2	0	0	1	0	0	0	0	0	0	0	0