城市闲置地块的生态自我修复特征研究
——以北京林业大学校园为例
The Characteristics of Ecological Self-restoration in Urban Idle Lands: A Case Study of Beijing Forestry University

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摘要

疏于人工管理的城市闲置用地会自发生长出一些植物，混杂无序的生长状态形成荒野自然景观。在荒野状态下自然生长的植被特征最能反映生态自我修复发生的特征。本文对北京林业大学校园一处闲置用地内的自生植被进行了研究，调查分析其生成变化特征、植物种类、优势植物群落、生长条件及周边同种成株的情况，探讨了城市闲置地生态自我修复的初始特征。结果表明，闲置场地封闭管理后，自生植物很快出现，3年后自生植被覆盖了场地近1/3的面积；自生植物绝大多数为乡土植物，草本植物种类多于木本植物；在优势植物群落的构成中木本植物群落和草本植物群落数量相差不大；场地日照充分的情况下，土壤条件的差异对草本植物和木本植物的分布有着明显的影响。研究认为，即便是在生长条件极差的城市环境中，只要停止或降低人为干扰，且具备植物生长的最基本条件（光照、土壤、种源），生态自我修复的现象就能迅速发生；在生态自我修复的初始阶段，乡土植物种类具有明显优势；迅速出现的以乡土乔木为建群种的木本植物群落，提示了城市环境中乡土木本植物的自生现象值得关注和深入研究。

关键词
生态修复；自生植物；荒野景观；城市闲置地；乡土植物

ABSTRACT
Natural plants would see a free growth in an idle land after an absence of management, leading to spontaneous biological processes that form the wildscape. Such vegetation demonstrates the characteristics of the ecological self-restoration. This paper studies the spontaneous species found on a site in Beijing Forestry University, inventories and analyzes the species, site conditions, possible maternal plants of them, and discusses the changes and characteristics of the community in its early establishment. The results show that several spontaneous plants sprout early, and cover nearly 1/3 of the site 3 years later. Most of spontaneous plant species are native, more of which are herbaceous, while little difference is found between the number of woody communities and that of herbaceous communities. Their distribution is obviously affected by soil conditions when the light is sufficient. This paper concludes that once the human disturbances are stopped or reduced, ecological self-restoration can occur rapidly with essential conditions for growth (light, soils, and seed sources), even poor as urban environment. At the early stage of ecological self-restoration, native plant species dominate obviously. It is worthy of attention to and further study on the spontaneous native woody communities as they emerge rapidly.

KEYWORDS
Ecological Restoration; Spontaneous Plant; Wildscape; Urban Idle Land; Native Plants

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1 引言

荒野不仅在西方有着深厚的历史文化内涵，也与中国传统的“天人合一”的自然观密切相关[1][2]，规划设计领域对于“荒野之美”的肯定之声越来越高[3][4]。因其在维护城市栖息地和丰富城市生物多样性方面具有重要作用，荒野对于城市生态系统提升具有积极意义[5][6]。场地由于闲置而长期无人管理会呈现出自然动植物混杂无序生长状态，出现自发的生物活动和演替过程[7]，这种生态自我修复会形成荒野自然景观。

在城市建设过程中，土地闲置现象时有发生，在闲置地块中会自发生长出一些植物。这些自生植物在景观管理上常被认为是杂草，不仅有损城市环境品质，也为景观养护管理带来了诸多问题。但近年来的研究推动了公众对自生植物的观念改变：自生植物的养护管理需求较低，且能够提供野生动物栖息地、提升城市景观的生态系统服务[8][9]，对于建设资源节约型城市、维持城市可持续发展有着重要意义。越来越多的研究开始关注各种城市环境条件下自生植物的物种组成[10]~[14]、观赏特征[11][12]、生长规律[12]和设计实践的可能性[10][12][14]。自生植物的多样性水平在不同绿地类型间存在差异，防护绿地和荒废地中的自生草本植物多样性要高于附属绿地和公园绿地[15]。这表明人类管理行为与自生植物的生长有着直接关系。而城市闲置地常由于缺乏管理会被自发生长出的植物覆盖，以较高的植物多样性水平在保护生物多样性方面发挥积极的作用[16]。但是，目前对于城市闲置地中自生植物生长的状态和基本规律，特别是对于没有人类管理行为的情况下发生的生态自我修复机制研究不足。本文以北京林业大学校园内的一处闲置地块为研究对象，调查其中的自生植物种类、生长条件和周边同种成株植物，分析植被生成的时空特征、植物群落特征及环境因子和种源条件的影响，以期深入了解闲置地中生态自我修复发生的初始现象和特征，为相关研究提供参考。

2 研究对象和方法

2.1 研究对象

研究场地位于北京林业大学校园内，属于待建设用地，计划用于建设教学办公建筑。在进行了场地清理后，由于建设计划搁置，场地暂时处于无人管理的闲置状态。在此期间，场地在无人类扰动的状态下很快发生了生态自我修复现象，出现了众多自生植物。因此选择该地块作为研究对象，研究城市闲置地块的生态自我修复发生的初始现象和特征。

1 Introduction

Wilderness is not only a profound cultural notion in the western world but also a correlate of the “harmony of man with nature” in Chinese traditional ideology[1][2], and the beauty of wilderness has been increasingly recognized in the field of planning and design[3][4]. Due to the important role it plays in maintaining urban habitats and enhancing urban biodiversity, wilderness is of positive significance to the improvement of urban ecosystems[5][6]. Natural plant and animal communities would see a free growth in an idle land after a long-time absence of management, leading to spontaneous biological processes and natural succession[7]. Such an ecological self-restoration will form the wildscape.

Idle lands are commonly found during urban construction, where plants sprout spontaneously. Such plants are often regarded as weeds unfavorable to both urban environmental management and landscape maintenance. However, recent studies on spontaneous plants have helped change the public’s view: They are an asset to sustainable city construction and development due to the low demand in maintenance and management and the delivered ecosystem services such as providing wildlife habitats and improving urban landscapes[8][9]. There are studies on the species composition[10]~[14], landscape characteristics[11][12], growth pattern[12], and design feasibility[10][12][14] of spontaneous plants under different urban environmental conditions. The richness of spontaneous plants varies between land uses (e.g., that in green buffers and wastelands is higher than in attached green spaces and parks[15]), revealing the direct influence of human management on the growth of spontaneous plants. Due to the absence of human management, the high plant diversity in urban idle lands contributes to the city’s biodiversity conservation[16]. However, research on the growth condition and pattern of spontaneous plants, especially the mechanism of ecological self-restoration without human interventions, is not yet sufficient. This paper attempts to inventory the species, site conditions, and possible maternal plants of the spontaneous plants found on a site in Beijing Forestry University, and analyze the changes and characteristics of the community in its early establishment, as well as the influence of abiotic factors and seed sources, hoping to enrich the case studies of associated research.

2 Study Area and Research Methods

2.1 Study Area

The study area, located in the campus of Beijing Forestry University, is to be constructed for a building for teaching and administration. Due to the halt of the construction, the site was temporarily idle without any management after demolition, when ecological self-restoration quickly occurred and spontaneous plants diversely appeared. It was therefore chosen as a sample where the characteristics of the early stage of ecological self-restoration in urban idle lands are studied.

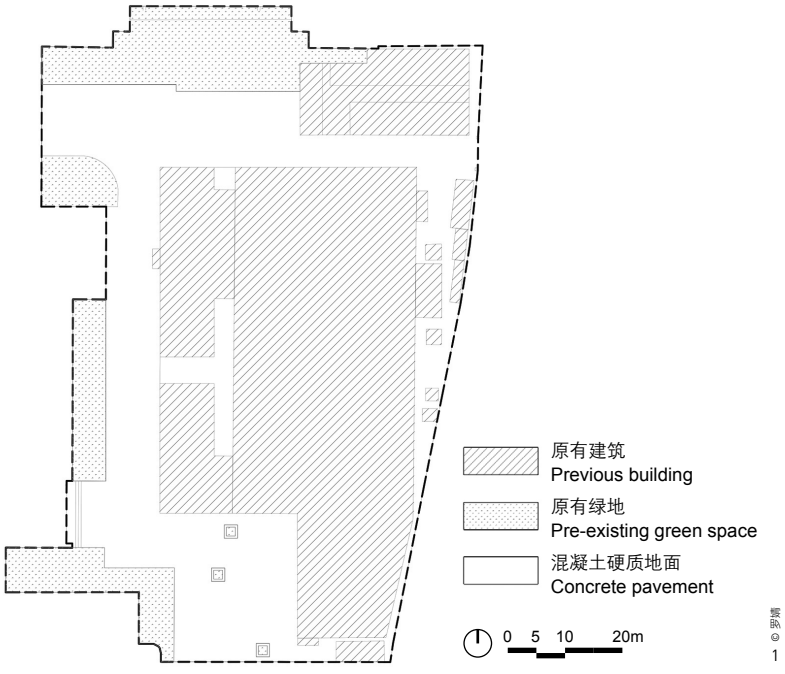

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表1：卫星影像资料
Table 1: Information of satellite images

影像采集日期 Acquisition date	图像分辨率 Spatial resolution
2017年8月23日 August 23, 2017	0.23 m × 0.23 m
2018年6月1日 June 1, 2018	0.11 m × 0.11 m
2018年8月23日 August 23, 2018	0.11 m × 0.11 m
2019年6月14日 June 14, 2019	0.11 m × 0.11 m
2019年9月22日 September 22, 2019	0.11 m × 0.11 m
2020年8月28日 August 28, 2020	0.11 m × 0.11 m

1. 场地平面图
2. 场地历年卫星影像图（来源：Google Earth）
3. 场地植被分布示意图

1. Site plan
2. Satellite images of the site in different years (Source: Google Earth)
3. Vegetation distribution on the site

场地总面积7 657.3m^2，其中混凝土硬质地面面积约2 774.6m^2；场地上原来建有临时建筑作为学生餐厅使用（占地面积3 696.4m^2），其地上建筑部分于2017年8月拆除，依然留有地面铺装（室内地板砖），透水透气性差，只在建筑墙体破拆处和混凝土地面间隙处存有土壤；绿地面积仅1 186.3m^2，土壤条件较好，适于植被生长。场地自拆建之日起建起围墙实行封闭管理，截至2021年3月底一直闲置，没有实施新的建设活动，场地内除堆积杂物外无任何养护管理行为发生（图1）。

2.2 研究方法

2.2.1 卫星影像分析

研究采用卫星影像分析场地植被分布及生长变化特征。卫星影像采用Google Earth全色历史卫星影像，使用BIGEMAP地图下载器下载，具体参数如表1所示。

2.2.2 现场踏查

研究采用现场踏查的方法于2020年9月至11月间对场地内的植被生长条件、植物种类及场地内外的种源植物情况进行了6次全面调查。研究对植物物种进行人工辨识，并逐株测量木本植物的胸径、地径、树高、冠幅和具体位置等信息，勘察记录场地内存有土壤的位置的宽度及深度；研究以场地为中心，调查自生木本植物在场地内外同种成株的分布和距离情况。

The site covers a total area of 7,657.3 m^2, of which about 2,774.6 m^2 is concrete pavement. A 3,696.4-square-meter temporary structure as a student canteen was demolished in August 2017 where the interior paving of floor tiles were remained with poor permeability, and thin soils exist in the gaps between the demolished walls and the concreate pavement. The pre-existing green spaces on the site, 1,186.3 m^2, have deep and fertile soils for vegetation growth. Since the demolition, the site has been enclosed and idle, without any construction or maintenance activities on the site except for piling building debris (Fig. 1) till the end of March 2021 (when the study began).

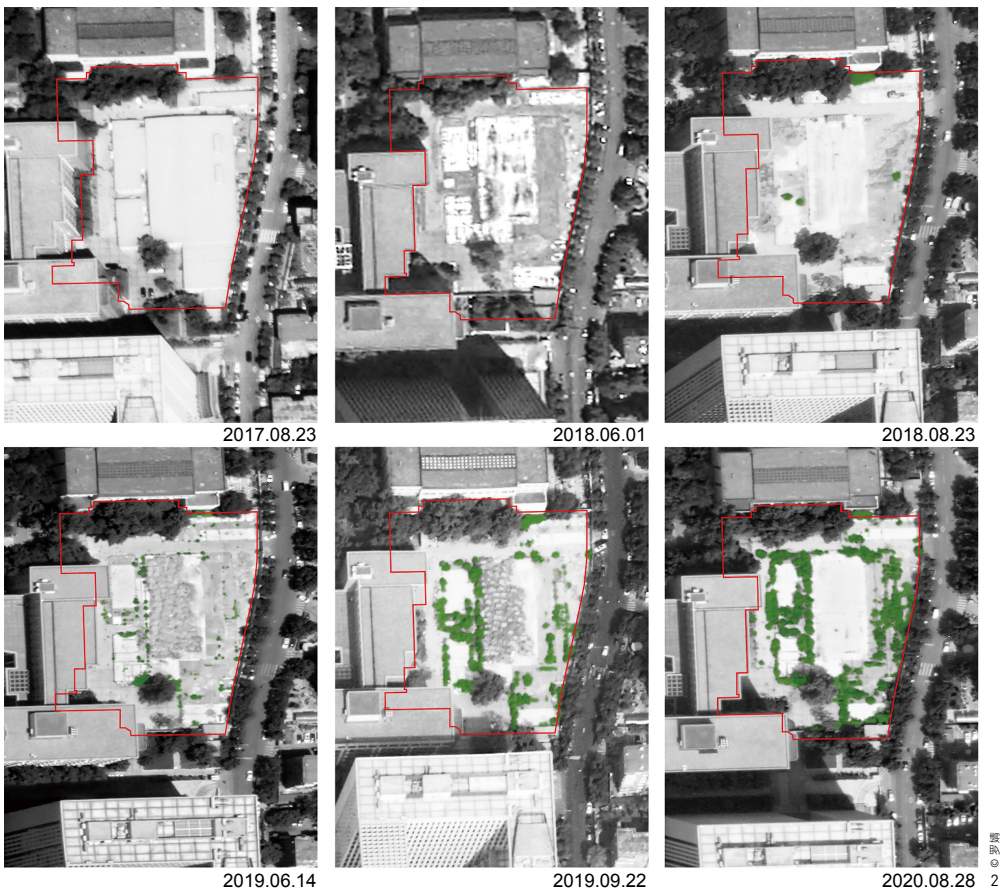
2.2 Research Methods

2.2.1 Satellite Image Analysis

To analyze the characteristics of vegetation distribution and growth on the site, the research adopted the full-color historical satellite images from Google Earth downloaded with BIGEMAP. The parameters of the images are listed in Table 1.

2.2.2 Site Inventory

From September to November 2020, 6 full site inventories were conducted covering the growth conditions, species, and possible maternal plants in- and outside the site. The plant inventory included species identification and the measurement of the diameter at breast height (DBH), basal diameter, height, crown diameter, location, and the width and depth of soils. The distribution of mature woody species, the possible maternal plants, in and outside the site were mapped.



2.2.3 光环境数字模拟分析

对北京市生态绿廊植物景观的研究发现，较强光照条件会引起草本植物多样性水平和均匀度指数降低，而这些草本植物具有较高的自发性[23]。受此启发，本研究分析了场地的光照条件差异对自生植物生长分布可能产生的影响。参考徐毅等人的研究[24]，以日照时数为测算因子对场地的光照条件进行数字模拟分析。根据不同自然光光环境模拟软件自身的特点及适用范围[17]~[19]，选择Ecotect Analysis软件对场地进行光环境数字模拟，分析场地的日照时数多少和分布情况。参考北京及河北地区草本植物物候观测数据[20]~[22]，选取5个与植物生长相关联的标志性时间节点分析场地的日照情况，对应设定数字模拟分析的时间节点为春分（3月21日）、清明（4月5日）、立夏（5月6日）、小暑（7月7日）、霜降（10月24日）。使用Ecotect Analysis软件设置北京地区气象参数并进行日照模拟计算。

3 研究结果与分析

3.1 植被生成的时空特征

2017年8月的卫星影像显示了建筑拆除前的场地情况（绿地面积仅

2.2.3 Digital Simulation Analysis of Light

Existing study on the plant landscape of Beijing Ecological Green Corridor reveals that strong lights may lead to lower richness and evenness of herbaceous species of high spontaneity[23]. In this research, the impact of light conditions of the site on the growth and distribution of spontaneous plants was studied. Referring to the research by Xu Yi et al.[24], the sunshine duration was simulated; and according to the application advantages and scopes of different digital stimulation softwares[17]~[19], Ecotect Analysis was selected for sunlight duration analysis and distribution of the site. Referring to existing phenological research findings of herbaceous plants in Beijing and Hebei[20]~[22], 5 days of representative solar terms impacting plant growth, namely Vernal Equinox (March 21), Qingming Festival (April 5), Summer's Begin (May 6), Slight Heat (July 7), and Frost's Descent (October 24), were selected to analyze the on-site light patterns.

3 Results and Analyses

3.1 Characteristics of the Early Establishment of Spontaneous Plant Community

The satellite image taken in August 2017 showed that the vegetation coverage of

占15.5%）。拆除后，2018年6月的影像中尚未出现清晰可辨的植物痕迹；2018年8月出现了明显的植物影像；从2019年6月的影像中可以清晰辨认出零散的树冠形态，几乎全部生长于硬质铺装的间隙；2019年9月，植被呈现出条带状及团块状的分布趋势；2020年8月，植被条带状及团块状的分布态势更加显著，局部已呈成片分布，植被覆盖度增长到30.7%，树木覆盖面积多于草本覆盖面积，两者的比例为1:0.65（图2，3）。

虽然硬质铺装地面对于植物生长极为不利，但临时建筑拆除一年后场地内就出现了明显的自生植物生长痕迹，此后植被生长发展特征显著。虽然自生植物起初只是在硬质铺装间隙处生长，但其生长扩展的速度很快，在三年后植被覆盖场地裸露区域接近1/3。

3.2 植被特征

3.2.1 自生植物种类

调查结果显示，场地中的原生植物有17种，自生植物35种（表2）。自生植物中有落叶乔木8种，为臭椿（*Ailanthus altissima*）、构树（*Broussonetia papyrifera*）、白蜡树（*Fraxinus chinensis*）等；落叶灌木1种，为荆条（*Vitex negundo* var. *heterophylla*）；一年生草本11种，包括某蒿（*Artemisia* sp.）、藜（*Chenopodium album*）、虎尾草（*Chloris virgata*）等；多年生草本10种，包括天名精（*Carpesium abrotanoides*）、积雪草（*Centella asiatica*）、野菊（*Chrysanthemum indicum*）等；木质藤本1种，为地锦（*Parthenocissus tricuspidata*）；一年生草质藤本1种，为牵牛（*Ipomoea nil*）；多年生草质藤本3种，为鹅绒藤（*Cynanchum chinense*）、葎草（*Humulus scandens*）、萝藦（*Metaplexis japonica*）。在所有科属中，禾本科植物和菊科植物居多，且草本植物种类明显多于木本植物。35种植物中仅有小蓬草（*Erigeron canadensis*）1种非乡土植物。

3.2.2 优势植物群落

调查结果显示，场地内自生植物分布情况存在局部差异，存在9种优势植物群落（图3），分别为：1）地锦—葎草；2）榆树—毛泡桐—旱柳—藜；3）毛泡桐—臭椿—榆树；4）旱柳—白蜡树—榆树—藜；5）鹅绒藤—葎草—藜；6）毛泡桐—臭椿—白蜡树—榆树；7）臭椿—榆树—白蜡树—桑；8）藜—狗尾草—知风草；以及9）葎草—鹅绒藤。

3.3 环境因子对自生植物的影响

3.3.1 土壤条件对自生植物生长分布的影响

调查发现，场地内的自生植物出现在原有绿地、角隅和建筑墙体破拆面三种土壤条件中（图4）。除了原有绿地土层深厚，角隅和建筑墙体破拆面处土层浅薄，主要是一些混杂建筑碎屑的土壤积存，没有特意进行土壤覆盖和改良。场地没有进行过施肥、灌溉等绿地养护管理行

the site was 15.5% before the demolition. After then, in June 2018, no identifiable vegetation was found; but 2 months later, vegetation can be identified in the image. Since June 2019, the scattered crowns could be clearly identified inbetween the pavement, and the image of September 2019 showed a strip and clump distribution of vegetation, which became more obvious and connected in August 2020, with the vegetation coverage increasing to 30.7% and the tree-herb ratio of the vegetated area was 1:0.65 (Fig. 2, 3).

Although concrete or tile paving surfaces are detrimental to plant growth, the growth pattern of the spontaneous plants observed on the site is increasingly obvious only after one year of being idle. They grew along with the gaps between paving at the beginning, however, covering an area nearly 1/3 of the bare area of the site only after 3 years.

3.2 Vegetation Characteristics

3.2.1 Spontaneous Plant Species

The inventories show that there were previously 17 plant species and later 35 species sprouted spontaneously (Table 2), and the latter ones include 8 deciduous trees (*Ailanthus altissima*, *Broussonetia papyrifera*, *Fraxinus chinensis*, etc.); 1 deciduous shrub (*Vitex negundo* var. *heterophylla*); 11 annual herbs (*Artemisia* sp., *Chenopodium album*, *Chloris virgata*, etc.); 10 perennial herbs (*Carpesium abrotanoides*, *Centella asiatica*, *Chrysanthemum indicum*, etc.); 1 woody vine (*Parthenocissus tricuspidate*); 1 annual vine (*Ipomoea nil*); and 3 perennial vines (*Cynanchum chinense*, *Humulus scandens*, and *Metaplexis japonica*). Poaceae and Asteraceae species are the majority, and herbaceous species significantly more than woody ones. Except *Erigeron canadensis*, all species are native.

3.2.2 Dominant Plant Communities

The inventories show the variation of vegetation distribution on the site: there are 9 plant communities (Fig. 3) respectively dominated by 1) *Parthenocissus–Humulus*; 2) *Ulmus–Paulownia–Salix–Chenopodium*; 3) *Paulownia–Ailanthus–Ulmus*; 4) *Salix–Fraxinus–Ulmus–Chenopodium*; 5) *Cynanchum–Humulus–Chenopodium*; 6) *Paulownia–Ailanthus–Fraxinus–Ulmus*; 7) *Ailanthus–Ulmus–Fraxinus–Morus*; 8) *Chenopodium–Setaria–Eragrostis*; and 9) *Humulus–Cynanchum*.

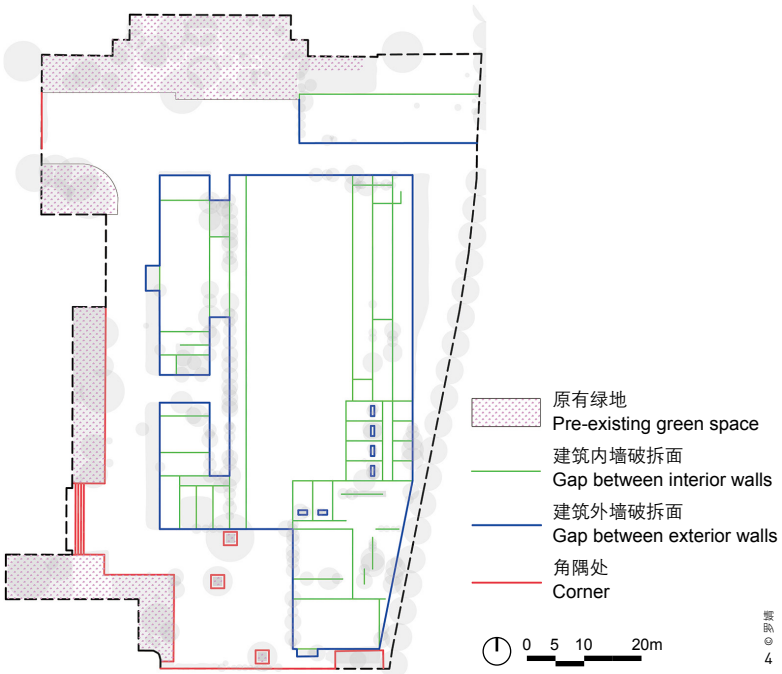
3.3 Influence of Environmental Factors on the Spontaneous Plants

3.3.1 Influence of Soil Conditions on the Growth and Distribution of Spontaneous Plants

The spontaneous plants are only found in the pre-existing green spaces, corners, and the gaps between the demolished walls (Fig. 4). Except for the pre-existing green spaces, the soils at the corners and the gaps are thin and mixed with building debris, without soil supplementing or cultivating. None fertilization, irrigation or other maintenance activities were conducted to the site. The overall terrain of the site is flat that ensures rainwater drainage, no waterlogging being found.

表2：研究场地内植物名录
Table 2: Plant list of the study site

类型 Life form	物种名称 Species	科 Family	原有或自生 Pre-existing or spontaneous
常绿乔木 Evergreen tree	圆柏 *Juniperus chinensis*	柏科 Cupressaceae	原有 Pre-existing
	白皮松 *Pinus bungeana*	松科 Pinaceae	原有 Pre-existing
	侧柏 *Platycladus orientalis*	柏科 Cupressaceae	原有 Pre-existing
落叶乔木 Deciduous tree	元宝槭 *Acer truncatum*	无患子科 Sapindaceae	原有 Pre-existing
	臭椿 *Ailanthus altissima*	苦木科 Simaroubaceae	二者均有 Both
	构树 *Broussonetia papyrifera*	桑科 Moraceae	二者均有 Both
	白杜 *Euonymus maackii*	卫矛科 Celastraceae	原有 Pre-existing
	白蜡树 *Fraxinus chinensis*	木犀科 Oleaceae	自生 Spontaneous
	胡桃 *Juglans regia*	胡桃科 Juglandaceae	原有 Pre-existing
	桑 *Morus alba*	桑科 Moraceae	自生 Spontaneous
	毛泡桐 *Paulownia tomentosa*	泡桐科 Paulowniaceae	二者均有 Both
	小叶杨 *Populus simonii*	杨柳科 Salicaceae	自生 Spontaneous
	旱柳 *Salix matsudana*	杨柳科 Salicaceae	二者均有 Both
	榆树 *Ulmus pumila*	榆科 Ulmaceae	自生 Spontaneous
落叶灌木 Deciduous shrub	平枝栒子 *Cotoneaster horizontalis*	蔷薇科 Rosaceae	原有 Pre-existing
	连翘 *Forsythia suspensa*	木犀科 Oleaceae	原有 Pre-existing
	女贞 *Ligustrum lucidum*	木犀科 Oleaceae	原有 Pre-existing
	绣线菊 *Spiraea salicifolia*	蔷薇科 Rosaceae	原有 Pre-existing
	欧洲荚蒾 *Viburnum opulus*	五福花科 Adoxaceae	原有 Pre-existing
	荆条 *Vitex negundo* var. *heterophylla*	马鞭草科 Verbenaceae	自生 Spontaneous
一年生草本 Annual	某蒿 *Artemisia* sp.	菊科 Asteraceae	自生 Spontaneous
	藜 *Chenopodium album*	苋科 Amaranthaceae	自生 Spontaneous
	虎尾草 *Chloris virgate*	禾本科 Poaceae	自生 Spontaneous
	牛筋草 *Eleusine indica*	禾本科 Poaceae	自生 Spontaneous
一年生草本 Annual	小蓬草 *Erigeron canadensis*	菊科 Asteraceae	自生 Spontaneous
	某蓼 *Persicaria* sp.	蓼科 Polygonaceae	自生 Spontaneous
	马齿苋 *Portulaca oleracea*	马齿苋科 Portulacaceae	自生 Spontaneous
	朝天委陵菜 *Potentilla supina*	蔷薇科 Rosaceae	自生 Spontaneous
	狗尾草 *Setaria viridis*	禾本科 Poaceae	自生 Spontaneous
	龙葵 *Solanum nigrum*	茄科 Solanaceae	自生 Spontaneous
	苦苣菜 *Sonchus oleraceus*	菊科 Asteraceae	自生 Spontaneous
多年生草本 Perennial	天名精 *Carpesium abrotanoides*	菊科 Asteraceae	自生 Spontaneous
	积雪草 *Centella asiatica*	伞形科 Apiaceae	自生 Spontaneous
	野菊 *Chrysanthemum indicum*	菊科 Asteraceae	自生 Spontaneous
	刺儿菜 *Cirsium arvense* var. *integrifolium*	菊科 Asteraceae	自生 Spontaneous
	狗牙根 *Cynodon dactylon*	禾本科 Poaceae	自生 Spontaneous
	香附子 *Cyperus rotundus*	莎草科 Cyperaceae	自生 Spontaneous
	知风草 *Eragrostis ferruginea*	禾本科 Poaceae	自生 Spontaneous
	麦冬 *Ophiopogon japonicus*	天门冬科 Asparagaceae	原有 Pre-existing
	芦苇 *Phragmites australis*	禾本科 Poaceae	自生 Spontaneous
	地黄 *Rehmannia glutinosa*	列当科 Orobanchaceae	自生 Spontaneous
	蒲公英 *Taraxacum mongolicum*	菊科 Asteraceae	自生 Spontaneous
竹类 Bamboo	早园竹 *Phyllostachys propinqua*	禾本科 Poaceae	原有 Pre-existing
木质藤本 Woody vine	地锦 *Parthenocissus tricuspidata*	葡萄科 Vitaceae	自生 Spontaneous
一年生草质藤本 Annual vine	牵牛 *Ipomoea nil*	旋花科 Convolvulaceae	自生 Spontaneous
多年生草质藤本 Perennial vine	鹅绒藤 *Cynanchum chinense*	夹竹桃科 Apocynaceae	自生 Spontaneous
	葎草 *Humulus scandens*	大麻科 Cannabaceae	自生 Spontaneous
	萝藦 *Metaplexis japonica*	夹竹桃科 Apocynaceae	自生 Spontaneous



4. 场地土壤条件示意图
5. 建筑内墙破拆面实景照片。自生植物在建筑内墙破拆面上旺盛地生长着。
6. 全年场地日照分布与自生植物覆盖情况
7. 通过5个标志性节点呈现的植物生长期内场地日照变化情况

4. Soil conditions on the site
5. Real photo of gap between interior walls where spontaneous plants thrive.
6. Annual sunshine duration contour map and spontaneous plant coverage
7. Sunshine variation on the site during the vegetation growing seasons represented by 5 solar terms

为，且场地整体地势平整，雨水可以自然排出场地，未发现雨水积存现象。

原有绿地中主要栽有乔灌木（表2），场地闲置后萌发自生植物20种，其中草本植物9种，木本植物7种，藤本植物4种。

花坛（原有绿地的一部分）、台阶与混凝土地面相夹的角隅空间极为狭窄，宽度为0.5~8cm，土壤厚度仅1~2cm。此处萌发自生植物18种，其中草本植物10种，木本植物6种，藤本植物2种，以藜为代表的草本植物占据优势。

场地内现有两类建筑墙体破拆面：一种为建筑内墙破拆面，宽约30cm，其中蓄积了厚约3cm的土壤，掺杂有大量建筑材料碎屑；此处萌发植物22种，其中草本15种，木本植物6种，藤本植物1种，优势种为藜、狗尾草等草本植物（图5）。另一种为建筑外墙破拆面，宽约12cm，与地基层的缝隙相连，蓄积土壤厚度约20cm；萌发自生植物17种，其中草本植物8种，木本植物7种，藤本植物2种，毛泡桐、臭椿、榆树等木本植物占据生长优势。

调查结果显示，场地中土壤条件对自生植物的种类和分布影响明显。角隅处和建筑墙体破拆处的土壤较薄，萌发的草本植物较多；建筑外墙破拆处的土壤较厚，那里的自生木本植物长势明显优于建筑内墙破拆处和角隅处。原有绿地里的土壤条件明显优于角隅和建筑墙体破拆

Existing shrub and tree species in the pre-existing green spaces are listed in Table 2. In total, there are 20 spontaneous plant species observed, of which 9 are herbaceous, 7 are woody, and 4 are vines, after the site was idle.

The corners and gaps between flowerbeds (as part of pre-existing green spaces), steps, and the concrete pavement are extremely narrow, where the soil is in a width of 0.5 to 8 cm and a thickness of 1 to 2 cm. 18 spontaneous species are found there, including 10 herbaceous plants (dominant and represented by *Chenopodium album*), 6 woody plants, and 2 vines.

Two types of gaps are found between the demolished walls: 1) the 30-centimeter-wide gaps between the interior walls, where the soil is 3-centimeter thick and mixed with building debris. 22 spontaneous species are found there, including 15 herbaceous plants, 6 woody plants, and a vine, among which herbs like *Chenopodium album* and *Setaria viridis* dominate (Fig. 5); and 2) the 12-centimeter-wide gaps between the exterior walls, connected to the building foundation, where the soil is about 20-centimeter thick. There, 17 species sprout, including 8 herbaceous plants, 7 woody plants, and 2 vines, with woody plants such as *Paulownia tomentosa*, *Ailanthus altissima*, and *Ulmus pumila* being dominate.

The inventories show that the soil conditions significantly influence the species and distribution of spontaneous plants on the site. Soils at the corners and gaps are thinner, and more herbaceous plants sprout; the soil in the gaps between exterior walls are thicker, where spontaneous woody species grow better than those grow at the corners and the gaps between interior walls. Pre-existing green spaces have sound soil conditions, however, species there are not richer than

处，但出现的自生植物种类并没有明显多于其他区域，这一现象是否受到原有绿地中已栽植植被的遮荫影响尚待进一步探究。由于原有绿地之外的区域没有既有植被，无法进行相同遮荫条件下的比对研究。

3.3.2 场地的光照条件对自生植物总体分布的影响

场地年日照时数分布的梯度曲线图显示（图6），年日照时数自东北至西南逐渐减少，年日照时数最多的区域可达3 400小时以上；受到周围建筑和围墙的影响，沿东侧和南侧围墙的带状区域、西侧建筑凹入的区域年日照时数明显低于场地东北部，最低的区域是场地西南角围墙和建筑包围处，年日照时数低于200小时。5个标志性的植物生长时间节点的日照分析显示，场地内绝大部分区域日照时数的分布相对均匀，光照条件充足；场地北部区域的光照条件更好，而南部和西部边缘受建筑和围墙影响严重，尤其是角落和靠近围墙的区域在春分和霜降时节的日照时数显著减少（图7）。

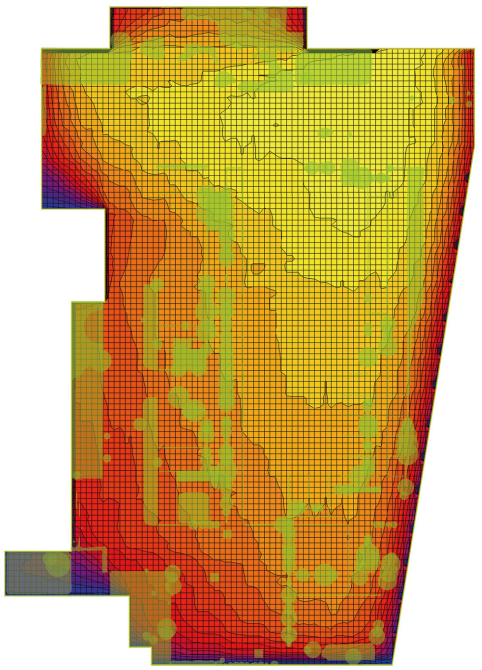
通过将光照分析结果与自生植被覆盖场地情况进行比对研究，发现自生植被沿土壤存在的区域呈清晰的线形分布；较大的自生植物团块集中于原有绿地中；在贴近场地东边、南边围墙和西边建筑的区域，年日

other places. The impact of other possible factors (e.g. the shades of the existing vegetation) needs to be verified by further research—Since pre-existing plants only grow in pre-existing green spaces, comparative studies on the shades on the site is hard to conduct in this research.

3.3.2 Impact of Light Conditions on the General Distribution of Spontaneous Plants

According to the annual sunshine duration contour map of the site (Fig. 6), the total sunshine duration decreases from northeast to southwest, with the maximum exceeding 3,400 hours. Subject to the shades from nearby buildings and fences, the sunshine duration drops down in the belt zone along the south and east fences and within the narrow corner adjacent to the building in the west, southwest of which has the minimum of fewer than 200 hours. The analysis of the light conditions on the 5 representative solar days suggests that the sunshine duration is sufficient and roughly even across most parts of the site. The north part has relatively better light conditions, while those along the fences in the south and the building in the west are the worst, particularly on Vernal Equinox and Frost's Descent (Fig. 7).

The overlapping analysis between the light contour map and spontaneous plant distribution reveals that the spontaneous plants were found in linear patterns and larger clusters of spontaneous plants found in the pre-existing green



辐射强度分析
Radiation intensity analysis

日照时数
Sunshine duration

等值线范围：0~3 400小时
Contour range: 0 ~ 3,400 hours

步长：200小时
Step size: 200 hours

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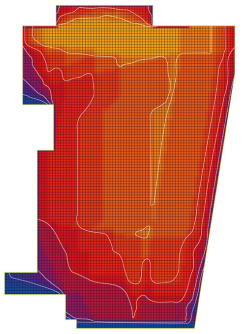
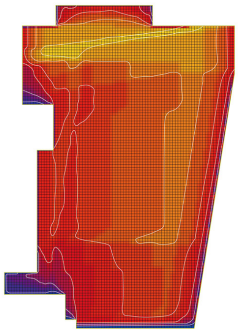
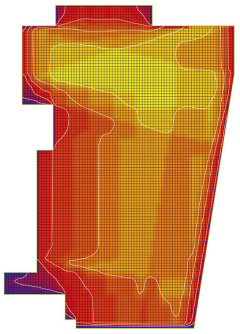
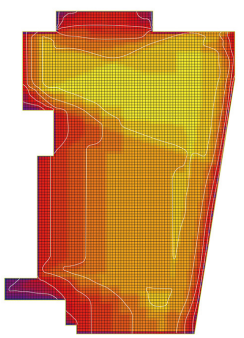
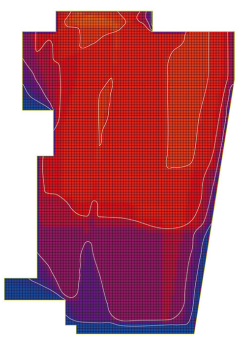

春分
Vernal Equinox


清明
Qingming Festival


立夏
Summer's Begin


小暑
Slight Heat


霜降
Frost's Descent

Hrs
14.0+
12.6
11.2
9.8
8.4
7.0
5.6
4.2
2.8
1.4
0.0

辐射强度分析
Radiation intensity analysis

日照时数
Sunshine duration

等值线范围：0~14小时
Contour range: 0 ~ 14 hours

步长：1.4小时
Step size: 1.4 hours

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照时数明显较少，但依然生长了不少自生植物。总体而言，自生植被分布的状态没有表现出与日照分布梯度曲线对应的迹象。

通过将光照分析结果与植物种类分布进行比对研究，未发现自生植物种类的分布与日照时数的分布变化有明显关联。以榆树—毛泡桐—旱柳—藜的木本植物群落为例，该群落沿直线南北分布，分布地年日照时数自2 400小时跨越至3 200小时；藜—狗尾草—知风草的草本植物群落散布于东部和西部的多个年日照时数不同的区域，也未表现出与日照时数分布变化相关联。

场地光照条件对自生植物总体分布的影响不显著，虽然场地上的全年日照时数分布有差异，但在植物主要生长期（春分至霜降）内场地基本光照均匀、充足。这可以解释自生植被覆盖区域和自生植物种类的分布都未表现出与光照时数分布变化有关联的原因，也说明光照条件不是影响该场地自生植被发展的主要因素。

3.3.3 自生植物种源调查及自生能力分析

除光照和土壤条件因素外，场地内自生植物的出现及分布情况还取决于植物的种源环境。植物以风力、水力、火力、生物携带及通过种子或其载体本身产生的机械力完成种子的传播和散布[25]，分析自生植物的种源环境可以更好地了解生态自我修复发生的条件。由于研究场地位于校园内，场地周边区域的人工养护管理程度均较高，自生草本植物的种源调查存在难度，而木本植物同种成株的调查具有可行性。在10种木本植物中乔木类居多（乔木8种，灌木1种，藤本1种），并且乔木树种主导了多个植物群落，因此研究针对乔木树种的同种成株情况在场地内外进行了调查。结果显示，毛泡桐、臭椿、构树和旱柳在场地内有存在，场地外白蜡树、小叶杨和榆树3种树木距离较近，只有桑距离场地最远，达154m（表3，图8）。

从木本自生植物的萌发量来看，毛泡桐、臭椿和榆树的数量最多，其次是白蜡树、旱柳和桑。通过比较植株的冠幅、树高等参数，生长优势明显的树木有毛泡桐、臭椿、榆树和旱柳。毛泡桐和榆树种源母株数量少，但场地内的幼苗萌发量却最多，且冠幅、株高较大；臭椿在场地内外种源母株数量众多，萌发量大，冠幅、株高大；场地外白蜡树的母株较多、距离较近，但幼苗萌发量和冠幅株高明显小于臭椿等；旱柳虽然母株数量少，幼苗萌发量却仅次于白蜡树，冠幅、株高大；桑的母株

spaces. Although the annual sunshine duration is short in the areas adjacent to the fences and buildings, quite a few spontaneous plants grow. To sum up, the distribution pattern of the spontaneous plants is not consistently related with the annual sunshine duration contour map.

The overlapping analysis between the light contour map and the species distribution reveals no significant correlation: The *Ulmus–Paulownia–Salix–Chenopodium* community distributes from south to north in a linear pattern, with the annual sunshine duration ranging from 2,400 to 3,200 hours; The *Chenopodium–Setaria–Eragrostis* community scatters in east and west of the site with different sunshine duration contours, and the distribution does not correspond to sunshine duration.

The light conditions have no significant impact on the general distribution of the spontaneous plants. Despite the differences in the annual sunshine duration of the site, the sunshine duration during the growing season (from Vernal Equinox to Frost's Descent) is sufficient and roughly even generally in the site. This explains why the distribution and species of the spontaneous plants are not correlated to the sunlight duration. In other words, light conditions are not the major factor that affects the growth of the spontaneous plants on the site.

3.3.3 Maternal Plant Investigation and Viability Analysis

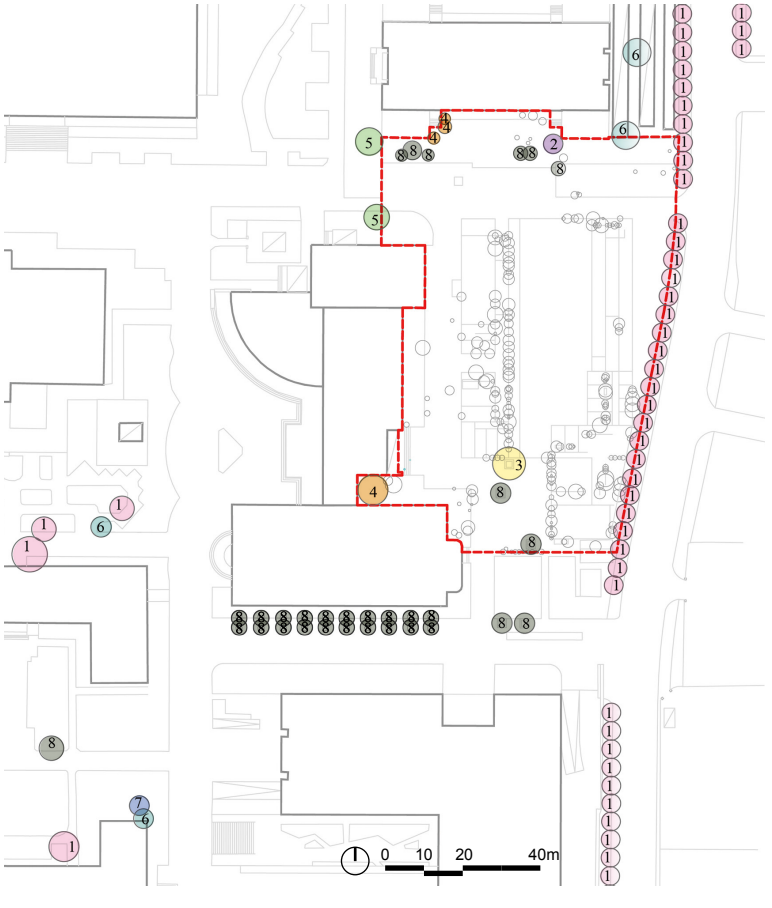
In addition to the light and soil factors, the presence and distribution of spontaneous plants depend on the maternal plants as well. Seeds are dispersed via wind, water, fire, and other creatures, or by the mechanical force of the fruits[25]. The analysis of possible maternal plants of spontaneous plants helps reveal the environmental conditions for ecological self-restoration. As the study site is located in a university campus that is intensively maintained, it is more feasible to trace the maternal plants of spontaneous woody plants, compared with herbaceous species. On the study site, most of the spontaneous woody plants are trees (8 tree species, 1 shrub, and 1 woody vine), dominating many communities. The survey results of the possible maternal plants in and outside the site show that mature *Paulownia tomentosa*, *Ailanthus altissima*, *Broussonetia papyrifera*, and *Salix matsudana* exist on the site; mature *Fraxinus chinensis*, *Populus simonii*, and *Ulmus pumila* are close to the site; and the nearest mature *Morus alba* is 154 m away from the site (Table 3, Fig. 8).

In terms of quantity, *Paulownia tomentosa*, *Ailanthus altissima*, and *Ulmus pumila* rank the top, followed by *Fraxinus chinensis*, *Salix matsudana*, and *Morus alba*. Comparing the crown diameter and height, *Paulownia tomentosa*, *Ailanthus altissima*, *Ulmus pumila*, and *Salix matsudana* are dominant species. *Paulownia tomentosa* and *Ulmus pumila* have the fewest maternal plants, yet they sprout the most seedlings, with larger crowns and heights. The quantity of the outside maternal plants of both *Ailanthus altissima* and *Fraxinus chinensis* are large, while the seedling quantity, crown diameter, and height of the former are all obviously larger than those of the latter. Despite the small amount of the maternal plants, the seedling amount of *Salix matsudana* is second to *Fraxinus*

表3：自生植物种源分布调查表

Table 3: Possible maternal plant distribution of spontaneous plants

树种 Tree species	自生幼株 Spontaneous seedling and sapling		场地内外同种成株 Possible maternal plants inside and outside the site	
	萌发量（株） Quantity of germination	冠幅（m） Crown width (m)	场地内数量（株） Quantity observed inside	场地外可能种源的最近距离（m） Distance to the nearest possible maternal plant outside (m)
毛泡桐 *Paulownia tomentosa*	53	1.0 ~ 4.0	1	94.7
构树 *Broussonetia papyrifera*	7	1.6 ~ 3.6	4	220.3
旱柳 *Salix matsudana*	19	1.0 ~ 4.2	1	98.7
臭椿 *Ailanthus altissima*	50	0.8 ~ 4.0	8	19.0
白蜡树 *Fraxinus chinensis*	23	0.6 ~ 2.5	–	1.0
小叶杨 *Populus simonii*	2	0.3 ~ 0.4	–	1.3
榆树 *Ulmus pumila*	50	0.6 ~ 4.0	–	0.5
桑 *Morus alba*	16	0.5 ~ 3.0	–	154.0



8. 种源分布图

8. Possible maternal plant distribution

距离远，幼苗萌发量次于旱柳，但冠幅、株高较小；小叶杨无论是萌发量还是冠幅株高都处于相对较弱的水平。综合考量，在8种乔木树种中，除了小叶杨和构树，其余6种树木都有着很强的自生优势，其中毛泡桐、臭椿和榆树的优势更为明显。

4 结论与讨论

4.1 生态修复与人为干扰

本研究对大学校园内一处闲置场地的植被自生情况进行了分析，在土壤条件极为苛刻的情况下，场地闲置封闭管理后一年即观察到植被自生现象，并且植被覆盖区域发展迅速，三年后自生植被覆盖场地的裸露区域接近1/3。这说明，当人类行为的扰动程度降低（建设行为和管护行为均终止）时，城市闲置地块中便会迅速发生生态修复现象。英戈·科瓦里克和安德烈斯·朗格尔对德国一处废弃的火车站的研究发现，废

chinensis, with larger crowns and taller heights. *Morus alba* has a distant possible maternal plant, though its seedling amount follows *Salix matsudana*, its crowns and heights are relatively small. *Populus simonii* is of low competitiveness among all indicators. In conclusion, except *Populus simonii* and *Broussonetia papyrifera*, the other 6 tree species have stronger viability, especially *Paulownia tomentosa*, *Ailanthus altissima*, and *Ulmus pumila*.

4 Conclusions and Discussions

4.1 Ecological Restoration and Human Intervention

This study analyzes the spontaneous vegetation in an idle site on a university campus in Beijing. Despite the harsh soil conditions, plants sprout spontaneously only after one year the site being idle and enclosed. The vegetation grows fast and has covered nearly 1/3 of the bare land in 3 years. This suggests that ecological

弃30年后场地上草地和林地混杂，草地面积较大，而之后10年林地面积扩展了近一倍，两者面积占比发生了反转[26]。本研究在演替初期场地中就有多个自生的木本群落和草本植物群落出现，场地封闭闲置3年后前者覆盖面积超过了后者开始占据主导地位，经历时间较短。两项研究结果虽然相似，但演替时间却相差甚远，自生植被演替过程中木本植被扩展的速度和影响因素值得进一步研究。

自然界中的火灾、风灾、洪水和入侵物种等都可能损害自然植被、破坏生态系统[27]，但往往人为扰动具有更大的破坏力，甚至可能完全破坏生态自我修复的能力[28]。要实现生态系统修复，一方面可停止或减少人为扰动，激发生态系统自我修复；另一方面，在了解影响生态系统自我修复过程及影响机制的基础上，借助人工措施改变限制因素可以促进植被发展，推动生态修复的进程。本研究中，在场地光照条件充分的情况下，自生植物的生长发展受到土壤条件的直接影响。如果土壤条件得到改善（如增加土壤厚度、降低硬质铺装的面积），本研究场地上物种构成和植被覆盖会发生很大改变。

4.2 植物自生现象与乡土植物

有研究对北京39个公园内的自生植物进行了调查，记录到242种植物，且大部分为乡土物种[29]。本研究场地内仅发现自生植物35种，较低的物种丰富度与场地面积小、场地内硬质铺装地面比例大的生境条件有关。场地内仅发现了一种非乡土植物（小蓬草），说明在城市闲置地块生态自我修复的初始阶段，乡土植物占有物种优势。但是，这也引发了作者关于入侵植物问题的思考：入侵植物或是具有入侵特性的植物容易形成绝对优势种群，进而影响生物多样性[13][15]。这一现象需要引起业内学者高度关注，生命力强健的外来入侵植物在疏于管理的情况下可能会迅速蔓延生长，对生态系统的稳定性产生威胁。

本研究调查记录的自生植物中有10种木本植物，物种多样性主要受草本植物种类影响。但是，与北京市公园绿地自生植物的调查结果相比（在242种植物中，灌木15种，木质藤本9种）[29]，本研究中木本植物种类占有更高的比例。有研究在杭州市建成区范围内进行了自生植物调查，记录到的木本植物种类的比例超过40%[11]。另外，本研究的植物群落构成分析结果显示，木本植物群落的数量和草本植物群落的数量相近。通过对8种乔木的种源条件及自生能力进行研究发现，多数木本乡土树种在萌发数量和长势上都表现出显著的自生优势，其中一些种类优

restoration occurs rapidly in urban idle lands when human interventions like construction or maintenance reduce. Studying an abandoned railway station in Germany, Ingo Kowarik and Andreas Langer found that the site was covered with grass (dominant) and trees after being abandoned for 30 years; another 10 years later, tree coverage doubled, exceeding that of grass[26]. In this study, several spontaneous woody and herbaceous communities were found at the early stage of the ecological self-restoration; 3 years later, the former covered a larger area than the latter, becoming obviously dominant. Although the research findings are similar, the time diverges from those observed by Kowarik and Langer. It requires further studies to explore the growth speed and impact factors of woody spontaneous species during the natural succession.

Natural hazards, e.g. fires, windstorms, floods, and species invasions, may damage natural vegetation and ecosystems[27]. Yet human interventions are often destructive that can damage their self-restoration capacity[28]. It is suggested to stop or reduce human interventions, and / or to facilitate vegetation development and ecological restoration based on the understanding of the self-restoration mechanism. In this study, with sufficient light, the soil conditions are what directly impact the growth of spontaneous plants—If the soils are improved by increasing the depth or decreasing paving, the species composition and vegetation coverage might change significantly.

4.2 Spontaneous Plants and Native Plants

A study investigating the spontaneous plants in 39 parks in Beijing recorded 242 spontaneous plant species, mostly native[29]. Only 35 spontaneous plant species were found on this study site, which may be limited by the small site area and the large ratio of hard paving on the site. Only one non-native species (*Erigeron canadensis*) was found on the site, suggesting a dominance of native species at the early stage of ecological self-restoration. However, this arouses a concern that invasive plants can easily form absolutely dominant populations, thus suppressing biodiversity[13][15]. This asks scholars to alert that robust invasive plants can spread rapidly in the absence of management, threatening the stability of ecosystems.

Among the spontaneous plant species observed on the study site, 10 are woody. The species diversity is thus mainly depended on the richness of herbaceous species. Yet compared with inventories of urban parks in Beijing (15 shrub species and 9 woody vines among 242 plants)[29], the woody plants in this study accounted for a larger share. An inventory of the spontaneous plants in the built-up areas in Hangzhou shows a woody proportion of over 40%[11]. Besides, the number of woody communities and herbaceous communities is close. The possible maternal plants and viability analyses of 8 tree species indicate that most native woody plants have a stronger germination and growth vigor, especially *Paulownia tomentosa*, *Ailanthus altissima*, and *Ulmus pumila*. Trees species spreading via wind dispersal see a shortest distance of possible maternal plants of nearly 100 m (94.7 m for *Paulownia tomentosa* and 98.7 m

势更为突出（毛泡桐、臭椿和榆树）；风力传播的树木最近可能种源距离接近100m（毛泡桐94.7m、旱柳98.7m），而动物传播的树木最近可能种源距离更远（桑154m）。这些结果都表明在城市环境中，乡土木本植物的自生优势值得引起关注和深入研究，尤其是生态自我修复初期阶段木本植物的生长规律，其研究结果将会为城市生态系统修复实践的物种选择提供借鉴。**LAF**

for *Salix matsudana*), and the species via animal dispersal see a larger distance (154 m for *Morus alba*). The findings suggest that the strong spontaneity and vigor of native woody plant species are worthy of future research efforts, particularly the growth pattern at the early stage of ecological self-restoration, which would offer references to the species selection for similar cases of urban ecosystem restoration. **LAF**

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