基于植被再野化的城市荒野生境重建
——以野花草甸为例

Reconstruction of Urban Wilderness Habitats Based on Vegetation Rewilding: Taking Wildflower Meadows as an Example

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摘要

城市环境中残存着一些以自然过程为主导的荒野生境片段，在生物多样性保育、维持城市生态过程、连接人与自然等方面具有不可替代的作用。植被再野化提供了重建城市荒野生境的重要途径，旨在恢复严重退化的城市植物群落的物种组成、结构及功能，使其逐渐野化并达到自然过程基本不受人类干扰的程度。本文以野花草甸景观为例，提出了主动利用景观生态流、拟自然设计与最小限度干预进行城市植被再野化的技术框架；从自我设计、微地形设计、拟自然群落设计、植物－动物关键种协同共生设计，以及自然柔性材料运用等5个方面详细探讨并提供科学参考。同时，以重庆市梁平区双桂湖湖岸公园绿地为例，阐述了在“自然－人工”斑块复杂镶嵌的城市景观中进行植被再野化与荒野生境重建的实践原则与应用范式。

关键词

城市荒野；城市植物景观；再野化；生境；草本植物群落；野花草甸

ABSTRACT

Fragments of wilderness dominated by natural succession exist in urban environments, and play a critical role in protecting biodiversity, supporting urban ecological processes, and connecting human beings with nature. Urban vegetation rewilding is a key approach to restricting urban wilderness by restoring the species composition, community structure and functions, eventually towards a self-maintained vegetation community. This paper, taking wildflower meadows as a reference, establishes a technical framework of urban vegetation rewilding by leveraging ecological flows and adopting quasi-nature design with minimum interventions. The framework covers 5 aspects, namely self-design, micro-topographic design, quasi-nature design, collaborative symbiosis design between plant community and keystone animal species, and design with natural materials. Studying the green space along the northwest lakeside of the Shuangguihu National Wetland Park in Liangping District, Chongqing, this paper provides a scientific guidance and technical paradigm for vegetation rewilding and urban wilderness restoration in the complex context of natural–artificial urban landscapes.

KEYWORDS

Urban Wilderness; Urban Plant Landscape; Rewilding; Habitat; Herbaceous Communities; Wildflower Meadow

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1 城市荒野及再野化

“荒野”（wilderness）是指地球表面尚未因受人类活动影响而发生明显改变、由自然生态过程主导的大片区域。荒野在生物多样性保护、自然遗产保护等方面发挥着不可替代的作用[1][2]，且基本无需额外的人工投入来维持其生态系统与生态系统服务[3]。荒野景观使人类与野性保持联系，凭借自由生长及生机勃勃的特性，成为了文化、道德与宗教中的重要元素[4][5]。尽管荒野景观可带来广泛的生态、经济和社会效益，但农耕、伐木、采矿与城镇化等高强度人类活动正导致荒野迅速退化甚至消失[6][7]。

高度人工化的城市环境中残存着片段化的荒野生境。城市荒野是存在于人工系统夹缝中的自然本底，通常位于城市内或城郊人迹难至的高地或沟谷，或是闲置、废弃的水体、林地、农田、工业用地（包括废弃矿坑）等，其生物群落的形成与自然演替在一定时间内基本不受人工干扰[8]。相较于需要精心养护的人工景观，城市荒野景观往往有利于空气、水体与土壤净化，更有利于促进人类身心健康[9]；城市荒野景观在城市绿地系统中的镶嵌分布提升了城市生态基础设施网络的连续性和有效性。然而，城市化造成土地开发需求不断增加，针对城市荒野生境保护、管控与补偿的政策措施仍不完善；在过度追求整洁秩序的审美意识下，人类对于荒野景观仍存在负面认知[10]。这些问题导致城市荒野生境日渐衰退与稀缺。

城市绿地中的植被在长期高强度的管理和维护下，往往存在景观单调、物种贫乏、结构单一、生态功能低下、资源消耗严重等问题。在此背景下，“再野化”（rewilding）理念被提出：再野化旨在终止人为干预并实施有效的修复设计，使退化的生物群落的物种组成、结构及功能恢复至接近自然荒野的状态[11]。城市植被再野化正是重建城市荒野生境，修复完善“荒野生境—人工绿地”复杂镶嵌的城市生态网络，实现低维持、可持续、高韧性城市景观系统的关键途径。

自20世纪90年代以来，西欧与北美地区开始启动城市植被再野化的相关研究与应用，城市植被再野化的关注焦点逐渐转向自生植物的管理及应用。琼·艾弗森·纳索尔于1995年发表《无序系统，有序框架》一文，认可了在城市中自然定居的自生植物群落的重要生态功能与美学价值[12]。诺伯特·库恩进一步提出了利用自生植被优化城市景观的

1 Urban Wilderness and Rewilding

Wilderness refers to a large area of unmodified or slightly modified earth surface retaining its natural character and ecological processes. Wilderness plays a critical role in the conservation of biodiversity and natural heritages[1][2], and no additional or minimum human-made investment is needed to sustain its ecosystem and ecosystem services[3]. Wilderness connects human beings with wildness, and is a significant element in culture, morality, and religion for its spontaneity and vitality[4][5]. Wilderness brings considerable ecological, economic, and social benefits, but is undergoing rapid degradation or even disappears due to intensive human activities like farming, logging, mining, and urbanization[6][7].

Fragments of wilderness exist in highly artificialized urban environment as well. Urban wilderness, manifesting the nature scattering among constructed systems, includes the highlands or valleys in the cities or suburbs with poor accessibility, or the idle or abandoned water bodies, forestlands, farmlands, and industrial lands (including wasted mining pits). The composition and natural succession of the biotic communities in the wilderness are free from human intervention for a certain length of time[8]. Compared to well-maintained landscapes, urban wilderness landscape provides better ecosystem services such as purifying air, water, and soil, and delivering more benefits for human health[9]. The scattering pattern of urban wilderness enhances the continuity and efficacy of urban ecological infrastructure. However, as the land is growingly developed during the urbanization, policies and measures on wilderness protection, regulation, and compensation are inadequate, and the public's aesthetics that admire cleanness and order remains negative about wilderness[10]. As a result, urban wilderness increasingly degrades and disappears.

Under long-term intensive management and maintenance, urban green spaces often appear homogenous, with low biodiversity, poor structures and ecological services, as well as high resource consumption. In such a context, the concept “rewilding” was proposed which advocates replacing human intervention with natural restoration on degraded communities so as to reconstruct the species composition, structure, and functions of them[11]. Urban vegetation rewilding is a key approach to restoring urban wilderness, improving urban ecological networks of wilderness–artificial green spaces, and building sustainable landscape systems that require little maintenance and perform stronger sustainability and resilience.

Since the 1990s, scholars from West Europe and North America started the studies on urban vegetation rewilding, which have shifted its focus to the management and application of spontaneous vegetation. In 1995, Joan Iverson Nassauer published the paper “Messy Ecosystems, Orderly Frames,” which recognizes the ecological functions and aesthetic values of urban spontaneous plant communities[12]. Norbert Kühn came up with the design strategy that

设计策略[13]。这一策略在德国北杜伊斯堡景观公园和卡尔—亚历山大矿山公园、美国高线公园、中国江洋畈生态公园等项目中均有运用。

然而，以限制人类干扰和利用自生植物为主的植被再野化措施存在群落演替方向不确定、演替时间长、过程中植被结构及功能稳定性较差，以及景观表现力欠佳等问题[13]。定向、高效且更加美观地建立野化植物群落现已成为城市植被再野化的新需求。近年来，模拟自然野花草甸群落设计营建植物景观的案例逐渐增多[14]；其中，荒野野花草甸具有稳定的群落结构、丰富的观赏效果与多种生态服务功能[15]，是城市植被再野化良好的参考对象。基于此，本文以野花草甸为例，提出以最小限度干预措施重建城市荒野生境、利用景观生态流和拟自然设计制定城市植被定向再野化的技术框架。同时，以重庆市梁平区双桂湖国家湿地公园西北侧湖岸绿地为例，探讨如何在“自然—人工斑块”复杂镶嵌的城市景观中构建可持续植被景观和重建荒野生境。

2 城市植被再野化技术框架——以野花草甸为例

基于自然荒野的景观与生态机制，城市植被再野化的基本技术目标为：通过分析荒野植物群落的物种组成、群落结构及生态功能，使其结构与功能接近荒野植物群落，最终实现在无人工或粗放管护条件下，借助自然演替和景观生态流的作用进行自我维持。本研究以野花草甸为例，提出城市植被再野化基本技术范式的关键流程（图1）：1）调控生态流，驱动植物群落的自我设计；2）充分利用微地形设计，创造风力与水力传播条件；3）模拟荒野野花草甸群落结构进行拟自然设计；4）植物群落—动物关键种协同共生设计；5）运用自然柔性材料（如残枝与块石等）进行设计。

2.1 自我设计

荒野生境的最佳管理方式之一是通过设置保护红线与制定“善意忽略策略”（benign neglect strategy）来减少人为干扰，以促进植被的自然演替[16][17]。为尽可能减少人工管护并适应自然管理做功，再野化的植被群落需要具备良好的自我设计能力以实现群落的自我维持。可从以下三个方面建立和发挥植物群落的自我设计能力：

optimizes urban landscapes with spontaneous vegetation[13]. This strategy has been applied in worldwide projects like Landscape Park Duisburg-Nord and Carl-Alexander Park in Germany, High Line Park in the United States, and Jiangyangfan Eco-Park, China.

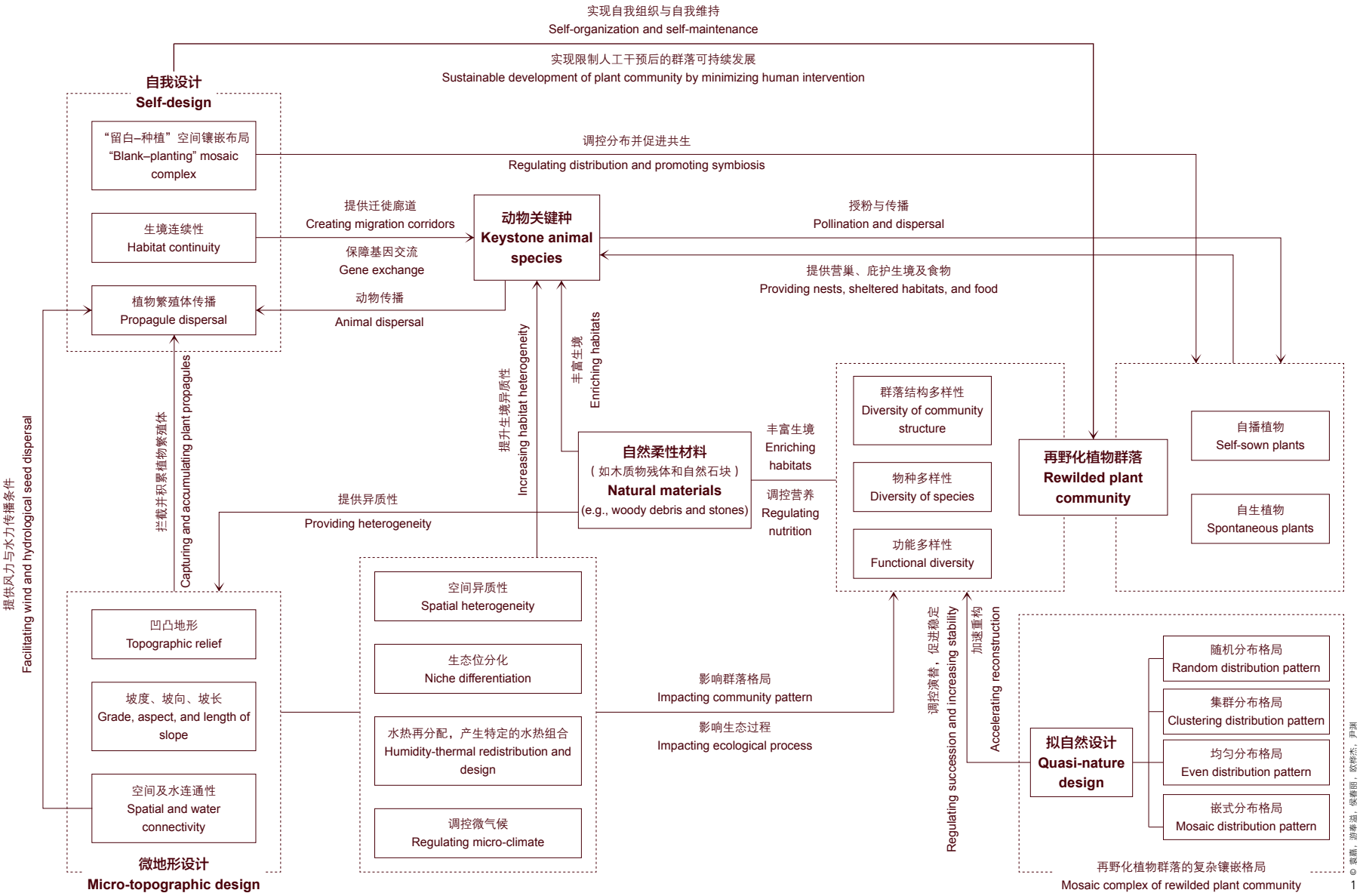
However, vegetation rewilding approaches that minimize human interventions and use spontaneous plants see limitations such like uncertain and long-time succession of communities, poor stability of vegetation structure and functions, and low landscape attractiveness[13]. New approaches to urban vegetation rewilding are required to build appealing wild plant communities with a directed succession and in an efficient way. In recent years, more and more restoration design practices of urban rewilded landscapes stimulate natural wildflower meadows[14] which have stable community structures, visual attractiveness, and diverse ecosystem services[15]. On this basis, this paper, taking wildflower meadows as a reference, proposes the methods to rebuild urban wilderness with minimum interventions, and establishes a technical framework of urban vegetation rewilding by leveraging ecological flows and adopting quasi-nature design. Studying the green space along the northwest lakeside of the Shuangguihu National Wetland Park in Liangping District, Chongqing, this paper provides a scientific guidance and technical paradigm for vegetation rewilding and urban wilderness restoration in the complex context of natural–artificial urban landscapes.

2 A Technical Framework of Urban Vegetation Rewilding: Wildflower Meadow Restoration

Based on the landscape and ecological mechanism of the wilderness, the primary technical objective of urban vegetation rewilding is to analyze the species composition, structure, and ecological functions of wild plant communities, imitating their structures and functions to achieve a self-maintained urban vegetation community along natural succession and ecological flows. Illustrating with a case of wildflower meadow restoration, this paper comes up with the key procedures of urban vegetation rewilding (Fig. 1): 1) regulating ecological flows to drive the self-design of plant communities; 2) using micro-topographic design to improve habitat heterogeneity, as well as the wind and hydrological seed dispersal; 3) mimicking the community structure of wildflower meadows; 4) establishing the collaborative symbiosis between plant community and keystone animal species; and 5) combining the design with natural soft materials, e.g., woody debris and rocks.

2.1 Self-design

One of the best management practices of the wilderness is to identify the protection boundary and develop benign neglect strategies so as to reduce human management and promote natural succession[16][17]. Rewilded plant community can be designed to improve its self-design capacity for self-maintenance in the following ways:



1. 城市植被再野化技术框架
1. The technical framework of urban vegetation rewilding

1）选用可自播繁衍的植物物种：难以自播或自播后无法完成生活史的植物物种在缺少替换与补植等人工干预的城市荒野生境中会被迅速淘汰。可自播繁衍的草本植物种类能够通过播种占据空间与资源，建立对入侵物种的竞争优势，维持群落组成与结构的稳定。可自播繁衍的植物是城市植被再野化的重要种源。种子能够长期存活于地表以下，并在自然灾害或次生灾害发生后重塑地表植被；种子随风、水与动物传播，在林地、湿地、阳台与屋顶、人行道或石墙缝隙等城市环境中萌发，完成野花草甸的迁移与复制。

1) Selecting self-sown species: Species that can hardly plant or establish itself would be eliminated soon in urban wilderness when human intervention is minimized. Self-sown herbaceous species can be dominant in space and resources, maintaining the stability of community composition and structure against invasive species. Self-sown species can provide important germplasm for urban vegetation rewilding. Their seeds survive as parts of soil seed bank that restructures the ground vegetation after natural disasters or secondary disasters. Via wind, water or animals, these seeds can disperse to other urban habitats such as forests, wetlands, terraces or rooftops, sidewalks, and cracks of stone walls, resulting in the migration and colonies of rewilded meadows.

2）为自生植物预留空间：自生植物是城市生物多样性的重要组成部分，对城市环境具有良好适应能力，是城市荒野生境形成的关键要素。再野化野花草甸设计应创建种植空间和留白空间的嵌套生境格局，不仅可以促进土壤种子库中自生植物的萌发生长，也为借助风、水及动物传播的自生植物提供了生长空间，进而可建立丰富多样的自生植物群落。

3）提高生境连续性：提高生境连续性有利于保障物种在生境斑块间的扩散与基因交流[18]，能够保证野花草甸的遗传多样性；通过拆除物理边界来保持设计地块的开放性；基于更大尺度的城市景观格局，以风廊、水廊及生物走廊连通场地与其他景观斑块；以及设计不同演替阶段的群落镶嵌分布。

2.2 微地形设计

地形变化是形成空间异质性的重要原因，宏观地形起伏对生物多样性的演变和分布具有调控作用[19]，而微地形的变化则是塑造植物生境的关键。荒野野花草甸景观因内部微地形变化（图2）而产生的特定水热条件将影响微气候并形成生态位分化，从而对植物群落的格局和生态过程产生深刻影响[20]-[22]。

微地形因素（包括坡度、坡向、坡长与起伏程度等）决定了土壤与水分的留存能力，以及温度和光照分布，从而影响植物群落的组成结构、数量分布及生长发育状况[23][24]。超过30° 的大斜率坡面土壤含量较低且利于排水，适于耐瘠薄与耐旱植物生长[22]；平缓的坡面湿度适中，且水湿变化较为丰富，设计营建缓坡并增加坡长能有效增加坡面面积，有利于增加植物群落的物种丰富度[25]；南向坡地利于聚热采光，有助于提升物种多样性并促进植物生长[26]。凹凸地形及其组合能通过制造地表的小微起伏缓冲或拦截水流以获取随水传播的植物繁殖体，从而建立自生植被群落。浅洼地与沟槽等浅凹地形可保持较高的土壤水分；池、塘、渠等深凹地形能够拦截并蓄滞地表径流，是形成小微湿地的地形要素，有利于构建湿地植物群落，并为周边生境提供良好水源、降低环境温度。小丘等凸地形能够形成遮荫，在为喜荫植物提供适宜生长条件的同时，可形成抵挡冷风的屏障或引导风向形成微型风廊。增加连续的凹凸地形变化有助于创造多样化的空间生态位，为不同植物种群的生长提供条件[27]。

2) Reserving room for spontaneous plants: Spontaneous plants are robust in urban environments, and play an important role in urban biodiversity and urban rewilding. Establishing a mosaic pattern of rewilded meadow, which both considers planting space and reverses blank space for the growth of spontaneous species in the soil seed bank and for the colony of seeds dispersed by wind, water, and animals. In this way, a diverse community of spontaneous plants can be established.

3) Enhancing habitat patch continuity: Enhancing the continuity among habitat patches facilitates species spread and gene flows[18], ensuring the genetic diversity of rewilded meadows. The physical boundaries between the habitat patches shall be removed. Connecting the restoration site with other habitat patches with ecological corridors for natural dispersal. Besides, adopting a mosaic distribution of plant communities at different succession stages is also encouraged.

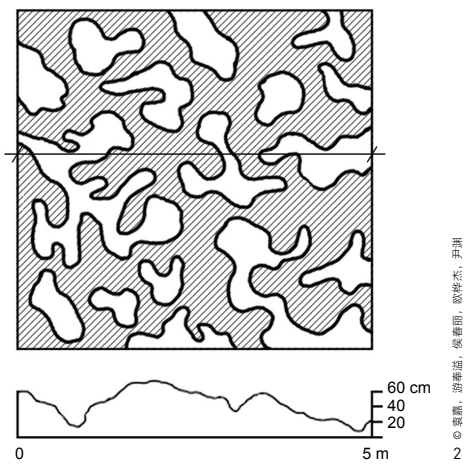
2.2 Micro-topographic Design

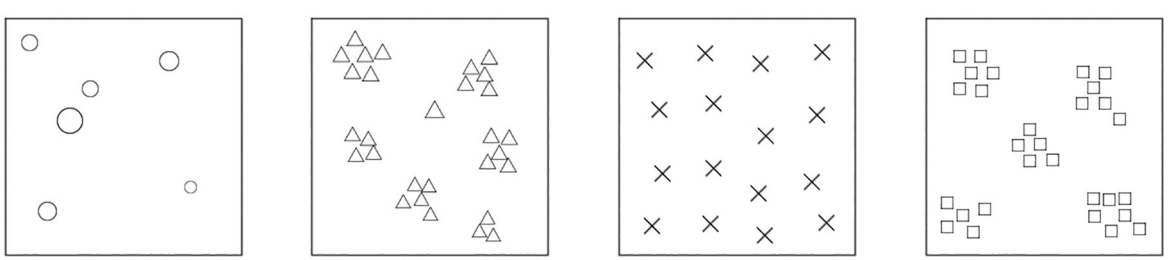
Topographic change is the main causality to spatial heterogeneity. The macro-scale terrain design would help regulate the evolution and distribution of biodiversity[19], while the micro-topography defines the plant species habitats. The humidity-thermal condition resulting from micro-topographic variation within natural meadows (Fig. 2) would impact the micro-climate and differentiate niche, which will then profoundly impact the pattern and ecological processes of plant communities[20]~[22].

Micro-topographic factors (including the grade, aspect, and length of slope; and the topography) define the preservation capacity of soil and water, and the solar and thermal distribution, which will then determine the composition, quantity, distribution, and growth of the plant communities[23][24]. For example, a steep slope of over 30° is often covered by thin soil layer, and has relatively good drainage condition that is suitable for drought-tolerant plant species[22]. Since gentle slopes would have a mesic moisture with a richer moisture gradient, the increase of the length of slope will enrich the plant species that grow in different moisture regimes[25]. South-faced slopes have better light and thermal conditions, which is conducive to enhancing the species diversity and facilitating plant growth[26]. Through the design of topographic relief, buffers can be created to gather the plant propagules via water dispersal, then establishing spontaneous plant communities. Shallow depressions and swales can keep soil moisture, while deep concave terrain such as ponds and canals can retain runoffs. These landform design measures are often used in constructing micro and seasonal wetlands, to provide water source for nearby habitats and adjust microclimate. Small hills can provide shade and suitable growth conditions for shade-requiring species, and form shelters against cold wind or guide the wind to form micro-wind-corridors. Enriching the topographic relief helps create diverse niches, providing suitable growth conditions for various plant communities[27].

2. 中国四姑娘山地区高山野花草甸及其内部微地形变化
3. 荒野野花草甸群落的水平分布格局示意图（改绘自参考文献[29]）

2. Wildflower meadows on the Mount Siguniang in China and the micro-topographical changes
3. Diagrams of the horizontal distribution of the wildflower meadow community (Adaptation source: Ref. [29])





随机分布格局
Random distribution

集群分布格局
Clustering distribution

均匀分布格局
Even distribution

嵌式分布格局
Mosaic distribution

2.3 拟自然设计

荒野野花草甸群落具备复杂的水平结构，包含三种基本分布格局（图3）：

1）随机分布，指植物个体在水平空间中偶然出现，个体间的位置没有必然联系；

2）集群分布，指植物个体成群成簇地密集分布；

3）均匀分布，指植物个体按一定间距分布[28]，当种群个体簇生集合成许多集群且集群间呈规则分布，则将形成一种特殊的集群分布形式——嵌式分布[29]。

基于荒野群落的形成机制进行拟自然设计是合理调控再野化野花草甸的演替过程、形成稳定群落结构的关键。植物被引入新地块时，往往依种子的散布而随机分布。设计应建立“留白—种植”空间的复合嵌套格局，不仅有利于群落自我设计，也可限制迁入物种的生长空间，促进自生植物形成集群格局。将环境适应能力良好并能提供重要生物多样性保育与环境调节功能的植物（如蜜粉源植物、寄主植物和净水植物）进行集群种植，形成优势种群，有利于抵御外来物种入侵。自播植物的种子一般落在母株附近萌发，能够较好地保持种群的集群分布格局，并随

2.3 Quasi-Nature Design

Natural meadows can be horizontally structured as in three patterns (Fig. 3):

1) Random distribution: plants haphazardly distribute horizontally, and each individual plant has no spatial relation with others;

2) Clustering distribution: plants densely distribute in clusters;

And 3) even distribution: plants distribute by certain distances[28], and when a number of individual clusters form a particular pattern, a mosaic distribution comes into being[29].

The aim of quasi-nature design is to regulate the succession of rewilded meadows and maintain their community structures by learning from sustainable communities in wilderness. For a randomized species assemblage of naturally colonized plants, the “blank–planting” mosaic complex not only facilitates self-design of the spontaneous communities, but also limits the growth of introduced plant species, fostering the establishment of the clusters of spontaneous plants which can have a better environmental adaptability, provide ecological benefits (e.g., nectar and pollen source, hosting, and water purification), grow into the dominant populations, and resist the invasion of exotic species. The seeds of self-sown plants often sprout near the maternal plants, which maintain the clustering pattern of mixed species and generally result in an even distribution over time[29]. A mixed-species meadow in an evenly distributing pattern often has a richer color combination and a higher attractiveness to wildlife and human beings[30][31].

时间趋向于均匀分布[29]。均匀分布格局往往有利于形成更为丰富的色彩组合，进而增强对野生动物的吸引力及景观观赏体验[30][31]。混播是营建均匀分布格局的良好方式，同时也能够极大降低成本投入与环境影响[32]。播种时要避免使用生长迅速、结种量过大、匍匐茎或根状茎过于发达的植物种类，避免形成单优群落。

2.4 植物群落－动物关键种协同共生设计

传粉昆虫维持着植物群落的有性繁殖与遗传活力，食用并携带植物繁殖体的小型鸟类与兽类则扮演着传播植物的关键角色[33]。这些物种对城市景观的植物分布和多样性具有重要调控作用，是“动物关键种”（keystone animal species）[34]，其种群生存繁衍情况与荒野生境的比例和面积密切相关[35]。引入动物关键种、促成“植物群落－动物关键种”的协同共生是城市植被再野化的核心目标和重要实现途径。

通过提供“踏脚石”、食物来源与营巢条件，可以吸引并保育动物关键种。城市野花草甸的选址应介于人工绿地斑块之间，以形成有效的“踏脚石”，并尽量形成廊道格局引导动物关键种的迁移，促进基因流[36]。选择蜜粉源丰富的乡土植物作为建群种可以为传粉昆虫提供充足的食物；增加蜜粉源植物的种类多样性能够有效增强传粉昆虫和植物的“取食－传粉”共生结构的复杂嵌套，从而提高野花草甸群落的结构稳定性和传粉昆虫的种群增长率[37][38]；将蜜粉源植物进行集群配置有助于传粉昆虫发现和搜集蜜粉[33]。野花草甸群落的地上亚层与地下分层可为动物关键种的栖息、完成生活史和繁衍提供多样化的生态位和巢穴空间。疏松土壤或卵石堆、块石堆提供的孔穴空间能够为部分不具备筑巢能力的传粉昆虫和小型兽类提供庇护空间；由木材、砖块或聚氯乙烯管等废弃材料建造的多孔穴小型设施也能够成为良好的巢穴空间[39]。

Mixture sowing can help establish an even distribution and reduce the cost and environmental impact significantly[32]; however, the use of species with rhizomes, a greater plant size or seed quantity should be avoided.

2.4 Collaborative Symbiosis Design Between Plant Community and Keystone Animal Species

Pollinator insects are vital to sustaining the sexual reproduction and genetic heredity of plant communities. Small birds and mammals that feed on and carry plant propagules play a key role to the propagule dispersal[33]. These species, as keystone animal species, regulate the plant distribution and diversity of urban landscapes[34]. The survival and reproduction of these species is largely impacted by the proportion and area of the wilderness[35]. Thus, one of the primary objectives of urban vegetation rewilding is to introduce the keystone animal species and encourage their collaborative symbiosis with plant communities.

Creating favorable stepping-stones, food sources, and nestling conditions can attract and conserve keystone animal species. Rewilded meadows should be located among artificial patches to form effective stepping-stones and corridors that could guide the migration of keystone animal species and enhance gene flows[36]. Native nectariferous plants provide sufficient food sources for pollinators. Increased diversity of nectariferous plant species enhances the mosaic complexity of the feeding–pollinating symbiosis structure, thus strengthening the stability of rewilded meadow and increasing the population of pollinators[37][38]. Clustering nectariferous plants can promote pollinators' nectar collection[33]. Increasing the number of aboveground and underground layers of the rewilded meadows can diversify niches and nestling spaces for the inhabitation, completion of life history, and reproduction

4. 中国川西荒野中的野花草甸及其内部分布的木质物残体与自然石块

4. Wildflower meadow in western Sichuan, and the woody debris and natural stones within.

5. 研究场地区位图及实施修复前航拍照片

5. Site location and aerial photo before restoration

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2.5 自然柔性材料的设计运用

荒野野花草甸内部往往大量分布着自然柔性材料，例如腐烂的树桩、倒木、枯枝等木质物残体，以及砾石、片石、卵石等自然石块（图4）。自然柔性材料附近分布的植物群落往往具有更丰富的物种多样性与群落结构复杂性，能够有效支撑生态系统的结构与组成异质性[40]。木质物残体在分解过程中能够释放氮、磷等营养元素，为周边生境提供营养；木质物残体和自然石块粗糙、龟裂的表面有利于土壤积存和植物种子附着，是良好的自生植物苗床；木质物残体和自然石块不仅能够为喜光植物提供更高的生长平台，还能够形成小范围的遮荫与潮湿空间，为耐荫植物和苔藓植物提供良好的生长条件，借此促进土壤碳平衡与水分涵养[41][42]。同时，木质物残体和自然石块既是鸟类与传粉昆虫的良好落脚点，又能够为喜阴湿环境的无脊椎动物提供生境，进而吸引鸟类停留取食。因此，主动置入与利用自然柔性材料应成为城市野花草甸再野化与荒野生境重建的重要设计措施。

3 设计案例：重庆双桂湖国家湿地公园植被再野化实践

3.1 研究场地与设计目标

研究场地位于重庆市梁平区中心地带，是双桂湖国家湿地公园湖区西北侧滨水空间内的公园绿地。场地面积约3.72hm^2，整体地势自北向南平缓降低，北侧紧邻梁平区新建开发区（图5）。实施修复前，研究区域原地势平缓，含有大面积的均质生境，难以促进生物多样性提

of keystone species. Loose soils, gravels or rocks, and small-sized porous spaces built with woody debris, bricks or PVC pipes can also provide ideal habitats for pollinators and small wild animals[39].

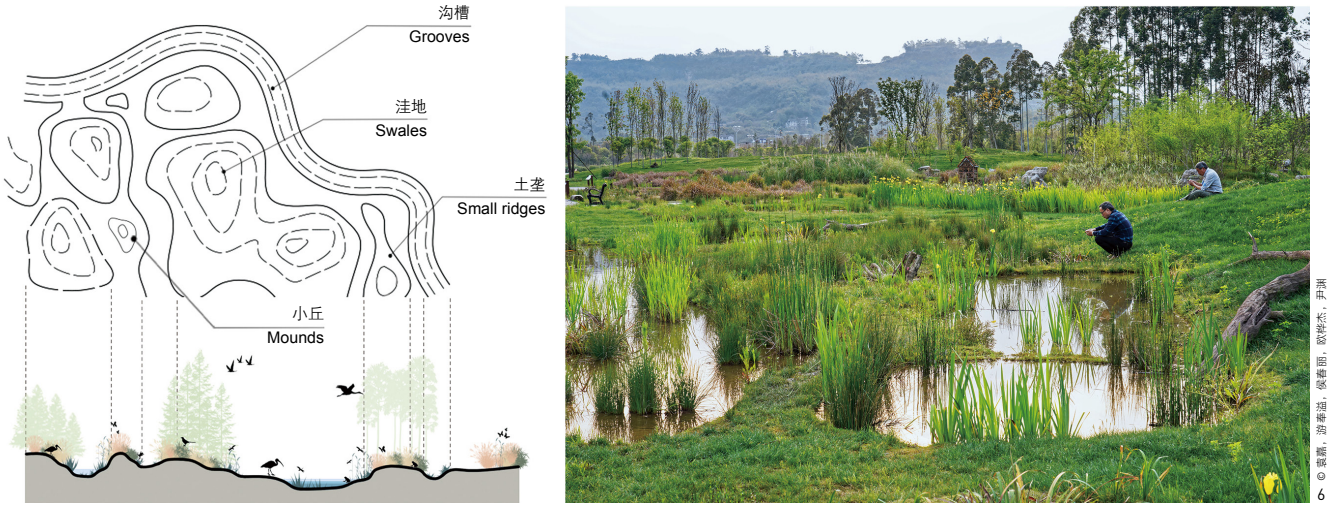
2.5 Design With Natural Materials

There are often massive natural materials within the natural meadow itself, including rotten stumps, logs, deadwood, gravels, rubbles, and pebbles (Fig. 4). The plant communities nearby such materials often see a richer biodiversity and greater structure complexity, supporting the heterogeneity of ecosystem structure and composition[40]. Woody debris would release nitrogen and phosphorus during decomposition, increasing the nutrient level of nearby habitats. The rough surfaces of woody debris and natural stones help with soil gathering and provide seed beds for spontaneous plants. These materials not only provide higher growth beds for photophilous plants, but also create micro-scale shading and moist habitats for shade-tolerant species and mosses which help adjust the carbon balance and water conservation of soil[41][42]. Also, woody debris and natural stones act as footholds for birds and pollinators, and provide habitats for invertebrates that favor shade and humid environment. Therefore, the use of natural materials shall be emphasized in the rewilding of urban meadow and urban wilderness rehabilitation.

3 Case Study: Vegetation Rewilding in Shuangguihu National Wetland Park, Chongqing

3.1 Study Site and Design Objectives

The paper studies the green space on the northwest lakeside of Shuangguihu National Wetland Park, which sits in the central area of Liangping District, Chongqing City. Covering an area of 3.72 hm^2, the site is high in the north and low in the south in elevation, and neighbors a newly developed zone in the north (Fig. 5). Before



6. 研究场地微地形营造与生境设计示意图与现场照片（摄于2020年4月）

6. Micro-topography creation and habitat design (taken in April 2020)

升，有害生物的入侵与扩散较为明显，影响景观的生态可持续性。场地内植物种类贫乏，以狗牙根（*Cynodon dactylon*）、结缕草（*Zoysia japonica*）等草坪草为群落优势种，鬼针草（*Bidens pilosa*）、喜旱莲子草（*Alternanthera philoxeroides*）、小蓬草（*Erigeron canadensis*）等入侵植物较多；草坪退化严重、景观品质差，生态系统服务低下。

研究区域是城市建成环境与双桂湖水体之间的重要生态屏障，需要提供生态缓冲和生物多样性保育等生态系统服务，并以最小化建设与管控成本实现景观的可持续性。自2018年起，研究团队（即本文作者）通过实施植被再野化进行生境修复，以期实现荒野意象与功能的回归，重建自然—人工复合系统的生态平衡。

3.2 微地形营造与生境设计

研究遵循并强调浅水区—湖岸带—过渡坡地—高地空间梯度上的生境变化与连续性，构建了宽度、深度、坡度变化丰富的洼地、沟槽、小丘、土垄等凹凸地形组合，提供多种多样的基面并产生多样化的水热条件，从而提升景观的生境异质性。设计增加了洼地与土垄结构中南向缓坡的占比与坡长，有利于温度累积和丰富水湿梯度变化，同时保障了高坡—湖体之间的自然径流过程与竖向生态交换的基本连续性。设计营建了由“塘—坑—沟—渠—湖”结构复杂水平镶嵌而成的小微湿地群（图6），重建了多景观层次、多生态序列的荒野生境。复杂性与连续性并

the restoration, the study area’s terrain was flat and homed a large area of homogeneous habitat, which resulted in a poor biodiversity and the invasion of harmful organisms, severely impacting the site’s ecological sustainability. The site was predominated by a few of grass species including *Cynodon dactylon* and *Zoysia japonica*, and invasive ruderals including *Bidens pilosa*, *Alternanthera philoxeroides*, and *Erigeron Canadensis*. The existing lawn was severely degraded and deteriorated in ecosystem services.

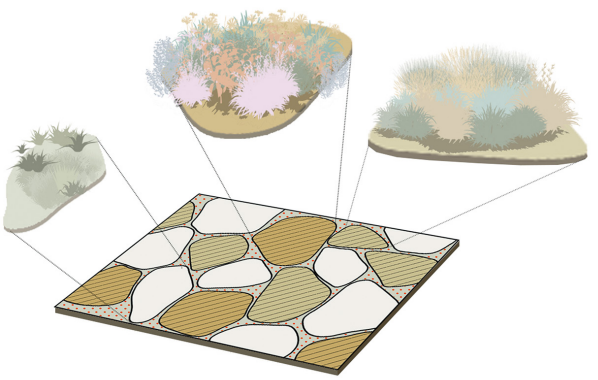
The site is one of the important ecological buffers between the built environment and water bodies in the city. It is required to provide ecosystem services such as ecological buffer and biodiversity conservation, and to ensure the landscape sustainability while minimizing construction and maintenance cost. Since 2018, the research team (the authors) have worked on habitat restoration via vegetation rewilding, facilitating the return of the wilderness in image and function, and rebuilding the eco-balance of artificial ecosystems with nature.

3.2 Micro-topography Creation and Habitat Design

In line with the habitat gradient and continuity from shallow water, lakefront, buffer slope to upland, the design created micro-topography such as swales, grooves, mounds, small ridges with dynamic changes in width, height, and slope. The combination of concave and convex microstructures can enrich the site’s contour and diversify humidity-thermal conditions, resulting in an increase of habitat heterogeneity. The design increased the amount and length of south-facing slope in swales and ridges to facilitate thermal accumulation and dynamic moisture content, and guarantee the continuity of natural runoffs and vertical ecological exchanges between the slopes and the lake. The design created clusters of small and micro wetland groups formed by mosaic complex of “pond–pit–swale–ditch–lake” (Fig. 6), thereby established the urban wilderness with multiple functional layers and multiple ecological sequences. With emphasis on the complexity and continuity of micro-topography creation, the design promotes the

表1：研究场地内新引入的植物物种
Table 1: The newly introduced plant species to the study site

阔叶草花集群（密集混栽成苗） The assembly of broad-leaf flower species (mixed seedlings densely planted)	高草集群（密集混栽成苗） The mixture of tall grass species (mixed seedlings densely planted)	均匀式种子混播组合 The seed mixture for evenly planting
大花萱草 *Hemerocallis hybridus*	斑叶芒 *Miscanthus sinensis* 'Zebrinus'	雏菊 *Bellis perennis*
钓钟柳 *Penstemon campanulatus*	灯心草 *Juncus effusus*	大滨菊 *Leucanthemum maximum*
佛甲草 *Sedum lineare*	黑心菊 *Rudbeckia hirta*	黑心菊 *Rudbeckia hirta*
黄金菊 *Euryops pectinatus*	节节草 *Equisetum ramosissimum*	金鸡菊 *Coreopsis basalis*
藿香蓟 *Ageratum conyzoides*	蓝羊茅 *Festuca glauca*	美女樱 *Glandularia* × *hybrida*
假龙头花 *Physostegia virginiana*	墨西哥鼠尾草 *Salvia leucantha*	蓍 *Achillea millefolium*
柳叶马鞭草 *Verbena bonariensis*	千屈菜 *Lythrum salicaria*	松果菊 *Echinacea purpurea*
毛地黄 *Digitalis purpurea*	细叶芒 *Miscanthus sinensis* 'Gracillimus'	天人菊 *Gaillardia pulchella*
鼠尾草 *Salvia japonica*		天竺葵 *Pelargonium hortorum*
千屈菜 *Lythrum salicaria*		黄花鸢尾 *Iris wilsonii*
山桃草 *Gaura lindheimeri*		
土人参 *Talinum paniculatum*		
玉簪 *Hosta plantaginea*		
八宝 *Hylotelephium erythrostictum*		



7. 留白空间－种植空间嵌套格局与集群分布布局

7. The blank–planting mosaic pattern and the clustering distribution of planting design

重的微地形设计有利于引导植物借助水流及动物媒介在场地内外扩繁，形成自我设计与维持的再野化植被。

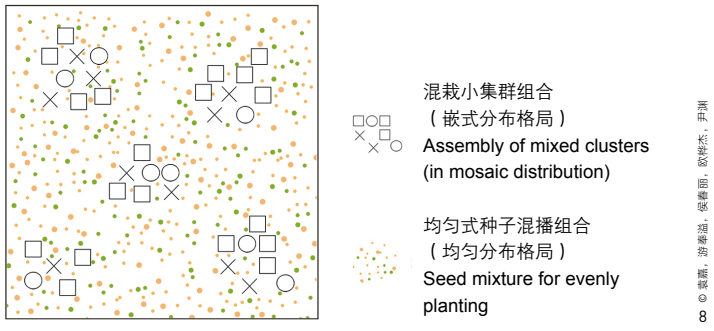
3.3 植物选择与空间布局

设计在场地内引入了30余种具有良好自播能力的多年生草本植物（表1），在水平空间布局上采用“留白—种植”的空间嵌套格局（图7）。为控制成本投入，种植空间仅占场地面积的40%左右。场地自北向南平缓降低的地势变化，以及重庆地区秋冬季盛行偏北风，使成熟种子随自然径流和风传播的基本方向一致；鸟类与小型哺乳动物进入场地寻觅水源的行动方向也与风力、水力传播方向接近。因此，设计主动调控了提供重要种源群落的种植空间的分布，使种植空间的数量与面积占比从北至南、由高到低逐渐递减，借助场地内生态流（水、风和动物）传播植物，实现低干预的植被再野化。此外，为保护双桂湖水体与土壤种子库，再野化实施期间不施用任何化学除草剂，仅人工拔除恶性杂草（如鬼针草和喜旱莲子草）。

natural dispersal in and out of the site via flows and animals, ensuring the self-design and self-maintenance of rewilded vegetation.

3.3 Plant Species Selection and Planting Design

Over 30 perennial species with excellent self-sown capacity were introduced to the site (Table 1), and the blank–planting mosaic complex was used horizontally (Fig. 7). For considerations on project cost, the planting space only covers 40% of the site area. The site gently sloped from north to south, coupled with the prevailing north winds in Chongqing in autumn and winter, resulting in a same basic direction of seed dispersal by natural runoffs and wind, which is also the same as the direction that birds and small mammals enter the site to collect water. Therefore, the design regulates the distribution of planting space, so that the number and area of planting space gradually decrease from north to south along the slope. In this way, ecological flows (e.g., water, wind, and animal) leverages plant spread, ensuring the low-intervention vegetation rewilding. In addition, to environmental protection reasons, no chemical herbicide was used during the entire rewilding process. Weeds (e.g. *Bidens pilosa* and *Alternanthera philoxeroides*) were suppressed manually.



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自然界中植物群落的镶嵌格局十分复杂，本研究采用嵌式分布与均匀分布格局，形成易操作、可控性好的水平种植格局图式（图8）。密集混栽具有重要生态功能的植物物种，形成小集群；这些小集群之间可形成规则的嵌式分布格局，以便施工人员定点种植；集群种植也有利于隔离具有直接竞争关系的植物物种。同时，选择种子萌发能力强、开花时间交错的植物物种，形成种子混播组合，均匀撒播以尽可能形成均匀分布格局。依据不同植物的种子千粒重与种子萌发率计算该物种种子在组合中所占的重量比例，使每个物种所占数量接近；在小集群之间的空隙播种混种组合，播种量约为5g/m^2。

3.4 动物关键种保育设计

研究设计的三种小集群模式分别对应了三种“植物群落—动物关键种”组团模式：

1）阔叶草花—传粉昆虫组团：以总状花序较大、色彩鲜明且蜜粉源丰富的阔叶草本植物为优势种，吸引并保育传粉昆虫种群；

2）高草—小型鸟类组团：以植株较大的观赏禾草为优势种，为小型鸟类提供庇护生境；

3）自生植物—土壤动物组团：随着自生植物在留白空间的富集逐渐形成集群，为依赖自生乡土草本植物的线虫、蚯蚓、甲虫、蜘蛛等土壤动物提供生存条件，进而借助土壤动物改善土壤结构与质量。

In nature, the mosaic pattern of plant communities is complicated. In the Shuangguihu case, the design horizontally adopted a combination of the mosaic complex and even distribution, which can be easily built and managed (Fig. 8). Plant species with important ecological functions (e.g., nectariferous plants and host plants) were densely mixed to form small clusters. The combination of small clusters can form a regular mosaic layout that allows for convenient fixed-point transplanting; and the cluster planting would separate competing species, helping maintain a diversified plant community. Mixed seeding was adopted by selecting the species with excellent germination capacity and different flowering seasons. Seed mixtures were evenly spread to form an even distribution pattern as much as possible; in the mixture, the proportion of each species was decided by seed TKW (thousand kernel weight) and germination rate, with the seeding rate being 5 g/m^2.

3.4 Conservation Design for Keystone Animal Species

Three small-clusters planting modes were employed respectively for three functional groups of plant–animal mutualism:

1) Broad-leaf herbs and pollinators, dominated by broad-leaf nectariferous herbs with large racemes and bright flowers which attract and facilitate the conservation of pollinators;

2) Tall grass and small birds, dominated by tall ornamental grass, providing shelters for small birds;

And 3) spontaneous plants and soil animals, native spontaneous plants survive and grow in the blank space, creating living conditions for soil animals (e.g., nematodes, earthworms, beetles, and spiders) and then improving the soil structure and quality.

These functional groups ensure the conservation of keystone animal species.

In terms of habitat creation, porous structures were introduced within the wildflower meadows, providing shelters for pollinators and small mammals that cannot build nests by themselves. Gentle slopes in small and micro wetlands

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8. 嵌式分布与均匀分布交错的水平种植格局示意图
9. “多孔穴小型构筑物—野花草甸—小微湿地—倒木”复合生物生境
10. 结合倒木、块石等自然柔性材料形成的不同尺寸、深度（即湿度）的连续微地形设计。

8. Mosaic planting and evenly distributing planting
9. A compound habitat is established by integrating small porous elements with wildflower meadows, small and micro wetlands, and downed logs.
10. Continuous micro-terrain design of different sizes and water depths combined with natural materials like logs and stones

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11. 再野化野花草甸景观
11. Rewilded wildflower meadow

这三个组团之间的相互嵌套也进一步保障了动物关键种保育的稳定性。

在生境营建方面，设计在野花草甸群落内部构建了多孔穴的小型构筑物，为无法自主筑巢的传粉昆虫与小型哺乳动物提供了庇护；洼地等小微湿地的边缘缓坡与留白空间组合，为蝴蝶等昆虫提供了啜饮泥浆的安全环境；小微湿地网络中放置了倒木和石块，为鸟类与昆虫提供了可短暂停留的落脚点；具有高度连续性的微地形既是青蛙等两栖动物的庇护空间，又不妨碍它们的自由运动；常年积水的深塘及水生植物群落为青蛙和昆虫若虫提供了水下栖息环境；灯心草（*Juncus effusus*）、千屈菜（*Lythrum salicaria*）等挺水植物和倒木则为昆虫提供了驻足和产卵空间（图9，10）。

3.5 绩效评估

良好的生境连续性保障了种植植物与自生植物在场地内的传播，使其不断扩繁并以走廊或网络形式分布。研究场地内的植被覆盖率、物种丰富度与结构多样性随时间推移而不断增加，展现了良好的群落自我设计与维持能力。2020年10月，研究团队在研究场地内开展调查统计，共记录草本植物116种，其中自生植物共83种。相较2018年项目实施前的调查（共记录草本植物63种），草本植物群落的物种数量增加了84.1%，自生植物物种占新增物种总数量的43.4%；自生植物与种植植物优势种群交混分布，良好共生。再野化的野花草甸群落形成了层次丰富、季相鲜明的植被景观（图11）；生境连续性、群落多样性及物种团复合镶嵌格局的复杂程度不断提高，保障了动物关键种的基因流与多样性，形成了稳定的野花草甸生态系统。修复后研究区域内动物关键种种类增长明显；其中，观测到的蝴蝶及草丛鸟种类增加最为明显。

(e.g. swales, pits, and ponds) were combined with the blank spaces, so that insects can safely sip water from damp patches for hydration. Logs and stones were placed in small and micro wetlands to provide footholds for birds and insects. The highly continuous micro-terrains provide shelters for amphibians (e.g. frogs) without impeding their free movement. Deep ponds and aquatic vegetation provide underwater habitats for frogs and nymphs; emergent plants (e.g. *Juncus effuses* and *Lythrum salicaria*) and woody debris provide halting and oviposition spaces for insects (Fig. 9, 10).

3.5 Performance Evaluation

A high habitat continuity ensures the spread of the planted and spontaneous species on the site in forms of corridors and networks. The vegetation coverage, species richness, and structure diversity increase over time, demonstrating the self-design and -maintenance capacity as expected. The research team carried out field investigation in October 2020 and found 116 herbaceous species, 83 of which are spontaneous. Compared to the survey results in 2018 before the rewilding, the number of herbaceous species increased by 84.1%; spontaneous plants accounted for 43.4% of all the newly increased species and well co-existed with the dominant plants. The rewilded meadow shows a vegetation with rich layers and distinctive seasonal changes (Fig. 11). The improvement of habitat continuity, community diversity, and mosaic pattern of functional groups guarantees gene flows and diversity of keystone species, and forms a stable wildflower meadow ecosystem. After the rewilding, the amount of keystone animal species, particularly butterflies and grassland birds, on the site increases remarkably.

除了为环境科学与生命科学的相关研究提供样本外，目前研究场地已成为重庆地区向公众传播生态文明建设与生物多样性保育知识的重要科普基地。在再野化野花草甸景观中，人们开展漫步探索，进行动植物识别与观测等在地自然教育行动（图12），传播了以“尊重、顺应、回归大自然”为核心的城市荒野认知。

4 结语

本文以荒野野花草甸为城市植被再野化及荒野生境重建的模板，从主动利用生态流、拟自然设计和最小限度干预等角度提出技术框架与应用范式，形成了一种应对城市动植物生境与整体生态系统退化的解决图景，对城市公共绿地、非林地乡村区域，以及林缘区域的再野化均有良好的参考价值。当前，来自土地开发与公众审美的挑战使得植被再野化的方法尚未在城市荒野保护与管理中广泛应用。未来，学者及行业人士需要以远见超越未知，不断揭示自然及城市荒野的形成与维持机制，改进公众对城市荒野景观的评估与认知；注重对再野化设计的定量探索，例如“留白—种植”嵌套格局中的适宜空间比例、入侵植物的防治与生态缓冲带结构组成，以及在不同空间尺度上建立多功能荒野生境的有效镶嵌与复合格局等；通过在退化绿地、闲置土地、孤立岛屿或林地等城市环境中应用自然荒野所呈现的生命智慧，逐步积累城市植被再野化与荒野生境重建的科学原则与技术方法，并为自上而下的政策和法规制定以及自下而上的实践探索提供科学依据。**LAF**

In addition to functioning as samples for the research on environmental science and life science, the site also provides opportunities for place-based ecological educational programs, which promotes the public’s knowledge about ecological civilization construction and biodiversity conservation. The rewilded meadow allows visitors to carry out walks and explorations, as well as the identification and observation of animals and plants (Fig. 12), promoting public awareness of urban wilderness and fostering the ideas that respects, adapts to, and return to nature.

4 Conclusion

With wildflower meadow as the restoration target for urban vegetation rewilding and wilderness reconstruction, this paper comes up with a technical framework and design paradigm that leverages ecological flows, quasi-nature design, and minimal intervention in urban rewilding. It offers a solution to the degradation of animal and plant habitats and urban ecosystems, which is of reference value to the rewilding of urban public green spaces, non-forest countryside areas, and forest edges. Challenged by urban development and public aesthetics, vegetation rewilding has not been widely applied in practices of urban wilderness protection and management. In future, scholars and professionals are expected to explore the mechanism of the formation and maintenance of natural and urban wilderness, improve public awareness of urban wilderness. Quantitative studies on rewilding design are needed to fully understand the appropriate-ranked proportion of the blank versus planting area, the control of invasive plants and structure of ecological buffer zone, as well as the solutions to optimizing the mosaic complex of multiple-purpose wilderness habitats on varied scales. The ecological wisdom represented by natural wilderness can also be applied in responding to the degradation of green spaces, idle lands, isolated islands or woods, so as to enhance scientific studies on the principles and technical methods associated with urban vegetation rewilding and wilderness restoration, and inform the formulation of top-down policies and bottom-up approaches to urban rewilding. **LAF**

12. 在再野化野花草甸中进行的自然教育行动
12. Public education programs in the rewilded wildflower meadow

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REFERENCES

[1] Mittermeier, R. A., Mittermeier, C. G., Brooks, T. M., Pilgrim, J. D., Konstant, W. R., da Fonseca, G. A. B., & Kormos, C. (2003). Wilderness and biodiversity conservation. *Proceedings of the National Academy of Sciences*, 100(18), 10309-10313. https://doi.org/10.1073/pnas.1732458100

[2] Daily, G. C. (1997). *Nature's services: Societal dependence on natural ecosystems*. Washington, DC: Island Press.

[3] Pimm, S. L., Ayres, M., Balmford, A., Branch, G., Brandon, K., Brooks, T., ... Wilcove, D. (2001). Can we defy nature's end? *Science*, 293(5538), 2207. doi:10.1126/science.1061626

[4] Cronon, W. (1996). U*ncommon ground: Rethinking the human place in nature*. New York, NY: W.W. Norton & Company.

[5] Botkin, D. B. (2001). *No man's garden: Thoreau and a new vision for civilization and nature*. Washington, DC: Island Press.

[6] Allan, J. R., Venter, O., & Watson, J. E. M. (2017). Temporally inter-comparable maps of terrestrial wilderness and the last of the wild. *Scientific Data*, 4(1), 170-187. doi:10.1038/sdata.2017.187

[7] Watson, J. E. M., Shanahan, D. F., Di Marco, M., Allan, J., Laurance, W. F., Sanderson, E.W., ... Venter, O. (2016). Catastrophic declines in wilderness areas undermine global environment targets. *Current Biology*, 26(21), 2929-2934. doi:10.1016/j.cub.2016.08.049

[8] Jorgensen, A., & Tylecote, M. (2007). Ambivalent landscapes—Wilderness in the urban interstices. *Landscape Research*, 32(4), 443-462. doi:10.1080/01426390701449802

[9] Page, J. (2016). *Tidy or tangled: How people perceive landscapes*. University of Maryland, Partnership for Action Learning in Sustainability. https://doi.org/10.13016/M2HH6C69B

[10] Kowarik, I., Hiller, A., Planchuelo, G., Seitz, B., von der Lippe, M., & Buchholz, S. (2019). Emerging urban forests: opportunities for promoting the wild side of the urban green infrastructure. *Sustainability*, 11(22), 6318. https://doi.org/10.3390/su11226318

[11] Kowarik, I. (2018). Urban wilderness: Supply, demand, and access. *Urban Forestry & Urban Greening*, (29), 336-347. https://doi.org/10.1016/j.ufug.2017.05.017

[12] Nassauer, J. I. (1995). Messy ecosystems, orderly frames. *Landscape Journal*, 14(2), 161-170. doi:10.3368/lj.14.2.161

[13] Kühn, N. (2006). Intentions for the unintentional. *Journal of Landscape Architecture*, 1(2), 46-53. doi:10.1080/18626033.2006.9723372

[14] Hoyle, H., Jorgensen, A., Warren, P., Dunnett, N., & Evans, K. (2017). "Not in their front yard"—The opportunities and challenges of introducing perennial urban meadows: A local authority stakeholder perspective. *Urban Forestry & Urban Greening*, (25), 139-149. https://doi.org/10.1016/j.ufug.2017.05.009

[15] Gibbons, B. (2014). *Wildflower wonders: The 50 best wildflower sites in the world*. London, England: A&C Black.

[16] Bernes, C., Jonsson, B. G., Junninen, K., Lõhmus, A., Macdonald, E., Müller, J., & Sandström, J. (2015). What is the impact of active management on biodiversity in boreal and temperate forests set aside for conservation or restoration? A systematic map. *Environmental Evidence*, 4(1), 25. https://doi.org/10.1186/s13750-015-0050-7

[17] Müller, A., Bøcher, P. K., Fischer, C., & Svenning, J. -C. (2018). 'Wild' in the city context: Do relative wild areas offer opportunities for urban biodiversity? *Landscape and Urban Planning*, (170), 256-265. https://doi.org/10.1016/j.landurbplan.2017.09.027

[18] Bollmann, K., & Braunisch, V. (2013). To integrate or to segregate: balancing commodity production and biodiversity conservation in European forests. In D. Kraus, & F. Krumm (Eds.), *Integrative approaches as an opportunity for the conversation of forest biodiversity* (pp. 18-31). Joensuu, Finland: European Forest Institute.

[19] Antonelli, A., Kissling, W. D., Flantua, S. G. A., Bermúdez, M. A., Mulch, A., Muellner-Riehl, A. N., ... Hoorn, C. (2018). Geological and climatic influences on mountain biodiversity. *Nature Geoscience*, 11(10), 718-725. https://doi.org/10.5281/zenodo.1341999

[20] Ivanov, V. Y., Bras, R. L., & Vivoni, E. R. (2008). Vegetation-hydrology dynamics in complex terrain of semiarid areas: 2. Energy-water controls of vegetation spatiotemporal dynamics and topographic niches of favorability. *Water Resources Research*, 44(3), W03430. https://doi.org/10.1029/2006WR005595

[21] Denney, D. A., Jameel, M. I., Bemmels, J. B., Rochford, M. E., & Anderson, J. T. (2020). Small spaces, big impacts: contributions of micro-environmental variation to population persistence under climate change. *AoB PLANTS*, 12(2), plaa005. https://doi.org/10.1093/aobpla/plaa005

[22] Hais, M., Chytrý, M., & Horsák, M. (2016). Exposure-related forest-steppe: A diverse landscape type determined by topography and climate. *Journal of Arid Environments*, (135), 75-84. https://doi.org/10.1016/j.jaridenv.2016.08.011

[23] Pereira, A. (2016). Plant abiotic stress challenges from the changing environment. *Frontiers in Plant Science*, (7), 1123. https://doi.org/10.3389/fpls.2016.01123

[24] Li, X., Fan, S., Guan, J., Zhao, F., & Dong, L. (2019). Diversity and influencing factors on spontaneous plant distribution in Beijing Olympic Forest Park. *Landscape and Urban Planning*, (181), 157-168. https://doi.org/10.1016/j.landurbplan.2018.09.018

[25] Yuan, J., & Dunnett, N. (2018). Plant selection for rain gardens: Response to simulated cyclical flooding of 15 perennial species. *Urban Forestry & Urban Greening*, (35), 57-65. https://doi.org/10.1016/j.ufug.2018.08.005

[26] Nadal-Romero, E., Petrlic, K., Verachtert, E., Bochet, E., & Poesen, J. (2014). Effects of slope angle and aspect on plant cover and species richness in a humid Mediterranean badland. *Earth Surface Processes and Landforms*, 39(13), 1705-1716. https://doi.org/10.1002/esp.3549

[27] Silvertown, J. (2004). Plant coexistence and the niche. *Trends in Ecology & Evolution*, 19(11), 605-611. https://doi.org/10.1016/j.tree.2004.09.003

[28] Niu, C., Lou, A., Sun, R., & Li, Q. (2015). *Foundations in ecology* (3rd ed.). Beijing, China: Higher Education Press.

[29] Song, Y. (2017). *Vegetation ecology*. Beijing, China: Higher Education Press.

[30] Dunnett, N. (2004). The dynamic nature of plant communities - pattern and process in designed plant communities. In D. Nigel, & J. Hitchmough (Eds.), *The dynamic landscape*. (pp. 97-114). London, England: Spon Press.

[31] Hoyle, H., Norton, B., Dunnett, N., Richart, J. P., Russell, J. M., & Warren, P. (2018). Plant species or flower colour diversity? Identifying the drivers of public and invertebrate response to designed annual meadows. *Landscape and Urban Planning*, (180), 103-113. https://doi.org/10.1016/j.landurbplan.2018.08.017

[32] Hitchmough, J., & Dunnett, N. (2004). Introduction to naturalistic planting in urban landscapes. In D. Nigel, & J. Hitchmough (Eds.), *The dynamic landscape* (pp. 1-32). London, England: Spon Press.

[33] Yuan, J. & Du, C. (2020). Design framework of collaborative symbiosis between urban plant landscape and keystone species: Taking wildflower meadows and pollinators as a case study. *Landscape Architecture*, 27(4), 50-55. doi:10.14085/j.fjyl.2020.04.0050.06

[34] Paine, R. T. (1969). A note on trophic complexity and community stability. *The American Naturalist*, 103(929), 91-93. https://doi.org/10.1086/282586

[35] Senapathi, D., Goddard, M. A., Kunin, W. E., & Baldock, K. C. R. (2017). Landscape impacts on pollinator communities in temperate systems: Evidence and knowledge gaps. *Functional Ecology*, 31(1), 26-37. https://doi.org/10.1111/1365-2435.12809

[36] Jha, S., & Kremen, C. (2013). Urban land use limits regional bumble bee gene flow. *Molecular Ecology*, 22(9), 2483-2495. doi:10.1111/mec.12275

[37] Menz, M. H. M., Phillips, R. D., Winfree, R., Kremen, C., Aizen, M. A., Johnson, S. D., & Dixon, K. W. (2011). Reconnecting plants and pollinators: Challenges in the restoration of pollination mutualisms. *Trends in Plant Science*, 16(1), 4-12. https://doi.org/10.1016/j.tplants.2010.09.006

[38] Rohr, R. P., Saavedra, S., & Bascompte, J. (2014). On the structural stability of mutualistic systems. *Science*, 345(6195), 416-425. doi:10.1126/science.1253497

[39] MacIvor, J. S., & Packer, L. (2015). 'Bee Hotels' as tools for native pollinator conservation: A premature verdict? *PLoS ONE*, 10(3), e0122126. https://doi.org/10.1371/journal.pone.0122126

[40] Seibold, S., Bässler, C., Brandl, R., Gossner, M. M., Thorn, S., Ulyshen, M. D., & Müller, J. (2015). Experimental studies of dead-wood biodiversity—A review identifying global gaps in knowledge. *Biological Conservation*, (191), 139-149. https://doi.org/10.1016/j.biocon.2015.06.006

[41] Silvan, N., Jokinen, K., Näkkilä, J., & Tahvonen, R. (2017). Swift recovery of Sphagnum carpet and carbon sequestration after shallow Sphagnum biomass harvesting. *Mires and Peat*, (20), 1-11. https://doi.org/10.19189/MaP.2015.OMB.198

[42] Slate, M. L., Sullivan, B. W., & Callaway, R. M. (2019). Desiccation and rehydration of mosses greatly increases resource fluxes that alter soil carbon and nitrogen cycling. *Journal of Ecology*, 107(4), 1767-1778. https://doi.org/10.1111/1365-2745.13162