

Urban Biodiversity: Connotation and Development Pathways

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Abstract Urban biodiversity is a critical foundation for the health and sustainable development of urban ecosystems. This paper systematically reviews the conceptual evolution and theoretical framework of urban biodiversity, providing an in-depth analysis of its connotative composition, including core elements such as biological components, habitat systems, and environmental factors, as well as spatial scale characteristics and functional attribute dimensions. Addressing the current challenges facing urban biodiversity conservation, this paper proposes a development pathway encompassing five dimensions: survey and monitoring, planning and control, policy and regulation, technological innovation, and social participation, with case studies from both domestic and international contexts. The research indicates that urban biodiversity conservation requires a systematic strategy involving multi-disciplinary collaboration, multi-stakeholder participation, and multi-scale coordination to achieve the goal of sustainable urban development with harmonious coexistence between humans and nature.

Key words Urban biodiversity, Ecosystem services, Urban ecological space, Biodiversity conservation, Sustainable development

0 Introduction

Since the 21st century, global urbanization has advanced at an unprecedented pace. According to the *United Nations' World Urbanization Prospects 2018 Report*, the global urban population has grown from 751 million in 1950 to 4.2 billion in 2018, and is projected to reach 6.8 billion by 2050, accounting for approximately 68% of the world's total population^[1]. While rapid urbanization has brought opportunities for economic and social development, it has also placed tremendous pressure on natural ecosystems. Biodiversity loss has become a global environmental crisis on par with climate change.

The continuous decline in biodiversity has attracted widespread attention from the international community. In 2019, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) released the *Global Assessment Report on Biodiversity and Ecosystem Services*, which noted that approximately one million species of animals and plants worldwide are threatened with extinction, with many species likely to disappear within decades. The current rate of species extinction is tens to hundreds of times higher than the average over the past 10 million years^[2]. Against this backdrop, the conservation value of urban biodiversity, as the primary gathering place for human activities, has become increasingly prominent.

In December 2022, the 15th Conference of the Parties (COP15) to the Convention on Biological Diversity adopted the Kunming-Montreal Global Biodiversity Framework, establishing conservation targets such as "protecting at least 30% of land and ocean areas by 2030" (the 30 × 30 target)^[3]. This framework explicitly incor-

porates urban biodiversity into the global conservation agenda, marking cities as emerging fields and critical battlegrounds for biodiversity conservation.

In January 2024, China's Ministry of Ecology and Environment released the *China National Biodiversity Conservation Strategy and Action Plan (2023 – 2030)*, which designates "urban biodiversity" as a priority action area and explicitly proposes the strategic goal of "promoting biodiversity-friendly city construction"^[4]. This signifies that urban biodiversity conservation has been elevated to a national strategy, urgently requiring systematic theoretical guidance and practical pathways.

However, compared with biodiversity research in natural ecosystems, the theoretical construction of urban biodiversity remains relatively lagging, with unclear boundaries of its connotation, associations with external factors yet to be clarified, and a lack of systematic guidance for development pathways^[5]. Based on this, this paper attempts to construct a systematic cognitive framework for urban biodiversity, exploring in depth from three dimensions: connotation, extension, and development pathways, with the aim of providing theoretical support and decision-making references for urban biodiversity conservation practice.

1 Connotation analysis of urban biodiversity

1.1 Core constituent elements The core constituent elements include biological components, habitat systems, and environmental factors. Biological components encompass urban wildlife, plants, microorganisms, and their genetic variations. The biological groups associated with cities are extremely diverse: from microorganisms to mammals, from algae to higher plants, and from soil fauna to birds, covering almost all major biological phyla^[6]. Urban habitat systems can be divided into two major categories: natural remnant habitats and artificial new habitats. Natural remnant habitats include residual natural vegetation, wetlands, and water bodies within cities; artificial new habitats include urban

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parks, community gardens, rooftop greening, vertical greening, and street trees^[7]. It is worth noting that "brownfields" in cities often form unique secondary successional communities, becoming important carriers of urban biodiversity.

Environmental factors include urban soil, water bodies, and atmosphere. Urban soil has unique physicochemical properties, often characterized by compaction, pollution, and nutrient enrichment; urban water bodies include rivers, lakes, wetlands, and artificial water systems, which are important components of urban ecosystems; the urban atmosphere is affected by greenhouse gas emissions and particulate pollution, exerting profound impacts on urban biodiversity patterns^[8].

1.2 Spatial scale characteristics At the macro scale, attention is focused on the pattern of urban and regional ecological networks. Cities are important components of regional ecosystems, and their biodiversity status is profoundly influenced by regional ecological processes. McDonald *et al.*^[9] research shows that global urban expansion between 2000 and 2030 is expected to directly occupy approximately 290 000 square kilometers of natural habitat, an area larger than the entire United Kingdom. The ecological connectivity between cities and surrounding natural areas is of critical significance for maintaining regional biodiversity.

At the meso scale, the focus is on urban green space systems and ecological corridors. Urban green space systems are the main carriers of urban biodiversity, and their spatial configuration, connectivity, and quality directly affect species distribution and migration. Ecological corridors are key channels connecting fragmented habitats and are crucial for maintaining the population vitality of urban species^[10]. Research indicates that for every 10% increase in green space connectivity, urban bird species richness can increase by approximately 5%^[11]. Domestic research also shows that integrating green space structure and functional connectivity analysis is an important method for urban biodiversity conservation planning^[12].

At the micro scale, attention is paid to small-scale habitats such as community gardens and rooftop greening. Although these "small habitat patches" are limited in area, they have cumulative effects on urban biodiversity due to their large numbers and wide distribution. Goddard *et al.*^[13] found that private gardens in Sheffield, UK, collectively account for approximately 23% of the city's total area, supporting rich plant and bird diversity. New habitat forms such as rooftop greening and vertical greening also provide new pathways for enhancing urban biodiversity.

1.3 Functional attribute dimensions Urban biodiversity plays a key role in maintaining the stability and resilience of urban ecosystems. Through ecological processes such as food web structure, nutrient cycling, and energy flow, biodiversity supports the normal functioning of urban ecosystems. Urban green spaces with high biodiversity often have stronger resistance to disturbance and recovery capacity, enabling them to better respond to climate

change, pests, and other disturbances^[14].

Urban biodiversity directly benefits urban residents through the provision of ecosystem services. According to the Millennium Ecosystem Assessment framework, ecosystem services can be divided into four categories: provisioning services (such as food and freshwater), regulating services (such as climate regulation and air purification), cultural services (such as recreation and aesthetic value), and supporting services (such as soil formation and nutrient cycling)^[15]. Research shows a positive correlation between biodiversity levels in urban green spaces and ecosystem service provision^[16].

Urban biodiversity has important social functions in promoting resident health and well-being and connecting people with nature. The "biophilia" hypothesis suggests that humans have an innate tendency to connect with nature, and contact with nature is beneficial to physical and mental health^[17]. Numerous empirical studies have shown that exposure to urban green spaces is significantly associated with health benefits such as stress relief, cognitive restoration, and increased physical activity^[18]. Furthermore, participation in urban biodiversity conservation activities can enhance community cohesion and promote environmental education.

1.4 Uniqueness of urban biodiversity Compared with biodiversity in natural ecosystems, urban biodiversity has the following unique characteristics:

First, high anthropogenic intervention and environmental stress adaptation. Urban environments are strongly influenced by human activities, and organisms must adapt to special stress conditions such as urban heat island effects, soil compaction, light pollution, and noise pollution. This "urban filtering" effect results in urban biological communities having unique species composition and functional characteristics^[19].

Second, the coexistence and competition between exotic and native species. Cities are hotspots for the introduction and establishment of exotic species, and the interactions between exotic and native species shape the unique patterns of urban biodiversity. On the one hand, exotic species may cause biological invasion, threatening native biodiversity; on the other hand, some exotic species can also provide food and habitat for urban wildlife, forming "novel ecosystems"^[7].

Third, deep coupling of ecological and social processes. Urban biodiversity is driven by both natural and socio-economic factors, and its distribution patterns are not only influenced by natural conditions such as climate, topography, and soil, but also profoundly affected by social factors such as urban planning, land use, resident preferences, and management systems^[20]. Domestic scholars have pointed out that identifying the influencing factors of urban built environment on biodiversity and designing optimization pathways are key to conservation work^[21]. This coupling characteristic requires urban biodiversity conservation to adopt interdisciplinary and cross-sectoral comprehensive strategies.

2 Development pathways for urban biodiversity

2.1 Survey, monitoring and assessment system construction

Conducting baseline surveys of urban biodiversity is the foundation of conservation work. Survey content should cover multiple dimensions, including urban ecosystem types, species composition, population status, and genetic diversity. Building intelligent monitoring networks is key to improving the efficiency of urban biodiversity monitoring. The application of modern information technologies such as remote sensing, Internet of Things, and artificial intelligence provides new means for urban biodiversity monitoring. Environmental DNA (eDNA) technology can detect the presence of wildlife without disturbing it, providing a non-invasive method for urban wildlife monitoring^[22]. The Singapore Index on Cities' Biodiversity (SI) is currently the most widely used urban biodiversity assessment tool. Developed jointly by the Singapore National Parks Board and the Convention on Biological Diversity Secretariat, this index comprises 28 indicators covering three dimensions: native biodiversity, ecosystem services, and biodiversity governance and management^[23].

2.2 Planning, control and spatial optimization Integrating biodiversity into territorial spatial master planning is a key measure for achieving conservation goals. The *China National Biodiversity Conservation Strategy and Action Plan (2023 – 2030)* explicitly proposes to "incorporate biodiversity conservation as an important component of territorial spatial planning"^[4]. This requires fully considering biodiversity conservation needs in planning formulation, delineating ecological conservation red lines, and optimizing ecological spatial patterns.

The construction of urban ecological security patterns is the spatial foundation for maintaining urban biodiversity. Ecological security pattern identification needs to comprehensively consider elements such as biodiversity hotspot areas, ecological corridors, and key nodes, constructing an integrated ecological network structure of "patches-corridors-matrix"^[24]. The comprehensive method for ecological security pattern construction proposed by Li *et al.*^[25] provides technical references for urban-scale ecological security pattern planning. Research shows that the impact of urbanization on biodiversity needs to be regulated through spatial planning, and establishing ecological security patterns is an effective conservation strategy^[26].

2.3 Technological innovation and application practice Nature-based Solutions (NbS) are an innovative pathway for addressing urban environmental challenges. The European Union defines NbS as "solutions that are inspired by, supported by, and utilize nature, providing environmental, social, and economic benefits in a cost-effective manner while enhancing resilience"^[27]. Scott *et al.*^[28] research points out that NbS provides a systematic reflective framework for re-naturalizing contemporary cities.

The rise of the Animal-Inclusive Urban Design concept marks a shift in urban biodiversity conservation from passive protection to

active design. This concept advocates fully considering the needs of wildlife in urban planning and design, creating urban spaces that are conducive to wildlife survival and movement^[29].

Green Infrastructure (GI) is an important carrier for integrating urban biodiversity conservation. Fang *et al.*^[30] review study published in *Sustainable Cities and Society* shows that integrating green infrastructure, ecosystem services, and nature-based solutions into urban planning can achieve multiple goals for sustainable urban development. Croeser *et al.*^[31] further found that spatial optimization of green infrastructure targeting biodiversity can significantly enhance landscape-scale ecological connectivity benefits.

2.4 Social Participation and Public Education Community biodiversity experience sites are important platforms for connecting the public with nature. The *China National Biodiversity Conservation Strategy and Action Plan (2023 – 2030)* proposes to "accelerate the promotion of public biodiversity experience facility construction"^[4]. These facilities can not only provide venues for nature education but also enhance public awareness and attention to urban biodiversity.

Urban biodiversity conservation requires interdisciplinary collaboration and multi-stakeholder governance. Knapp *et al.*^[32] emphasize that urban biodiversity research needs to strengthen communication and collaboration across multiple fields and disciplines, building capacity-building systems for urban biodiversity research, education, and practice. Domestic practice shows that biodiversity conservation in urban community renewal requires context-specific strategy design, with the exploration of habitat gardens in Changning District, Shanghai, providing useful experience^[33]. Collaborative participation by government, enterprises, research institutions, social organizations, and the public is the key guarantee for achieving urban biodiversity conservation goals.

3 Prospects

At the research level, efforts should be made to strengthen basic theoretical research on urban biodiversity, deepen understanding of urban ecosystem structure and function; promote interdisciplinary integration research, integrating perspectives from ecology, urban planning, public administration, and public health; and strengthen long-term monitoring and experimental research to provide scientific support for conservation practice.

At the policy level, efforts should be made to promote the mainstreaming of urban biodiversity conservation, incorporating it into decision-making across various fields of urban development; improve the legal and regulatory system to provide institutional guarantees for urban biodiversity conservation; and strengthen international exchange and cooperation, actively participating in global urban biodiversity governance.

At the practice level, efforts should be made to carry out urban biodiversity conservation practice according to local conditions, exploring conservation models that fit local realities;

strengthen technological innovation and achievement transformation to enhance the scientific nature and effectiveness of conservation work; and cultivate social participation mechanisms, building a conservation pattern of collaborative governance among government, enterprises, and the public.

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