博 士 論 文

Research on Urban Wetland Landscape Evaluation and Design Optimization based on Biodiversity Conservation Methods - Urban Wetlands in China: Xixi, Tongjian Lake and Qingshan Lake as Case Studies

生物多様性保全アプローチに基づく都市湿地景観の評価と設計の最適化に関する研究──中国の都市湿地: 西渓、通健湖、青山湖をケーススタディとして

北九州市立大学国際環境工学研究科

2023 年 2 月

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Doctoral Thesis

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February 2023

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Preface

This thesis addresses the problems of lacking further concept of biodiversity conservation, being short of long-term biodiversity conservation sustainability awareness and unclear design methods and effects in the current urban wetland landscape design. Through field research and comparative research of three different types of typical urban wetland landscapes in specific regions: urban core, urban fringe and urban suburban, the thesis analyses the key issues and design methods affecting urban wetland biodiversity, clarifies the main factors of their problems, proposes suitable solutions, and establishes a scientific and reasonable design theoretical framework and methodological practice. The ultimate goal is to make urban wetland landscapes more biodiverse and provide better ecological services, meanwhile to meet people's needs for cultural, physical and psychological well-being, and last to provide theoretical references for the design and management departments of urban wetland landscapes for scientific planning.

Acknowledgements

This work could not have been completed without the support, guidance, and help of many people and institutions, for providing data and insights, for which I am very grateful.

Firstly, I would like to give my sincere thanks to my supervisor Prof. Hiroatsu Fukuda, who has given me invaluable guidance. During my study in these three years, He has been generous to offer me useful suggestions, answer my question and discuss research questions with me. I also would like to express the deepest appreciation to Prof. Weijun Gao and his wife. They constant support and encouragement throughout the whole processes.

Secondly, I would also express my sincere gratitude to other professors and teachers who had given me constructive suggestion to my thesis. And thank my university colleagues, Pro. Yijun Lu, who details guidance and helpful comments on my thesis encourage me to overcome difficulties and think more critically during the processes of writing; and Dr. Guofu Yang, who gives me guidance and research support; and Dr. Mei Lyu, Dr. Tao Zhang, Dr. Rui Zhou, Dr. Shimeng Wang, Dr. Lifei Song from whom I get tremendous help and encouragement.

At last, many thanks to my family for their love and encouragement, especially my father, my mother and my husband.

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ABSTRACT

Urban wetlands are an indispensable part of the urban ecosystem, and improving their biodiversity plays an important role in optimizing urban ecological functions and enhancing urban ecological services. This thesis addresses the problems of lacking further concept of biodiversity conservation, being short of long-term biodiversity conservation sustainability awareness and unclear design methods and effects in the current urban wetland landscape design. Through field research and comparative research of three different types of typical urban wetland landscapes in specific regions: urban core, urban fringe and urban suburban, the thesis analyses the key issues and design methods affecting urban wetland biodiversity, clarifies the main factors of their problems, proposes suitable solutions, and establishes a scientific and reasonable design theoretical framework and methodological practice. The ultimate goal is to make urban wetland landscapes more biodiverse and provide better ecological services, meanwhile to meet people's needs for cultural, physical and psychological well-being, and last to provide theoretical references for the design and management departments of urban wetland landscapes for scientific planning.

The richness and variety of animals largely depend on the diversity and complexity of vegetation. Therefore, the study of urban wetland biodiversity in this thesis focuses on the study of its vegetation diversity. The entire study is divided into five sections and eight chapters. Related research work and unsolved key questions will be given in each chapter. All the chapters constitute the main research content in a logical sequence.

In Chapter 1, REASEARCH BACKGROUND AND PURPOSE OF THE STUDY. The present situation and the research advances in urban wetlands is investigated, and the technical route and innovation points that can be applied to urban wetlands are introduced. And the purpose and content of this study is proposed.

In Chapter 2, STUDY AREA AND METHODOLOGY. Firstly, a basic overview of Hangzhou is presented, including the geographical environment, climate, local resources, and economy. Secondly, the geography, conservation planning, and design and tourism development of three typical urban wetlands located in the core, fringe, and suburban areas of Hangzhou are described. Finally, the methodology of the study is described, including data collection methods and data analysis methods.

In Chapter 3, CHANGES IN PLANT DIVERSITY IN URBAN WETLANDS ALONG URBAN-RURAL GRADIENT IN HANGZHOU. In this section, plant diversity in three urban wetlands are surveyed, and differences in plant diversity between the three and associated influencing factors are investigated.

In Chapter 4, IMPACT OF ECOLOGICAL DESIGN ON PLANT DIVERSITY IN URBAN WETLANDS IN DIFFERENT REGIONS. Ecological design practices in three urban wetlands are researched. Use structural equation model to filter out the design practices that have a significant impact on plant diversity and their pathways of influence.

In Chapter 5, URBAN WETLAND EVALUATION INDICATOR ESTABLISHMENT. Based on the analysis of the plant diversity and ecological design practices in chapter 3 and chapter 4, this section provides a scientific evaluation of urban wetlands in two aspects: the scenic beauty estimation in wetlands, and comprehensive evaluation of wetlands. Differences in urban wetlands in different regions are analyzed.

In Chapter 6, A FRAMEWORK STUDY ON THE ECOLOGICAL PLANNING AND DESIGN OF URBAN WETLAND LANDSCAPES BASED ON BIODIVERSITY. This section introduces the theory of landscape ecology and landscape ecological planning, and constructs a theoretical system that coordinates the complex relationship of "design-ecology-aesthetics". Through the analysis and optimization of the classical landscape framework, an Urban Wetland Biodiversity Landscape Design (UWBLD) framework and a paradigm for landscape ecological planning and design of urban wetlands in different regions are proposed.

In Chapter 7, AN EMPIRICAL STUDY: URBAN WETLANDS AS A POTENTIAL HABITAT FOR AN ENDANGERED AQUATIC PLANT, *ISOETES SINENSIS*. Ecological planning and design can enhance the plant diversity of urban wetlands and improve the urban wetland environment. Furthermore, the improved urban wetlands, in turn, can serve as micro refuges for the endangered plants. This study takes *Isoetes sinensis* as an example to explore the feasibility of introducing endangered plants into urban wetlands to identify potential habitats through field studies, eco-physiological experiments, and urban wetland surveys in the central district of Hangzhou, thereby verifying that the improvement of Hangzhou's urban wetland ecology is conducive to the enhancement of urban biodiversity.

In Chapter 8, CONCLUSION AND PROSPECT. The whole thesis of each chapter has been presented, and the future work of optimization of urban wetland was put forward.

王 玥 博士論文の構成

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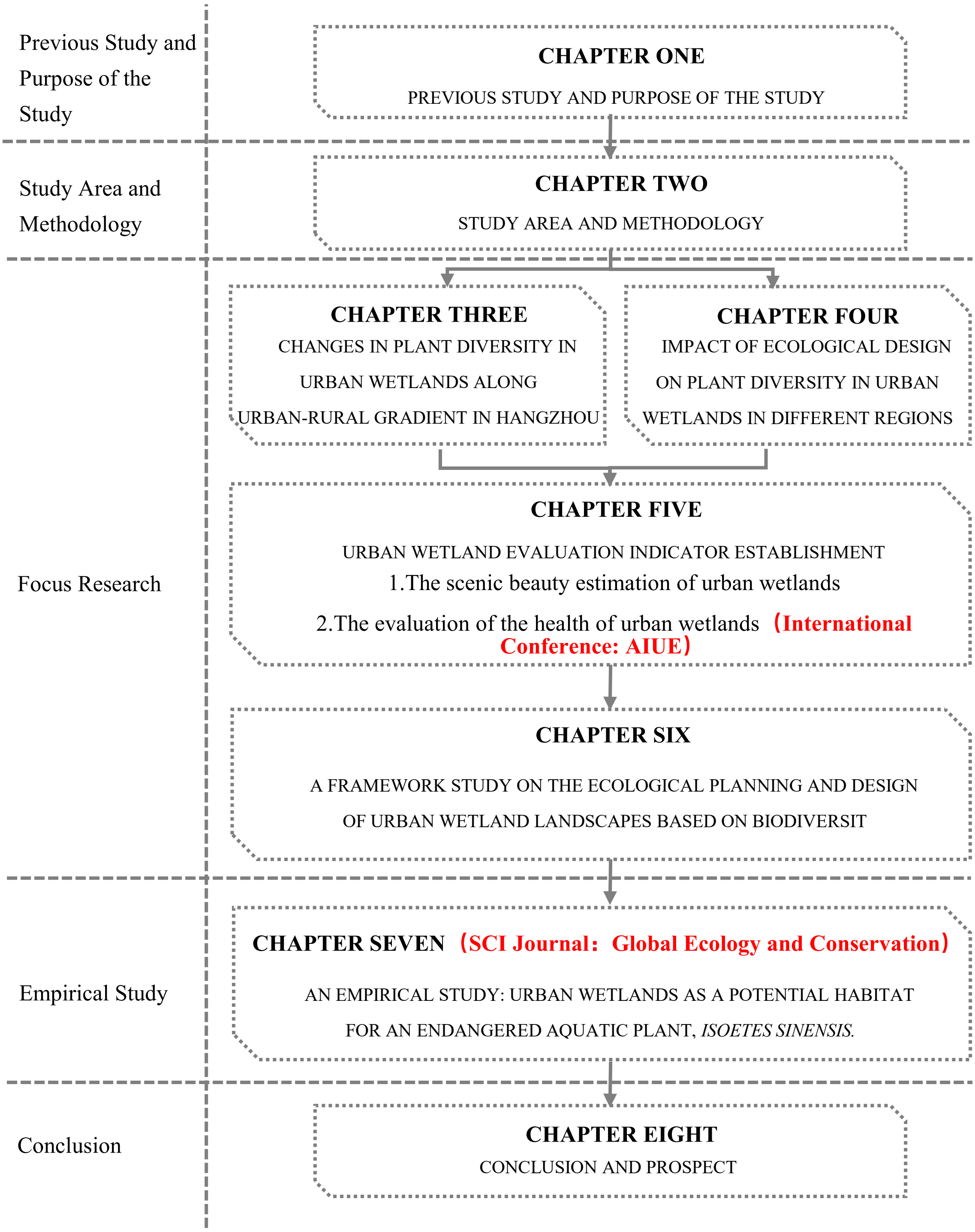
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Chapter 1

RESEARCH BACKGROUND AND PURPOSE OF THE STUDY

CHAPTER ONE: RESEARCH BACKGROUND AND PURPOSE OF THE STUDY

1.1 Background

Biodiversity is an important support for human survival and the basis for sustainable economic and social development, as well as an important evaluation indicator for the ecological health of the human habitat, and is of great significance for the ecological balance and sustainable development of cities. With the development of cities, urban areas are subject to intense and frequent human activities disturbing them. On the one hand, with the degradation of ecosystems, the continuous reduction of natural habitats and the intensification of habitat fragmentation, urban biodiversity is facing a drastic decline; on the other hand, the similarity of human habitat modification in urban areas (through the transmission of cultural genes, i.e. mutual learning) and the common preference for specific landscapes, driven by the ecological-economic biotic homogenization between cities, leading to a gradual approach in terms of biological taxa and diversity between urban green space landscapes. Human activities are an important factor in the rapid loss of biodiversity on a global scale[1](Figure 1-1). The loss of biodiversity is accompanied by the loss of biculturalism and biocultural ethics, which is one of the reasons for the homogenization of cities.

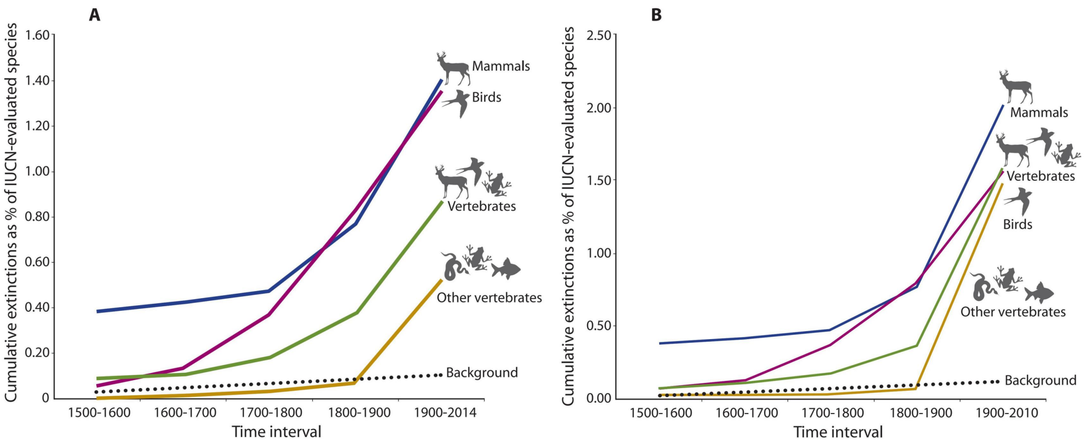

Fig. 1-1 Cumulative vertebrate species recorded as extinct or extinct in the wild by the IUCN (2012). Graphs show the percentage of the number of species evaluated among mammals (5513; 100% of those described), birds (10,425; 100%), reptiles (4414; 44%), amphibians (6414; 88%), fishes (12,457; 38%), and all vertebrates combined (39,223; 59%). Dashed black curve represents the number of extinctions expected under a constant standard background rate of 2 E/MSY. (A) Highly conservative estimate. (B) Conservative estimate[1].

According to the UN report, by 2050 the global population will reach 9.7 billion and 68% of the population (i.e. 6.6 billion people) will live in urban areas. between 2001 and 2018, China was the fastest-growing country in terms of built-up area, accounting for 47.5% of the global growth in a built-up area. The high rate of urbanization has led to damage to ecosystems and loss of biodiversity, which ultimately leads to a decline in ecosystem services and brings about health problems in the human habitat, thus affecting human physical and mental health issues. In this context, research and enhancement of urban biodiversity conservation have become an important and urgent task and a hot topic of social concern nowadays.

Wetlands, forests, and oceans are known as the world's three major ecosystems and are known as the "kidneys of the earth", with important ecological functions such as water conservation, water purification, climate regulation, flood storage and drought prevention, and maintenance of biodiversity. Due to the lack of awareness of the function and ecological value of wetlands, they have become one of the fastest-disappearing components of urbanization in the process of urban construction and expansion[2],[3]. Large areas of wetlands are occupied and filled for urban construction, industrial wastewater and residential sewage are discharged directly into urban fringe wetlands, and the urban ecology is severely damaged, seriously affecting the local hydrology and climate. Data from the Second National Wetland Resources Survey shows that between 2009 and 2013, the total area of wetlands in China was 53,602,600 hectares, a decrease of 3,396,300 hectares and a reduced rate of 8.82%, with natural wetlands decreasing by 3,376,200 hectares[4]. With the rescue and protection of wetlands, the area of protected wetlands has increased to 23,243,200 hectares, an increase of 5,259,400 hectares, and the wetland protection rate has increased from 30.49% to 43.51% now[4]. Between 2016 and 2021, a comprehensive conservation phase for China's wetlands was reached. Data from the Third National Wetland Resources Survey shows that the total area of China's wetlands increased to 56.35 million hectares, while the number of nature reserves also increased from 577 to 602, and the number of wetland parks increased from 468 to 901, with a wetland conservation rate of 52.65%, making China's wetland conservation a historic achievement[5](Figure 1-2, 1-3, 1-4).

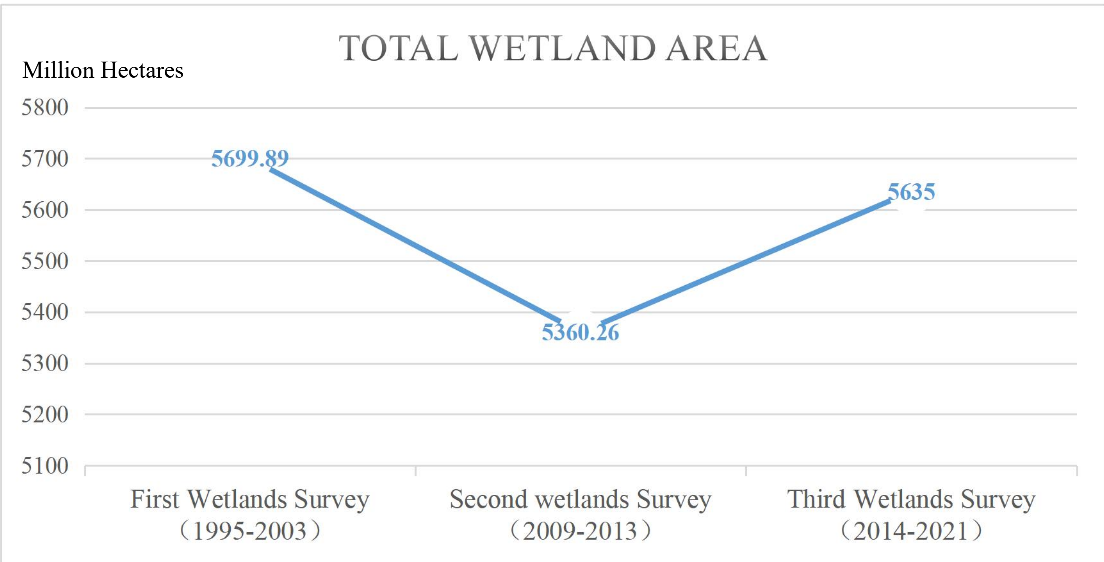

Fig. 1-2 Change of total area of wetland in China

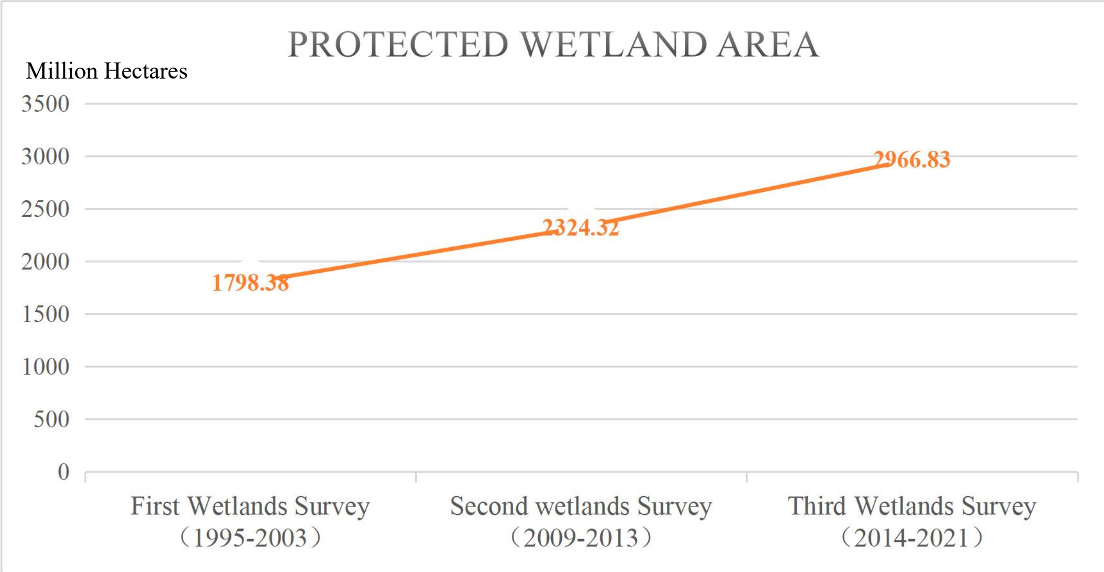

Fig. 1-3 Change of protected area of wetland in China

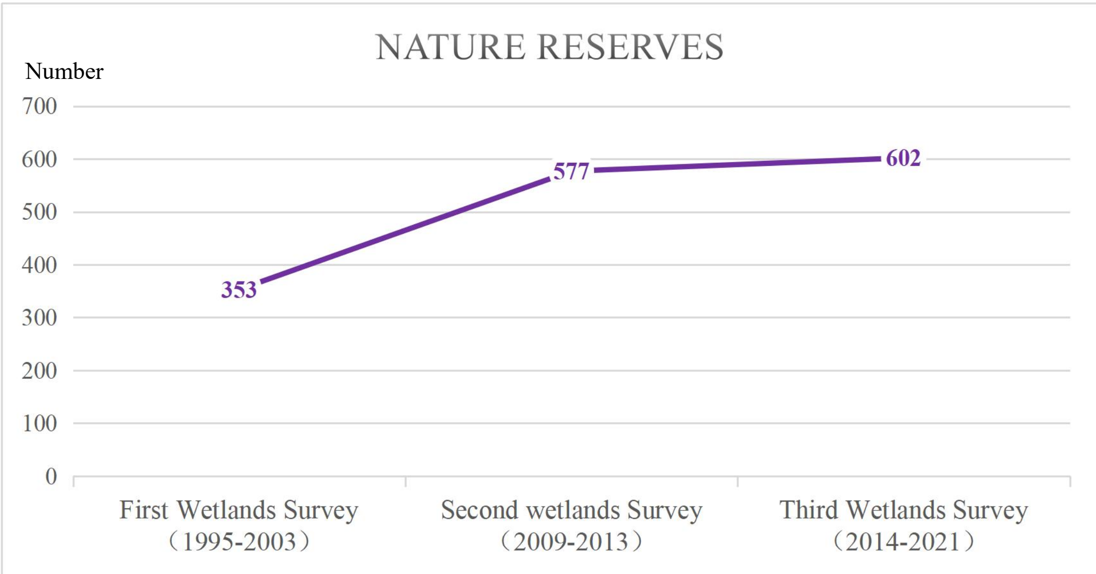

Fig. 1-4 Change of number of nature reserves of wetland in China

As the pace of urbanization continues to increase, some wetlands in urban-rural and rural areas have gradually evolved into urban wetlands. Urban wetlands are an important part of the urban ecosystem, which performs valuable ecological service functions for urban residents, such as purifying water (thereby increasing its quality) and conserving water sources[6],[7] . As the protection and construction of urban wetlands have received increasing attention in recent years, some damaged urban wetlands have been repaired, thereby improving the health of wetland landscapes and ecosystems[8]-[10]. The diverse habitats in urban wetlands also were vital habitats for animals and plants in urbanized areas[11],[12]. The function of urban wetlands to maintain local biodiversity has been further improved, most notably through habitat design and appropriate man-made management and protection. Therefore, when rapid urban development leads to rapid loss of biodiversity, scientific and rational urban wetland landscape design strategies and methods need to be established to protect urban biodiversity.

1.2 Purpose and significance of the study

1.2.1 Purpose of the study

However, although there is currently more attention to biodiversity conservation in urban wetland landscape planning and design, in design practice, landscape designers tend to consider more from the perspective of aesthetics and landscape art, while the concept of biodiversity conservation is still inadequate; the use of ecological technology is not maturely combined with ecological principles; the design method takes more into account the current landscape factors, lacking long-term sustainability thinking for biodiversity conservation; Inadequate management of the effects of subsequent biodiversity conservation and so on, the result is that the actual wetland landscape planning and design are not ideal for the conservation of local biodiversity.

How can urban wetland landscape design truly reflect the concept of biodiversity conservation? How effective are design approaches for different regional types of urban wetland landscapes in conserving urban biodiversity? How can landscape design approaches sustainably maintain the biodiversity of urban wetland landscapes in the region and provide better ecological services? How can biodiversity conservation be harmonized with the artistic, socio-economic and cultural tendencies of urban wetland landscapes? How can a sound design theoretical framework be constructed to guide the design of urban wetland landscapes to enhance local biodiversity? These are all questions that need to be considered when addressing the relationship between urban wetland landscape design and biodiversity conservation (Figure 1-5).

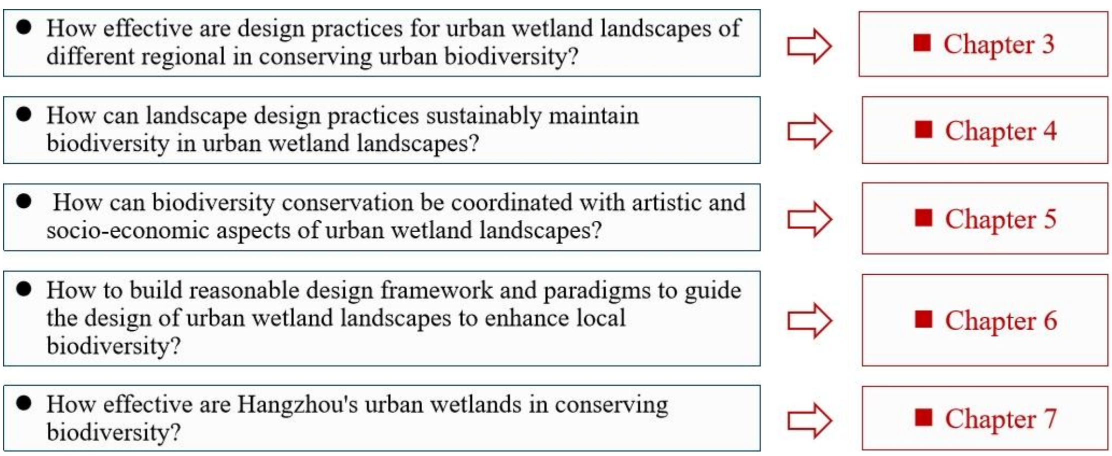

Fig. 1-5 The scientific questions to be addressed in each chapter

1.2.2 Significance of the study

Cities are not just a threat to biodiversity, but urban ecosystems that are harmonized with nature can also provide opportunities for biodiversity conservation. Urban ecosystems also have native species that are adapted to their complex environments and can encourage new species to colonize them by creating near-natural, stable habitats. In addition, with scientific planning and restoration of urban ecosystems, species initially lost during urban development may be able to return to the city[13].

In recent years there has been a growing body of research on urban wetlands and biodiversity conservation, and it is widely recognized that urban wetland ecological processes are influenced by social and economic factors. Socioeconomic factors can affect the urban wetland landscape, change the hydrological conditions of urban wetlands, and then affect the composition and structure of urban wetland biodiversity. Accelerated urbanization allows wetlands embedded in urban landscapes to provide a diverse habitat for living organisms. Numerous studies have found that human-led landscape design can restore and conserve biodiversity, and even enhance local biodiversity. This points to a complementary way forward. In urban wetland conservation, urban wetland landscape planning and design can be an effective way to address urban biodiversity issues. However, due to the complexity of the urban environment, biodiversity conservation-oriented landscape planning and design are still at the stage of continuous research exploration, and breakthroughs in research ideas and tools are urgently needed. There is a relative lack of research on the impact of urban wetland landscape design on biodiversity, and relevant theories have not yet been developed, and there is a lack of systematic research reports.

Hangzhou has a large water area with a variety of water bodies and a wide distribution of wetland landscapes such as rivers, lakes and streams. With the advancement of urbanization, the area of urban wetlands in Hangzhou has shown a significant increase, and some wetlands in the combined urban-rural parts and rural areas have been transformed into urban wetland landscapes through landscape design pathways, which in turn has triggered changes in biodiversity in the area. Therefore, it is typical to choose this area as a case study to investigate the impact of urban wetland landscapes on biodiversity.

Vegetation is a common underlying indicator in all types of wetland assessment methods [14]. Plants are used as an important indicator of wetland ecosystem health because they are immobile, relatively easy to sample and identify, and respond well to human disturbance [15],[16]. In addition, as an important component of wetland ecosystems, plants can also form complex trophic networks by providing oxygen, food and shelter to other living organisms such as fish and waterfowl.

This study is based on a plant diversity survey and takes Hangzhou as the research object, expecting to compare the plant diversity of representative lake wetland landscapes in three different regional types: urban core, urban fringe and urban countryside, to investigate their impact on wetland health, to analyze the ecological problems in wetland landscape design, to understand the intrinsic links between urban wetland landscape design methods affecting urban biodiversity, to establish a scientific and rational design theoretical framework, further explore the paradigm of urban wetland landscape design under different geographical conditions, and provide scientific guidance for urban wetland landscape planning and design.

1.3 Relevant research progress at home and abroad

1.3.1 Definition of urban wetlands

Wetlands, are known as "the kidneys of the earth", "the cradle of life", "the birthplace of civilization" and "the gene pool of species ". In the World Nature Conservation Syllabus, wetlands are listed alongside forests and oceans as one of the three major global ecosystems. The Convention on Wetlands of International Importance especially as Waterfowl Habitat (Wetlands Convention), signed by 36 countries including Canada and Australia in February 1971, defines wetlands as natural or artificial, permanent or temporary marshes, peatlands and waters, containing standing or flowing, fresh or brackish water bodies, including areas of marine water shallower than 6 meters at low tide.

The 2008 Convention on Wetlands, in its Resolution 27 "Wetlands and Urbanization", explicitly introduced the concepts of urban wetland and peri-urban wetland, stating that urban wetlands are "wetlands located within the boundaries of cities (towns)"; and peri-urban wetlands are "wetlands located on the outskirts of cities and in the countryside adjacent to cities". Hettiarachchi et al. [17]emphazise that urban wetlands are "wetland types that are located in landscapes where human beings play a dominant role".

The definition and concept of urban wetlands have also been extensively studied by domestic scholars. Sun Guangyou et al.[18] defined urban wetlands as the type of wetland ecosystem distributed in the city (town), or the suburban area of the city, based on the distribution and existence range of urban wetlands. Wang Haixia et al.[19] pointed out that urban wetlands are the types of wetlands that are distributed in the core and suburban areas of cities, are closely related to the formation and development of cities, and provide a guarantee for the achievement of urban construction goals. Wang Guoxin[20] defines urban wetlands as urban wetlands are wetland areas located at the edge of the city, integrated into the urban landscape and greening system, and capable of providing a variety of ecological services to the city and its residents, including natural rivers, lakes, ponds, marshes, river floodplains, seashores and various artificial water conservancy and waterscape areas. Liu Lingcong et al.[21] define urban wetlands as ecosystems in urban areas that have a transitional nature between land and water, as well as humanistic, recreational and educational values that cannot be replaced by natural wetlands, but with strong human interference. According to Zhang Hui et al.[22], urban wetlands are natural or man-made aquatic and terrestrial gradual biological and environmental components that are scattered in urban areas, regrouping the wetland categories of the Multilateral Treaty on Wetlands, and contributing to the achievement of urban sustainable development objectives. The main types of urban wetlands are lakes, rivers, marshes, ponds, impoundments, reservoirs, ditches, canals and urban coastal wetlands.

Integrating the definitions of urban wetlands by scholars at home and abroad, this paper summarises the characteristics of urban wetlands into the following aspects: 1) defined geographically, urban wetlands refer to wetlands distributed within cities and urban fringe areas; 2) wetland types include permanent rivers, coastal freshwater lakes and artificial wetlands; 3) urban wetlands are an important part of urban composite ecosystems; 4) urban wetlands are subject to human disturbance; 5) urban wetlands themselves are wetland ecosystems, so they not only have unique structures and function, but also have important and special ecosystem functions and services[23].

Therefore, this paper defines urban wetlands as a type of wetland ecosystem that constitutes one of the important components of urban ecosystems, is located within or adjacent to urban territories, has close links with other components of urban complex ecosystems, and has a unique ecosystem structure, function and service characteristics[23],[24], including permanent rivers, coastal freshwater lakes and artificial Among them, artificial wetlands are divided into four types: reservoirs and ponds, canals and water conveyance rivers, urban artificial landscape and recreational water surfaces, and aquaculture farms[25].

Natural wetlands are based on ecological service functions and their different ecological functions can be measured and evaluated, while urban wetlands emphasize their recreational, entertainment and ecological education functions for the public in addition to their ecological service functions, which are irreplaceable in natural wetlands[26]. In the process of rapid urbanization, urban wetland parks can be a good balance between wetland conservation and rational use.

1.3.2 Progress of research on ecological restoration of urban wetlands

Urban wetlands are a type of complex ecosystem, consisting of natural components such as biological elements, physical environmental elements and human components such as social, economic and cultural elements. In the process of human transformation and use of urban wetlands, urban wetland ecosystems have incorporated a large number of artificial elements, and the native natural systems have been severely damaged, losing their natural succession function and self-regulating ability. With the dramatic increase in population, rapid urbanization has led to a drastic reduction in the wetland areas, serious fragmentation of wetland internal habitats and deterioration of water quality, coupled with the invasion of alien species, which has led to a significant reduction in biological species in urban wetlands, damaging the ecological environment of wetlands, compromising their ecosystem health and reducing their ecological and social service role. With an emphasis on urban environmental improvement, various urban wetland conservation measures have been implemented for the ecological restoration and management of urban wetlands.

(1) Relevant foreign studies

Foreign research on the ecological restoration of wetlands started earlier, at the end of the 20th century, hydrological and water environment restoration research was conducted mainly for water environment management in marshes and lake wetlands. At the 5th International Wetlands Conference held in Australia in 1996, scholars from various countries discussed how to improve wetland benefits, prevent and solve problems such as wetland loss, functional decline, and biodiversity reduction, as well as protect and reconstruct countermeasures and measures for wetlands[27], and preliminary explorations were made in wetland degradation evaluation and wetland restoration methods. From 2001 to 2009, research focused on ecosystem and functional restoration and evaluation of wetlands, including vegetation restoration and plant community succession, artificial wetlands for water pollution management, ecosystem management and evaluation, and biodiversity restoration, and showed a significant increase in 2008[28]. Zedler J.B. et al.[29] assessed the degradation of the ecological services of wetlands globally, further promoting wetland restoration towards research aimed at functional restoration and forming an evaluation method for wetland restoration from an ecosystem perspective. In the last decade, or so after 2010, with the gradual intensification of global climate problems[30], the For example, Barbier E.B.[31] assessed the ecological service functions of various types of estuarine coastal wetlands around the world and suggested that climate change would accelerate the degradation of coastal systems. In the coming period, breakthroughs in theories and methods for the conservation and sustainable restoration of wetland functions under the dual disturbance of human activities and climate change are important directions for wetland restoration research[28].

(2) Relevant domestic research

The main research content of domestic wetland restoration is the same as that of foreign countries. Before 2010, the research mainly focused on wetland water eutrophication control and water pollution management, as well as research on wetland protection and sustainable development countermeasures, and the research was nearly 10 years later than in foreign countries. Cui et al.[32]evaluated the effect of wetland restoration based on 7 years of observation of wetland restoration in the Yellow River Delta using indicators such as water quality, soil salinity, organic matter, plant communities and bird species; Cui Baoshan et al.[33] proposed the theory and method of wetland ecosystem health evaluation based on ecological principles, clarifying that wetland health evaluation should be based on structure, function, change, and disturbance The evaluation theory of three aspects, namely, ecological characteristics of wetlands, functional integrative characteristics and socio-political environmental characteristics, was formed, which led to the development of a research stage with the systematic restoration of wetland functions as the main goal. After 2010, scholars began to focus on hotspot directions such as wetland biodiversity, organic carbon, and climate change, and used new technologies and methods to establish wetland restoration research models; Ling, L et al. combined remote sensing (RS) and geographic information systems (GIS) in an attempt to implement wetland restoration on the West Songnen Plain[34]; Cui, LL et al. studied the spatial heterogeneity of coastal wetland degradation in Jiangsu and proposed objectives and techniques for wetland restoration[35]; Tan, YH et al. used conditional logit models and stochastic parametric logit models to evaluate the individual utility associated with wetland attributes in order to evaluate the environmental improvement effect in the restoration process of coastal wetlands in the Ximen Island Marine Special Protection Area , concluding that coastal wetland restoration has positive implications for improving mangrove area, water quality and biodiversity[36].

Scholars at home and abroad have used different methods and techniques to construct various types of wetland restoration models and evaluation models at different stages, and have conducted a series of studies on wetland ecological restoration, such as wetland ecosystem health evaluation, wetland ecosystem service value evaluation, wetland biodiversity evaluation and protection, and comprehensive wetland evaluation, providing scientific guidance for the reasonable protection and restoration of local urban wetland ecosystems.

1.3.3 Progress in research on plant diversity and wetland health in urban wetlands

Wetland ecosystems are an important part of global climate regulation, and the protection of wetland ecosystems has become one of the main research directions of scholars, and wetland health assessment is an important indicator of the effectiveness of wetland restoration and protection measures, which can provide important and effective information to promote the restoration of damaged wetlands and wetland management[37]. The evaluation of wetland ecosystem health is a comprehensive study of the characteristics of the ecosystem in the presence of external disturbances, combined with the structure of the wetland ecosystem itself and the functional patterns it produces, to carry out further systematic diagnosis and to analyze and summarise early warning indicators of ecosystem degradation; to provide more reliable technical parameters for wetland restoration and management, and to come up with more feasible restoration and management methods. The analysis will provide more reliable technical parameters for wetland restoration and management, and a more feasible restoration and management method to better utilize wetland ecosystems to improve the natural environment and provide a better human environment[22]. Scholars at home and abroad have also conducted many studies on the evaluation of wetland ecosystem health.

(1) Relevant foreign studies

In the late 20th century, the U.S. Environmental Protection Agency (EPA) evaluated and systematically studied the ecological health of estuarine wetlands using response indicators, exposure indicators, habitat indicators, disturbance factors, and other indicators, and the results were subsequently applied to wetland management and planning[38]. Breine used the F-IBI indicator system to evaluate the health status of riverine wetlands in the upper Flanders, which proved to be more presentable[39]. In the early century, Breauxa et al. evaluated the ecological health of wetlands in San Francisco Bay, California, using five sub-indicator layers, including land use, biological habitat status, and dominant vegetation[40]. The most comprehensive evaluation of wetland ecosystem health is the US EPA's Level III evaluation system, which includes the Hydrogeomorphic (HGM) method and the Indexes of Biological Integrity (IBI) method. The Level III evaluation method, which includes the Hydrogeomorphic Method (HGM) and the Indexes of Biological Integrity (IBI), has been widely adopted and used by scholars in many countries[41].

(2) Relevant domestic studies

The earliest studies on wetland ecosystem health in China were mainly a review of relevant theories and research examples from foreign studies. In 2001, Cui Baoshan et al. conducted research on the concept and connotation of wetland ecosystems, health indicators, research trends and their restoration, and other research advances, proposing theories and methods for evaluating wetland ecosystem health, highlighting the importance of unity and differentiation at the spatial and temporal scales[33]. After that, some scholars successively constructed evaluation systems from wetland ecological services, wetland functions, ecological structures, ecosystems and other indicators to evaluate the health of local urban wetland ecosystems. In recent years, domestic scholars have increasingly applied the "three-level evaluation method" proposed by the EPA, of which the IBI method in Level III is the most widely used[42],at present, benthic animals and fish are mostly used as indicator species in IBI applications in China[43], the use of vascular plants and algae as indicator organisms is relatively rare[44].

The indexes of biological integrity (IBI)[45] select individual species or populations of representative animals, plants or microorganisms present in the wetland ecosystem to reflect the health of the wetland ecosystem from different perspectives. The species selected are generally key species in the wetland ecosystem, sensitive to environmental changes and able to respond to external disturbances through changes in their behavior or morphology[46]. The core indicators established in the Biotic Integrity Index evaluation method are sensitive to external disturbance and can reasonably reflect the external disturbance to that ecosystem[47], by analyzing the IBI values of different indicators in response to external disturbances, it is possible to indirectly reflect the extent to which the health of wetland ecosystems is affected[48]. The Biotic Integrity Index is a more comprehensive evaluation index system that generally covers several categories of indicators such as nutrient structure, community composition, and species tolerance of the wetland ecosystem, and the core indicators selected are representative[49].

Vegetation is a common underlying indicator in all types of wetland assessment methods [14]. Plants are used as an important indicator of wetland ecosystem health because they are immobile, relatively easy to sample and identify, and respond well to human disturbance[15],[16]. In addition, as an important component of wetland ecosystems, plants can also form complex trophic webs by providing oxygen, food and shelter to other living organisms such as fish and waterfowl. There has been some work done on the evaluation of wetland health using the plant IBI index, and the results have played an important role in the conservation and management of wetlands, however, these studies have also focused on the evaluation of natural wetland health[50]-[52]. Compared to natural wetlands, urban wetlands are more subject to artificial disturbance, where the creation of plant communities for ornamental purposes and the introduction of exotic ornamental plants lead to some differences in their plant species from natural wetlands, which may have a different effect on urban wetland health. The use of wetland sensitive plants as indicator plants to monitor wetland health is a new technique for wetland ecological restoration.

1.3.4 Progress of research on the ecological design of urban wetlands

Urban wetlands are an important part of urban ecosystems, providing important ecological functions for cities[11],[12] while also creating aesthetically attractive spaces and providing recreational opportunities for urban residents[53]. In the context of sponge cities and urban double repair, the conservation and planning design of scientific and reasonable urban wetland parks is of great importance[54]. As urban wetland conservation and construction have received increasing attention, through scientific and reasonable conservation and planning design, some damaged urban wetlands have been repaired, and wetland landscape and health have been improved[9], and the biodiversity of urban wetlands has been significantly improved[6],[7], forming an urban wetland park with integrated functions of conservation, science popularisation and recreation, focusing on the ecological, economic and social benefits of wetlands[55].

Ecological design and restoration is an important approach in urban wetland conservation, and many ecological techniques and methods and ecological materials are also widely used in the conservation and construction of urban wetlands[56],[57], which play an important role in enhancing the biodiversity of urban wetlands[58]. As urban wetlands that can provide a healthy, comfortable and beautiful living environment for people, their good landscape effects are also worthy of attention.

(1) Relevant foreign studies

In the 1970s, some internationally developed countries such as the United States, Japan and Germany began to focus on the construction and restoration of ecological environment, and more attention began to be paid to the study of urban wetland space, from the ecological perspective, the water bodies, embankments, beaches, wetlands, vegetation and organisms as a complete ecosystem for unified planning and design, to restore the intrinsic connection of natural factors, and ultimately achieve the ecological restoration of waters The study also aims to achieve the integrated objectives of flood control, water quality, biological reproduction and human recreation.

In terms of wetland design, foreign urban wetland landscape design mainly applies the principles of landscape ecology to urban water environment management and planning and considers the relationship between water quality improvement and landscape in its design, such as the conversion of Alpeito Pier in Liverpool, UK, and the canal riverside conversion in Manchester. In recent years, many countries in the USA and Europe have combined urban wetland landscape and function studies with urban ecology and developed numerous models, such as the Pressure-State-Response (PSR) model, CLUE-S model and CA-Markov model, to evaluate the current status of wetlands, predict future changes in urban wetlands and provide a basis for formulating reasonable countermeasures for wetland protection. 2004 In 2004, many European countries joined together to set up the European Pond Conservation Committee, and held its first meeting in Geneva, with the theme of "Conservation and monitoring of pond biodiversity". Since then, countries in Europe and the United States have begun to focus on the conservation of urban wetland biodiversity, using different ecological techniques, such as ecological regulation models at the land-water interface, flexible design, and the construction of "river-wetland" complexes, to improve the heterogeneity of urban wetland habitats and increase urban wetland biodiversity . The construction of wetland parks is also a development direction advocated by the Convention on Wetlands, and most wetland parks in foreign countries focus on environmental protection, as well as science education and ecotourism, and the extent to which ecotourism is developed and used is increasing[59].

(2) Relevant domestic research

In the context of the construction of ecological civilization, the protection and management of wetlands in China are receiving more and more attention. The report of the 19th National Congress has put forward the action instruction of "strengthening the protection and restoration of wetlands", and the third national land survey has also specified wetlands as a first-class land category. The importance of the wetland environment to the ecological security pattern of China is self-evident.

In recent years, with the development of urbanization, the issue of urban wetland landscapes has received more gradual attention, and relevant research has focused on the restoration and reconstruction of river and lake wetland ecosystems and the planning and design of wetland parks based on ecological restoration, including wetland substrate restoration, hydrological process restoration, water environment restoration, and wetland biology and habitat restoration, for example, the planning and design of Hainan Xinying Mangrove National Wetland Park, with restoration, conservation to achieve ecological restoration and environmental landscape improvement in mangrove wetlands, while using the advantages of existing resources to create a multi-type landscape environment[60]. In terms of ecological techniques and methods, innovative research has been carried out on substrate terrain modification and dredging techniques, wetland phytoremediation techniques, microbial restoration techniques, artificial wetland purification techniques, water flow level control techniques, wetland barge modification techniques and so on. At present, many cities in China are carrying out urban wetland restoration and landscape design work one after another, such as Changchun and Harbin in the Songhua River Basin, Tianjin in the Haihe River Basin, Jinan in the Yellow River Basin, Hangzhou, Shanghai and Suzhou in the middle and lower reaches of the Yangtze River, Xi'an in the northwest, and Lhasa on the Qinghai-Tibet Plateau, all of which have implemented major ecological projects for urban wetland restoration and set up many national wetland parks,which have played an important role in improving the local ecological environment.

The current landscape design of urban wetlands at home and abroad mostly starts from the landscape level and gradually emphasizes ecological functions and biodiversity conservation. Landscape design researchers have proposed a variety of ecological technology methods and strategies based on the landscape design requirements of urban wetlands, such as wetland bubbles, ecological barges, ecological floating beds and so on. Different types of urban wetlands vary in terms of factors such as socio-economic environment and functional needs, and there are also differences in the direction or details of wetland landscape design.

1.3.5 Progress of research on urban wetland landscape assessment

In recent years, with the development of landscape evaluation research, other disciplines such as psychology and ecology have been combined into the realm of landscape evaluation[61]. Wetland landscape evaluation refers to the evaluation of the quality of a wetland landscape in terms of its multifaceted value, including both the evaluation of the quality of the objective components that make up the wetland landscape and the evaluation of the quality of the perception of the wetland landscape to the viewer. People can perceive and evaluate the beauty of the landscape through vision, hearing, smell and touch, of which visual perception is the main way. Up to 70% of human activities are guided by visual perception and thinking behavior[62],[63].

Most of the domestic and international studies on the visual landscape evaluation of urban wetlands have been conducted on plant landscapes, evaluating the beauty degree of wetland plant landscapes by analyzing factors such as the type of plants, community structure, color, seasonal phase, hierarchy, and depression[64]-[66], Acar, Bulut, Zhang et al. wetland landscapes for a comprehensive evaluation of the visual environment of the landscape[67]-[69] to explore the influence of the overall landscape hierarchy, elemental coordination, garden path morphology, and contextual beauty on the visual environment of the landscape, but few scholars have conducted studies on the evaluation of the visual environment quality of urban wetland landscapes based on ecological design approaches.

The more common method of urban wetland landscape evaluation is the comprehensive establishment of a mathematical model based on visual environment theory, combined with elements of urban wetland landscape characteristics, which includes the beauty degree evaluation method, semantic difference analysis, hierarchical analysis, regression analysis, correlation coefficient test, etc. Expert assessment based on objective landscape attributes and public assessment based on viewers' perceptions is the two most basic models of landscape assessment [70], of which scenic beauty estimation (SBE) is a psychophysical approach to evaluating the aesthetic quality of landscapes[70], which investigates how human subjective preferences change in response to changes in landscape attributes and seeks ways to plan and design landscapes scientifically through the study of the relationship between the two[71]. However, due to the inadequate correspondence between people's visual perception and the spatial characteristics of the landscape and the characteristics of the design elements, and the failure to test the correlation and constraint between the elements, the evaluation results are not very guiding in concrete practice. The Semantic Differential (SD) method is used to evaluate landscape quality by extracting landscape elements as evaluation factors of beauty degree and combining them with factor analysis to extract mutually independent factors to build quantitative models[72],[73], SD combined with SBE cany reflect The combination of SD and SBE can reflect the strengths and weaknesses of the landscape and enhance the objectivity of the results[74]-[76]. However, the SD method usually sets the score based on the positive and negative extremes of the 'adjective pairs' [75], and the 'adjective pairs' score is still highly subjective. The objectivity of the scores is affected by the fact that too many "adjective pair" scores can make respondents lose patience.To find a more objective, accurate and effective method for evaluating factors affecting landscape scenic beauty, the expert evaluation method was used for SBE evaluation, which consists of experts identifying landscape factors and scoring the factors quantitatively, excluding the subjectivity of the respondent and the untruthfulness of the data, and is more suitable for evaluating objective factors, making the results more objective[77]-[79]. Therefore, it has become a research trend in recent years to explore a combination of subjective and objective evaluation methods in the evaluation of landscape beauty[80].

1.3.6 Existing research gaps and outlook

(1) Most existing biodiversity conservation strategies focus on the conservation of natural territories or specific species left in the urban built environment, which is essential to reduce the disturbance of natural habitat patches by human activities[81]. The objectives and strategies of biodiversity conservation and urban planning and design are often separate, and most existing biodiversity conservation plans are located at the end of the urban planning and design process [82].

(2) Although biodiversity conservation is often listed as one of the important objectives in urban planning and design, especially in the planning of green space systems, it is rarely integrated into the procedures and concrete practices of urban planning and design[83]. As a result, there are also some common problems in the current conservation and design of urban wetland landscapes: the design approach is more technical than theoretical; the design outcome is more landscape than functional; some projects lack sustainability planning and design, etc.

(3) For planning designers, the lack of understanding of the relevance of biodiversity to spatial planning and design makes it difficult to apply and implement the findings of species resource surveys and bio-spatial functional zoning provided by biologists in the planning preparation and implementation process[81],[84]. The discipline of landscape architecture should and must play a central role in addressing the biodiversity challenges of urban and rural habitat ecosystems. Nature-based solutions provide an alternative perspective for urban biodiversity enhancement, i.e. plant landscape creation, from the perspective of holistic, integrated and multi-beneficial human-nature relationships.

(4) Most studies at home and abroad are limited to the study of single wetlands and lack comparative studies on different types of urban areas and different functions of wetlands. In addition, the existing studies are biased towards the study of temporal dynamics, and there are fewer studies on the urban-rural gradient scale, therefore, the integration study of the temporal and spatial dynamics of wetland landscape patterns based on the perspective of urbanization, and the comparative study of biodiversity and landscape for different types and functions of urban wetlands The comparative study of the relationship between biodiversity and landscape in different types and functions of urban wetlands will be the focus of future research.

1.4 Technical route and innovation points

1.4.1 Technical routes

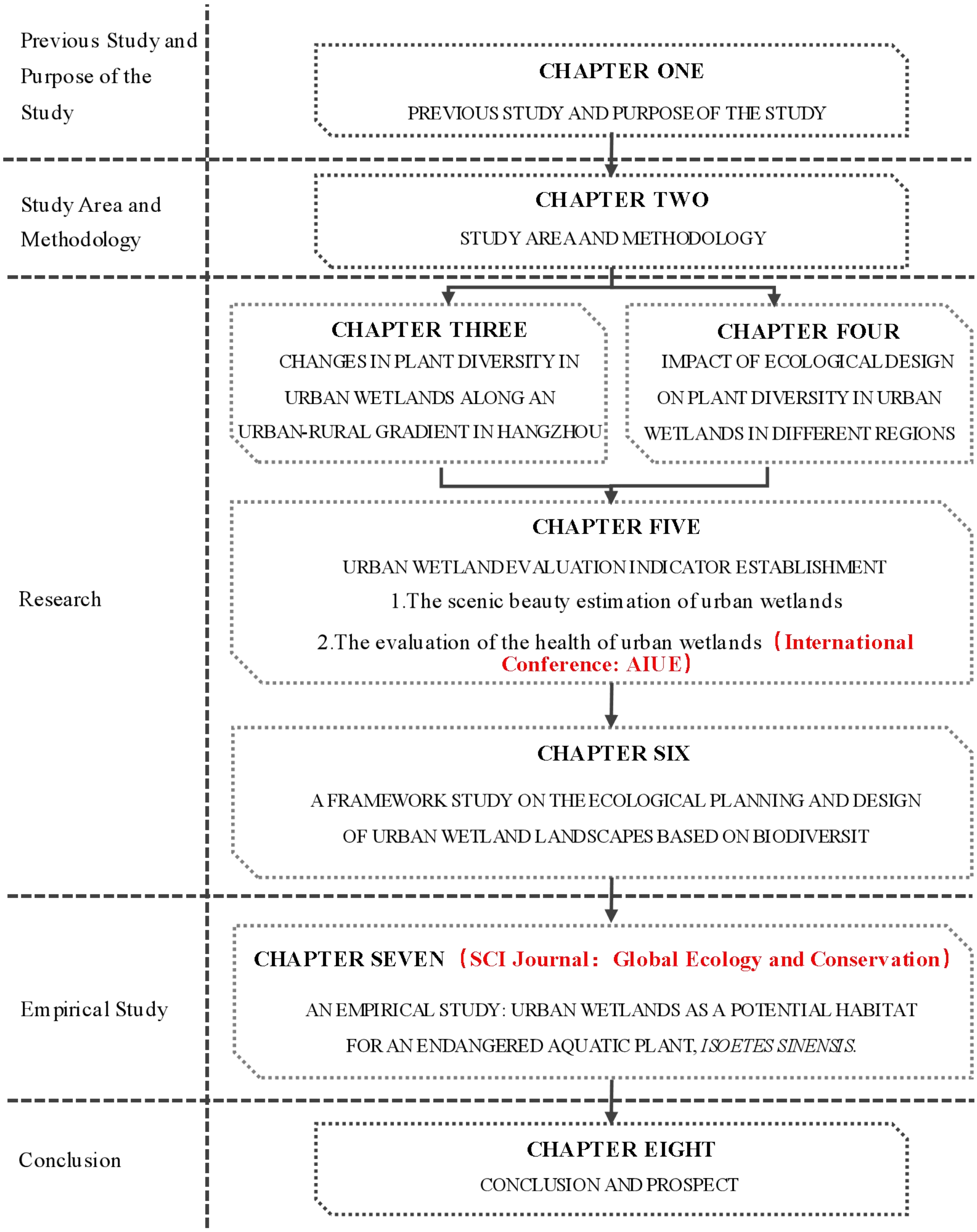

Fig. 1-6 Chapter name and basic structure

The research ideas and methods of this thesis are shown in the figure above. The research is oriented towards the demand-oriented construction and development of urban wetlands, based on the principles and methods of biodiversity conservation, to build a scientific and rational theoretical framework for urban wetland landscape design, and to establish a paradigm to guide the landscape design of different regional types of urban wetlands.

Firstly, the problems that exist between urban wetland landscape design and biodiversity conservation today are analyzed, and it is the primary issue of the whole study. With the help of literature data collection and practical research, we analyze the actual needs of urban biodiversity conservation for wetland landscape ecological design and explore effective methods and pathways for conservation practice.

Secondly, parallel research will be carried out to analyze the causes of the problems from different perspectives, and take them as the core of the research, such as how to achieve synergistic development of landscape and biodiversity conservation in design methods; how to combine new methods and technologies with wetland landscape design; how to reflect the design concept of sustainability, etc., to gradually clarify the theoretical framework of wetland landscape design in the context of biodiversity conservation. This will gradually clarify the theoretical framework of wetland landscape design in the context of biodiversity conservation.

Finally, based on the above main research, the findings are integrated and a paradigm for the design of different regional types of urban wetland landscapes appropriate to the current environment is proposed. In the study, special studies and opinions of other researchers on related issues are emphasized and combined with the findings of this project.

1.4.2 Points of innovation

This study was conducted to analyze the problem of urban wetland landscape design and urban biodiversity conservation and to propose a paradigm of urban wetland landscape design for different regional types. The results of the study can be submitted to provincial and municipal urban planning and design departments for reference and will provide scientific references for urban biodiversity conservation and urban wetland planning and managers, aiming to benefit local governments' urban planning and biodiversity conservation work practices.

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Chapter 2

STUDY AREA AND METHODOLOGY

CHAPTER TWO: STUDY AREA AND METHODOLOGY

2.1 Basic overview

Hangzhou is the capital city of Zhejiang Province, China, located in the south wing of the Yangtze River Delta, the western end of Hangzhou Bay, the lower reaches of the Qiantang River, the southern end of the Beijing-Hangzhou Grand Canal, with a total area of 16,850 square kilometers, is an important central city in the Yangtze River Delta and a transportation hub in southeast China[1], and is also an important scenic tourism city, the first batch of national historical and cultural cities.

Since the 1950s, the regional scope of Hangzhou has undergone constant changes. In April 1958, Hangzhou County was abolished as a suburb of Hangzhou, and in January 1960, Qiantang Association was established, and in March 1961, Yuhang County was merged into Hangzhou Qiantang Association to establish a new Yuhang County. At the beginning of 1990, the Mid-Levels District was abolished and merged with the old Gongshu District to form a new Gongshu District. In 1994, Hangzhou was upgraded to a sub-provincial city. On December 12, 1996, Binjiang District was newly established in Hangzhou. There are seven counties (cities) of Xiaoshan, Tonglu, Yuhang, Lin'an, Jiande, Fuyang and Chun'an. In 2000, the Hangzhou Municipal Party Committee put forward the expansion strategy of "expanding the city to the east, tourism to the west, developing along the river, and developing across the river", and since then, Hangzhou has experienced three rounds of "withdrawing the city and building a district". In March 2001, Xiaoshan and Yuhang were withdrawn from the city and set up districts, and the urban area of Hangzhou increased from 683 square kilometers to 3068 square kilometers. In December 2014, Fuyang was withdrawn from the city to establish a district, and the urban area increased to 4876 square kilometers. In August 2017, Lin'an was withdrawn from the city to establish a district. The urban area was expanded by 64% to 8002.8 square kilometers. On April 2, 2019, the Zhejiang Provincial Government approved the establishment of Hangzhou Qiantang New District.

On March 11, 2021, the People's Government of Zhejiang Province issued the Notice on Adjusting the Administrative Divisions of Hangzhou City, and so far, the administrative jurisdiction of Hangzhou has included 10 municipal districts of Shangcheng, Gongshu, West Lake, Binjiang, Xiaoshan, Yuhang, Linping, Qiantang, Fuyang and Lin'an, 2 counties of Tonglu and Chun'an, and 1 county-level city of Jiande, with a total area of 16,850 square kilometers, making it the largest city in the urban area of the Yangtze River Delta. In September 2021, according to the seventh national census, Hangzhou was listed as a megacity (Figure 2-1).

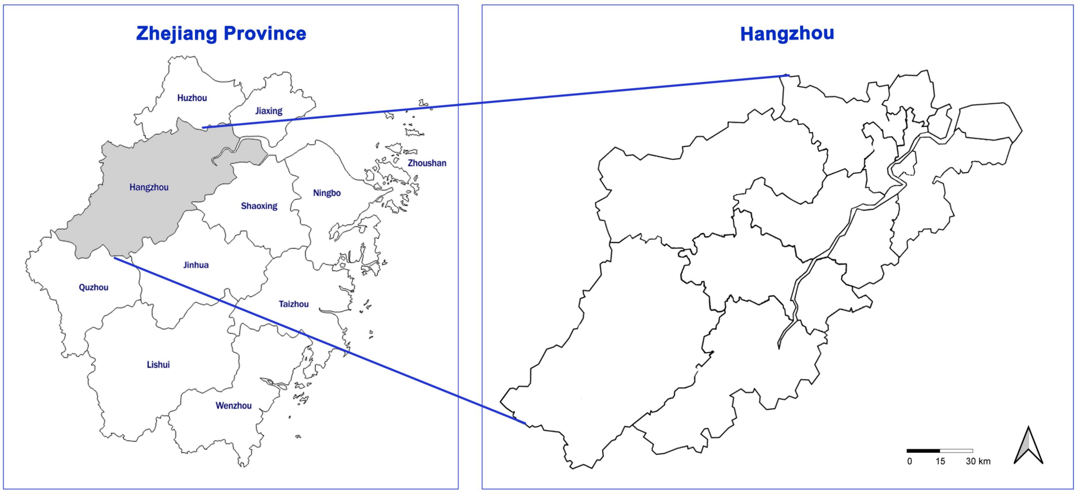

Fig. 2-1 Hangzhou City Planning Area Map

In the past hundred years, the expansion of urban construction land in Hangzhou has been obvious, and the center of gravity of Hangzhou has undergone a change process of "north-northwest-northeast-southeast-south", changing from expansion to a single direction to a balanced development trend in multiple directions; The core area of the city presents a spiral development process dominated by frog leap growth, filling growth, and edge growth, and the overall performance of the research area is characterized by marginal growth always occupying a relatively important position[2]. In 2019, the "Hangzhou Land and Spatial Master Plan Development Strategy 2050" proposed the urban structure of "one main city, four pieces and three vice cities", that is, one main urban area; Chengxi, Qiantang Airport, Zhijiang-Fuyang and Linping four main city areas; Tonglu, Jiande and Chun'an are three sub-central cities. The 2021 Hangzhou Land and Spatial Master Plan (2021-2035) proposes to build a new spatial pattern of megacities with "one core, nine stars, dual network integration, and three rivers and green wedges", and comprehensively promote urban and rural development to achieve common prosperity. Hangzhou city presents the characteristics of one core, multiple centers, urban and rural gradient development.

2.1.1 Geography

Located in the southern flank of the Yangtze River Delta and the western end of Hangzhou Bay, Hangzhou is an extension of the intersection of the "Silk Road Economic Belt" and the "21st Century Maritime Silk Road" and a strategic hub city of the "Online Silk Road". The city is bounded between latitudes 29° 11'-30° 34' N and longitudes 118° 20'-120° 37'E. The city is about 250 km long in the east-west direction and about 130 km wide in the north-south direction. Hangzhou's mountains and rivers are interdependent, the lake city is combined, and the five waters of rivers, rivers, lakes, seas and streams are guided together, and the scenery is picturesque, which can be called "paradise on earth". The city's hilly and mountainous areas account for 65.6% of the total area, concentrated in the west, central and southern regions; Plains account for 26.4%, mainly distributed in the northeast; Rivers, rivers, lakes and reservoirs accounted for 8.0%. It has the largest reservoir in the southern coastal region of China, the Xin'anjiang Reservoir (also known as Qiandao Lake), the world's longest artificial canal, the Beijing-Hangzhou Grand Canal, and the Qiantang River, famous for its high tides, passing through the city[3].

Hangzhou has a subtropical monsoon climate with four distinct seasons, mild and humid, abundant sunshine and abundant rainfall. In 2019, the average annual temperature in Hangzhou was 18.1°C and the average annual rainfall was about 1647.7 mm. The summer climate is hot and humid, and it is one of the four new furnaces. Winters are cold and dry. Spring and autumn have a pleasant climate and are the golden season for sightseeing. Hangzhou is rich in products, unique agricultural production conditions, crops, trees, livestock and poultry varieties, planting more than 260 varieties of forest fruits, tea mulberry, flowers and so on, Hangzhou silkworm mulberry, West Lake Longjing tea is famous throughout the country.

2.1.2 Ecology

Hangzhou is a city famous for water, Hangzhou's historical prosperity is closely related to water, and its special geographical location and hydrological characteristics make Hangzhou one of the cities with the richest types of wetlands and the largest wetland area in China. In recent years, Hangzhou has gradually created a water-friendly livable city with "clear water, clear river, green bank and beautiful scenery" through the implementation of a number of ecological protection system projects with the concept of "five water co-governance" and "clean water, smooth river, green bank and beautiful scenery". For a long time, the Hangzhou Municipal Party Committee and the Hangzhou Municipal Government have attached great importance to the protection and utilization of wetlands, with high starting point planning, high-intensity investment, and large project promotion, Hangzhou's wetland protection and utilization are at the forefront of the country, and Hangzhou's "Xixi Model" is famous all over the world[4]. In recent years, the protection of urban water environment has also achieved remarkable results, in 2020, the proportion of surface water in the city reaching Class I - III. is 98.1%, an increase of 3.8% over 2019[5], providing a good research area for urban wetlands.

2.1.3 Overview of urban wetlands in Hangzhou

Hangzhou is a city of wetlands, not only West Lake, Xixi, Qiantang River, Hangzhou Bay, but also many rivers and lakes, long coast, its special geographical location and hydrological characteristics make Hangzhou one of the cities with the richest wetland types and the largest wetland area in China. By the end of 2020, the total area of wetlands in the city will be 135,150.83

hectares, accounting for 8.02% of the total area of the city(Table 2-1). The water surface of rivers, reservoirs and ponds in the city's wetlands is large, with 48,935.87 hectares, 55,262.50 hectares and 26,170.03 hectares respectively[6]. The wetland types are mainly constructed wetlands, offshore and coastal wetlands and river wetlands, accounting for 66.2%, 19.1% and 14.2% respectively[7]. It has basically formed a wetland protection pattern of "Three Rivers" (Qiantang River, Fuchun River, Xin'an River), "Seven Lakes" (West Lake, Qiandao Lake, Qingshan Lake, South Lake, Xiang Lake, Baima Lake, Sanbaitan), "One River" (Canal) and "One Creek" (Xixi).

Table 2-1 Statistics of wetland area in Hangzhou by type

Wetlands	Wetland type	Wetland area (ha)	Proportion
Offshore and coastal wetlands	Coastal freshwater lakes	779.30	0.58
	Estuarine waters	19873.34	14.70
River wetlands	Permanent rivers	24053.71	17.80
	Floodplain wetlands	1132.28	0.83
Lake wetlands	Permanent freshwater lake	1244.23	0.92
Swampy wetlands	Swampy meadows	30.60	0.02
Constructed wetlands	Reservoir	69880.55	51.71
	Canals,water transmission rivers	5310.92	3.93
	Aquaculture farms	12845.90	9.50
Total		135150.83	100.00

Table data source: Hangzhou Wetland 14th Five-Year Plan[6].

In recent years, Hangzhou governments at all levels have attached great importance to wetland protection, and a total of 15 important wetlands of various types have been identified and issued to the public, with a total area of 2843.37 hectares Hangzhou's rich wetland resources constitute a variety of ecological landscapes, for example, the Qiandao Lake Reservoir (Xin'anjiang Reservoir) wetland is the main source of drinking water in Hangzhou, and it is also a famous leisure tourism resort at home and abroad; Xixi National Wetland Park is the first national wetland park in China that integrates urban wetlands, agricultural wetlands and cultural wetlands. West Lake Wetland is one of the few lake-like cultural heritage sites that has been inscribed on the World Heritage List; The Beijing-Hangzhou Ancient Canal is the world's longest artificial canal and water transmission river[7].

2.2 Research scope and selection of research subjects

2.2.1 Definition of the scope of the study

Hangzhou after many rounds of withdrawal of urban construction area adjustment, now the urban structure presents a core multi-center, urban and rural gradient development characteristics, in addition to the main urban area of Hangzhou, there are a number of districts, county-level town centers, in the complex urban structure system, it is difficult to make a simple division according to the urban structure of "urban core area, urban edge area and countryside", and it is not suitable for classifying urban wetlands according to this.

Therefore, this project defines the research area of urban wetland as a comprehensive urban structure zoning and urban green space classification standard, and divides the area from the perspective of ecological pattern, with traffic lines as the boundary. First of all, the urban ring highway is usually centered on the urban core area, showing a multi-level, ring-shaped, radial distribution, and the location of the construction of the ring highway often reflects the urban construction pattern; Secondly, there are wide green protective belts built on both sides of the ring highway, which have a significant impact on the urban ecological environment and ecological pattern, and they are more suitable as a natural boundary and are more suitable as the zoning boundary of the urban wetland research of this topic. Therefore, the research area in this paper is limited to the main urban area and the peripheral area of Hangzhou, and the research area of urban wetlands is defined as follows (Figure 2-2):

Urban core area: the main city area within the first layer of the ring road;

Urban fringe area: the urban-rural transition area between the first layer of the ring highway and the secondary ring highway;

Urban Suburban area: Countryside areas outside the secondary ring highway.

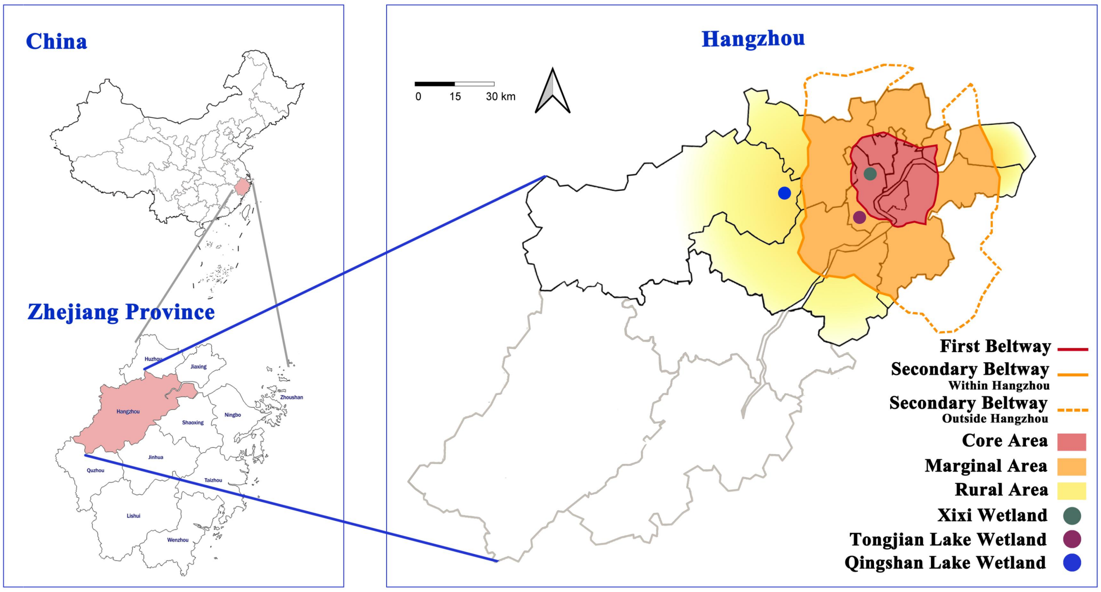

Fig. 2-2 Hangzhou Urban Wetland Study Area Zoning Map

2.2.2 Selection of research subjects

After the zoning standards of the research area are determined, a representative urban wetland case is selected from three different regional types: urban core, urban edge and urban suburb, and relevant research are carried out. They are Xixi Wetland National Wetland Park (urban core area), Tongjian Lake Wetland Park (urban fringe area), and Qingshan Lake Wetland Park (urban suburban area) (Figure 2-3). The reasons for choosing these three typical wetlands as research subjects are as follows:

(1) The selected study subjects are representative

Xixi Wetland in the core area of Hangzhou is a typical lake-type urban wetland with natural and artificial interaction, which not only retains the natural foundation of urban wetlands, but also undergoes scientific and systematic planning and design and artificial transformation, and has become a famous national tourist scenic spot, playing the most important human settlement environment and tourism culture functions of urban wetlands. Tongjian Lake Wetland Park in the edge of the city is a newly built urban wetland park, and the main function is flood control, drainage and storage, taking into account the improvement of water environment and water landscape improvement, through the overall planning and design to form wetland landscapes of different sizes, and provide urban residents with social functions of leisure and entertainment. The Qingshan Lake Wetland in the urban suburban area is also a lake-type urban wetland artificially built based on natural background conditions, which not only has the ecological environment of the aquatic wet wetland at the junction of the water bank, but also plans and designs the landscape such as the greenway around the lake. Therefore, Xixi Wetland, Tongjian Lake and Qingshan Lake were selected as the research objects, which are typical representatives.

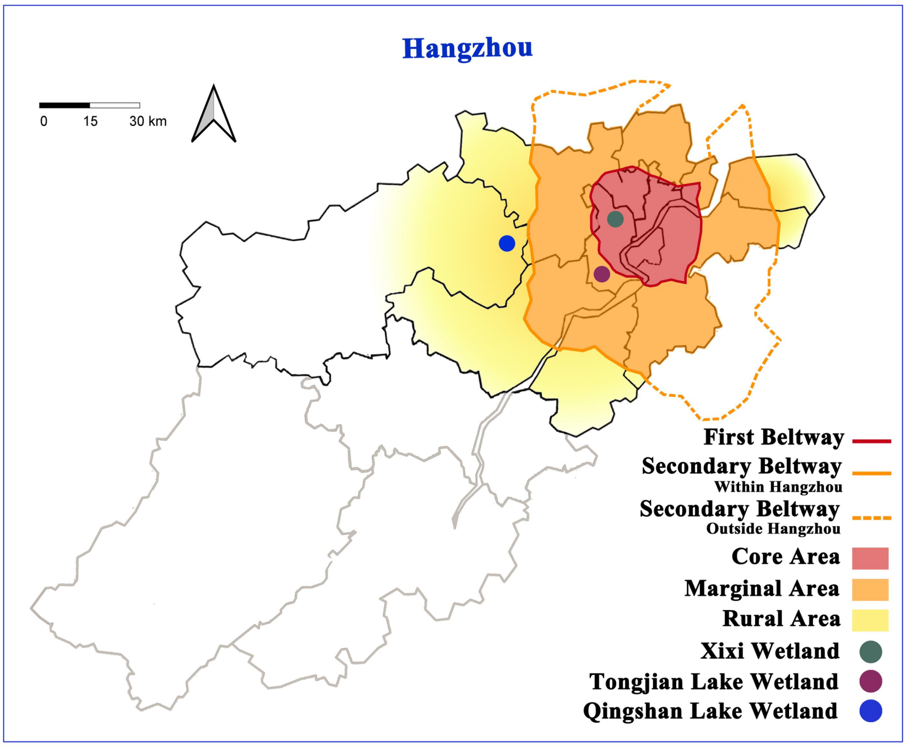

Fig. 2-3 Location map of three typical urban wetland areas in Hangzhou

(2) There are obvious differences between the three typical urban wetlands

The structure and function of wetland ecosystems are closely related to the urbanization process, social and economic development of Hangzhou, and the improvement of residents' quality of life. Due to the different geographical location and functional positioning, there are also obvious differences in the three wetland parks.

Xixi Wetland Park is a national 5A level wetland park, after scientific and reasonable planning and design, the wetland has a nature reserve, which is not affected by human activities, and the wetland ecosystem protection is relatively complete; The park has a leisure and natural viewing area open to the public, providing social functions such as education and science, leisure and entertainment, and aesthetic viewing; In addition, as a 5A-level scenic spot, it has high popularity, is located in the core area of the city, has good traffic accessibility, perfect infrastructure, and rapid value-added of surrounding land, which is conducive to the play of its economic functions. Therefore, the main functions of Xixi Wetland Park are reflected in the comprehensive functions of ecology, economy and society.

Tongjian Lake Wetland Park is located in the edge of the city, is a newly built urban wetland park, its community structure is still unstable, resulting in low biodiversity and habitat complexity, low ecological function; After scientific and reasonable planning and design, the leisure and entertainment functions are relatively perfect, but the educational and scientific functions are insufficient, and the social functions need to be improved; However, due to the fact that there are many scenic spots around the wetland park, the linkage between scenic spots is good, the traffic accessibility is better, the surrounding infrastructure is improved rapidly, and the economic function development is better.

Qingshan Lake Wetland Park is located in the urban suburban area, with a large area of water, but the habitat complexity and biodiversity are relatively low, and most of the surrounding areas are under construction, the infrastructure is not perfect, so the ecological and economic functions are not high; The landscape design of the wetland park is mainly for artificial greenways and landscape belts on both sides, the landscape space is relatively single, and the proportion of vegetation area is not high, which also leads to the slow development of social functions.

The three urban wetland parks have obvious differences in regional location, completion time, functional positioning, and planning and design concepts (Table 2-2), analyze the ecological problems existing in wetland landscape design, understand the internal relationship between urban wetland landscape design methods and urban biodiversity, and help distinguish the significant impact and correlation of different different elements on urban wetland biodiversity. Help us establish a scientific and reasonable design theory framework, further explore the paradigm of urban wetland landscape design under different regional conditions, and provide scientific guidance for urban wetland landscape planning and design.

Table 2-2 Basic information of three typical urban wetland parks

Typical urban wetlands	Location	Area	Functional positioning	Crowds	Planning start time	Planning and construction
Xixi Wetland National Park	The core of the city	11 km^2	Wetland protection + science education + leisure and entertainment	International/ national tourist population + Hangzhou citizens	In 2005	Completed in 2009
Tongjian Lake Wetland Park	The fringe of the city	4.33 km^2	Flood control and drainage and storage + leisure and entertainment	Hangzhou citizens are the mainstay	In 2020	Completed in 2023
Qingshan Lake Wetland Park	The suburban of the city	64.5 km^2	Ecological conservation + leisure and entertainment	Hangzhou citizens are the mainstay	In 2016	Continuous construction

2.3 Overview of the research subjects

2.3.1 Urban Core area - Xixi Wetland

(1) Geographical location

Xixi National Wetland Park (30° 15'59"N, 120° 3'47"E) is located in the western part of Hangzhou, within the ring highway circle, less than 5 km from the West Lake, belonging to the wetland type in the core area of the city. Spanning the two administrative districts of Xihu District and Yuhang District, from the west side of Zijingang Road in the east, to the east side of the green belt of the Ring Road in the west, from the south along the mountain and river, and to the north to Wener West Road, the average length from east to west is about 4.6 km, the average width from north to south is about 3.7 km, and the total area is nearly 11 km^2, making it the first national wetland park in China. Xixi Wetland is a secondary wetland at the edge of the city formed on the basis of the remains of Guhetan and under the influence of human farming and fishing activities for more than 1,000 years[8]. In 2005, Hangzhou Xixi National Wetland Park was established with the approval of the State Forestry Administration, in 2009 the wetland park was included in the list of wetlands of international importance, and in 2012 Hangzhou Xixi Wetland Tourism Area was officially awarded the title of "National 5A Tourist Scenic Spot"[9] (Figure 2-4).

Fig. 2-4 Actual view of Xixi Wetland (photo by the author)

(2) Conservation and planning

The comprehensive protection project of Xixi Wetland is divided into three phases (Figure 2-5), the core area of the first phase is about 3.46 square kilometers, the project was started in August 2003 and opened on May 1, 2005. The content of the first phase of the project is mainly to improve the water quality of the wetland, restore the function of the wetland, and protect and restore the ecosystem of the Xixi Wetland, which is the core part of the Xixi Wetland. Among them, about 94% of the ecological protection areas and ecological restoration areas and about 2.1% of the historical heritage reserves have been preserved, and the most distinctive parts of the Xixi Wetland water landscape have been completely preserved. The first phase includes two major ecological conservation areas, Chaotian Twilight Ecological Conservation Area, Shrimp Dragon Beach and Feijiatang. In addition, eight major cultural and natural landscapes and 124 regional buildings have been built, such as Qiushui'an. The second phase of the Xixi Wetland Project covers an area of about 4.89 square kilometers (including the overlap with the first phase), featuring wetland ecology as the theme, Fanyin culture and local culture. The second phase of the project was launched in May 2006 and fully completed in May 2008, focusing on the four main contents of "ecological environment, history and culture, landmark attractions, and scientific research and science". The third phase of the Xixi Wetland Comprehensive Protection Project, covering an area of 3.35 square kilometers, was officially launched in January 2008 and completed in May 2009. The area mainly presents a "belt, two pieces, multiple points" appearance. "One belt" refers to the wetland natural landscape belt centered on Wuchanggang and involving the interior of the plot; The "two pieces" are bounded by Wuchang Port and are divided into two parts: east and west, the western part shows the water village style and the Wuchang Hongshi culture, and the eastern piece shows the farming and fisherman culture; "Multi-point" refers to the scenic spots and tourism service points set up according to the current situation, conditions and needs in the area, including Wuchang Folk Village, Hongyuan, Dragon Boat Racing, Guanyin Nunnery, etc. The third phase is mainly based on the protection and improvement of the regional ecological environment, the Wuchang (Hong's) culture as the connotation, and the important block of Xixi Wetland characterized by any wetland natural harmony mode. The completion of the third phase of the comprehensive protection project of Xixi Wetland marks the comprehensive and effective protection of Xixi Wetland[10].

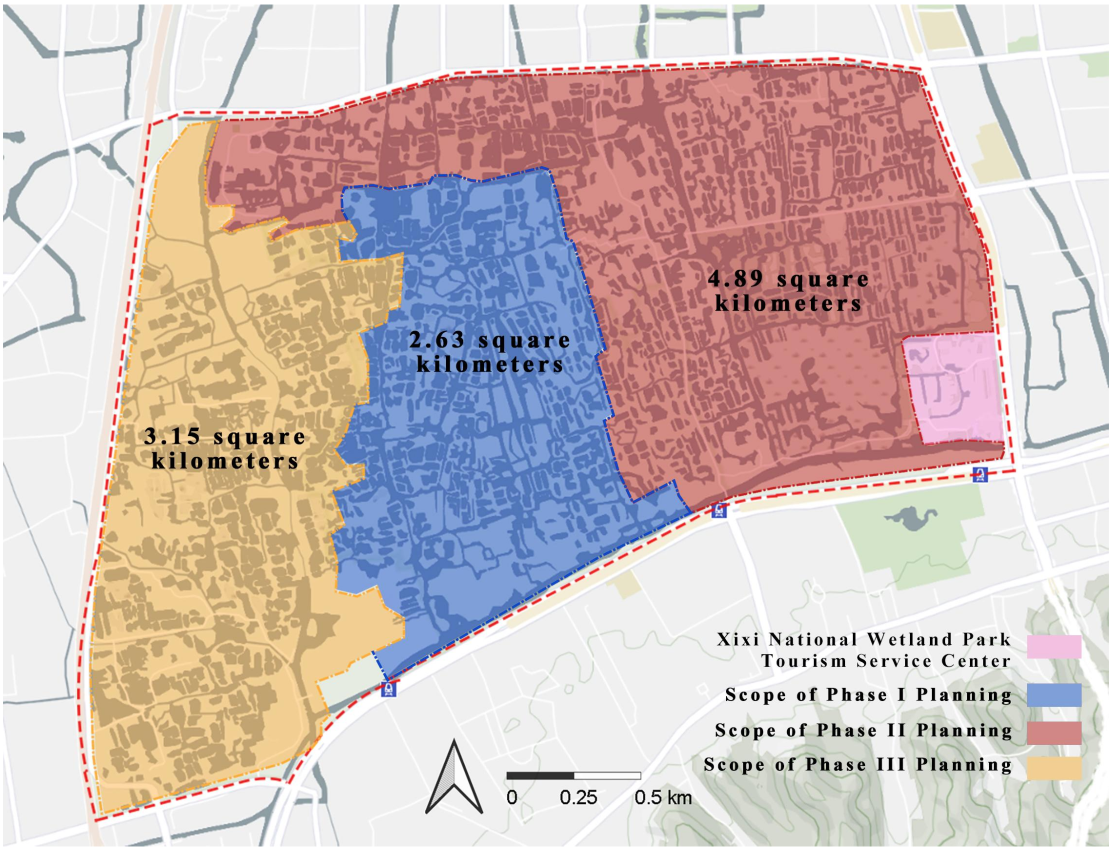

Fig. 2-5 Xixi National Wetland Park Phase I, II and III Planning Scope Map

Therefore, the nature of Hangzhou Xixi Wetland National Park is: to protect the regional ecological environment, improve the water quality of the wetland, protect the biodiversity of the wetland as the starting point, with the fresh and elegant natural landscape, the profound cultural and historical landscape as the highlight, the protection and moderate utilization of the national wetland park.

(3) Tourism development

Xixi Wetland is divided into the eastern wetland ecological protection and cultivation area, the central wetland ecological tourism and leisure area and the western wetland ecological landscape sealing area. Tourism is mainly open to the central wetland ecological tourism and leisure area, and parts of the east and west, built with "three and ten scenery". The realization of the goal of "clean water, green shore and beautiful scenery" has improved the environmental quality of Xixi Wetland and increased the charm of ecological tourism in Xixi Wetland. In 2015, Xixi Wetland achieved tourism operating income of 276 million yuan, which to a certain extent fed the ecological protection of Xixi Wetland, so that the ecological resources of the wetland can be sustainable and healthy[11].

Relying on rich plant resources and profound cultural resources, Xixi Wetland has created key festival products such as "Plum Exploration Festival, Flower Dynasty Festival, Dragon Boat Festival, Fire Persimmon Festival, and Tinglu Festival" to further inherit the wetland culture. Integrating the existing science popularization resources, continuously optimizing the layout of the science popularization education tour system and the tour route, forming a science popularization education system of "one museum (China Wetland Museum), two centers (wetland research center, wetland science popularization center), two districts (bird watching area, ecological protection area), three gardens (Hangzhou Wetland Botanical Garden, Fishery Experience Park, Agricultural Experience Park), four stations (ecosystem positioning observation and research station, environmental monitoring station, biodiversity observation station, wildlife epidemic source disease monitoring station)", and through the ecological information display platform The construction of software such as intelligent terminals has truly become a veritable outdoor classroom and a "national science popularization education base". At present, more than 1 million young people come to Xixi Wetland every year to receive wetland science education[11].

2.3.2 Urban Fringe Area - Tongjian Lake Wetland

(1) Geographical location

Tongjian Lake is located in the southwest of Hangzhou city of the river area of Shuangpu Town west hills and the intersection of the south plain, the Zhijiang area is strategically located, southeast of the Qiantang River, west to Lingshan, Longwu scenic spot and Fuyang border, north of the West Lake Scenic Area, is the West Lake Scenic Area to the "two rivers and one lake" scenic spot transition area, belongs to the edge of the city wetland park.

Tongjian Lake was formerly known as "Jinniu Lake", the original lake surface of about 2 square kilometers, the landform belongs to the low hills and alluvial plain landform transition section, the plain area is relatively flat and open, the ground elevation is generally 5.0m ~ 9.0m. In low-hilly areas, the elevation of the summit is generally less than 250m. Its origin and production period are basically the same as those of West Lake. The surface of the lake has gradually shrunk due to the reclamation of the lake in the 1960s, and only more than 100 acres remain (Figure 2-6).

Fig. 2-6 Actual view of Tongjian Lake Wetland (photo by the author)

(2) Conservation and planning

In 2017, Hangzhou approved the "Zhijiang Area Water Conservancy Comprehensive Plan", and Tongjian Lake is an important part of the water conservancy engineering system in the Zhijiang area, playing the role of draining water from mountainous areas and distributing irrigation and ecological environment water. Therefore, Tongjian Lake was launched as a flood control drainage and storage project, and the task was to focus on flood control, drainage and storage, taking into account the improvement of water environment and water landscape, with a total planning area of about 4.33 square kilometers. The excavation area of the storage area is 1.35km^2 of the storage area, and the elevation of the lake bottom is 2.5m. Due to the high terrain of the block where the Tongjian Lake Regulation and Storage Area is located, the normal water level is set at 6.5m, and the normal water level of the river network is 5.5 to 5 .8m, and there is a water level difference, so the control gate needs to be set at the connection between the storage area and the river network to promote the flow of water and water purification.

The protection of Tongjian Lake Park is given priority, restoration first, the establishment of a benign and orderly development model between the wetland and the city, the restoration of site memory, the protection of the original ecological wetland style, the construction of a harmonious development of an urban wetland park between a person and nature. The overall plan is "one axis, three cores and six areas". One axis, that is, the overall planning with water as the main axis, do a good job in the water system improvement article. Inheriting Tongjian Lake's "Soup Perch" and celebrity allusions as the main axis of culture, and at the same time expanding the water surface of

Tongjian Lake as the spatial axis, all the resources in the area are integrated in the two dimensions of time and space to form a complete swimming line. The four cores are the three core themes of "pastoral, wetland and culture" in the planning and design. The three themes closely follow the overall positioning of "ecology, agriculture and culture", which is not only the refinement of the the wetland conservation area, the Binhu Park area, the wetland science popularization area, the farming experience area, the water walking area, and the eight-tone listening area (Figure 2-7).

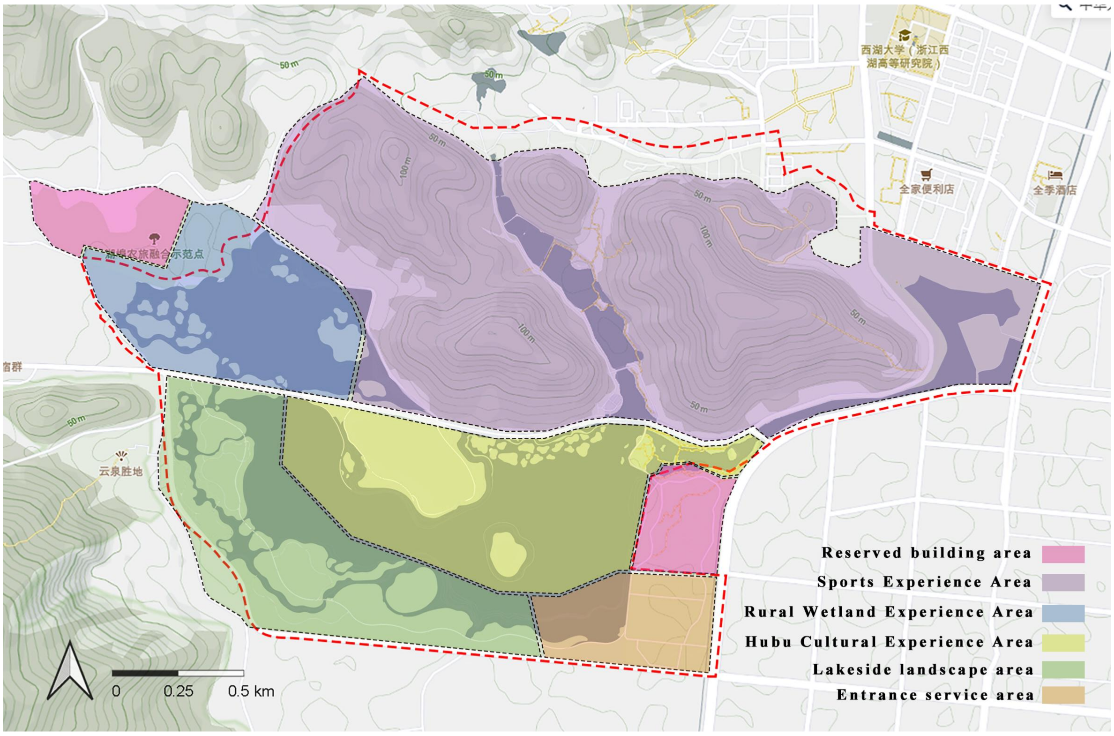

Fig. 2-7 Planning function zoning map of Tongjian Lake Wetland

(3) Tourism development

In September 2020, the first phase of Tongjian Lake Park was completed. The three major plates of Lihu Lake, Flower Sea and Yunqi are opened, adding a new rural country leisure park to restore the ecology for citizens and tourists. The number of daily tourists during the Eleventh National Day holiday is about 8,000 to 9,000 person-times, and the highest peak of tourists entering the park occurs on several weekends after the festival, and the number of daily tourists basically exceeds 10,000.

2.3.3 Urban Suburban Area - Qingshan Lake Wetland

(1) Geographical location

Qingshan Lake is located in Qingshan Town, Lin'an District, Hangzhou, 38 kilometers away from the main urban area, 5 kilometers in the eastern suburbs of Lin'an District, and outside the Hangzhou Secondary Ring Expressway, which belongs to the suburban wetland park. Qingshan Lake was built in 1964, surrounded by mountains, with a good ecological environment, an area of 64.5 square kilometers, and a water area of 10 square kilometers (Figure 2-8).

Fig. 2-8 Actual view of Qingshan Lake Wetland (photo by the author)

(2) Conservation and planning

The theme positioning of the Qingshan Lake block in the "Qingshan Lake National Forest Park Master Plan" is water forest sightseeing and water recreation, a total of 18 scenic spots are set up, wetland forest sightseeing and water entertainment projects are carried out, and health care and recreation forest recreation landscapes are cultivated in suitable construction areas, which are combined with the surrounding forest health resort reception facilities.

Now the attractions have been built, such as water forest, water park, green road around Qingshan Lake, visitor center, cruise ship dock service point, fishing area, etc. Among them, the water forest and water park are concentrated in the north area of the lake, the 1 million square meters of pond fir forest area, which is the core landscape area of the Qingshan Lake block, forming an experience mode in which trees grow in the water, boats swim in the forest, birds sing on the branches, and people walk in paintings to watch and entertain. The greenway around the lake is a general recreation area, with a total length of 42.195 kilometers, including 5 important nodes, 7 general nodes, 4 large stations, 2 medium-sized stations, 4 small stations, and 16 landscape platforms(Figure 2-9).

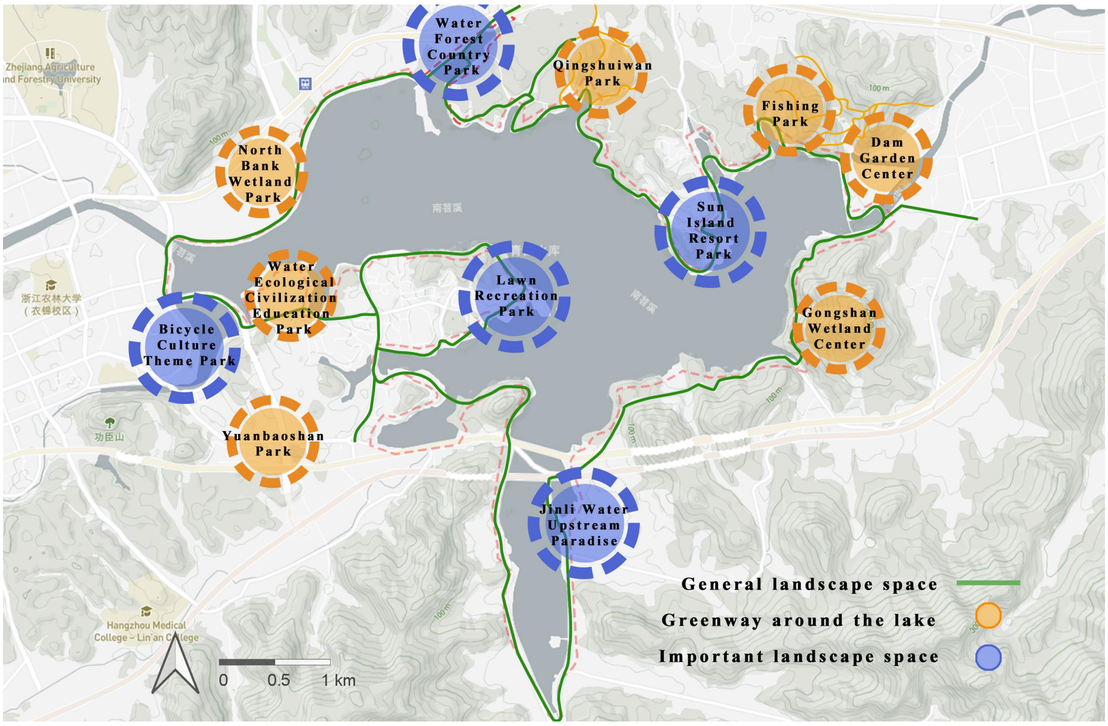

Fig. 2-9 Planning of Greenway around Qingshan Lake Wetland

2.4 Methodology

Different data collection and data analysis methods were used according to the research content of each chapter, such as SEM, SBE, SD, AHP, ect. The first part explores the ecological design practices that significantly affect the plant diversity of wetlands through a survey of the current situation of urban wetlands; the second part finds the ecological design practices that significantly affect the landscape quality of wetlands through an evaluation of urban wetlands and calculates the functional weights of wetlands; the framework and paradigm of ecological design are proposed based on the conclusions of the above two parts, and finally, an empirical case is used to verify the feasibility of the strategy(Figure 2-10).

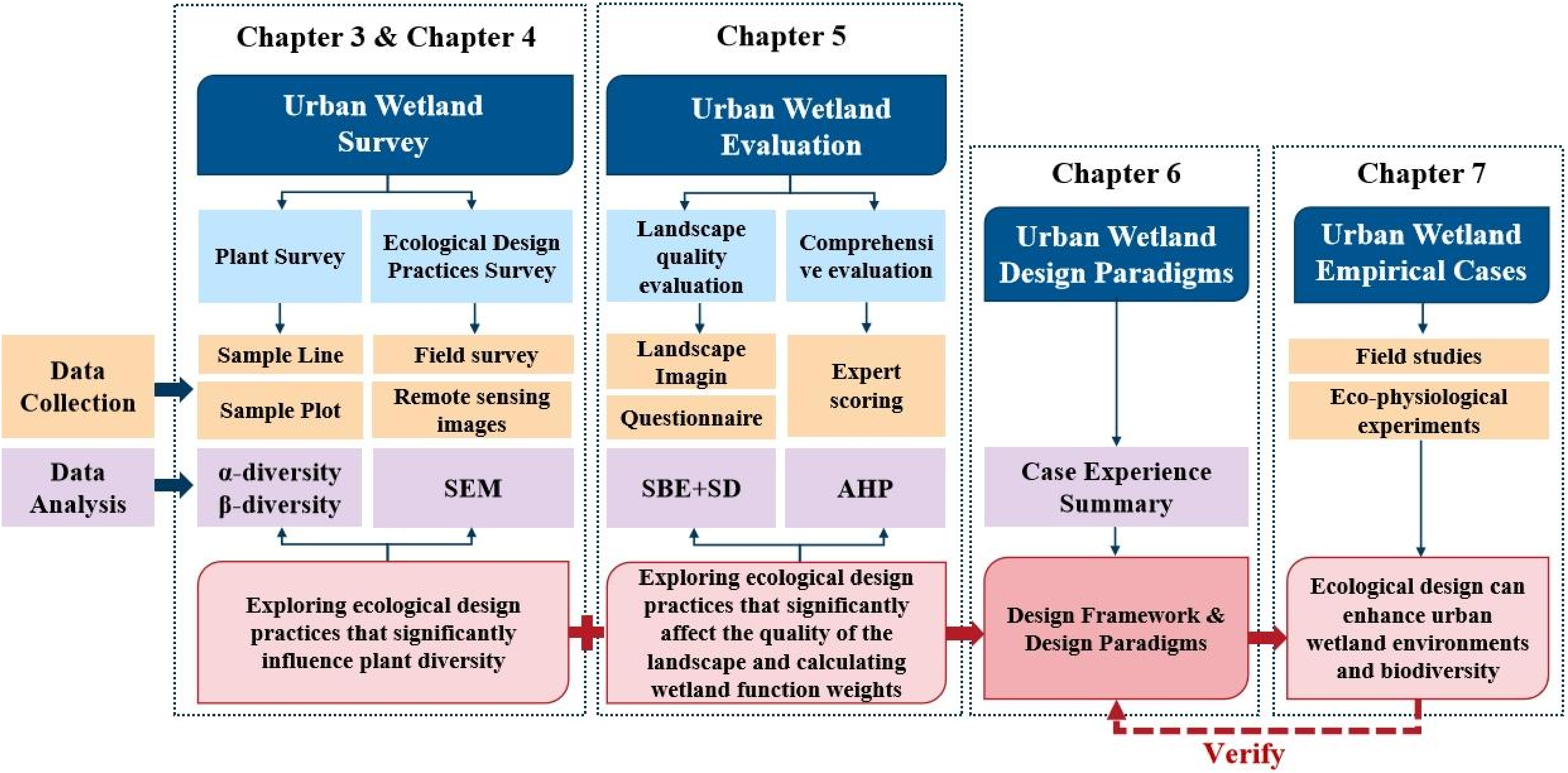

Fig. 2-10 Flow chart of research methodology

2.4.1 Data collection methods

(1) Botanical field survey method

A botanical field survey of urban wetlands in Hangzhou from October 2021 to May 2022. The sampling method and the sample line method were used. Three sample lines with a length of 30 m, perpendicular to the water - land boundary zone and transiting from the aquatic area to the mesophytic area along the wetland boundary, were set in each study area. Within each sample line, one 2 m × 2 m sample plot was set every 2 m. The interval between each sample line was 12 m. The plant species, number, and coverage in each sample plot were recorded. The sample plot was located using a GPS, and the geographical coordinates, altitude, and surroundings of the sample plot were recorded at the same time.

(2) Field survey method

Through field surveys of urban wetland parks in three different locations in Hangzhou (urban core, fringe and countryside areas), an overall understanding of the current status of planning and construction of urban wetland parks is established, and field surveys, data statistics and sampling of the planning and design construction of wetland parks are conducted. The data statistics mainly focus on the number, area and proportion of ecological design practices applied, and the sampling includes photo collection and water sample collection.

(3) Remote sensing images

A combination of remote sensing and ground-based measurements was used to classify and survey the wetlands in the study area. For the remote sensing method, high-resolution satellite image maps of the study area were visually interpreted using Arcmap 9.3[85] to determine their wetland types and areas.

(4) Questionnaires

A questionnaire was designed and data collection for the user evaluation was carried out using both field distribution and web-based questionnaire distribution in the study area. Data statistics and analysis were carried out with the help of Excel and SPSS 26.0. The questionnaires were distributed to three groups of people, the first group being experts in environmental studies and ecology for expert scoring and assigning weights; the second group being professionals studying and working in environmental design, urban planning, ecological design and other related professions; and the third group being lay people from the general public.

(5) Water Environment Field Survey

Based on remote sensing observation, a certain area of water (not less than 5%) will be selected from the wetland types identified by remote sensing to conduct field surveys from August to

October 2021 to verify the accuracy of remote sensing identification while obtaining the wetland types, and at the same time, a portable Doppler flow velocity and water level detector (DPL-LS12) will be used to record the water depth and flow velocity in the wetland and take water samples for Water quality analysis.

2.4.2 Data analysis methods

(1) Species diversity analysis

The Patrick Richness Index (D), Shannon Diversity Index (H') and Pielou Uniformity Index (J) were selected to compare the α diversity of the three wetland plants, and the Whittaker Index (βws) and Jaccard Similarity Index (C) were selected to compare the β diversity of the three wetland plants for urban wetland plant diversity analysis, on which these indices were not only independent of sample size but also more independent for sparsely distributed and distribution-rich species.

The flora of the seed plants[86] and ferns[87] in the study area were classified into five ecological factors: light, temperature, humidity, soil response and soil fertility.

(2) Structural equation modeling

Structural equation modeling is a comprehensive statistical and analytical method for analyzing the relationship between multivariate data based on the covariance matrix of variables[88]. Structural equation modeling predetermines the dependencies between factors in a system based on the researcher's a priori knowledge and can discern the strength of the relationships between factors, as well as fit and judge the overall model[89]. In this study, structural equation modeling was used to analyze the relationship between ecological design practices and biodiversity in urban wetlands.

(3) Scenic beauty estimation (wetland landscape evaluation)

Scenic beauty estimation (SBE) is a psychophysical approach to evaluating the aesthetic quality of a landscape[70], which investigates how human subjective preferences change in response to changes in landscape attributes, and seeks ways to plan and design landscapes scientifically by examining the relationship between the two[71].

The Semantic Differential (SD) method is used to evaluate the quality of the landscape by extracting landscape elements as evaluation factors of beauty and combining factor analysis to extract mutually independent factors to build a quantitative model[72],[73], SD combined with SBE can reflect the strengths and weaknesses of the landscape, enhancing the objectivity of the results[74],[76].

(4) Hierarchical analysis method (comprehensive wetland evaluation)

The hierarchical analysis method in mathematical modeling is applied to quantitatively evaluate multiple indicators at different levels that affect the overall effectiveness of urban wetlands. Analytic Hierarchy Process (AHP) is an effective method to deal with multi-objective decision-making proposed by T.L. Saaty, an American operations researcher in the 1970s. It can decompose a complex problem into several levels and several factors from different perspectives, make simple comparisons and calculations among the factors and derive weights for the degree of importance of different options to provide a basis for the selection of decision options[90],[91]. The method can effectively analyze the non-sequential relationship between the levels of the target criterion system, build up an orderly recursive hierarchy model, then analyze the factors of each level quantitatively by judging objective facts, calculate the relative importance weights of each indicator in the judgment matrix of each level using mathematical methods, and obtain the weight values of all indicators relative to the target by combining the relative importance weights of each level within the recursive hierarchy.

Considering the different contributions of each evaluation indicator in the evaluation system and the different degrees of influence on wetlands, this study uses hierarchical analysis to determine the weights of the comprehensive evaluation indicators of urban wetlands.

2.5 Summary

This chapter makes a general introduction to the geographical environment, social economy and ecological environment of Hangzhou in the research area, elaborates on the rich wetland resources of Hangzhou, the municipal government's investment in the construction of urban wetlands, the significant improvement of wetland water quality, and the combination of urban wetland landscape and biodiversity in the protection and utilization of urban wetlands, which provides us with a good research foundation. The classification, classification, area, proportion, protection and utilization of urban wetlands in Hangzhou are analyzed and summarized, and it is found that lake-type wetlands are more typical urban wetland types, and the types of research objects are determined. Due to the special conditions of Hangzhou's withdrawal and construction of the city, this chapter analyzes and explains the zoning and definition of the research area, clarifies the basis and area of the division of the urban core, marginal area and suburban area, and selects representative lake-type urban wetlands as the research objects, and introduces the basic overview of the three typical urban wetlands in detail.

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Chapter 3

CHANGES IN PLANT DIVERSITY IN URBAN WETLANDS ALONG URBAN-RURAL GRADIENT IN HANGZHOU

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3.1 Introduction

Plant community plays a fundamental role in wetland ecological functioning and is of great importance for the maintenance of wetland structure and function[1]. The distribution pattern and species diversity of plants reflect the natural environment and quality of wetlands[2], which are also important indicators for measuring the ecological service value and ecosystem stability of wetlands[3]. For urban wetlands, the species abundance and diversity of the plant community will have a positive impact on the restoration of wetland functions, which can also provide essential living conditions for wild animals in the city[4]. In addition, urban wetland plants are also an important part of the wetland landscape[5].

Studies on plant diversity have provided support for the conservation and management of wetlands[5]-[7]. However, these studies have mainly focused on plant diversity in natural wetlands[8][9]. Compared with natural wetlands, urban wetlands are subject to more artificial interference, and the introduction of exotic ornamental plants has led to differences in the flora [10] . In addition, the research on urban wetlands has typically been centered on dynamic changes [11], ecosystem service functions[12][13], ecological value[14][15], and ecological restoration, protection, and management[16][17], while the research on the plant diversity of urban wetlands remains limited. Urbanization promotes the transition from the urban center to the suburbs; however, it is still unclear whether there will be differences in the plant diversity of wetlands located in the core, edge, and suburban areas of cities due to their different population for service, ecological functions, types and degrees of interference, and the internal driving factors of the differences. To our knowledge, there is still a lack of understanding of how the plant diversity of urban wetlands responds to changes along an urban gradient.

Hangzhou is located in eastern China. In recent years, the city has expanded rapidly, and the area and number of urban wetlands has increased significantly[18], and the plant species of the urban wetland have also changed evidently[19]. Comparing the plant diversity of urban wetlands in different regions of the city and implementing reasonable planning strategies for the urban wetland ecosystem according to their functions and landscape characteristics can improve diversity, contribute to urban wetland conservation, and improve urban ecological landscape management[20]. In this study, we used Hangzhou as the study area and selected three urban wetlands in the urban core area, the edge area, and the suburban area to investigate wetland plant species and compare the plant diversity. We aimed to elucidate how the plant diversity of urban wetlands changes during the transition from the urban center to the suburban regions. We also analyzed the driving factors of the differences in plant diversity, thereby providing a reference for the protection, planning, and utilization of urban wetlands in the area.

3.2 Methodology

3.2.1 Plant survey

A total of 40, 21, and 20 study sites were selected from Xixi Wetland, Qingshan Lake Wetland, and Tongjian Lake Wetland, respectively, for the investigation of plant species diversity by random selection, considering accessibility (Fig. 3-1). The sample plots were based on the method reported by Fang et al.[21]. Three sample lines with a length of 30 m, perpendicular to the water－land boundary zone and transiting from the aquatic area to the mesophytic area along the wetland boundary, were set in each study area. Within each sample line, one 2 m × 2 m sample plot was set every 2 m. The interval between each sample line was 12 m. The plant species, number, and coverage in each sample plot were recorded. The sample plot was located using a GPS, and the geographical coordinates, altitude, and surroundings of the sample plot were recorded at the same time.

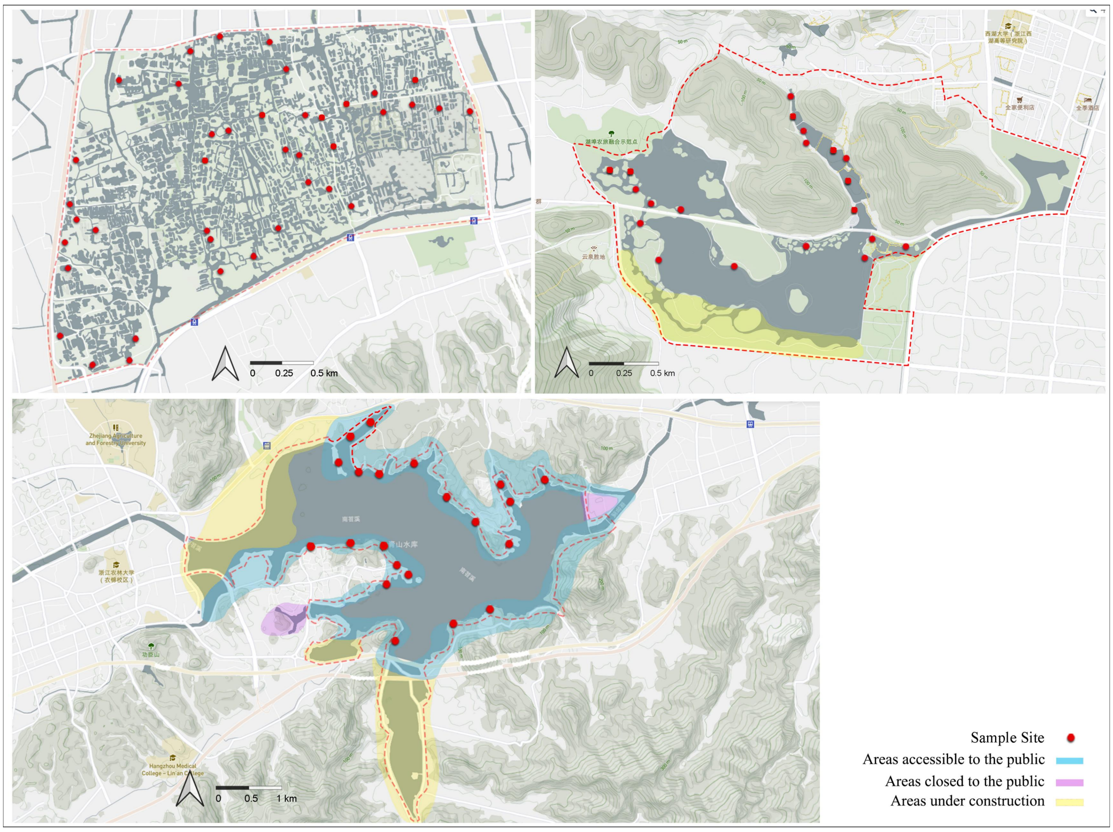

Fig. 3-1 Study area of the three urban wetlands

3.2.2 Statistical analyses

The Patrick index (D), Shannon-Wiener index (H), and Pielou index (J) were selected to compare the α-diversity, and the Whittaker index (β_{ws}) and Jaccard similarity index (C) were selected to compare the β-diversity as follows:

Patrick index:

$$D = S \quad (1)$$

Shannon-Wiener index:

$$H = -\sum_{i=1}^{s} P_i \ln P_i \quad (2)$$

Pielou index:

$$J = H/\ln S \quad (3)$$

In the above equations, S is the total number of species in the sample plot, and Pi is the number of individuals of the i species.

Jaccard similarity index:

$$C = a/(a + b - c) \times 100\% \quad (4)$$

In the equation, a is the number of common species between two wetlands, and b and c are the numbers of unique species between two wetlands.

Whittaker index:

$$\beta_{ws} = S/ma - 1 \quad (5)$$

In the equation, S is the total number of species recorded in the studied object, and ma is the average number of species in each sample.

The floras are classified according to the areal-types of Chinese genera of seed plants[22] and pteridophyte[23]. Invasive plant species are determined according to Ma[24] and Yan et al.[25]. Meanwhile, any rare or endangered plants and national key preserved wild plants are determined by Fu[26] and NFA[27]. According to the Ellenberg Indicator Value (EIV)[28] and Song et al.[29], all of the ecological factors were classified as one of nine levels with numerical ranges also given. We selected five ecological factors including light, temperature, moisture, soil reaction and soil fertility to classify plants in terms of indicator values, which were recorded in Song et al.[29] (Table 3-1). As EIVs for some plant species were not available in the literature, the indices were calculated by referencing known species growing in the same habitat.

Table 3-1 Gradations of plant ecological indicator values[29]

Levels	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Light	Full shadow	Between 1 and 3	Shadow	Between 3 and 5	Half shadow	Between 5 and 7	Half light	Light	Full light
Temperature	Frigid	Sub-frigid	Cool temperate	Mid-tempe rate	Warm-tem perate	Sub-war m torrid	Warm-torrid	Sub-torrid	Torrid
Moisture	Super xerophyte	Between 1 and 3	Xerophyte	Between 3 and 5	Mesophyte	Between 5 and 7	Hygrophyte	Between 7 and 9	Hepophyte
Soil reaction	Extremely acidic soil	Between 1 and 3	Acidic soil	Between 3 and 5	Weakly Acidic soil	Between 5 and 7	Neutral soil	Between 7 and 9	Alkaline soil
Soil fertility	Extremely poor soil	Between 1 and 3	Poor soil	Between 3 and 5	Mid-rich soil	Between 5 and 7	Rich soil	Super-rich soil	Extremely rich soil

3.3 Results

3.3.1 Comparison of plant composition

A total of 336 plant species, 254 genera, and 104 families were recorded in Xixi Wetland. A total of 179 plant species belonging to 150 genera and 74 families were recorded in Qingshan Lake Wetland. A total of 112 plant species, 96 genera, and 57 families were recorded in Tongjian Lake Wetland (Fig. 3-2). The number of plant species in the three wetlands differed significantly, though there were similarities in the dominant species among the three wetlands, including the families Compositae, Rosaceae, and Gramineae. The top 10 most abundant families were similar among the three wetlands, with the same nine families in Xixi Wetland and Qingshan Lake Wetland, families in Qingshan Lake Wetland and Tongjian Lake Wetland, eight families were shared. exceptions include Labiatae and Leguminosae in Qingshan Lake and Scrophulariaceae and Iridaceae in Tongjian Lake (Fig. 3-3).

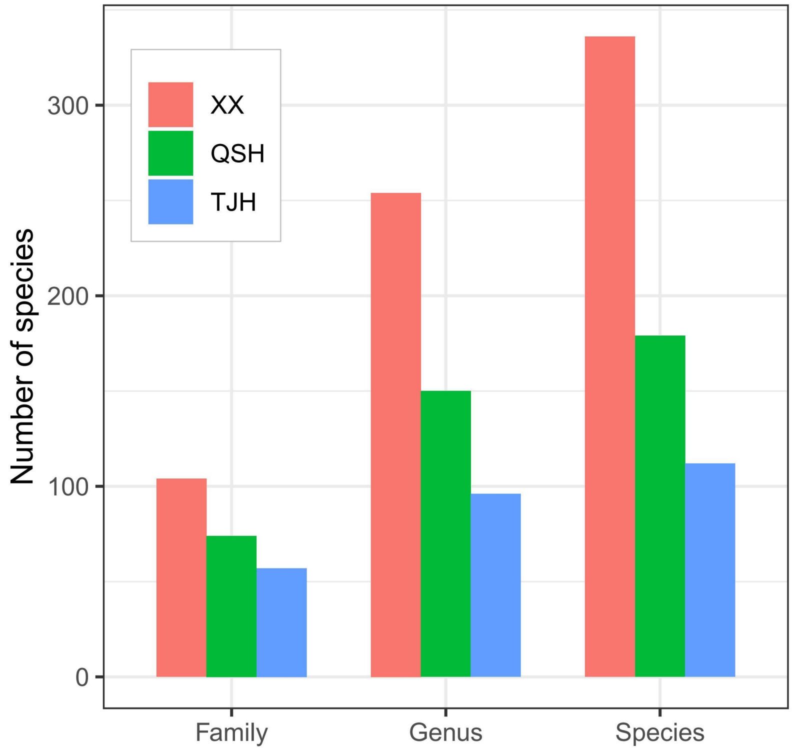

Fig. 3-2 Comparison of plant families, genera, and species in the three wetlands

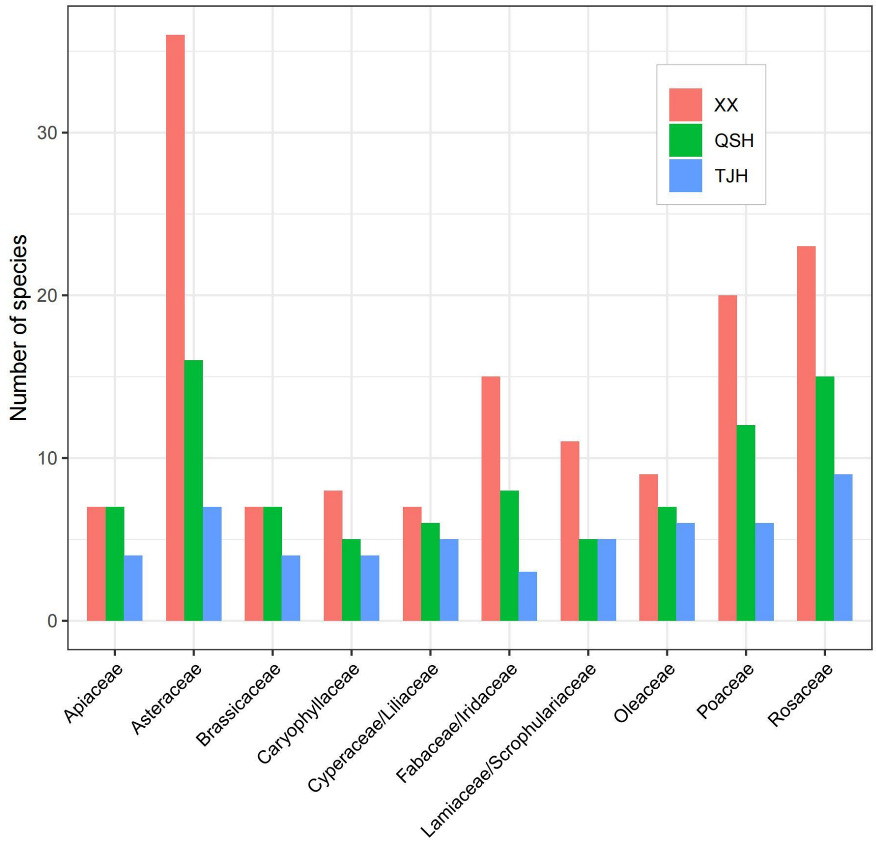

Fig. 3-3 The top 10 richest families in the three urban wetlands

Among the three urban wetlands, Xixi Wetland had the highest Patrick index (D), Shannon-Wiener index (H), and Pielou index (J), which was significantly different from the other two wetlands. These indexs of Qingshan Lake Wetland all were lowest, while similar to that of Tongjian Lake Wetland (Table 3-2). Xixi Wetland and Qingshan Lake Wetland had the lowest Whittaker index (β_{ws}) and the highest Jaccard similarity index (C), and the species similarity between them was high (Fig. 3-4). The comparison of cultivated plants and autophytes in the three urban wetlands showed that the number of species of autophytes in Xixi Wetland was the highest. Tongjian Lake Wetland had the least number of species of autophytes but the highest number of species of cultivated plants. The number of cultivated plant species in Qingshan Lake Wetland was the lowest (Table 3-3).

Table 3-2 α-diversity comparison of the three urban wetlands

	Xixi Wetland	Qingshan Lake Wetland	Tongjian Lake Wetland
Patrick index	56.5±17.7a	28.3±16.3b	36.8±13.9b
Shannon-Wiener index	3.09±0.63a	1.72±0.88b	2.27±0.51b
Pielou index	0.36±0.06a	0.25±0.13b	0.28±0.05b

* Different letters indicate statistically significant differences among the three urban wetlands

Table 3-3 Comparison of the richness of cultivated plants and autophytes in the three urban wetlands

	Xixi Wetland	Qingshan Lake Wetland	Tongjian Lake Wetland
Cultivated Plant	16.6±9.2a	7.2±4.3b	17.4±8.5a
Autophytes	39.9±12.2a	21.1±12.9b	19.5±6.5b

* Different letters indicate statistically significant differences among the three urban wetlands

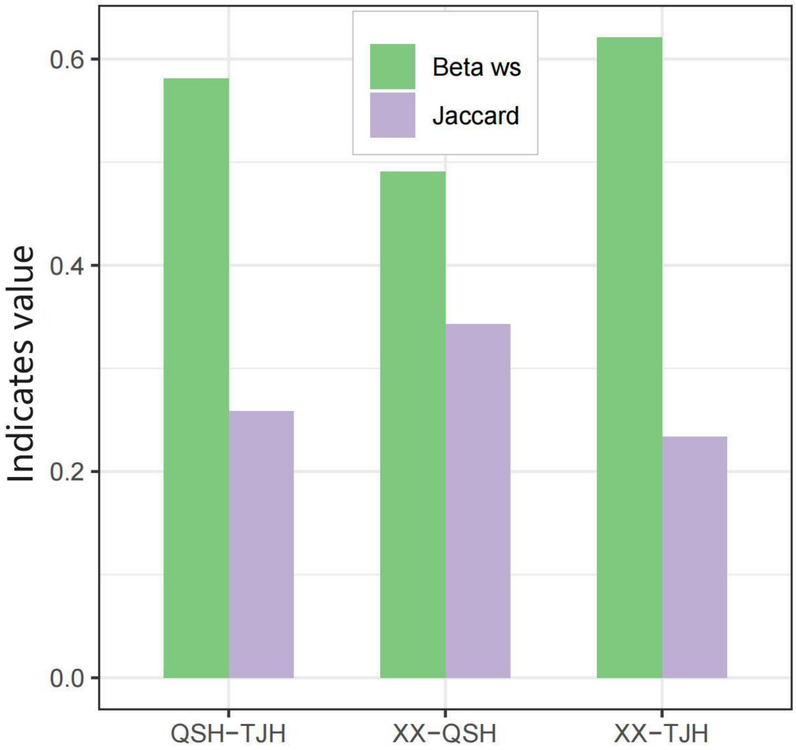

Fig. 3-4 β-diversity comparison of the three urban wetlands

3.3.2 Comparison of flora

The comparison of flora showed that the genera in both Xixi Wetland and Qingshan Lake Wetland could be classified as 14 areal types. In Xixi Wetland, the northern temperate distribution type was dominant with 46 genera, followed by the pantropical distribution and the cosmopolitan areal type with 39 genera and 38 genera, respectively. In Qingshan Lake Wetland, the northern temperate distribution was dominant with 32 genera, followed by the cosmopolitan distribution type and the pantropical distribution type with 28 genera and 21 genera, respectively. Tongjian Lake consisted of 13 distribution areal types, among which 19 genera were of the cosmopolitan distribution type, followed by 18 genera in the northern temperate distribution type and 14 genera both in the pantropical distribution type and Old World Temperate distribution type. Unlike the Xixi Wetland and Qingshan Lake Wetland, there were no plants belonging to the central Asian distribution type in Tongjian Lake Wetland (Fig. 3-5).

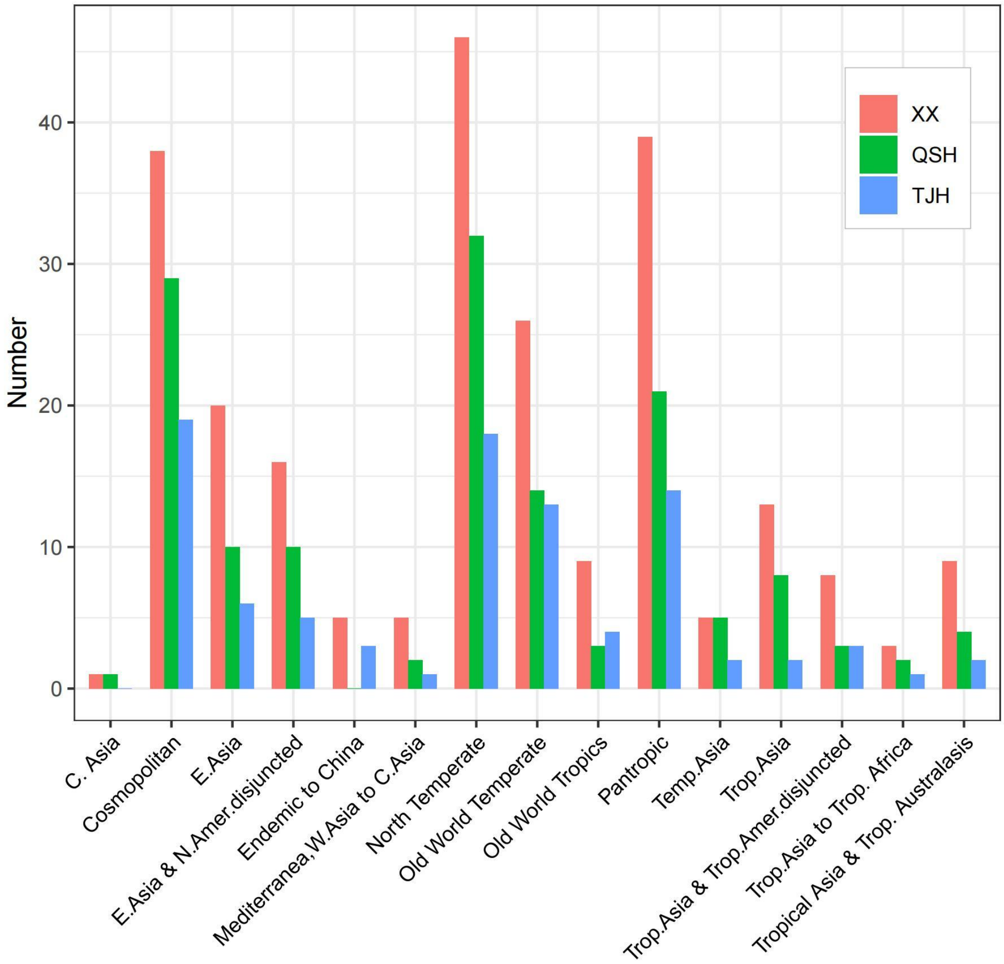

Fig. 3-5 Areal types of the genera in the three urban wetlands

A total of 12, 11, and 10 species of invasive plants were recorded in Xixi Wetland, Qingshan Lake Wetland, and Tongjian Lake Wetland (Fig. 3-6), respectively, primarily consisting of species belonging to Compositae including Erigeron annuus, E. philadelphicus, E. sumatrensis, E.canadensis, Crassocephalum crepidioides, Conyza bonariensis, Senecio scandens and Bidens biternata. Other invasive plant species included Eichhornia crassipes, Veronica persica, V. arvensis, Pilea somai, Plantago virginica, Alternanthera philoxeroides and Melilotus indicus.

The investigation results of rare and endangered plants and national key preserved wild plants showed that there were eight species recorded in Xixi Wetland, including artificially cultivated Metasequoia glyptostroboides, Ginkgo biloba, Camptotheca acuminata, and Nelumbo nucifera; the experimentally cultivated endangered species Isoetes sinensis and Ranalisma rostrata; and naturally grown Fagopyrum cymosum and Glycine soja. There were three species recorded in Tongjian Lake Wetland, including artificially cultivated M. glyptostroboides, G. biloba, and Eucommia ulmoides. However, only one species, namely M. glyptostroboides, was recorded in the

Qingshan Lake Wetland (Fig. 3-6).

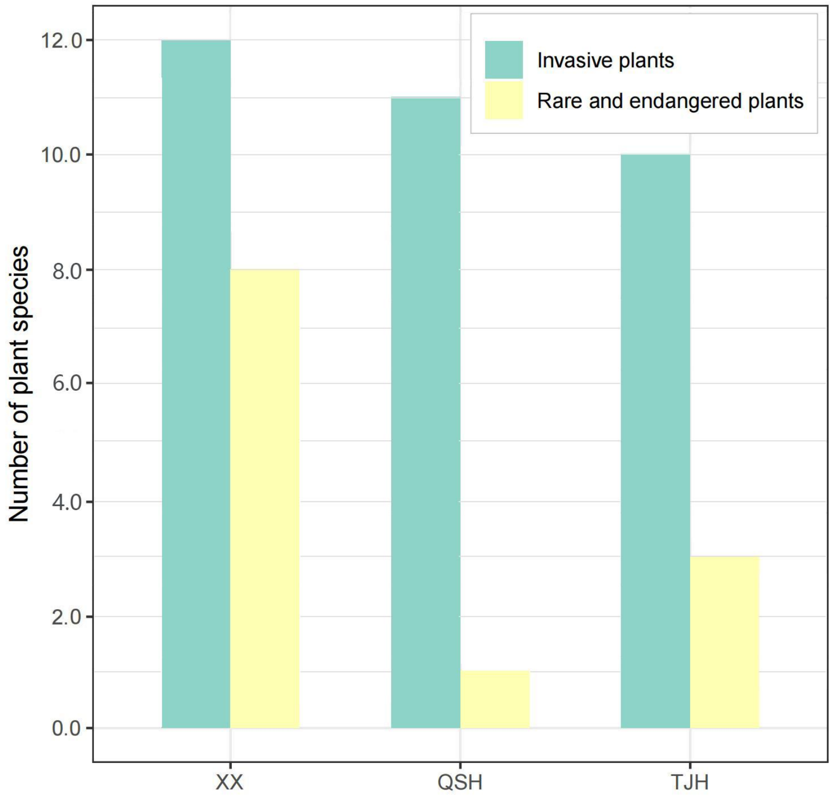

Fig. 3-6 Comparison of invasive plants and rare and endangered plants in the three urban wetlands

3.3.3 Comparison of ecotypes

By comparing the ecotypes of plants, it was found that the plants in the three urban wetlands showed a similar trend (Fig. 3-7).

In terms of the demand for light, the three wetlands had a relatively large number of half-shade to heliophyte (grade 5–8) species, of which the half-light species (grade 7) were the most abundant. However, the proportion of half-shade plants (grade 5) in Qingshan Lake Wetland was the lowest, accounting for 7.8%, while the proportions of half-shade plants (grade 5) in Xixi Wetland and Tongjian Lake Wetland were 12.8% and 12.5%, respectively (Fig. 3-7A). Among the three urban wetlands, warm-temperate to warm-tropical (grade 5–7) species were dominant. The proportion of sub-high temperature (grade 8) species in Qingshan Lake Wetland (1.1%) was the lowest, whereas the proportion of sub-high temperature species in Tongjian Lake Wetland (3.6%) was the highest (Fig. 3-7B).

In response to water demand, the three urban wetlands were dominated by mesophytic plant species (grade 5) (Fig. 3-7C). The proportion of hygrophytic plants (grade 6–9) was higher in Tongjian Lake Wetland (50.9%) than in Xixi Wetland (45.8%) and Qingshan Lake Wetland (45.3%).

There were many slightly acidic to neutral plants (grade 5–7), accounting for 89.6%, 88.9%, and 89.3%, respectively, in Xixi Wetland, Qingshan Lake Wetland, and Tongjian Lake Wetland. There were a few species of acidophilous plants (below grade 4) and basophilic plants (above grade 8) (Fig. 3-7D).

The highest proportion of plants that prefer medium to fertile soil (grade 5–7) was in Tongjian Lake Wetland, accounting for 97.3%, while the proportion in Qingshan Lake Wetland was the lowest, accounting for 91.6% (Fig. 3-7E). There was no difference in the EIV values of water and soil reactions among the three urban wetlands, but there were differences in the EIV values of light, temperature, and soil fertility (Table 3-4).

Table 3-4 Comparison of ecological requirements of plants in the three urban wetland

	Xixi Wetland	Qingshan Lake Wetland	Tongjian Lake Wetland
L	6.45±1.09b	6.60±1.07a	6.52±0.99ab
T	5.96±1.06ab	5.93±0.98b	6.08±1.03a
M	5.73±1.33a	5.74±1.41a	5.77±1.31a
R	5.34±0.92a	5.32±0.92a	5.33±0.92a
F	5.71±0.77ab	5.63±0.82b	5.74±0.65a

* Different letters indicate statistically significant differences among the three urban wetlands

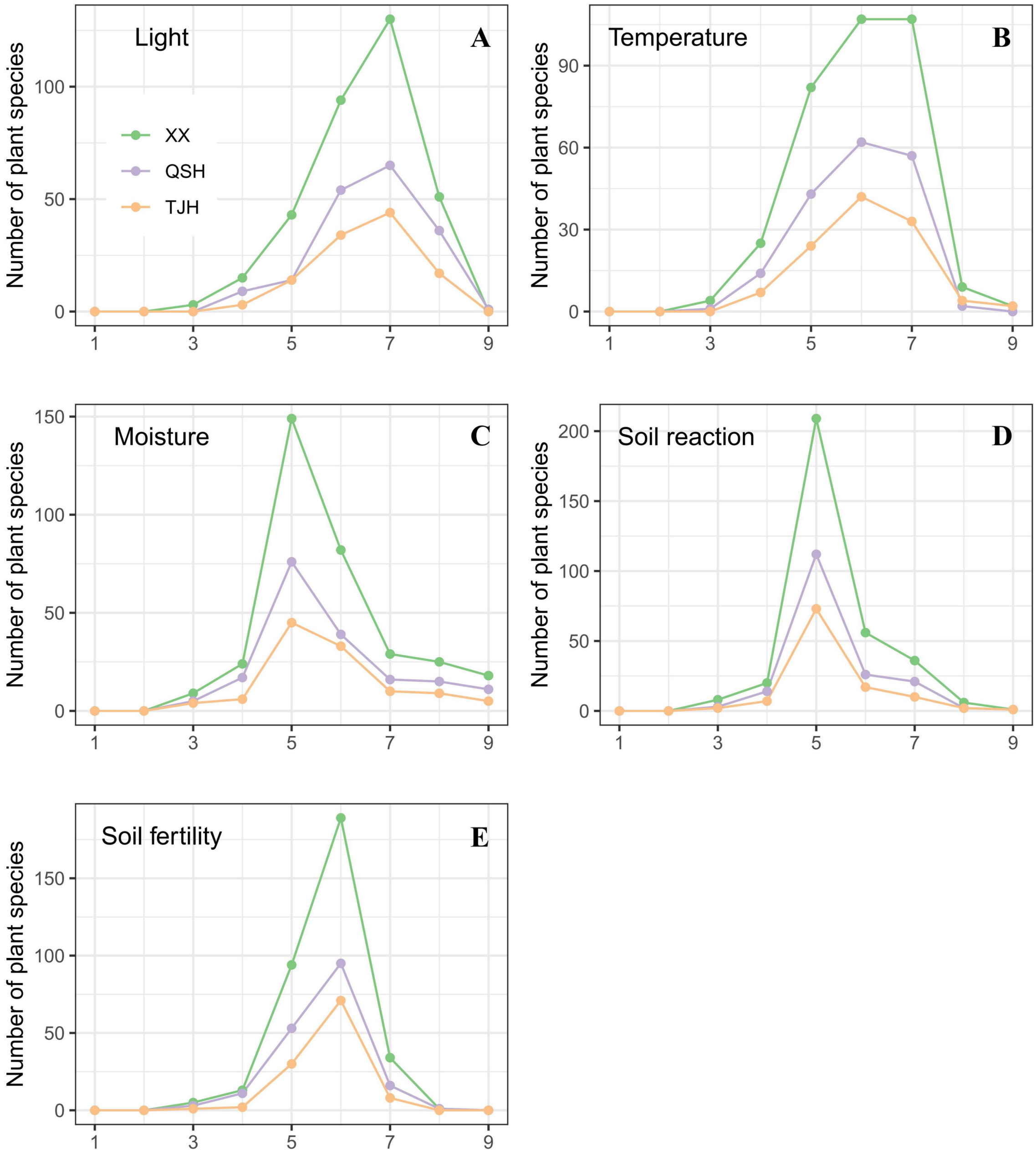

Fig. 3-7 The number of plant species base on EIV values of the three urban wetland

3.4 Discussion

The number of plant species in Xixi Wetland was significantly higher than that in the other two wetlands, which was related to the natural environment, age of the wetland, and functional orientation of Xixi Wetland. Xixi Wetland is the oldest wetland among the three urban wetlands. The high-density network of rivers divides the wetland into different-sized patches, and the elevation difference creates a transition from the humid environment at the edge to the Mesozoic environment at the center[30], which creates a high degree of habitat heterogeneity, providing more opportunity for species diversity[19]. As a tourist attraction, Xixi Wetland comprises a large number of ornamental plants used in flower exhibitions annually, which has increased plant species richness. A previous study on the plant diversity of Xixi Wetland recorded a total of 424 vascular plants in this area[31], which is slightly higher than our results. This may be due to the limitation of our study sample plots, which did not cover the entire region. Qingshan Lake Wetland is located in the countryside. Although indigenous autotrophic plant species are generally abundant in this wetland, there are a few cultivated ornamental plant species. As a reservoir wetland, the edge of the water body is connected to the natural mountain, thereby lacking a shoal boundary between the water and the shore. Therefore, it is difficult for the plants in the amphibious junction zone to survive[32][9], resulting in significantly fewer plant species than in Xixi Wetland. Tongjian Lake Wetland has the highest number of artificially cultivated plant species. This may be because Tongjian Lake Wetland is a newly built wetland where landscape plants for ornamental purposes are widely cultivated. However, local natural plant communities have not been established yet. Furthermore, some indigenous autotrophic herbaceous plant species are regularly manually cleared, further reducing the indigenous vegetation. Thus, the species richness of Tongjian Lake Wetland is relatively low. Although the plant species richness in Qingshan Lake Wetland is higher than that in Tongjian Lake Wetland, the plant distribution in the sample plot of Qingshan Lake Wetland is uneven, and the sample plots with only a few plant species also are relatively common. This has led to the lower plant evenness of the wetland, with the average species richness and the α-diversity being unexpectedly lower than that of Tongjian Lake Wetland.

β-diversity indices are important indicators for studying community structure and species composition and can reflect the variation in the species composition of communities in different habitats along an environmental gradient[33][34]. Among these indices, the Whittaker index (β_{ws}) directly reflects the relationship between β-diversity and species richness and is widely used in research[35]. The Jaccard similarity index (C) is used to calculate the β-diversity index among communities when there might be no obvious environmental gradient between communities in different habitats[36], which can simply and directly estimate the β-diversity index between a pair of places[37]. The greater the similarity index, the lower the β-diversity index. The Jaccard similarity index (C) and Whittaker index (β_{ws}) values among the three urban wetlands indicated that the community composition and structure of Xixi Wetland and the more closely located Tongjian Lake were quite different, while the difference between Xixi Wetland and the comparatively farther Qingshan Lake was smaller. This is inconsistent with the theory that with an increase in the distance between two communities, the difference between the community structure and composition will also increase, thus showing a higher β-diversity (distance attenuation effect of the community) [38][39]. This may be because Tongjian Lake Wetland is a newly built wetland, and the extensive use of exotic ornamental plants for landscape purposes and the frequent manual removal of local natural weeds have led to a large change in the plant composition of the wetland. Compared with the β-diversity index of natural wetlands[40], the β-diversity index of the three urban wetlands was relatively low, which is caused by the cultivation of artificial plants in urban wetlands. This reduces plant diversity. The high similarity of the main plant families and genera and the distribution of flora also indicated that the three urban wetland landscapes exhibited a trend of homogenization, which is also common in urban green spaces[41].

Generally, there are more invasive plant species in areas with a higher degree of urbanization [42]. However, we found that although the three wetlands located in the urban core area, urban fringe area, and urban-suburban area were influenced by urbanization to different degrees, the number of invasive species in the urban wetlands of the three areas was relatively similar, which is inconsistent with the differences in the species richness of the three wetlands. This may be related to the characteristics of invasive plants, which have high environmental adaptability and can quickly occupy suitable habitats[43]. In wetlands, invasive plants usually prefer grassland with a high light intensity and revetment habitat at the junction of land and water[19]. Among the invasive plants in the three wetlands, photophygous Compositae species accounted for the largest proportion, and the A. philoxeroides growing in the water land junction zone was the most common in the three wetlands, which is consistent with the results of Shen et al.[30]. The entry of invasive plants might affect the local plant diversity[44]. Therefore, particular attention should be paid to monitoring the dynamics of invasive plants in the water - land junction zone and area with high light intensity in the daily management of urban wetlands to maintain ecological security and species diversity.

Eight rare and endangered species and national key preserved wild plants were recorded in Xixi Wetland, which is more than four species recorded by Zhang et al.[31]. This may be related to changes in the listed endangered plants and national key preserved wild plants [27]. Conversely, it may also be related to the measures that have been carried out in Xixi Wetland in the past two years for protecting rare and endangered plants through introducing these plant species to the suitable habitation of the urban wetlands[45]. Wang et al.[46] also tried to carry out similar work in other urban wetlands, which proved to be effective. The use of urban wetlands to protect wetland plants, especially endangered plants adapted to wetland habitats, is a good way to increase local biodiversity and can become an ex situ conservation center of wetland plant diversity. Some artificially bred endangered plants with good landscape value can also be used for wetland landscaping[47]. For instance, instead of using Taxodium ascendens to create a homogenous landscape in Qingshan Lake Wetland, the endangered plant Glyptostrobus pensilis could be substituted, resulting in a similar landscape effect and habitat suitability. This would not only increase the wetland plant diversity but may also contribute to the conservation and utilization of endangered species.

The comparison of ecotype indices showed that there were some differences in plant adaptability among the three urban wetlands. Cultivating plants is the main way to increase green spaces. Salinitro et al.[48] found that urban greening has created more shade habitats, leading to an increase in the number of sciophilous plants. Xixi Wetland has dense vegetation, more shade habitats, and the largest proportion of sciophilous plants, and thus the light EIV value was relatively low. By comparison, Qingshan Lake Wetland had the least cultivated plants and more open land habitats with high light intensity, which may be the reason why the proportion of semi-shade plants in the wetland was the lowest, and the EIV value of light was high. There were many species of sub-high-temperature plants and fertile soil plants in Tongjian Lake Wetland, which led to the high EIV values of temperature and soil fertility. This explains why more tropical ornamental plants, such as Pelargonium hortorum and Aspidistra elatior, are cultivated in Tongjian Lake Wetland. In additional, cultivated plants introduced for ornamental purposes tend to prefer fertile soil[49].

Plant diversity can reflect the impact of factors such as habitat change, habitat fragmentation, and human preference, which change along urban and rural gradients[50][51]. Due to the high degree of human interference and natural landscape destruction[52], total species richness is generally low in the urban center [50]. However, the results showed that Xixi Wetland, located in the center of the city, had the highest plant diversity. This wetland, due to it being the main tourist destination, has benefitted from the introduction of a large number of exotic ornamental species, which has improved species richness [53]. On the contrary, the management mode of Xixi Wetland protects indigenous autotrophic plants by not periodically clearing them[54]. This mode of wetland management has created good conditions for improving species richness. Although Tongjian Lake Wetland is not in the center of the city, it also has rich tourism resources in its vicinity. As a newly built wetland, artificial vegetation were planted densely in large areas in Tongjian Lake Wetland, which significantly restricts autophytes[55]. The autophytes are also cleared through routine management. This intensive human intervention management mode has led to a significant reduction in the plant species richness of Tongjian Lake Wetland. The degree of human intervention and management of Qingshan Lake Wetland in the countryside is very low, the shrub vegetation flourishes, and a single superior plant community dominates, leading to its plant diversity being comparatively lower than that of Xixi Wetland.

The distance between the wetland and the urban built-up area, the function of the wetland, the intensity of the artificial interference, and the management mode were all important factors affecting the plant diversity of the wetlands. Fully understanding the factors influencing wetland plant diversity can contribute to wetland planning, construction, protection, and utilization in the urbanization process. Compared with natural wetlands, urban wetlands can be artificially built to provide more suitable environments for plants. The management mode of Xixi Wetland maintains the overall plant landscape in a natural and wild state. It also represents a good example of plant landscape planning. Therefore, according to the different functions and services of wetlands, future urban planners and managers should consider the diverse characteristics of wetland plants in different regions when selecting appropriate interference intensities and management modes for wetlands. In addition, the conservation of urban wetlands is not limited to the protection of wetland organisms and habitats but also includes the protection of the wetland landscape and wetland ecosystem health[56]. Therefore, the invasion of wetland alien species, water pollution, and other factors that affect the health of wetland ecosystems are also important to pay attention in wetland management and protection.

3.5 Summary

Plant species were more abundant in Xixi Wetland than in Qingshan Lake Wetland and Tongjian Lake Wetland. The introduction of exotic ornamental species in Xixi Wetland and the management model that is protective of autophytes have created good conditions for improving species richness. This approach may become a model for improving plant diversity in urban wetlands. The introduction of cultivated plants for ornamental purposes in urban wetlands may lead to plant homogenization between urban wetlands. The most common invasive species in the three urban wetlands were photophygous Compositae species and A. philoxeroides growing in the water–land junction zone. Therefore, in the daily management of urban wetlands, special attention should be paid to monitoring the dynamics of invasive plants in the water–land junction zone and the high light intensity area. In the protection of endangered plants, it is a good attempt to use suitable habitation in urban wetlands to protect aquatic endangered plants. The newly built Tongjian Lake Wetland introduced a large number of ornamental plants, which increased the EIV of plants for temperature and soil fertility. As a result of differences in the distances between the wetlands and urban built-up area, the function of the wetland, the intensity of the artificial interference, and the management mode, the species diversity differed among Xixi Wetland, Tongjian Lake Wetland, and Qingshan Lake Wetland. In the future, the diverse characteristics of wetland plants in different regions should be considered by urban planners and managers to implement differentiated wetland utilization.

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Chapter 4

A STUDY OF THE EFFECTS OF ECOLOGICAL DESIGN ON PLANT DIVERSITY IN DIFFERENT URBAN WETLANDS

CHAPTER FOUR: A STUDY OF THE EFFECTS OF ECOLOGICAL DESIGN ON PLANT DIVERSITY IN DIFFERENT URBAN WETLANDS

4.1 Introduction

Ecological design is an important approach in the conservation and restoration of urban wetlands, with many ecological techniques and methods and ecological materials being used extensively in the conservation and construction of urban wetlands[1][2] to promote the enhancement of their biodiversity[3]. The link between landscape ecological design and biodiversity conservation has been confirmed in previous studies[3][4],. for example, increasing the stability of regional biodiversity by creating natural or semi-natural habitat[5]; the design of medium-sized grasslands, mudflats or ponds is beneficial to bird habitats and enhances bird diversity[6]; and the construction of artificial wetlands can also help maintain, or enhance biodiversity[1]. However, there are relatively few ecological design practices involved in these studies, and they do not adequately reflect the different types of ecological design practices and impacts on biodiversity, especially the lack of research on the pathways through which ecological practices affect plant diversity.

Wetland plants build the structure of wetland ecosystems and are fundamental to the function of wetland ecosystems, and are also rapidly influenced by ecological design practices[7]. In the process of urbanization, some natural wetlands have gradually evolved into urban wetlands as built-up areas expand. The plant diversity of different urban wetlands may also change due to differences in location, functional positioning, and ecological design practices. Therefore, is there an intrinsic link between plant diversity and ecological design practices in urban wetlands of different locations, types and functions, and which ecological design practices have an impact on plant diversity? The answers to these questions can provide a basis for the conservation, planning and use of urban wetlands, and help to improve their biodiversity and ecological services.

Located in eastern China, Hangzhou has seen a rapid urban expansion in recent years, turning natural wetlands that were once located in the countryside into urban wetlands, resulting in a significant increase in the area and number of wetlands in different parts of the city[8], resulting in a significant increase in the area and number of wetlands in both the urban fringe and countryside areas. In this paper, three different types of wetlands with diverse functions in the core area, fringe area, and suburb area of Hangzhou City were taken as study cases, through investigation of plant diversity and ecological design practices in wetlands, the specific objectives are: (1) to understand whether there are differences in ecological design practices in wetlands in different urban areas; (2) to analyze the main ecological design practices affecting plant diversity in wetlands in different urban areas; (3) to explore the relationship between ecological design practices and plant diversity in the planning and design of urban wetlands.

4.2 Methodology

4.2.1 Sample plot set-up

From March to May 2022, a survey on the status of plant diversity and ecological design was conducted in three urban wetlands. The typical sample sites were selected based on the principles of typicality, representativeness and accessibility[9], with a sample size of 30 m x 30 m. Typical sample sites were selected according to the following methods: (1) the sample sites were distributed as evenly as possible, with a minimum interval of 50 m[10]; (2) sample sites with artificial designs such as roads, overhead paths, hard squares and structures were selected; (3) sample site types covered as many types as possible, including waterfront, mountain and grassy slopes. A total of 81 typical sample sites were selected for the three urban wetlands, including 40 in the Xixi Wetland, 21 in the Qingshan Lake Wetland and 20 in the Tongjian Lake Wetland.

4.2.2 Ecological design practices statistics

To conduct a more comprehensive evaluation and analysis of ecological design practices and to find the factors affecting plant diversity, a total of 34 observed variables of ecological design practices in four categories, namely water quality protection design, shoreline maintenance design, ecological facility design and plant diversity design, were collated and summarised concerning relevant literature on ecological design[11]-[13], and quantitative criteria were set (Table 4-1). Among them, the quantity statistics were counted in the field, the length statistics were measured in the field, the degree of topographic slope change was assigned by subjective evaluation, the area share was quantified statistically using Auto CAD, and the plant diversity was expressed by the Shannon-wiener index (H'), which was calculated as follows.

$$H' = -\sum \ Pi \ln Pi/S \qquad (1)$$

In the equation, S is the total number of species in the sample and Pi is the number of individuals of the ith species.

Table 4-1 Description of indicators and quantitative criteria for ecological design practices in urban wetlands

Type of indicator	Serial No.	Ecological design approach	Definition	Quantification criteria
Design factors for water quality protection	A1	Degree of variation in inlet topography	Variation in the topographic pattern of the wetland inlet system.	1 to 15° for 1 point, 15° to 30° for 2 points; over 30° for 3 points
	A2	Natural purification	The waters of the area are cleaned layer by layer using natural elevation differences and stacked water.	Number of statistics
	A3	Artificial wetland purification systems	Artificial wetlands are unique "soil-plant-microbial" wetland ecosystems made up of fill and aquatic plants. The area of the artificial wetland purification system in the region and the amount of water treated per day.	Statistical area
	A4	Ecological floating islands	Number and area of ecological floating islands in the region.	Number of statistics
	A5	Aeration and oxygenation	Forms and numbers of falling bodies of water, fountains, gushing springs, etc.	Number of statistics
	A6	Change in terrain slope	The degree of variation in the slope of the terrain in the area.	1 point for few changes; 2 points for many changes; 3 points for complex changes
	A7	Rainwater garden	Number and area of depressed green spaces, depressional cisterns, puddles, ditches etc. where rainwater can be collected and pooled.	Number of statistics

Type of indicator	Serial No.	Ecological design approach	Definition	Quantification criteria
Design factors for water quality protection	A8	Permeable paving	Permeable paving types and areas such as permeable bricks, wood chip paving, water retaining permeable masonry bricks and recycled ceramics.	Number of statistics
Design factors for shoreline maintenance	B1	Natural form shoreline	The proportion of the 3 shoreline forms: natural, organic and geometric.	Statistical length
	B2	Ecological barges	Ecological barge types and proportions such as gently sloping inlet barges, pine stump barges, scenic rock barges, living stump barges and river banks.	Statistical length
Design factors for Ecological facility	C1	Ecological materials	The application of ecological materials such as permeable bricks, permeable concrete, wood and biodegradable natural plants.	Number of statistics
	C2	Slow traffic system	A network of pedestrian and cycle paths in the region.	Statistical area
	C3	Overhead paths	Facilities such as ecological bridges, elevated walkways and migration corridors in the area maintain habitat connectivity and reduce disturbance to flora and fauna from human activities.	Statistical area
	C4	Ecological Education Promotion	The number of eco-exhibit galleries, information boards, signage and other facilities in the region, as well as ecological activities that the public can participate in, guide and promote the learning and study of ecosystems.	Number of statistics

Type of indicator	Serial No.	Ecological design approach	Definition	Quantification criteria
Design factors for Ecological facility	C5	Organic composting	Garden waste and food waste are composted or provided with biomass energy.	Yes/No: 1 point/0 point
	C6	Waste reuse	The recycling of abandoned sites, plants, machinery and equipment, materials, etc.	Yes/No: 1 point/0 point
	C7	Renewable energy use	The use of renewable energy sources such as solar thermal collection, photovoltaic power generation, wind energy, bioenergy, geothermal energy and energy-saving lighting materials.	Number of statistics
	C8	Water saving measures	Water-saving irrigation (drip irrigation, sprinkler irrigation, etc.), water-saving plant use (native plants, drought-tolerant plants, etc.), water-saving appliances (sensor taps, water-saving sanitary appliances, etc.), etc. in the region.	Number of statistics
	C9	Temperature control, cooling, noise reduction and sound-dampening measures	Artificial fog, fountains, waterfalls, ventilation, plant shade, shading facilities, inlaid grass paving, background music, dynamic water features, etc.	Number of statistics
	C10	Public water-friendly spaces	The number and use of public water-friendly spaces.	Statistical area
	C11	Eco-building	The number of buildings and structures such as eco-toilets, eco-parking lots, and elevated facilities on the ground floor of buildings, and the application of vertical greening.	Number of statistics

Type of indicator	Serial No.	Ecological design approach	Definition	Quantification criteria
Design factors for Ecological facility	C12	Type and intensity of artificial disturbance	Type and intensity of activities in the area such as infrastructure, environmental pollution, night lighting, tourism, polder, grazing, gathering, indiscriminate hunting, etc.	Number of statistics
Design factors for Plant diversity	D1	Plant diversity	A statistical index of the diversity of plant species in the region. Sample method	Calculating the Shannon-wiener index
	D2	Vegetation area	Area of vegetation in the region.	Statistical area
	D3	Plant community structure	The life type composition of the plant communities in the area classifies the types of plant community structure in the sample plots, including tree, shrub, grass, shrub-grass, tree-grass, tree-shrub, tree-irrigation and tree-shrub-grass.	Number of statistical types
	D4	Habitat diversity	Dense forest, sparse forest, scrub, forest edge, grassland, open land; waterfront, river bank, marsh, shallow water, lake, river, island; slow water, fast water, still water, etc.	Number of statistical types
	D5	Plant adaptability	The health of plant growth in the area.	Poor 1 point; Moderate 2 points; Good 3 points
	D6	Artificial plant species	Artificial plant species in the area.	Statistics as a percentage
	D7	Native plant species	Native plant species in the region.	Statistics as a percentage

Type of indicator	Serial No.	Ecological design approach	Definition	Quantification criteria
Design factors for Plant diversity	D8	Hydrophyte species	The species, number and area of distribution of submerged, submerged, floating, floating and wet plants.	Number of statistics
	D9	Invasive alien plant species	Species of invasive alien plants and the extent of damage, such as water hyacinth, drought-loving lily grass, one-year-old canopy, and North American one-stem flower.	Number of statistics
	D10	Artificially simulated natural habitat	Artificial piles of rocks, rubble, wood piles, fallen leaves, earth burrows, vine-filled shelves, hollow bricks, dead wood and weeds, and diverse vegetation layers create a diverse biological habitat.	Number of statistics
	D11	Ecological conservation measures	Permeable tubes, organic mulch for the garden (bark, wood chips, gravel, fallen leaves, etc.), rational pruning, soil improvement, use of water retention agents, ecological pest and disease control, etc.	Number of different measures

4.2.3 Model construction and data analysis

The correlation between all variables was analyzed using the Person method to determine whether there was a significant correlation between the two relationships (Figure 4-1,4-2,4-3). The blue series indicates a positive correlation, the red series a negative correlation, and the darker the color the higher the correlation coefficient. The asterisks marked in the upper right-hand corner of the small panels indicate the degree of significance: *** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$.

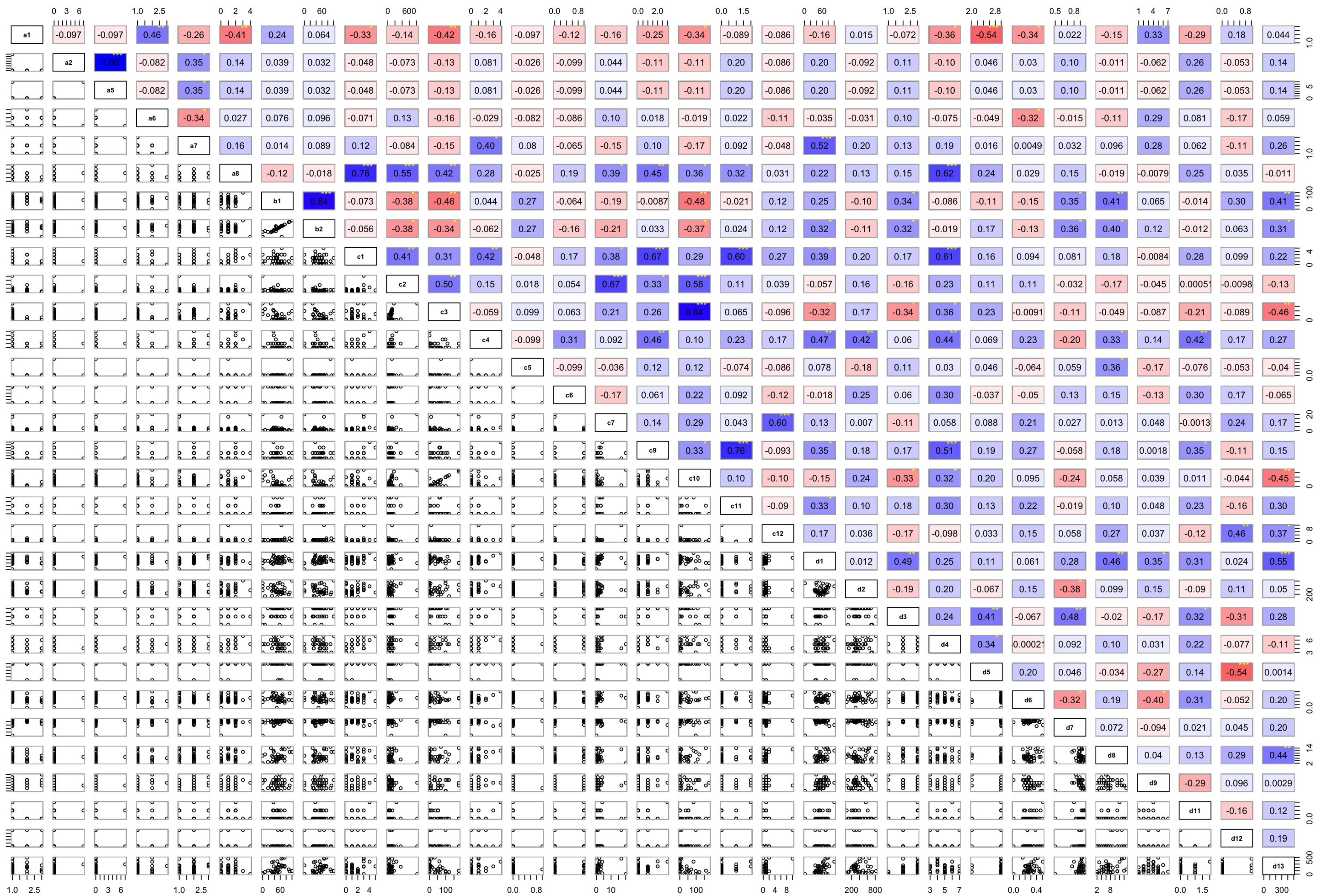

Fig. 4-1 Correlation diagram of the variables of the ecological design approach of the Xixi Wetland

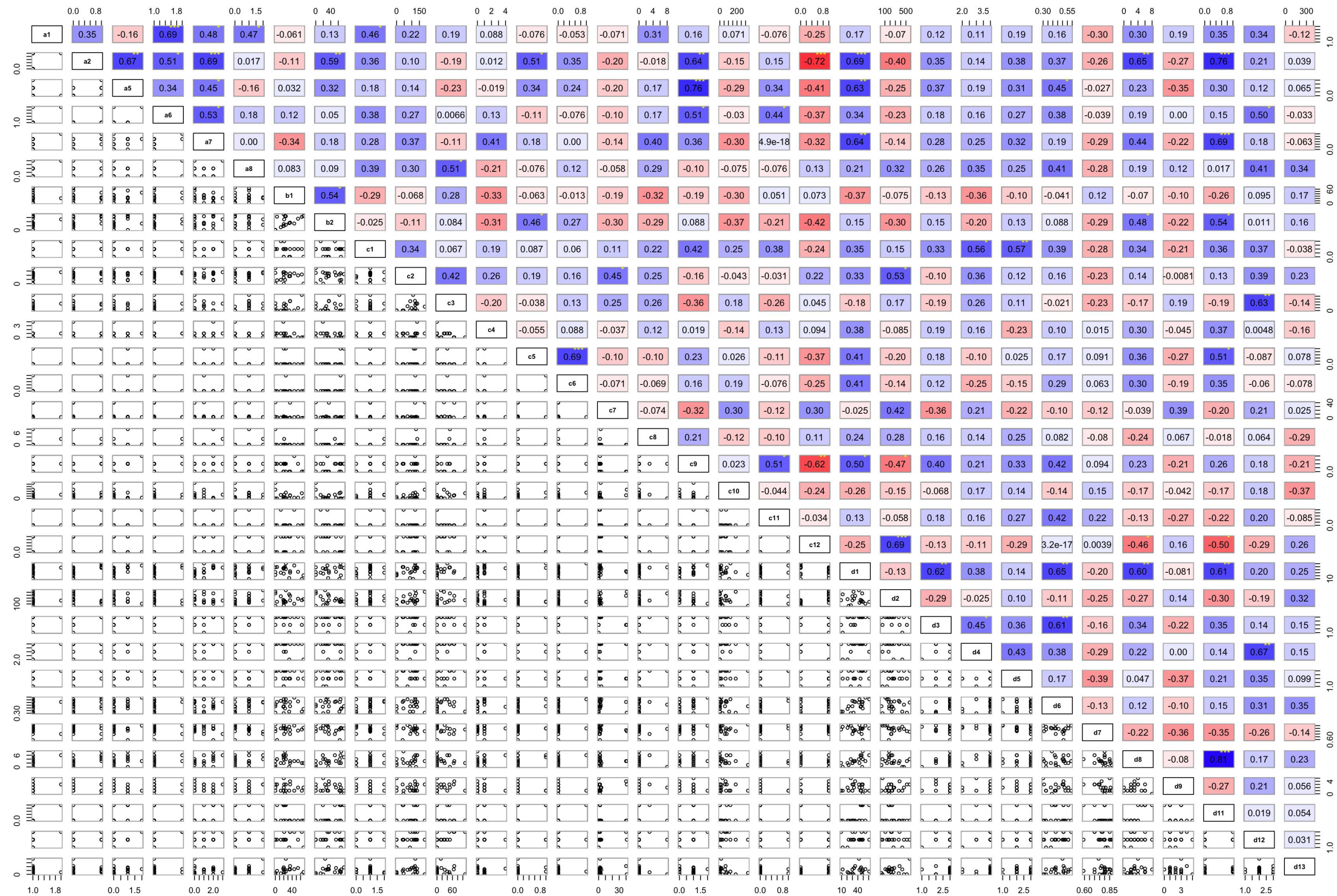

Fig. 4-2 Correlation diagram of the variables of the ecological design approach of the Tongjian Lake Wetland

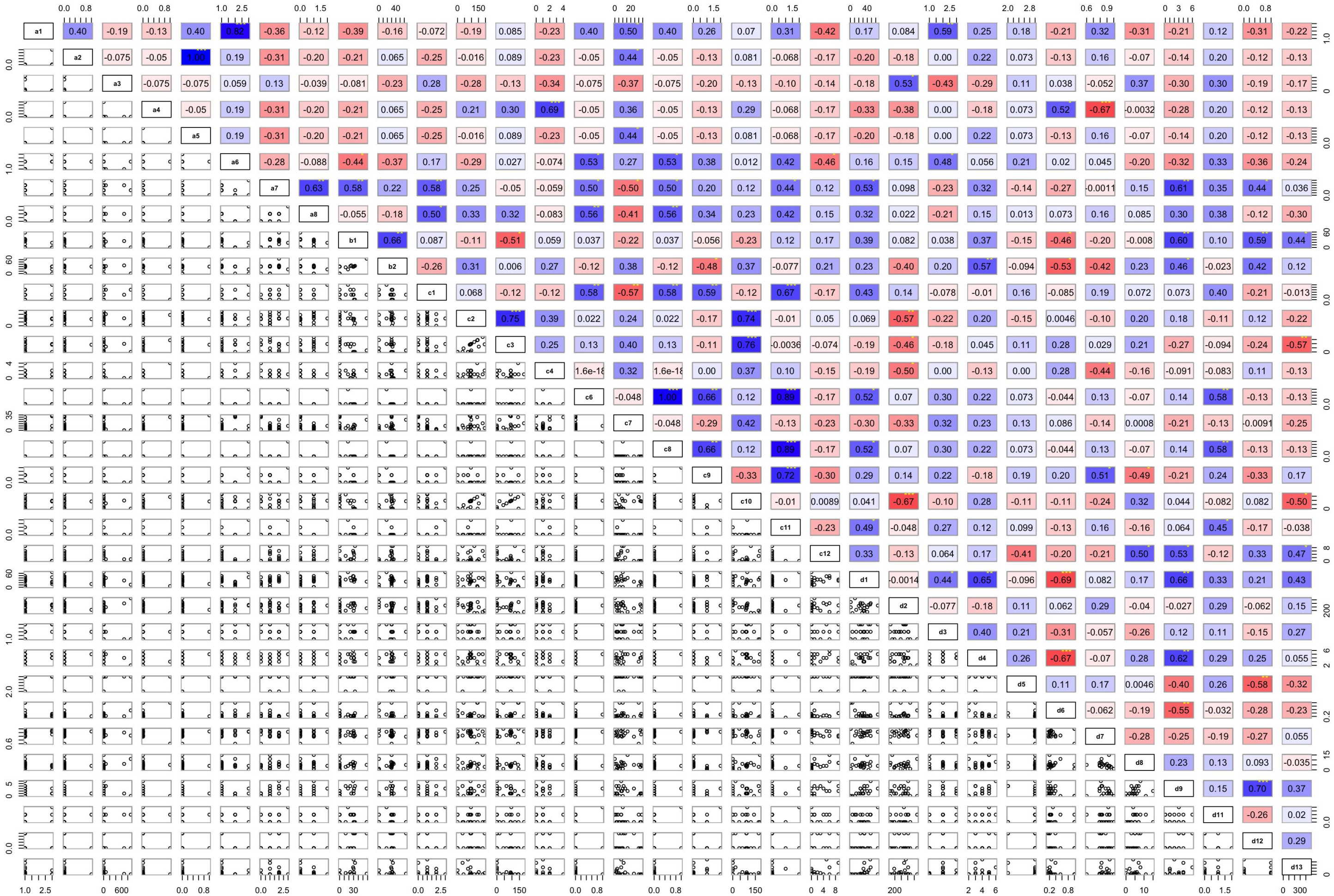

Fig. 4-3 Correlation diagram of the variables of the ecological design approach of the Qingshan Lake Wetland

A structural equation model (SEM) was applied to calculate and test the relationships and pathways between ecological design practices and plant diversity. Plant diversity (D1) was used as the explained variable in the model, and 33 other design practices were used as the explained observed variables. Based on the analysis of the correlations between the three wetland observed variables, and in conjunction with related studies, the hypothesis was formulated that: A conceptual model of the effect of urban wetland ecological design practices on plant diversity was constructed (Figure 4-4). The values of each observed variable were substituted into the hypothetical model, and the Lavan package in R 3.4.1 was used to run the structural equation model for calculation, detection and correction, and to adjust and optimize the intermediate variables when assessing the pathways of influence of ecological design practices on plant diversity.

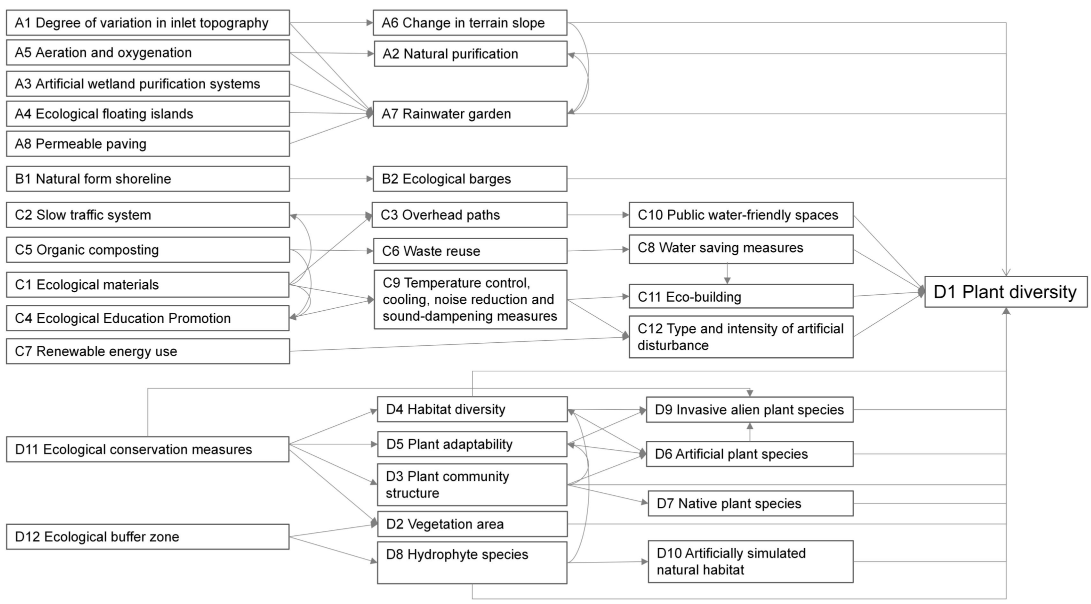

Fig. 4-4 Hypothetical model of urban wetland ecological design practices affecting wetland plant diversity

4.3 Results

4.3.1 Ecological design practices for urban wetland landscapes in different regions

Analysis of the scores for each ecological design practice in the three urban wetlands, with box plots (Figure 4-5) and ANOVA (Table 4-2). The results showed that the seven ecological design practices of permeable paving (A8), natural form shoreline (B1), waste reuse (C6), plant diversity (D1), aquatic and hydrophyte species (D8), invasive alien plant species (D9) and ecological buffer zone (D12) were significantly higher in the Xixi Wetland than in the other two wetlands. Three ecological design practices.The four factors of rainwater garden (A7), plant adaptability (D5), artificial plant species (D6) and ecological conservation measures (D11) were significantly higher in the Tongjian Lake Wetland than in the other two wetlands. However, the three factors of vegetation area (D2), habitat diversity (D4) and native plant species (D7) were significantly lower than the other two wetlands. Artificial wetland purification systems (A3), renewable energy use (C7) and type, intensity of artificial disturbance (C12) and overhead paths (C3) were significantly higher in Qingshan Lake Wetland than in Tongjian Lake Wetland and Xixi Wetland, and plant community structure (D3) and ecological barges (B2) were significantly lower.

The values of three factors close to or equal to zero for ecological floating islands (A4), organic composting (C5) and water saving measures (C8), indicating that these three ecological designs practices were rarely used in all three wetlands. The eleven ecological design practices of a degree of variation in inlet topography (A1), natural purification (A2), aeration and oxygenation (A5), change in terrain slope (A6), ecological materials (C1), slow traffic system (C2), ecological education promotion (C4), temperature control - cooling - noise reduction - sound abatement and other facilities (C9), public water-friendly spaces (C10), Eco-building (C11) and artificial simulation of natural habitats (D10) are not significantly different in any of the three urban wetlands.

Table 4-2 Analysis of variance of ecological design practice factors in three wetlands

	A1	A2	A3	A4	A5	A6	A7	A8	B1
P	0.08	0.62	0.04*	0.68	0.40	0.13	0.00***	0.01*	0.00***

	B2	C1	C2	C3	C4	C5	C6	C7	C8
P	0.00***	0.10	0.94	0.02*	0.21	0.21	0.02*	0.00***	0.09

	C9	C10	C11	C12	D1	D2	D3	D4	D5
P	0.43	0.12	0.39	0.01*	0.00***	0.02*	0.00***	0.00***	0.00***

	D6	D7	D8	D9	D10	D11	D12
P	0.00***	0.00***	0.00***	0.00***	0.20	0.00***	0.01*

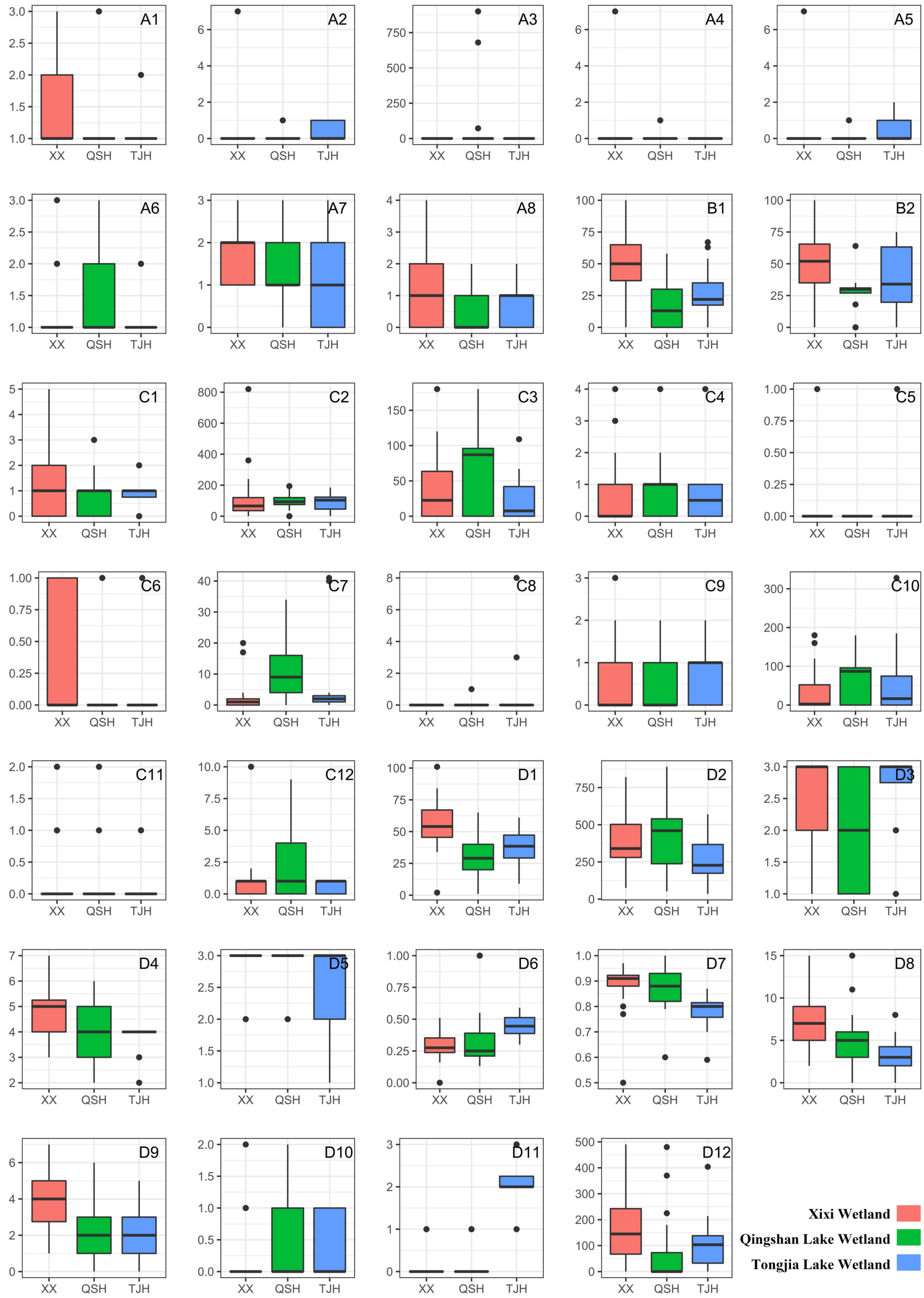

Fig. 4-5 Box plot of the three urban wetland eco-design approach scores (different serial numbers represent different eco-design practices in Table 4-1)

4.3.2 Analysis of the relevance of ecological design practices

Person correlation analysis (Table 4-3) showed that of the 34 observed variables, a total of 88 pairs were significantly correlated ($P < 0.05$) in the Xixi Wetland, 51 pairs were significantly correlated ($P < 0.05$) in the Tongjian Lake Wetland and 79 pairs were significantly correlated ($P < 0.05$) in the Qingshan Lake Wetland. Nine of the observed variables rainwater garden (A7), ecological buffer zone (D12), ecological education promotion (C4), plant community structure (D3), hydrophyte species (D8), Eco-building (C11), ecological materials (C1), ecological barges (B2) and invasive alien plant species (D9) in the Xixi Wetland had significant positive correlations for plant diversity (D1), and overhead paths (C3) have significant negative correlations for plant diversity. The seven observed variables of rainwater garden (A7), plant community structure (D3), hydrophyte species (D8), natural purification (A2), aeration and oxygenation (A5), artificial plant species (D6) and artificially simulated natural habitats (D10) in the Tongjian Lake Wetland had a significant positive correlation on plant diversity. The seven observed variables of waste reuse (C6), water saving measures (C8), Eco-building (C11), rainwater garden (A7), plant community structure (D3), habitat diversity (D4) and invasive alien plant species (D9) in the Qingshan Lake Wetland had significant positive correlations for plant diversity, and artificial plant species (D6) had significant negative correlations for plant diversity.

Table 4-3 Correlation between ecological design practices and plant diversity in three urban wetlands

Xixi Wetland			Tongjian Lake Wetland			Qingshan Lake Wetland		
Ecological design approach	Correlation coefficient	p	Ecological design approach	Correlation coefficient	p	Ecological design approach	Correlation coefficient	p
A7	0.52	***	A2	0.69	***	D4	0.65	**
D12	0.55	***	A7	0.64	**	D9	0.66	**
C4	0.47	**	A5	0.63	**	A7	0.53	*
D3	0.49	**	D3	0.62	**	C8	0.52	*
D8	0.46	**	D8	0.60	**	D3	0.44	*
C11	0.33	*	D6	0.65	**	C11	0.49	*
C1	0.39	*	D10	0.61	**	C6	0.52	*
B2	0.32	*				D6	-0.69	***
D9	0.35	*						
C3	-0.32	*						

*** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$, The different serial numbers represent the different ecological design practices in Table 4-1.

4.3.3 Pathways for ecological design practices to influence plant diversity

The fit of the structural equation models was determined using X^2/df, P and RMSEA, with X^2/df less than 3, P > 0.05 and RMSEA < 0.1 indicating a good model fit [14],[15]. Based on the above criteria, the models were tested for fitness (Table 4-4), and all three wetland models met the requirements of the fit indices and passed the test of the experimental data.

Table 4-4 Model fitness tests for the three urban wetland structure equations

	Xixi Wetland	Tongjian Lake Wetland	Qingshan Lake Wetland
X^2	14.658	3.274	12.038
df	11	7	21
P	0.199	0.859	0.525
RMSEA	0.091	0.001	0.001

df: degrees of freedom, RMSEA: root mean square and square of asymptotic residuals

In the Xixi Wetland, rainwater garden (A7), plant community structure (D3), hydrophyte species (D8) and invasive alien plant species (D9) have a direct positive effect on plant diversity (D1), with plant community structure (D3) having the highest coefficient of influence (Figure 4-6); ecological conservation measures (D11) hurt plant diversity to some extent.

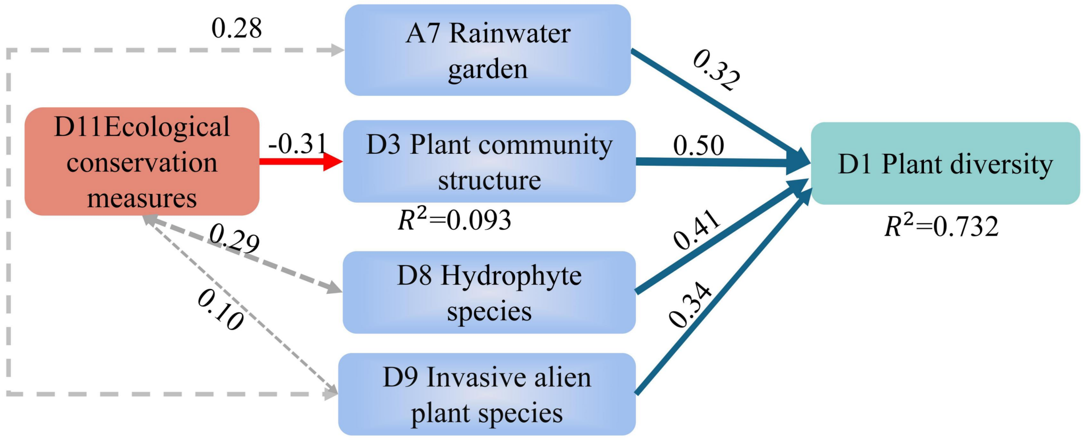

Fig. 4-6 Pathways for assessing the effects of ecological design practices on plant diversity in the Xixi Wetland structural equation model. R^2 represents the extent to which each independent variable is explained in the overall model. The number next to the arrow represents the standardized local effect (blue for positive correlation, red for negative correlation) and the degree of significance, and the thickness of the arrow indicates the degree of correlation between the two variables (the stronger the correlation, the thicker the arrow).

In the Tongjian Lake Wetland, rainwater garden (A7), artificial plant species (D6) and hydrophyte species (D8) can directly and positively influence plant diversity (D1), with the artificial plant species (D6) having the largest influence coefficient (Figure 4-7). Ecological conservation measures (D11) have the opposite result on plant diversity as the Xixi Wetland and can increase plant diversity by influencing habitat diversity to increase artificial plant species and thus plant diversity.

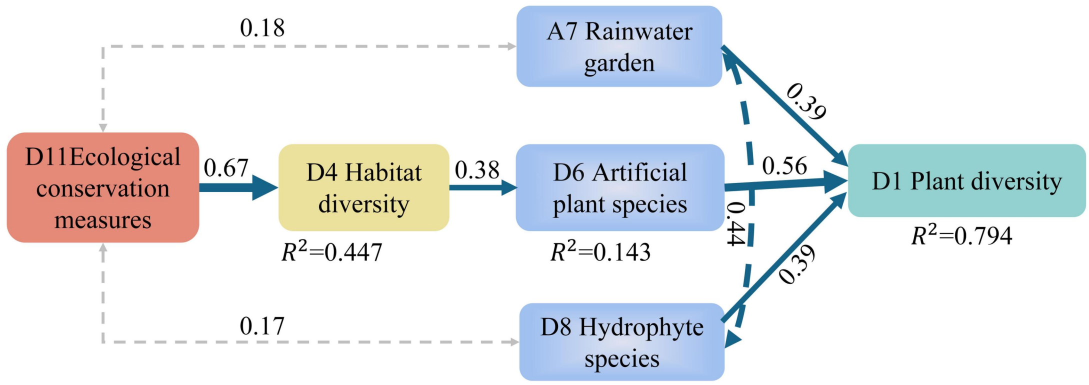

Fig. 4-7 Pathways for assessing the effects of ecological design practices on plant diversity in the Tongjian Lake Wetland structural equation model. R^2 represents the extent to which each independent variable is explained in the overall model. The number next to the arrow represents the standardized local effect (blue for positive correlation, red for negative correlation) and the degree of significance, and the thickness of the arrow indicates the degree of correlation between the two variables (the stronger the correlation, the thicker the arrow).

In contrast to the Tongjian Lake Wetland, the artificial plant species in the Qingshan Lake Wetland have a somewhat negative relationship with plant diversity, which is influenced by both ecological conservation measures (D11) and habitat diversity (D4). The degree of variation in inlet topography (A1) positively affects plant diversity (D1) by increasing the change in terrain slope (A6) with coefficients of 0.82 and 0.34 respectively; permeable paving (A8) increases plant diversity (D1) by affecting rainwater garden (A7) with coefficients of 0.63 and 0.51 respectively; both plant community structure (D3) and type and intensity of artificial disturbance (C12) had a significant effect on plant diversity, with type and intensity of artificial disturbance (C12) having the greatest effect with an impact coefficient of 0.59 (Figure 4-8).

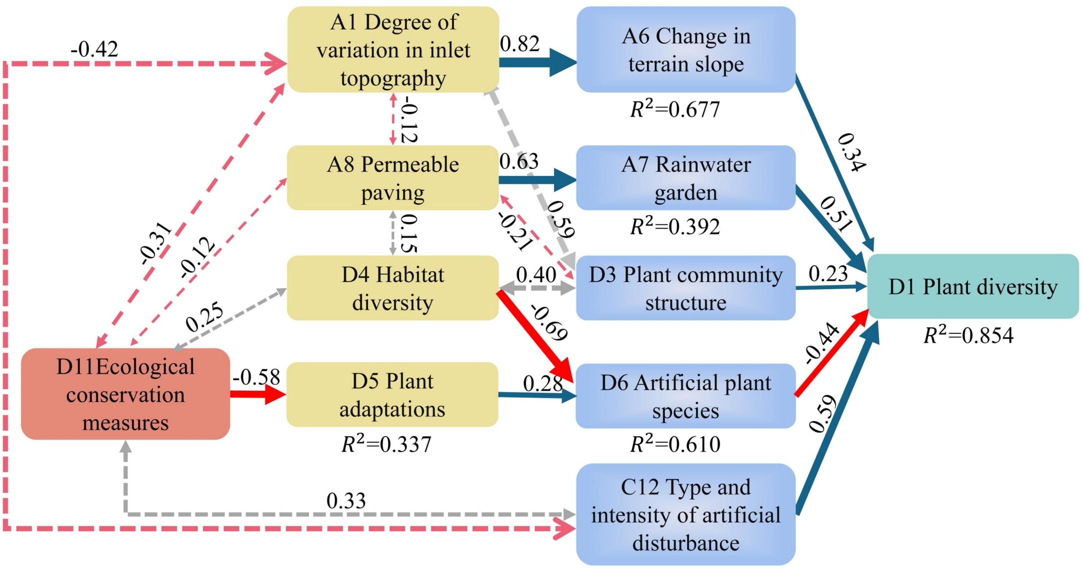

Fig. 4-8 Pathways for assessing the effects of ecological design practices on plant diversity in the Qingshan Lake Wetland structural equation model. R^2 represents the extent to which each independent variable is explained in the overall model. The number next to the arrow represents the standardized local effect (blue for positive correlation, red for negative correlation) and the degree of significance, and the thickness of the arrow indicates the degree of correlation between the two variables (the stronger the correlation, the thicker the arrow).

4.4 Discussion

4.4.1 Differences in ecological design practices for urban wetlands in different regions

Based on the spatial location, service users and functional positioning of urban wetlands, the design techniques applied in the design of urban wetlands in different areas may vary [16]. The Xixi Wetland was built a long time ago and is a national wetland park based on the original fishing base and natural wetland resources, with wetland ecological protection and display and ornamental tours as its main functions. The planning and design have preserved the natural appearance of the wetland, and the plant species, landscape materials and design style have been harmonized with the natural appearance as far as possible, while more ecological design techniques and technologies have been applied[17]-[19]. The survey also found that seven ecological design practices - permeable paving (A8), natural form shoreline (B1), waste reuse (C6), plant diversity (D1), aquatic and hydrophyte species (D8), invasive alien plant species (D9) and ecological buffer zone (D12) - were significantly higher in the Xixi Wetland than in the other two wetlands. In the Tongjian Lake Wetland, the rainwater garden (A7), plant adaptability (D5), artificial plant species (D6) and ecological conservation measures (D11) were significantly higher than in the other two wetlands, but the vegetation area (D2), habitat diversity (D4) and native plant species (D7) were significantly lower than in the other two wetlands. This may be since the

Tongjian Lake Wetland is a newly constructed wetland, mainly used for urban flood control and drainage projects, and has the functions of tourism and ornamental, water environment improvement and water resources protection, therefore artificial plant species for ornamental purposes are widely cultivated and these plants require more ecological conservation measures to improve plant adaptability, while the vegetation area of this wetland is small and habitat diversity is low; for water environment improvement and water resources protection, more physical ecological design techniques for water conservation, such as stacked water, fountains and other dynamic water features. The artificial wetland purification system (A3), renewable energy use (C7), and the type and intensity of artificial disturbance (C12) were significantly higher and the plant community structure (D3) was significantly lower in the Qingshan Lake Wetland than in the other two wetlands. The Qingshan Lake Wetland is located in the urban countryside and has a large area of artificial wetlands around it. The natural community is characterized by a single superior plant community, and the landscape features of the water forest and the greenway around the lake are prominent. The wetland has been designed with a large number of artificial energy-saving lighting facilities in terms of renewable energy ecological design practices, while the large planting of pond fir forests with a simple community structure has resulted in a low level of plant community structure in the Qingshan Lake Wetland.

4.4.2 The impact of ecological design practices on plant diversity in urban wetlands in different regions

The pathway analysis of the three wetlands found that the Qingshan Lake Wetland had the most ecological design factors affecting plant diversity and the most complex pathways, while the Xixi and Tongjian Lake Wetlands had the fewest factors and simpler pathways. The Qingshan Lake Wetland has a large number of mono-optimal plant communities with a relatively simple structure, and usually, plant communities with a simple structure are more susceptible to disturbance by external environmental factors[20]. The Tongjian Lake Wetland is a new urban wetland, except for a few ecological factors that significantly affect plant diversity, most of the ecological design factors may require longer practice to reflect their impact on plant diversity. The Xixi Wetland has been under construction for a long time and the plant community structure of the wetland ecosystem is more stable, and this more stable plant community is more resistant to external disturbances[21].

Ecological conservation measures (D11) appear in the structural equation models for all three wetlands, but there are two different effects, positive and negative, between the different wetlands. The Xixi Wetland has a relatively stable plant community structure and a high plant diversity with a high number of autochthonous plants[22]. Ecological conservation within this wetland is more concerned with the autochthonous plants in the community, the clearing of which may alter the structure of the plant community and lead to a reduction in plant diversity. In contrast to the Xixi

Wetland, Tongjian Lake, as a new urban wetland, has more artificially planted ornamental plants and the selection of landscape plants is more biased towards the introduction of exotic species, but exotic plants are less locally adapted[23] and are less adaptable than naturally growing plants, whereas appropriate ecological conservation measures can provide suitable habitats for their growth, thus increasing the diversity of habitats within the wetland and ultimately through the increase in the number of artificial ornamental plant species. Research by Lu Chunhui[24] also shows that reasonable ecological conservation measures can keep various communities in check with each other, forming a benign competitive growth mechanism between species and increasing plant diversity. In addition, extensive planting of artificial plants in new urban wetlands will promote plant diversity in the short term[25].

The ecological conservation measures (D11) in the Qingshan Lake Wetland are lower than in the Tongjian Lake Wetland and higher than in the Xixi Wetland, and although some ecological conservation measures are in place to improve plant adaptability, this still leads to a decline in the number of relatively poorly adapted exotic ornamental plants due to mortality. In addition, the relatively high habitat diversity of the Qingshan Lake Wetland has increased the amount of native natural plants, which in turn has reduced the proportion of artificial plants in this wetland. The lower number and proportion of artificial plant species in a natural community indicates that the community has a greater proportion of naturally growing plants and may instead have higher plant diversity[26].

The artificial plant species (D6) had no significant effect on the plant diversity of the Xixi Wetland, probably because the Xixi Wetland is dominated by native autochthonous plants with 83.4% native species[22], and the low proportion of artificially planted species did not have a significant effect on its plant diversity.

Rainwater garden (A7) were the factor with a positive significant effect in all three wetlands, indicating that rain garden design can significantly enhance plant diversity in urban wetlands. This is because rain gardens can better bridge the relationship between the city and nature, establish a diverse habitat[27] and provide ecological functions such as ornamental landscapes and biodiversity conservation[28]; the collected rainwater runoff can be used for plant growth[29], increasing the diversity of habitat patches and the spatial structural diversity of the habitat, which also contributes to the conservation of biodiversity and the improvement of the urban ecological environment[30], while the higher community biodiversity also ensures the ornamental effect of the community[31].

Hydrophyte species (D8) had a positive and significant effect on the Tongjian Lake Wetland and the Xixi Wetland. Tongjian Lake is a new urban wetland, in the early stages of construction focusing on the beauty of the wetland landscape effect, has been artificially planted more water-wet plants. The Xixi Wetland has many pond patches with a wide variety of native aquatic and wet plants that are highly adaptable. In addition, the Xixi Wetland is conducive to the return and conservation of aquatic plants due to its relatively stable community structure. Two endangered aquatic plants, the *Isoetes Sinensis* and the *Ranalisma rostrata Stapf* have been introduced to the wetland using suitable habitats to enhance the plant diversity within the wetland. The Qingshan Lake Wetland has a large lake area, the water shoreline is mostly an articulated boundary with the mountain, with steep barges, few shallows and little suitable habitat for typical wetland plants[32][33], therefore, the Hydrophyte species in this wetland do not contribute significantly to plant diversity.

Plant community structure (D3) had a positive and significant effect on plant diversity in the Qingshan Lake Wetland (coefficient 0.23) and Xixi Wetland (coefficient 0.50). Structurally stable plant communities tend to have a high level of plant diversity[34]. The Xixi Wetland has strong structural stability of plant communities and a rich variety of species in the plant landscape community[35]. Although the Qingshan Lake Wetland is influenced by large areas of pond fir forest with a simple community structure, resulting in a low level of plant community structure, the natural communities within this wetland also have more complex and stable plant communities, which in turn reinforces the positive relationship between the two in this wetland. The Tongjian Lake Wetland is mostly grass + tree structure, with a relatively simple community structure.

There is a positive correlation between invasive alien plant species (D9) and plant diversity in the Xixi Wetland, indicating that the higher number and more frequent occurrence of invasive plants in the Xixi Wetland are associated with more human activity in the urban core, which is often the main factor leading to the introduction of invasive plants[36]. The Xixi Wetland plant survey also found[22]a high number of invasive plant species in this wetland.

4.4.3 Ecological design practices for urban wetlands in different regions in the context of urbanisation

Rapid urban expansion has turned natural wetlands that were once located in the urban countryside into urban wetlands, and wetland biodiversity has been significantly affected [37], and urban wetland design efforts have been faced with additional biodiversity conservation issues[38]. The relationship between ecological design practices and plant diversity in wetlands is influenced by the distance of the wetland from the built-up urban area and the service function of the wetland. A good understanding of the ecological design practices that affect the plant diversity of wetlands can provide a basis for the planning, construction, conservation and utilization of wetlands in the urbanization process.

Wetlands in urban cores are often subject to higher levels of artificial disturbance [39]. On the one hand, urban sprawl leads to severe fragmentation of wetland habitats, while on the other hand, higher human traffic also exerts greater environmental pressure on wetland habitats, which makes it more important for wetland design in urban cores to consider how to increase the environmental capacity of wetlands and improve their resilience.

4.5 Summary

This paper uses structural equation modeling to analyze the factors and pathways associated with the influence of landscape ecological design practices on plant diversity in urban wetlands in different regions. The ecological design practices in the Xixi Wetland, Tongjian Lake Wetland and Qingshan Lake Wetland showed some differences due to the distance between the wetland and the built-up area of the city and the service function of the wetland. The number of ecological design practices applied in the Xixi Wetland is significantly higher than that in the Qingshan Lake Wetland and Tongjian Lake Wetland. All three urban wetland ecological design practices had a significant impact on plant diversity, with ten ecological design factors having a significant impact on plant diversity in the Qingshan Lake Wetland, and five ecological design factors having a significant impact on plant diversity in both the Xixi and Tongjian Lake Wetlands. Urban wetlands require particular attention in planning and design to adopt the appropriate ecological design for different urban areas and wetlands with different service functions. Urban planners and managers need to think about highlighting the characteristics of different regional wetlands through landscape ecological planning and design in order to achieve conservation of wetland plant diversity and differentiated wetland utilization.

Based on three typical urban wetlands, this study explores the relationship and pathways of influence between ecological design practices and plant diversity. However, due to the limited number of samples, factors that do not enter the final model do not mean that they do not have a significant influence on plant diversity in urban wetlands, and in further research, typical wetland cases can be added and the study of the relationships between biodiversity factors can be extended to more comprehensively explore the influence relationships between ecological design practices and biodiversity in urban wetlands, providing a targeted scientific basis for urban wetland landscape conservation and planning design.

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Chapter 5

URBAN WETLAND EVALUATION INDICATOR ESTABLISHMENT

CHAPTER FIVE: URBAN WETLAND EVALUATION INDICATOR ESTABLISHMENT

5.1 Introduction

Urban wetland is considered as a system compose of urban ecosystem, which not only provides good living environment and leisure space for urban residents, but also plays an important role in biodiversity protection and the development of tourism industry and regional economy. In particular, scientific and rational protection, planning and design of Urban Wetland Park is of great significance against the background of "sponge city" and "double construction"[1]. With increasing attention of the protection and construction of urban wetlands, through reasonable conservation and planning methods, several damaged urban wetlands have been repaired, the landscape and health of wetlands have been improved[2]-[4] and the biodiversity of urban wetlands has also been significantly improved[5][6], which have formed urban wetland parks integrating conservation, public science outreach, leisure and other functions, reflecting the ecological, economic and social benefits of the wetland[7]. Intensive research activities have been carried out in recent years on wetland ecosystem service evaluation[8][9], wetland landscape performance evaluation1, wetland plant landscape evaluation[1][10][11], wetland health evaluation[12]-[14], wetland tourism resources evaluation[15], wetland social function evaluation[16], etc., and established different evaluation systems of various indicators.

5.2 Scenic Beauty Estimation evaluation of urban wetland

The beauty of the wetland landscape often affects the public's intention to visit and how often they visit, which in turn mediates the transmission of wetland ecological services to residents and their participation in wetland protection. Therefore, in the planning, design and management of wetlands to achieve sustainable development of wetlands, it is first necessary to understand the relationship between ecological design and beauty in urban wetlands.

Ecological design and restoration have been widely used in the protection and construction of urban wetlands[17][18]. For example, the application of various ecological technologies and methods and the use of ecological materials have played an important role in improving urban wetland biodiversity[3][19]. The overarching goal of urban wetland protection and management is to achieve the synergistic improvement of ecological benefits and landscape effects. It has been found that there the use of ecological design methods to improve biodiversity is related to public aesthetic preferences[20] and landscape design[3][21], such as how increased plant diversity is more attractive to tourists[22]. The design of natural habitat methods also helps to increase regional biodiversity[23] and improve the quality of wetland landscapes. Additionally, it should be pointed out that artificial wetland technology can maintain and improve biodiversity[17]. However, the studies on wetlands tend to focus on natural wetlands at the expense of wetlands in different cities. This situation leads to the question of what characteristics of ecological design practices influence the perceived beauty of wetland landscapes in urban areas. How do ecological design, wetland landscapes, and biodiversity interact? The answers to these questions will help formulate corresponding management strategies that can be applied to improve the quality of urban wetland habitats and alleviate the tension between urban wetland protection and utilization.

As vision dominates the psychological feelings and thinking behaviors in human activities[24][25], the beauty of wetland landscapes directly affects the residents' willingness to visit such areas and participate in their protection. Since the 1960s, a large number of theoretical research and practical work have been carried out to scientifically evaluate the visual environment of the landscape[26]-[28]. There are two main landscape evaluation models: an expert evaluation based on the objective attributes of the landscape and a public evaluation based on the viewer's inner perception. Among them, scenic beauty estimation (SBE) is a kind of landscape aesthetic quality evaluation method based on psychophysics[29], which studies how people's subjective preferences change with changes in landscape attributes. Moreover, it can be used to identify methods for scientific planning and the design of landscapes through the study of the relationship between the people's subjective preferences and landscape attributes[30]. However, due to the lack of correspondence between people's visual perceptions, the spatial characteristics of the landscape, and the characteristics of the design elements, the correlation and restriction tests between the elements have yet to be carried out. Accordingly, the evaluation results offer less guidance when applied in a specific practice. The semantic differential (SD) extracts landscape elements as evaluation factors for beauty, and combines factor analysis to extract independent factors, establish quantitative models, and evaluate landscape quality[31][32]. When combined with SBE, it can clearly reflect the advantages and disadvantages of the landscape, thereby enhancing the objectivity of the results [33]-[35]. Yet, it should be noted that the SD method typically determines the score based on the positive and negative poles of the "adjective pair" [34]. Whilst the subjectivity of "adjective pair" scoring is still strong, the inclusion of too many "adjective pair" scoring items will make the testee lose patience, thus affecting the objectivity of the score. In response, the expert evaluation method is used for SD evaluation to identify a more objective, accurate, and effective factor evaluation method that affects the beauty of the landscape. This method is used by experts to determine and quantify the landscape factors, excluding the subjectivity of the subject and the non-authenticity of the data. This is more suitable for evaluating objective factors, making the results more objective [36]-[38]. In the evaluation of scenic beauty, the exploration of a combination of subjective and objective evaluation methods has become a research trend in recent years[39].

The structural equation model (SEM) is introduced in this study to further explore the relationship between ecological design, biodiversity and scenic beauty in urban wetlands, and clarify the interactions that take place between the three. The SEM is used to establish, estimate, and test causal relationship models[40] and process complex multivariate data[41]. Notably, it is capable of studying both observable variables and hidden variables (variables that cannot be directly observed) and the direct and indirect effects between variables, and allows measurement errors in each variable[42]. The utilization of the structural equation model provides a theoretical basis for the planning and design of urban wetland landscapes.

As the pace of urbanization continues to increase, some wetlands in urban-rural and rural areas have gradually evolved into urban wetlands. Due to differences in geographical location and functional positioning, there is variation in the needs of wetland landscapes and changes in biodiversity. This study takes three urban wetlands located in the urban core area, marginal area and rural area of Hangzhou as examples. The SBE and SD evaluation methods are combined to evaluate the beauty of the wetland landscape, whilst SEM is used to analyze its association with biodiversity and ecological design practices. The present study aims to achieve the following: (1) Understand the differences in the beauty of wetland landscapes in different urban areas; (2) Analyze the main factors influencing the beauty of wetland landscapes in different urban areas; (3) Discern the correlation between urban wetland landscapes and plant diversity and ecological design; (4) Put forward theories and scientific basis for the protection, planning, and design of urban wetland landscapes across different regions and functions.

5.2.1 Methodology

This research is based on multidisciplinary works, and we developed a research framework (Figure 5-1). The framework includes five steps: (1) Take the photographs and record the landscape data of wetland by field surveying; (2) Literature collection and determine the key factors affecting the landscape; (3) Scenic beauty evaluation base on photographs; (4) SD evaluation base on key factors affecting the landscape which were divided into plant diversity and ecological design; (5) Analyse the impact path of ecological design and plant diversity on SBE with structural equation model (SEM) by synthesizing steps 3 and 4.

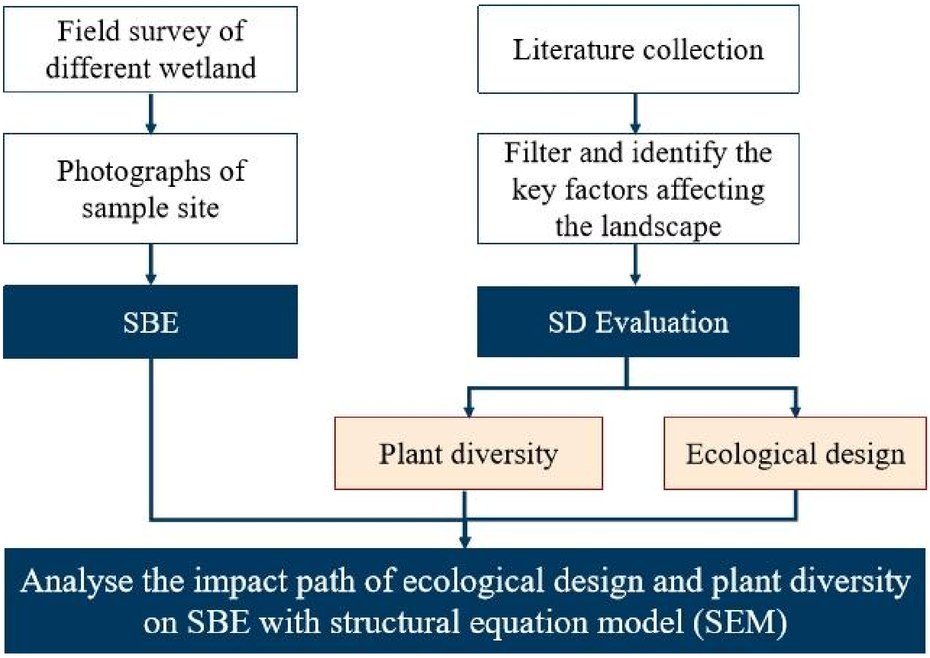

Fig. 5-1 Research framework for evaluation of urban wetland landscapes

(1) Data generation

The SBE score is determined by the characteristics of the landscape itself and the aesthetics of the selectors[43]. As a unified landscape evaluation object, the photos taken in Xixi Wetland, Tongjian Lake Wetland, and Qingshan Lake Wetland as part of this study form the basic data for the quantitative analysis of beauty evaluation, so as to ensure that the evaluation basis is consistent.

30 samples were randomly selected for each wetland; the landscape was then photographed and recorded. To reduce the impact of the shooting belt on the landscape evaluation, the relevant parameters and limiting conditions were unified when shooting: (1) The researchers shot the photos on sunny days in November 2021 between 9:00-17:00; (2) The same camera was used and fixed at a shooting height of 1.6m; (3) Horizontal shooting was adopted; (4) All photos were taken by the same person to maintain a consistent photo composition and selection scale.

To ensure the collected landscape photos accurately reflect the selected wetland landscape and increase the comparability[44], each sample point took four photos from directions in the south, east, north and west to the center of the sample point, respectively[45][46] (Figure 5-2). Due to terrain restrictions, it was not possible to take 4 photos of some sample points. In total, 320 photos were taken. The following screening methods were used: (1) The photos with excessive exposure, blurred image quality and interference from vehicles or people were removed; (2) The photo that best represents the landscape type of each sample point was selected[35]. Ultimately, 90 representative valid sample photos were screened and numbered.

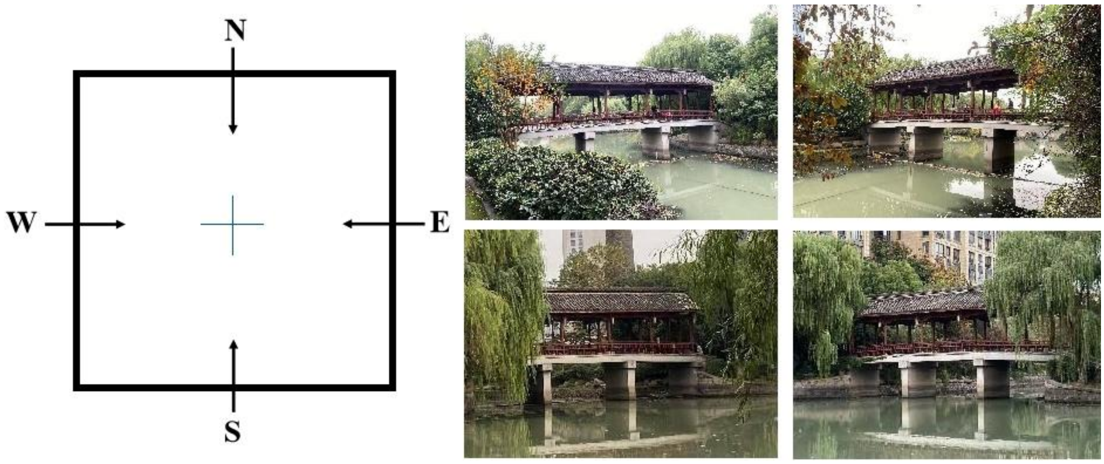

Fig. 5-2 Photographic method of urban wetland landscapes

Once the photo-taking was completed, a survey sample with an area of 30m×30m was set up at each sample site to record the plant species, habitat types, community structure levels, and the number of ecological technologies present. Additionally, remote sensing images were used to determine the proportion of hard landscapes for each sample site.

（2）Evaluation method

The evaluators consist of both professional and non-professional groups, of which 140 were in the professional group, including 6 well-known scholars in this field of study, 134 landscape design professionals, and 160 non-professionals.

There was no significant difference between the indoor slide evaluation results and the on-site evaluation[29][47]. The photos taken were made into slideshows, played indoors, and the SBE scoring was carried out. The 7-point beauty evaluation was used as the measurement standard[48], which included “Love”, “Prefer", “ Like”, “Normal”, “Dislike”, “Hate” and “Detest”, with corresponding scores of 3, 2, 1, 0, -1, -2, -3, respectively. Before scoring, the scoring purpose and scoring requirements were explained to the raters. Additionally, sample slides were shown to familiarize the raters with the setup and allow them to establish their own standards prior to commencing with the scoring. In the official scoring, each slide was shown for 8s[49], with the raters recording the scores for each landscape on the questionnaire in the order they were presented on the slides.

Although studies have shown that different evaluation subjects have a clear degree of consistency in terms of aesthetic attitudes[50]-[52], the evaluation based on the SD factor layer suggests that the perception abilities of the experts and professional group students are better than that of the general public[53]-[55]. Therefore, the SD evaluation of the subjective factor layer is scored by 30 professional group personnel, while the objective factor layer is quantitatively evaluated by 6 industry scholars in the professional group. When evaluating the subjective factor layer SD, each slide was shown for 1min[35].

（3）Beauty evaluation

To minimize the differences in aesthetic standards between different evaluators, a beauty standardization formula was used to standardize the evaluation scores and obtain the beauty value of the on-site landscape. The calculation formula is as follows:

$$Z_{ij}= (R_{\mathrm{ij}} - \overline{R}_j)/S_j \quad (1)$$

$$Z_i = \sum_j Z_{ij}/N_j \quad (2)$$

Where, Z_{ij} is the standardized value of the *j*-th judge's evaluation of the *i*-th sample landscape; is the direct score of the *j*-th judge's evaluation of the *i*-th landscape, and the average value of all the evaluation values of all the landscapes by the *j*-th judge, and S_j is the standard deviation of the evaluation values of all the landscapes by the *j*-th judge; Z_i is the mean standardized score value of the *i*-th landscape, and Nj is the total number of judges.

（4）Landscape factor evaluation

Referring to the relevant literature to determine the key factors that affect the beauty of the wetland landscape[56]-[59], 15 evaluation factors were organized and summarized from the perspective of aesthetics and ecological design using the Delphi method and factor screening. Finally, the 5 subjective evaluation factors and 5 objective evaluation factors for the evaluation of wetland beauty were filtered out, graded, and assigned scores of 2, 1, 0,-1, and -2, respectively (Table 5-1).

Table 5-1 Score of evaluation factors for the beauty of urban wetland landscape

Landscape factor	Landscape factor description	Evaluation index				
		2	1	0	-1	-2
Plant richness X1	Number of plant species in wetlands	46 kinds and above	36-45 kinds	26-35 kinds	16-25 kinds	15 types and below
Habitat diversity X2	Number of habitats in wetlands	6 types and above	5	4	3	2 types and below
Plant community structure X3	The life-type composition of trees, irrigation, and grasses of plant communities in wetlands	5th floor and above	4	5	2	1
Naturalness X4	The degree of naturalness of plants, shoreline forms, landscape materials, etc. in wetlands	Very natural	Natural	General	Unnatural	Extremely unnatural
Color harmony X5	The richness of color changes in plants, buildings, facilities, etc. in the landscape	Very harmoni ous	Harmony	General	Discord	Extremely discordant
Suitable for spatial scale X6	The suitability of the area, size, height and other dimensions of each landscape element	Very suitable	Suitable for	General	Not suitable	Very unsuitable
Coordination of landscape	The degree of coordination of	Very coordina	coordinat	General	Uncoordi	Very uncoordin

elements X7	materials, colors, styles, etc. of each landscape element	ted	ion		nated	ated
Ecological technology X8	Number of applications of ecological technologies in wetlands	26 kinds and above	21-25	16-20	11-15	10 types and below
Hard landscape ratio X9	Proportion of hard landscapes such as paving and structures in wetlands	5% and below	6%-10%	11%-20 %	21%-30%	31% and above
Cultural expression X10	Whether the landscape elements are designed with cultural symbols, folklore, historical allusions, etc.	A lot	Many	General	Less	No

（5）Structural equation model

The structural equation model was used to analyze the potential influence of urban wetland ecological design on wetland scenic beauty and plant diversity. The framework of the model was mainly based on the previous research and the filed investigation of our research group. Previous study had shown that ecological design can maintain and improve biodiversity[17], and the diversity of vegetation types has an important positive impact on improving the quality of landscape visual environment[66]. Meanwhile, the characterization factors of plant diversity and ecological design are mainly based on the field survey of our research group. It should be noted that SBE was included in the model as an interpreted variable. Ecological design and plant diversity have the potential to affect SBE, and a hypothetical framework is constructed (Fig. 5-3). The lavan package in R 3.4.1 was used to run the structural equation model. The adequacy of the model and data was verified by using the $\chi 2$ test and approximate root mean square error (RMSEA).

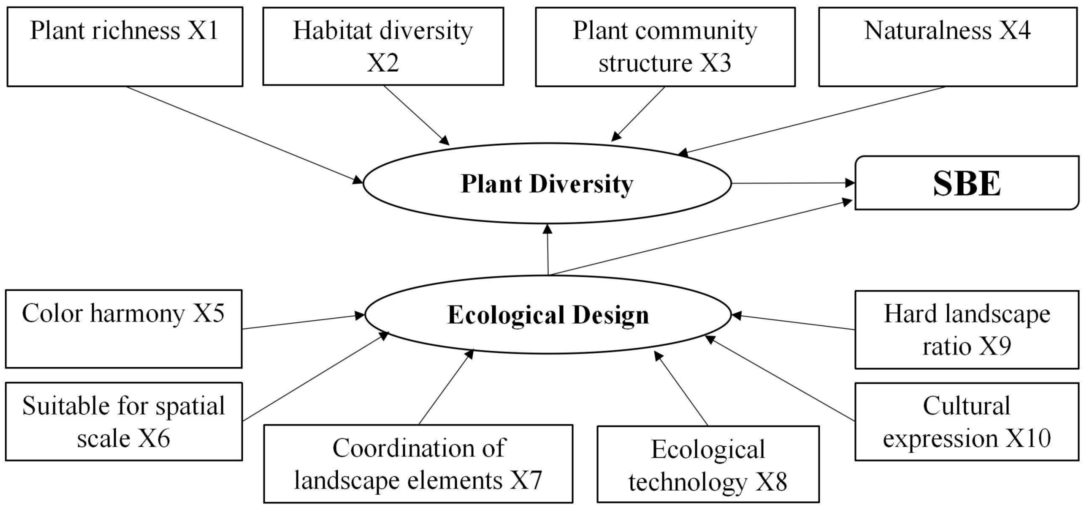

Fig. 5-3 Hypothetical model of urban wetland ecological design affecting the beauty of wetland landscape

5.2.2 Results

(1) Comparison of SBE

A total of 300 questionnaires were distributed, all of which were recovered, with a recovery rate of 100%. After removing invalid questionnaires with incomplete scores and questionnaires with exactly the same score values, a total of 290 valid questionnaires remained, with an efficiency rate of 97%.

The evaluation results of the scenic beauty of the three urban wetlands show (Fig. 5-4, Table 5-2) that the SBE range of Qingshan Lake Wetland is -0.76~0.95, and there are 17 landscapes with SBE values ⩾ 0; the SBE range of Xixi Wetland is -1.15~0.84, and there are also 17 landscapes with SBE values ⩾ 0; the SBE range of Tongjian Lake Wetland is -0.85~0.87, and there are 12 landscapes with SBE values ⩾ 0. Among the three urban wetlands, the scenic beauty score is the highest in Qingshan Lake Wetland. The SEB value indicates that the respondents' overall evaluations of the landscape quality of Qingshan Lake Wetland and Xixi Wetland were positive, whereas their satisfaction with the wetland landscape of Tongjian Lake Wetland was low. The CV values of the coefficient of variation of the three wetland scenic beauty score values are very similar (Table 5-2), indicating that the overall quality of the landscape sample photos selected for the three wetlands is more appropriate, and also that there are no excellent or very poor landscapes.

There are 46 landscapes with SBE values ⩾ 0 in the three wetlands, accounting for 51.1% of the total number. This indicates that the respondents' overall preference for wetland landscapes is neutral. The variance analysis showed that there was no significant difference in scenic beauty between the three wetlands (P＞0.05).

Table 5-2 Evaluation scores of the beauty of three urban wetlands

Wetland	Minimum value	Maximum value	Mean	Standard deviation	Coefficient of variation
Qingshan Lake Wetland	-0.76	0.95	0.002	0.43	0.107
Xixi Wetland	-1.15	0.84	0.000	0.46	0.117
Tongjian Lake Wetland	-0.85	0.87	0.000	0.49	0.122

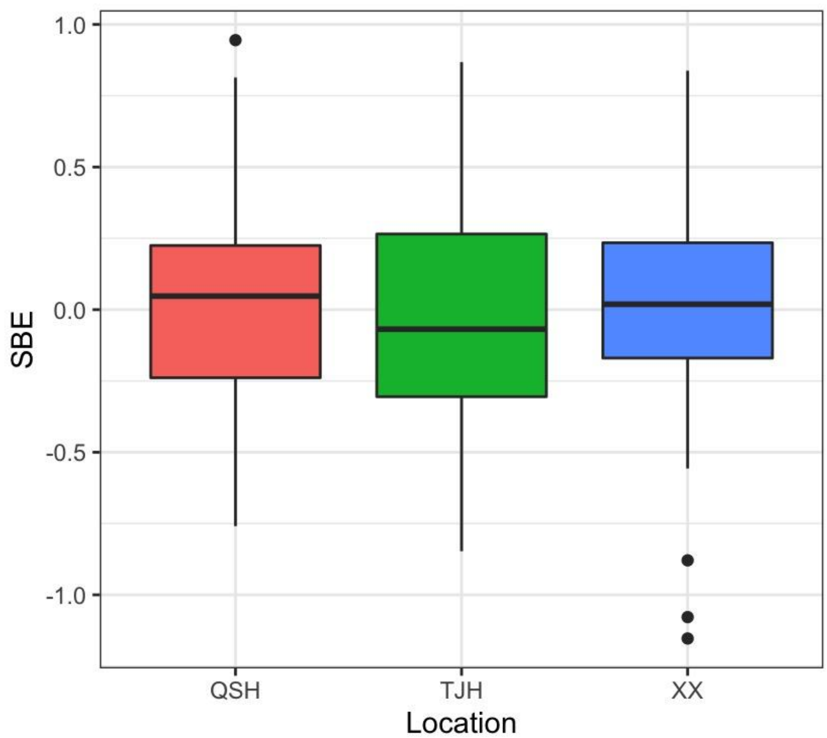

Fig. 5-4 A box diagram of the beauty rating of the three urban wetland landscapes. QSH：Qingshan Lake Wetland, TJH：Tongjian Lake Wetland, XX：Xixi Wetland

Photos with high SBE scores are typically characterized by open water, clear reflections of plants, structures, and the sky, obvious close-up, middle-view, and long-view levels, rich plant species and community structures, large vegetation areas, and good coordination of artificial landscape elements (Fig.5-5 a-f). The photos with lower scores have insufficient landscape levels, single colors, simple community structures, poor water quality in some landscapes with open water surfaces, exposed soil on the revetment, poor plant growth, and other factors affecting the landscape (Fig.5-5 g-l).

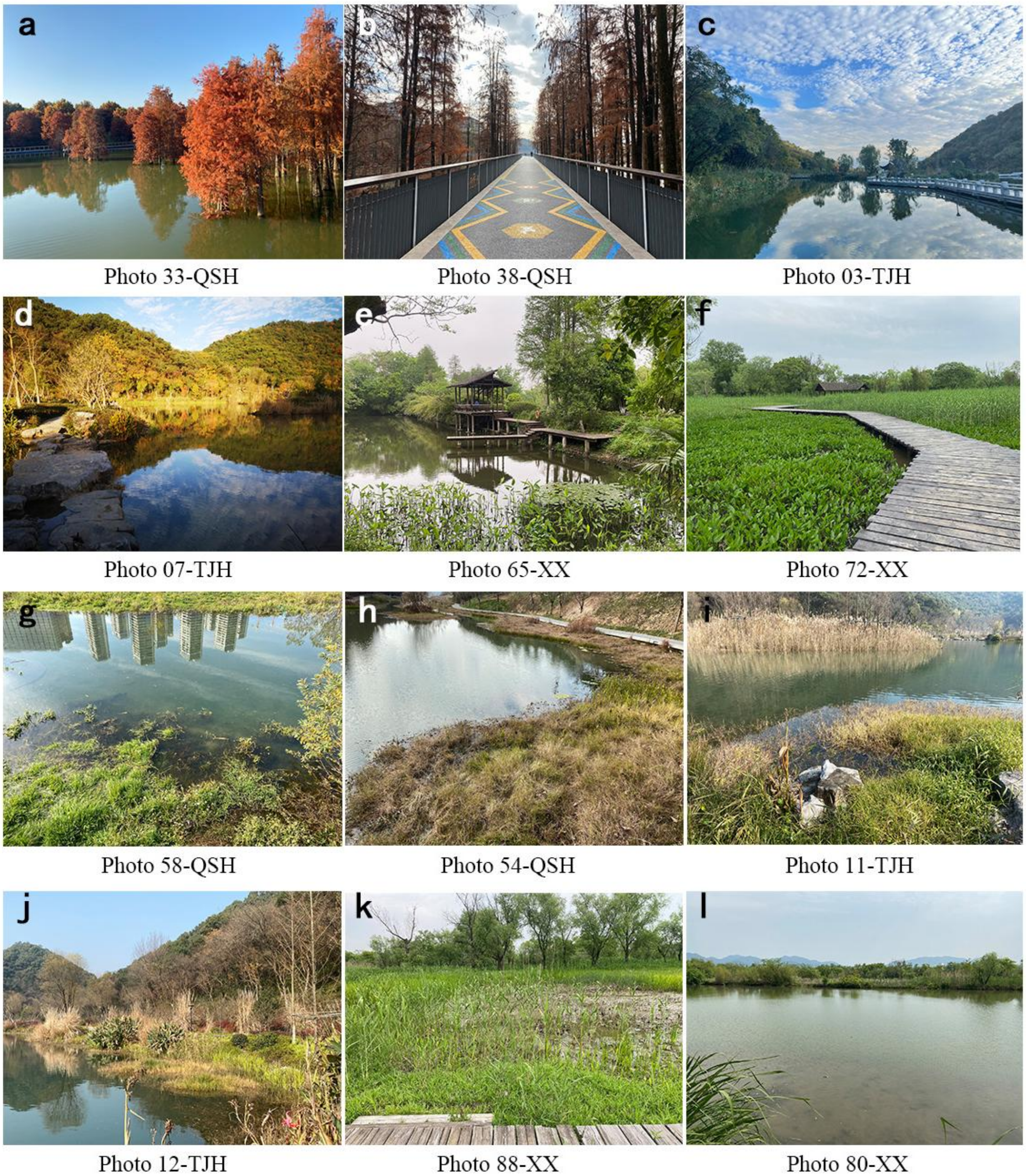

Fig. 5-5 Photos of the three urban wetlands with higher scenic beauty scores (a-f) and lower scenic beauty scores(g-l). QSH: Qingshan Lake Wetland, TJH: Tongjian Lake Wetland, XX: Xixi Wetland. The number represents the corresponding photo number from photo 1 to 90.

A cross-listing table was drawn of the photos in the three wetlands and a non-parametric chi-square test was performed according to the respective scoring values of the professional group and the non-professional group. The results showed that the overall score of the non-professional group was higher, with the score fluctuating relatively little; the overall score of the professional group fluctuated relatively large, and most of the score values were lower than the score of the non-professional group. Among the 90 photos, the scores of the professional group and the non-professional group were approximately the same for 81 of the photos. Notably, there were significant differences in the scores of 9 photos, all of which pertained to the landscape photo evaluation of Tongjian Lake Wetland (Fig. 5-6). This may be related to the fact that Tongjian Lake Wetland, as a newly built urban wetland, does not fully reflect the expected design effect after completion, resulting in a low score value for the expert group.

Fig. 5-6 Comparison of professional and non-professional groups' SBE in three urban wetlands (the numbers 1-30, 31-60, 61-90 represent the landscape photos of Tongjian Lake Wetland, Qingshan Lake Wetland and Xixi Wetland, respectively)

（2）Evaluation of SD

The 10 landscape factors in the three urban wetlands were comprehensively scored and drew the box diagram (Fig. 5-7), In order to compare the differences of landscape factors that affect the beauty of different types of urban wetlands, we conducted an analysis of variance of 10 landscape factors (Table 5-3) and the further multiple comparison tests between groups to find the differences that affect the beauty of three different urban wetlands. The results showed that the scores for plant richness, appropriate spatial scale and coordination of landscape elements in Xixi Wetland were significantly higher than those in Qingshan Lake Wetland and Tongjian Lake Wetland. Meanwhile, the scores for plant community structure, ecological technology, and hard landscape proportion in Qingshan Lake Wetland were significantly lower than those in the other two wetlands. There were no significant differences among the three urban wetlands for the four landscape factors of habitat diversity, naturalness, harmony, and cultural expression.

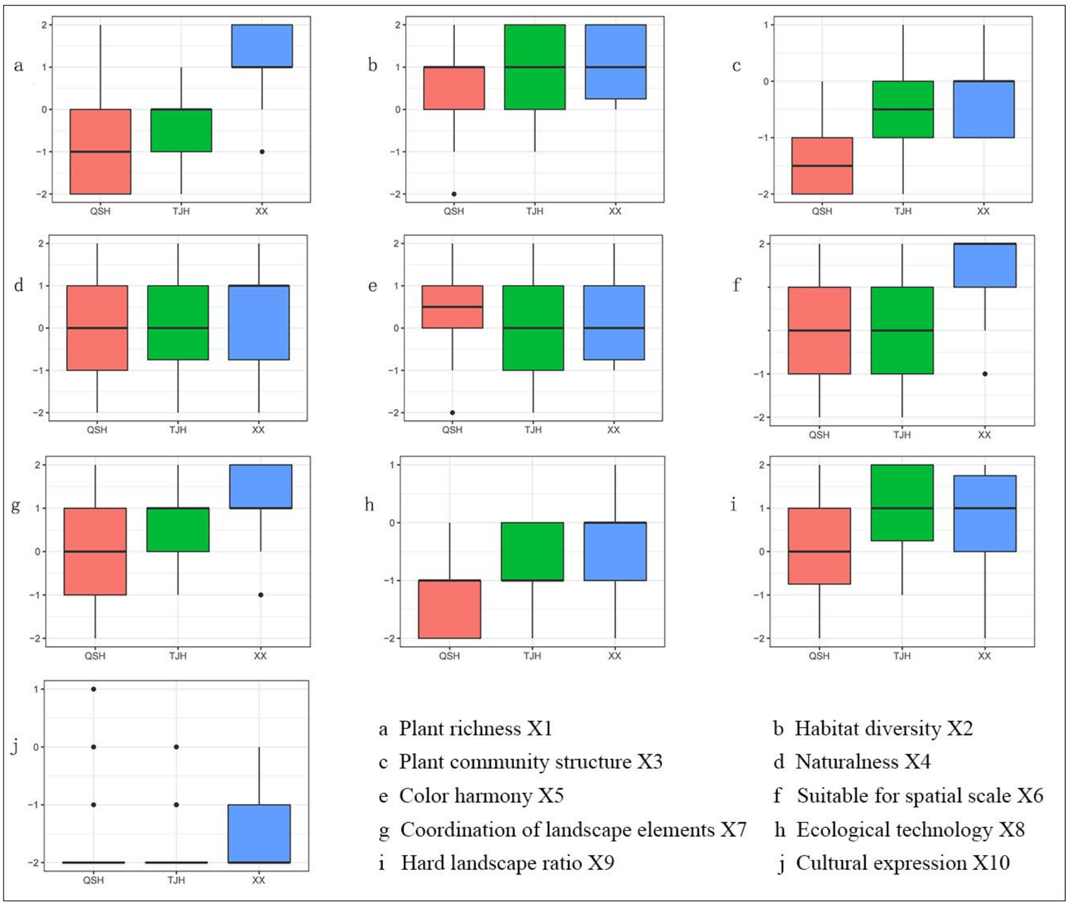

Fig. 5-7 The scoring box diagram of 10 landscape factors in the three urban wetlands: QSH：Qingshan Lake Wetland, TJH：Tongjian Lake Wetland, XX：Xixi Wetland

Table 5-3 Variance analysis of 10 landscape factors across the three selected urban wetlands

Landscape factor	P value	Landscape factor	P value
Plant richness X1	0.000 ***	Suitable for spatial scale X6	0.000***
Habitat diversity X2	0.265	Coordination of landscape elements X7	0.000 ***
Plant community structure X3	0.000***	Ecological technology X8	0.004 **
Naturalness X4	0.523	Hard landscape ratio X9	0.027 *
Color harmony X5	0.784	Cultural expression X10	0.256

*** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$

(3) Wetland landscape evaluation model

The evaluation model of wetland scenic beauty was constructed, taking the SBE evaluation standardized value of the scorers as the dependent variable and 10 evaluation factors as the independent variable. SPSS 26.0 was used to carry out backward stepwise regression and the relevant factors affecting the beauty of wetland landscape were determined. The regression coefficient of the wetland landscape evaluation model shows that (Table 5-4) only the "color harmony ” factor of Qingshan Lake Wetland had a significant impact on beauty evaluation. Meanwhile, the "plant richness" and "color harmony ” factors of Tongjian Lake Wetland significantly affected the aesthetic appreciation of the scorers. Further, the "new biodiversity", "habitat diversity", "color harmony", "harmony of landscape elements", "cultural expression" and "habitat diversity" factors had a significant impact on the perceived beauty of Xixi Wetland. The tolerance of the three models is less than 1 and the expansion factor (VIF) value is less than 3 (an expansion factor between 1-10 demonstrates there is no multicollinearity relationship between the independent variables), indicating that the dependent variables and independent variables in the evaluation model have a significant linear relationship and also that the three regression models are effective.

The evaluation model of Qingshan Lake Wetland landscape is $SBE = -0.086 + 0.204X5$.

The evaluation model of Xixi Wetland landscape is $SBE= 0.227 + 0.245X1 + 0.201X5 + 0.193X7 + 0.344X10 - 0.226X2$

The evaluation model of Tongjian Lake Wetland landscape is: $SBE = 0.94 + 0.244X1 + 0.154X5$

Table 5-4 Independent variable coefficients of the step-by-step regression model

Wetland	**Variable**	**Partial regression coefficient**	**Standard error**	**Standardized partial regression coefficient**	**t**	***p***	**Toler-ance**	**VIF**
Qingshan Lake Wetland	Constant	-0.086	0.072	-	-1.198	0.241	-	-
	Color harmony X5	0.204	0.060	0.540	3.392	0.002	0.973	1.000
Xixi Wetland	Constant	0.227	0.255	-	0.889	0.383	-	-
	Plant richness X1	0.245	0.085	0.457	2.888	0.008	0.445	2.249
	Color harmony X5	0.201	0.074	0.446	2.721	0.012	0.396	2.419
	Coordination of landscape elements X7	0.193	0.066	0.348	2.951	0.007	0.413	1.253
	Cultural expression X10	0.344	0.107	0.416	3.211	0.004	0.798	1.507
	Habitat diversity X2	-0.226	0.101	-0.376	-2.245	0.034	0.664	2.524
Tongjian Lake Wetland	Constant	0.94	0.87	-	1.086	0.287	-	-
	Plant richness X1	0.244	0.86	0.431	2.840	0.008	0.918	1.089
	Color harmony X5	0.154	0.60	0.387	2.549	0.017	0.918	1.089

（4）The relationship between ecological design, plant diversity, and landscape beauty

Using the data collected from the three cases, the model constructed in this study was tested for χ2 (P > 0.05) and the approximate root mean square error verification (RMSEA < 0.05). Additionally, the model was simplified by removing those variables that had no significant impact. The results show that the model is in good agreement with the experimental data. The structural equation model constructed from the data derived from the three urban wetlands shows (Fig.5-8 a) that ecological design practices have a direct positive impact on plant diversity and scenic beauty, although no significant relationship was observed between plant diversity and scenic beauty.

To further explore how ecological design, plant diversity, and scenic beauty mutually influence each other in urban wetlands across different regions, three separate urban wetland structure equation models were constructed, of which only the structure equation model of Xixi Wetland was constructed successfully. The model shows that in Xixi Wetland, ecological design practices indirectly affect the beauty of the wetland landscape through plant diversity (Fig. 5-8 b).

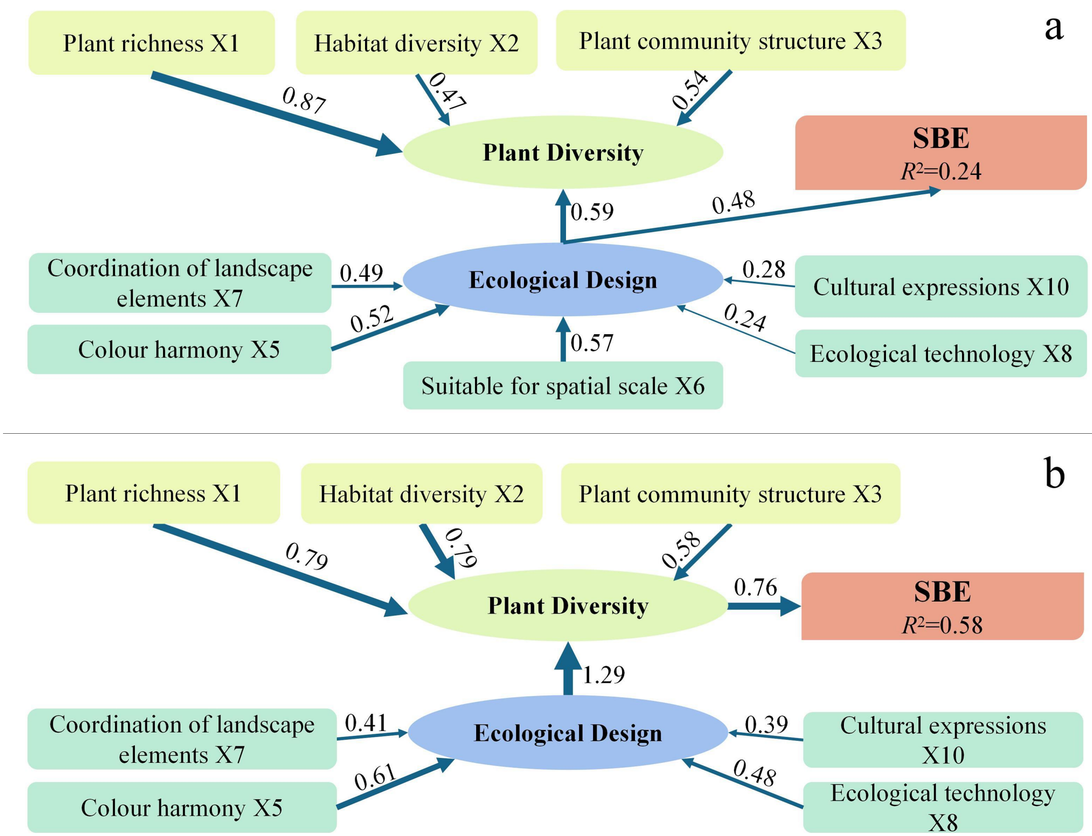

Fig. 5-8 The structure equation models of all the three urban wetlands (a) and Xixi Wetland (b) evaluate the influence of ecological design techniques on the beauty of the landscape. R2 represents the degree of interpretation of variables in the entire model. The number next to the

arrow represents the local effect of standardization and the degree of significance. The thickness of the arrow is used to indicate the degree of correlation between the two variables (the stronger the correlation, the thicker the arrow).

5.2.3 Discussion

（1）Landscape evaluation of urban wetlands in different regions

The average beauty of urban wetland landscapes across the three different regions is similar, and there is no significant difference among the wetlands (Table 5-2). The findings here are similar to the research results of Shen[60] and Liu[61], though the scores are lower than Zhang [22]. The results for Xiazhu Lake wetland park in Deqing may be related to the large fluctuation in the beauty value of the park.

Xixi Wetland has the most significant factors affecting the scenic beauty, while Qingshan Lake Wetland has the least. As an urban wetland in the core area, Xixi Wetland has been effectively managed and maintained for nearly 20 years. It is rich in plant species and its plant communities have largely stabilised[62]. Plant diversity has the most apparent impact on the scenic beauty of the wetland. The landscape design of the wetland retains the original fishing and farming style, whilst also incorporating elements such as patterns, symbols, and aspects of folk culture that reflect the broader regional culture. It should also be noted that the color changes and morphological expressions of artificial and natural landscape elements are highly coordinated, and there is an abundance of elements of cultural expression. These factors directly and significantly affect the scenic beauty of Xixi Wetland. Regarding the beauty rating of the Xixi Wetland landscape, it was also found that the beauty value of 17 samples was ≥ 0, and the overall public evaluation was positive.

The Tongjian Lake Wetland provides an open space for leisure and entertainment for residents in the marginal areas of the city and a large number of ornamental plants have been planted to form a colorful plant landscape effect. Therefore, the plant richness and color harmony of Tongjian Lake Wetland play a significant role in the beauty of the landscape. However, since Tongjian Lake Wetland is a newly built wetland, it features too many artificial hard landscapes, decreasing the degree of integration with the environment. Only 12 samples received a beauty value ≥ 0, and the public's positive evaluation was low.

Qingshan Lake Wetland is located in an urban countryside area. In an effort to achieve differentiated development, it has constructed a plant theme park mainly consisted by Taxodium distichum var.imbricatum and a greenway around the lake. The landscape type is relatively homogenous compared to the other two wetlands. Moreover, the water surface is open and the proportion of vegetation is not high in the wetland. Therefore, among the ten factors, only the rich colors formed by artificial greenways and the forestry of T. distichum var.imbricatum have a significant impact on the beauty of the landscape. However, as a result of the combination of natural mountains and lakes and artificial landscapes in Qingshan Lake Wetland, the public highly appraises its beauty. In the survey results, there are 17 samples of the wetland with beauty values ≥ 0, and the highest scoring samples are also in the Qingshan Lake Wetland. It can be seen that the public's overall evaluation of the wetland landscape that integrates man-made and natural elements is also positive.

By comparing three different types of wetlands in the city, the study respondents' preferences for the functional positioning of wetlands near natural ecosystems indicate that in addition to visual influence, landscape evaluation may also be affected by the interviewee’s expected psychological positioning of the subject of evaluation.

(2) The main factors affecting urban wetland landscapes

Color harmony is the landscape factor that has a significant influence on the beauty of the landscape in the three wetlands. In the landscape with the highest score in Xixi Wetland, spring plants form a unified green color, accompanied by dark gray buildings and light gray wooden plank roads to form a harmonious landscape color palette. Its color harmony is reflected in the preeminence of green plant tones and supplemented by structures (Fig. 5-5 e), which is consistent with Zhou's[63] research suggesting that “the larger the proportion of main colors, the higher the beauty value”. In the landscape with the highest score, Tongjian Lake Wetland, the color harmony largely manifests in how the color of the sky is reflected by the large surface area of the water, which contrasts with the warm colors of autumnal plants (Fig. 5-5 c, d) .Research from Arriaza et al.[64] has also shown that a strong color contrast can significantly improve the quality of the visual environment of the landscape. In the landscape with a high score in Qingshan Lake Wetlands, the color harmony is reflected in the richness of colors of the autumn scenery of forestry from T. distichum var.imbricatum have a significant impact on the beauty of the landscape. However, as a result of the combina, whilst the artificial colors on the overhead path act as embellishment (Fig. 5-5 b). Plant landscape design posits that color richness is related to the seasonal phases of plants: in specific seasons, people will be more inclined to spaces with a sense of color[45]. For plant configuration, greater consideration can be given to the use of plants with seasonal performance, paying particular attention to their texture and color matching[61].

In the construction of wetland plant communities, plant richness plays an important significance and role. A community landscape that lacks species diversity is not in line with the point of view of ecology and its aesthetic value must be lacking[65]. Diverse vegetation types exert an important and positive effect on improving the quality of the visual environment of the landscape [66]-[68]. In the landscape photos of Xixi Wetland with relatively high beauty values, it is usually a wetland landscape with high plant richness and a larger area of wetland plants that score highly (Fig. 5-5 e, f). In the photos of Tongjian Lake Wetland, the wetland landscape that combines natural native plants with artificially planted ornamental plants achieved the highest score and was more popular with the public (Figure 5-5 c, d). Meanwhile, there is less artificial interference in Qingshan Lake Wetlands, it is easy to form single-optimal communities, and the vegetation type is relatively singular. At the same time, there are relatively few artificially planted plants, such that the plant richness factor has little effect (Fig. 5-5 a, b).

The three landscape factors of cultural expression, coordination of landscape elements, and habitat diversity only play a significant role in the beauty of the landscape in Xixi Wetland. By drawing on traditional fishing and farming culture and folklore, Xixi Wetland has designed various cultural pavilions and landscape facilities. In the landscape photos of the wetland, patterns, symbols and structures that reflect cultural characteristics can be seen. Additionally, the beauty rating is also higher, which implies that the public may prefer designs that embody cultural expressions. Tongjian Lake Wetland and Qingshan Lake Wetland feature very few design aspects that reflect regional culture, such that cultural expression factors do not play a significant role in the beauty of the landscape of the two wetlands.

There are many decisive factors determining the coordination of landscape elements, such as the material, color, form, and style of artificial elements, such as roads, structures, and landscape sketches. Landscapes featuring natural materials, colors, and styles that are in harmony with the environment tend to have higher scenic beauty values[69],[70], which is similar to our evaluation of the scenic beauty of Xixi Wetland and finding that those landscapes with higher scores tended to have a greater use of natural materials (Fig. 5-5 e, f). The materials of the artificial landscape elements in the Tongjian Lake Wetland are relatively new and the proportion of concrete materials is too high. To meet the needs of navigation, the volume of the bridge body is generally too large, and there is minimal coordination with the surrounding environment. Although the number of artificial landscape elements in Qingshan Lake Wetland is small and they are relatively homogenous in type, this factor has not significantly affected the scenic beauty of Qingshan Lake Wetland.

In the case of Xixi Wetland, it was found that habitat diversity negatively influenced the perceived beauty of the landscape: the higher the habitat diversity, the more negatively the respondents viewed the landscape. Although habitat diversity is conducive to improving biodiversity, for the beauty of the landscape, too many habitats may produce messy visual perception, thus affecting the perceived beauty of the landscape. Therefore, in the design of urban wetlands, it is necessary to find a balance between the beauty of the landscape and the protection of habitat diversity.

（3）The relationship between ecological design, plant diversity, and landscape beauty

Previous studies have shown that the plant diversity and landscape beauty of urban wetlands can simultaneously be improved through appropriate ecological design[20]. This study also found that, in general, ecological design practices have a positive and significant impact on plant diversity and scenic beauty. Through ecological design, it can not only promote wetland plant diversity, but also enhance wetland scenic beauty (Figure 8 a). However, in different case wetlands, the impact path of ecological design on scenic beauty is not consistent. For example, in Xixi Wetland, the application of its ecological design method significantly affects plant diversity, thus improving the scenic beauty of wetland (Figure 8 b), while in the study of Tongjian Lake Wetland and Qingshan Lake Wetland, this relationship is not significant. The reason for this result may be related to the time-delay effect of the impact of ecological design techniques on plant diversity. The structure of the artificially modified or reconstructed wetland ecosystem often takes time to succeed to the desired state of design. Xixi Wetland, as a wetland with a long construction time, plant diversity has been able to reflect the contribution of ecological design; However, Tongjian Lake Wetland and Qingshan Lake Wetland have relatively short construction time and can not directly reflect the relationship between plant diversity and scenic beauty. In Figure 8 a, SBE depends on the subjective attitude of the interviewees, which leads to a relative high random error. Therefore, the relationship between ecological design and plant diversity construction model analysis may cause the R2 of the model low.

Xixi Wetland is an urban wetland built on the basis of primitive fishing and farming and natural wetland resources. Accordingly, wetland ecological protection and display and wetland viewing are its main functions. The planning and design apply more ecological design practices, retain the natural style of the wetland, and incorporate a wide range of local plants[71]-[73]. The plant community structure in the wetland is relatively stable. At the same time, Xixi Wetland is very tolerant of autogenous plants in conservation and management and will not clean up these plants [74]. This has promoted the improvement of wetland plant diversity and created an urban wetland landscape that is satisfactory and pleasing to the public. Similarly, in her research on rain gardens, Yang[75] proposed that landscape ecological design can improve plant diversity and significantly affect the visual quality of the landscape. Therefore, scientific and well-considered ecological planning and design can provide urban wetlands with a stable and rich plant landscape, thereby enhancing the beauty of the wetland landscape.

The improvement of plant diversity in urban wetlands is conducive to the restoration of wetland functions and enhances the stability of the ecosystem, whilst also providing living conditions for more wild animals in urban wetlands[76]. In addition, urban wetland plants shape the broader wetland landscape. Through the application of reasonable ecological design practices in the planning and design of new urban wetlands, creating a beautiful wetland plant landscape featuring a diversity of plants can enhance the public's love and preference for urban wetlands, so as to better cater to the ecological service function of urban wetlands. For existing urban wetlands, an appropriate design can be used for allowing plants to move in naturally or artificially, thus increasing the diversity of wetland plants and further enhancing the beauty of the wetland landscape.

(4) Suggestions to enhance the beauty of urban wetland landscapes

Xixi Wetland is an urban wetland that has adopted ecological protection as its main function in the urban core area. Its plant richness, color harmony, cultural expression, and coordination of landscape elements can all positively and significantly affect the beauty of the landscape, while habitat diversity plays a reverse role. Therefore, in the planning and design of ecologically protected wetlands based on natural landscapes, ecological design practices should be used to create diversified plant landscapes, all the while paying close attention to the harmonious collocation of colors. At the same time, the proportions, materials, and forms of landscape element design should be coordinated and integrated into certain cultural design elements. Nevertheless, the types of habitats should be controlled so as not to create a cluttered image. As a newly built wetland on the edge of the city, the plant richness and color harmony of Tongjian Lake Wetland can positively and significantly affect the beauty of the landscape. However, because it is a newly built park with more artificial landscapes, the degree of integration with the environment is not high and its overall beauty was the lowest. Therefore, in a newly built wetland park, a variety of plants can be increased artificially, and attention should be paid to the color matching of the four seasons of the plants. At the same time, the planning and design should retain the original vegetation of the site as much as possible, reduce the excessive construction of the artificial landscape, and also pay attention to the coordination and integration design of the artificial landscape elements and the overall environment. Qingshan Lake Wetland, an urban and rural wetland, utilizes artificial landscape design to increase the beauty of landscape colors, although the wetland landscape type is relatively homogenous. It is recommended to increase the diversity of plants, especially aquatic plants, in future landscape plant design, and strengthen the artificial management and conservation of wetlands.

5.3 Comprehensive evaluation of urban wetland

Comprehensive evaluation can synthesize a large number of complex factors for analysis and use multiple indicators of different scales for evaluation, which better reflect the comprehensive function of the evaluated object[77]. Zhang et al.[78] proposed three indicators of evaluation, which are ecological function, water purification function and economic and social function, and established an index system suitable for evaluating the sustainable operation of constructed wetlands by using comprehensive index evaluation and analytic hierarchy process; Zhang et al.[79]

built the efficiency index system to evaluate the development of coastal wetland protection, utilization and management from the economic, social and ecological aspects. However, these studies are still limited to the study of a single wetland. Rapid urbanization has led to the transformation of a large number of natural wetlands into urban wetlands, the number and functions of urban wetlands have changed significantly, and the development of their ecological, economic and social functions is also different. However, comprehensive evaluations of urban wetlands with various functions in different regions is rare. Understanding the diversity of these urban wetlands and establishing a comprehensive evaluation system will contribute to alleviate the contradiction between urban wetland conservation and utilization.

In this paper, three different types of wetlands with diverse functions in the core area, fringe area and suburb area of Hangzhou City were taken as study cases, through investigation and comprehensive evaluation of the wetland parks, the specific objectives are: (1) to build an index system for comprehensive evaluation of urban wetland parks, and to explore the impact of different evaluation indicators on the comprehensive functions of urban wetland parks; (2) investigate whether there are differences in the comprehensive evaluation of urban wetland parks with various functions in different regions, and analyze the main factors leading to these differences.

5.3.1 Methodology

1) Establishment of Index System

Based on field investigation on three urban wetland parks and referring to relevant literatures[80]-[86], 9 factors and 41 indicators were selected from three aspects of ecology, economy and social functions, which were used to establish a stepped urban wetland comprehensive evaluation index system at the target level, criterion level, factor level and indicator level(Table 5-5).

Table 5-5 Weights and scores of comprehensive evaluation index system of three urban wetland parks

Target level	Criterion level	Weight of A to B	Factor level	Weight of B to C	Indicator level	Weight of A to D	Xixi Wetland score	Tongjian Lake Wetland	Qingshan Lake Wetland
Comprehensive evaluation of Wetland A	Ecological function B1	0.72	Biodiversity C1	0.52	High plant diversity D1	0.105	4.98	2.52	3.01
					High animal diversity D2	0.068	4.14	3.66	3.65
					Large number of native plants D3	0.096	4.94	2.49	3.96
					Less harmful invasive plants D4	0.108	3.25	2.94	2.97
			Habitat complexity C2	0.25	High complexity of community structure D5	0.066	4.92	3.81	3.14
					High diversity of community types D6	0.048	4.58	2.84	2.24
					High diversity of natural habitats D7	0.046	4.59	2.66	3.01
					High diversity of artificial habitats D8	0.012	3.54	4.04	2.57
			Water ecological environmentC3	0.15	High water transparency D9	0.022	3.14	4.24	3.12
					Perfect rainwater collection system D10	0.016	4.07	4.28	2.81
					Perfect sewage purification system D11	0.049	1.94	2.55	1.68
					Good water purification effect D12	0.023	3.27	3.33	1.71
			Ecological	0.08	Many ecological Revetments D13	0.028	4.76	2.76	3.07

					Many ecological buildings D14	0.010	2.73	1.49	0.86
					Many ecological pavements D15	0.012	3.57	2.66	2.90
					Many energy-saving and water-saving facilities D16	0.007	1.80	3.01	2.42
	Economic function B2	0.16	Tourism economy C5	0.49	High popularity D17	0.030	4.71	3.61	3.00
					High ornamental value D18	0.022	4.52	4.05	3.24
					Good traffic accessibility D19	0.012	4.97	3.06	3.62
					Good linkage of surrounding scenic spots D20	0.008	4.30	3.30	1.98
					High environmental capacity D21	0.006	4.21	3.07	4.36
			Regional development C6	0.51	Increase of residents' income D22	0.043	4.49	3.03	2.19
					Infrastructure improvement D23	0.018	3.33	4.29	2.42
					Increment of surrounding land value D24	0.012	4.95	3.07	2.72
					Promotion of regional image D25	0.008	4.88	3.06	3.41
	Social function B3	0.12	The function of Educational Science C7	0.50	Many popular science publicity signs D26	0.009	4.06	1.26	2.86
					Many popular science venues and facilities D27	0.008	3.17	0.90	0.66
					Strong awareness of ecological protection D28	0.018	3.82	2.26	2.95

					More scientific monitoring and research D29	0.007	4.29	1.71	1.60
					Many natural education institutions D30	0.008	3.80	1.02	0.65
					Regional culture display D31	0.005	4.45	1.51	1.41
					Inheritance of traditional folk customs D32	0.004	4.81	1.05	0.70
			Leisure and entertainment functionsC8	0.20	Many leisure and entertainment venues D33	0.006	3.72	3.11	2.49
					Many equipment for fitness activities D34	0.003	2.85	2.45	2.43
					Complete supporting service facilities D35	0.005	4.37	3.42	2.92
					Rich natural experience D36	0.010	4.23	1.56	2.13
			Aesthetic function C9	0.30	Plants are rich in color D37	0.009	3.83	4.10	3.32
					Seasonal changes are abundant D38	0.008	3.82	3.92	3.29
					High diversity of landscape space D39	0.009	4.21	3.28	2.36
					Good hydrophilicity D40	0.007	4.53	4.32	2.27
					Prominent theme plants and characteristic plants D41	0.004	2.65	2.75	4.38

2) Comprehensive Evaluation System

Analytic hierarchy process (AHP) is a systematic analysis method based on human decision-making thinking, combining qualitative and quantitative analysis. It can decompose complex problems into several levels and several factors from different angles, simple comparison and calculation among various factors are conducted, and the weights of different scheme importance levels are obtained, which providing basis for the selection of decision-making schemes[87],[88]. Considering that the contribution of each evaluation index in the evaluation system is different, and the impact on the wetland is also different, this study uses AHP to determine the weight of urban wetland comprehensive evaluation index.

According to the hierarchical structure of the criteria layer, the element layer and the indicator layer determined by the comprehensive evaluation system, questionnaires were distributed to 20 experts and scholars to compare the importance of the index factors participating in the evaluation in pairs and score them by 1-9 according to the degree of importance. Constructing 13 judgment matrices, and 1, 3, 5, 7 and 9 were used as the scales, the meanings of the scales are as follows: two elements are equally important, one element is slightly more important than the other, much more important, absolutely more important; 2. 4, 6 and 8 indicate that the importance is between 1, 3, 5, 7 and 9, while the reciprocal of the above numbers has the opposite meaning (Table 5-6).

Table 5-6 Scale of AHP

Scale	Meaning
1	The two factors are of equal importance compared to each other
3	One factor is slightly more important than the other
5	One factor is more important than the other
7	One factor is much more important than the other
9	One factor is absolutely more important than the other
2，4，6，8	The intermediate state of the above two judgments
Reciprocal	If the importance ratio of factor i to factor j is a_{ij}, then the importance ratio of factors j to factor i is a_{ji}=1/a_{ij}

Note: The pairwise comparison judgment matrix R has the following properties: (1.aij>0; 2.aij=1/aij; 3.aij=1(ij=1，2，…，n)

Using expert scoring to calculate the average score of experts, and establish the judgment matrix of comprehensive evaluation layer and index layer $A = (a_{ij})_{n\times n}$, where a_{ij} indicates the judgment value of the i evaluation index a_i relative to the j evaluation index a_j for the comprehensive evaluation importance to Wetland Park, and n is the number of evaluation indexes of the judgment matrix. The weight value of each index is obtained by mathematical calculation with AHP method.

The consistency index CI is used to test whether the relative priority in the evaluation of weight index is logically confused.

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{1}$$

Here, λ_{max} is the maximum characteristic root of the judgment matrix, and n represents the number of corresponding indicators, i.e. the order of the matrix. Generally speaking, when $CI < 0.10$, it can be regarded as no logical confusion, in other words, the calculated weights are acceptable.

3) Index Scoring and Comprehensive Evaluation

The scoring standard of each indicator is divided into five grades: 5-very good, 4-good, 3-average, 2-poor, and 1-very poor[89]. According to the specific conditions of the three wetland parks, each index is scored and evaluated, and the comprehensive evaluation index of the three wetland parks is calculated. Through the establishment of the comprehensive evaluation index system of Urban Wetland Parks and the statistical analysis of the weight value of each index factor, the comprehensive evaluation model of Urban Wetland Parks is constructed:

$$CEI = \sum_{i=1}^{41} W_i F_i \tag{2}$$

Here, the results of comprehensive evaluation index (CEI) are reflected by the index CEI in the formula; F_i is evaluation score of single index; W_i is weight of each index to the total target level; Finally, the comprehensive evaluation results of three wetland parks are obtained.

4) Comprehensive Evaluation Criteria

The grading standard of Urban Wetland Parks is determined by the five-level scale evaluation method[90](Table 5-7).

Table 5-7 Evaluation criteria of Wetland Park

CEI level	Comment
CEI< 0.4	Pretty bad
0.4≤ CEI< 0.55	Poor
0.55≤ CEI< 0.7	Average
0.7≤ CEI< 0.85	Good
CEI≧0.85	Excellent

5.3.2 Results

1) Weight Analysis of Influencing Factors of Comprehensive Evaluation of Hangzhou Urban Wetland Parks

The matrices at all levels of the comprehensive evaluation of Hangzhou Urban Wetland Parks passed the consistency test, and the weights of the factors at each level were obtained in turn (Table 1). The results showed that the ecological function accounted for the highest weight and the social function accounted for the lowest weight, indicating that the public focus more on the ecological function in the use of urban wetland parks.

Among the four factors in the ecological function, the biodiversity weight is the highest, followed by the habitat complexity weight, and the ecological facilities weight is the lowest. Which suggested that the biodiversity protection values more in public understanding of ecological functions.

The weight values of the two factors included in the economic function are basically similar, suggesting that regional development and tourism economy are equally important to the economic function of Urban Wetland Parks, and both contribute to the economic function of Urban Wetland Parks.

Among the three element level factors included in the social function, the educational and scientific function has the highest weight value, followed by the aesthetic function, and the leisure and entertainment function has the lowest weight value, indicating that the public focus more on the educational and scientific functions of the Urban Wetland Parks, and pays less attention to the leisure and entertainment functions.

2) Comprehensive Evaluation of Hangzhou Urban Wetland Parks

The comprehensive evaluation results of the three wetland parks show (Table 5-8) that the comprehensive score of Xixi Wetland Park is the highest, and the evaluation level is good. The comprehensive score of Tongjian lake and Qingshan Lake Wetland Park is lower, and the evaluation level is general. Xixi Wetland Park has the highest economic function score, which may be due to the fact that Xixi Wetland is a 5A scenic spot with strong tourism function and regional development function, which contributes to the development of surrounding economy; the scores of ecological function and social function are close. Similarly, Tongjian Lake Wetland Park has the highest score of economic function, followed by ecological function score, and the lowest evaluation of social function. This may be because Tongjian Lake Wetland Park is a new park located in the urban fringe, the ecological function and social function remains to be improved, but it has good linkage with surrounding scenic spots, which promotes the development of surrounding economic functions. However, the ecological function and economic function score of Qingshan Lake Wetland Park are relatively low, and the social function score index is the lowest. This may be related to the geographical location of Qingshan Lake is far from the city center, the number of tourists is insufficient, and the wetland landscape is not prominent.

Table 5-8 Comprehensive evaluation index and grade of three Wetland Parks

Target level	Overall	Evaluation	Criterion level	Score
Comprehensive evaluation of Xixi Wetland	0.82	Good	Ecological function	0.793
			Economic function	0.897
			Social function	0.789
Comprehensive evaluation of Tongjian Lake Wetland	0.59	Average	Ecological function	0.592
			Economic function	0.70
			Social function	0.478
Comprehensive evaluation of Qingshan Lake Wetland	0.57	Average	Ecological function	0.594
			Economic function	0.591
			Social function	0.458

5.3.3 Discussion

1) Weight Analysis of Influencing Factors for Comprehensive Evaluation of Urban Wetlands

Among the three elements of the criteria layer, the wetland ecological function has the highest weight, which is significantly higher than the weight of economic function and social function. It is consistent with the results of Guo et al.[91] in the evaluation of the plant landscape quality of Longyan Urban Wetland Park, which found that the ecological function weight was much higher than the other two factors. It suggests that the design concept of giving priority to ecological function is of prime importance to the construction of Urban Wetland Park. The economic function weight is close to the social function weight, and the economic function weight is slightly higher, which is similar to the comprehensive evaluation result of the urban wetland park by Luo[84], indicating that the urban wetland park has a higher impact on driving economic development for the local residents, while the social functions such as education, science, leisure and entertainment need to be improved.

Among the ecological functions, biodiversity has the highest weight, indicating that biodiversity protection is significant for providing ecological service function[92]. Similar result was also found in the study of the evaluation system of Guanyintang Urban Wetland Park in Bishan County that the weight value of "species richness" is the largest7. The public concern level on the three indicators of wetland social function in order from high to low is educational and scientific function, aesthetic function and leisure and entertainment function, which is consistent with the findings of song Shuang et al.[16]. The reason might be that the public hopes to obtain educational and scientific experience in the use of wetland parks; Comparing with the aesthetic function, the leisure and entertainment function is also important, but the similar function is also provided in other types of urban parks, therefore, the characteristic wetland landscape viewing experience is more valued for public.

2) Grade of Urban Wetland Parks According to Comprehensive Scoring Index

The comprehensive score index of Xixi Wetland Park is the highest, and the evaluation level is good. The comprehensive scores of Tongjian lake and Qingshan Lake Wetland Park are relatively low, and the evaluation level is general. This may be related to the geographical location, functional localization, design concept and other factors of the urban wetland park.

Xixi Wetland Park is a national 5A level Wetland Park. With scientific and reasonable planning and design, there are natural reserves in the wetland, which are not affected by human activities, therefore, the wetland ecosystem conservation is relatively complete; The park has recreational area and natural viewing area open to the public, providing social functions such as education, science, leisure and entertainment, and aesthetic viewing; In addition, as a 5A level scenic spot, it has a high reputation and is located in the core area of the city, which has good traffic accessibility, complete infrastructure and rapid value-added of surrounding land, which is beneficial to the development of economy. Therefore, Xixi Wetland Park has gained a good evaluation grade due to its favorable geographical location, scientific planning and design, and sound ecological, economic and social functions.

Tongjian lake is a new-built urban wetland park with unstable community structure, resulting in low biodiversity and habitat complexity, and low ecological function score; Through scientific and reasonable planning, the leisure and entertainment functions are relatively perfect, but the educational and scientific functions are insufficient, leading to low social function scores; However, as the Wetland Park is surrounded by many scenic spots, the linkage between the park and scenic spots is good, the traffic accessibility is convenient and the surrounding infrastructure is improved rapidly, resulting in a high score in economic function.

Qingshan Lake Wetland Park has a large area water fields, but the habitat complexity and biodiversity are relatively low, and most of the surrounding areas are under construction and the infrastructure is not perfect, so the ecological function and economic function scores are not high; The landscape design of the wetland park mainly includes artificial greenways and landscape belts on both sides. The landscape is relatively single and the vegetation area accounts for a low proportion, which also leads to a low social function score.

3) Decision-making Suggestions for Improvement of Landscape Based on Comprehensive index

In terms of evaluation indexes, Xixi Wetland Park has a low score in two indicators: sewage purification system and energy-saving and water-saving facilities. This may be caused by the traditional fishing and tourism in the wetland, the relatively large sewage discharge, the age-old construction of the park and the aging of energy-saving and water-saving facilities. For the protection and utilization of the wetland in future, the comprehensive quality of the wetland park can be improved by building a sewage purification system, improving the water ecological environment, transforming energy-saving and water-saving facilities, and improving the functions of ecological facilities.

The low scores of Tongjian Lake Wetland Park are mainly concentrated in the educational and scientific function indicators, while the scores of ecological buildings and natural experience are also relatively low. Therefore, the educational and scientific functions of the wetland park can be improved as a whole by appropriately increasing science popularization signs, adding science museum and introducing natural education in the park; Secondly, the comprehensive quality of the wetland park will be improved by creating highly diversified natural habitats and building ecological transformation of buildings to enhance the natural experience of the park.

Qingshan Lake Wetland Park obtained low scores in many indicators, which are mainly concentrated in the functional indicators of education and science, but also include the indicators of sewage purification system, water purification effect, ecological buildings, energy-saving and water-saving facilities, linkage of surrounding scenic spots, improvement of residents' income, and diversity of landscape space. Aiming at different function demands, scientific and reasonable overall planning needs to be carried out with the wetland park to achieve comprehensive improvement in ecological, economic and social functions.

5.4 Summery

The SBE method was used to evaluate the beauty of 90 landscape samples taken from three urban wetlands. The results showed that although the respondents' overall evaluation of the landscape environmental quality of Qingshan Lake Wetland and Xixi Wetland was positive, and the evaluation of Tongjian Lake Wetland was negative, there was no significant difference between the perceived beauty of the three wetland landscapes. Among the three urban wetlands, the factors affecting the beauty of the landscape were the highest in Xixi Wetland and the lowest in Qingshan Lake Wetland; the SBE model of the three wetlands found that the presence of high plant richness, harmonious colors, adequate cultural expression, and coordinated landscape elements helps to improve the beauty of the wetland, whilst too many habitat types may negatively impact the beauty of the wetland landscape. Through scientific and reasonable ecological design, while enhancing the plant diversity of urban wetlands, it can also enhance the beauty of the wetland landscape, thus proving a reference for the protection and planning and design of urban wetland landscapes.

The scenic beauty of urban wetland is affected by many factors. This study proved that a reasonable ecological design can improve the plant diversity of urban wetland, thus affecting the landscape of urban wetland. It provides an idea for urban wetland planning and designers. During the development and utilization of urban wetlands, ecological design techniques should apply to design practice widely, which is conducive to the integration of ecological protection, landscape aesthetics and sustainable utilization of urban wetlands in the process of rapid urbanization.

In this section, the analytic hierarchy process (AHP) was used in the comprehensive evaluation of Hangzhou urban wetlands, the comprehensive evaluation system of Urban Wetland Parks was established with 9 criteria layers and 41 index layers of ecological, economic and social functions of Urban Wetland Parks. Using the weight calculation of the evaluation factors at all levels, the weights and ranking of the factors at all levels were obtained. The order of the weights of the three factors at the criterion level from large to small is: ecological function > economic function > social function. The comprehensive evaluation indexes of the three urban wetland parks were obtained through further scoring calculation, the order of evaluation grade from high to low is:

Xixi Wetland Park > Tongjian Lake Wetland Park > Qingshan Lake Wetland Park. Our main conclusions are as follows: The ecological function of urban wetland park landscape is the most significant factor in the comprehensive evaluation system. Due to the different geographical location, functional positioning and planning design of wetland parks, their comprehensive evaluation levels show differences. The Wetland Park in the core area of the city has superior geographical location, good traffic accessibility and complete supporting facilities, the protection and utilization of the wetland should fully exert its comprehensive value of ecological, economic and social functions. The Wetland Park in the urban fringe has good traffic accessibility, which is favorable for developing its economic function, improve its social function, provide more abundant leisure space for urban residents, to finally enhance the overall value of the wetland park. For the Wetland Park in the urban rural areas has poor traffic accessibility, it can give priority to its ecological function and drive the development of economic and social functions with ecological characteristics.

Using AHP method in the comprehensive evaluation of Urban Wetland Parks enables the quantifiable research of non-quantitative factors. However, the evaluation model is also limited by the variance of subjective factors of experts, which will affect the objectivity of the evaluation indicators to a certain extent. In further studies, combination of AHP and other analysis methods can be explored to make the evaluation system more scientific and accurate. In addition, for wetland parks with different geographical locations and different functions, different comprehensive evaluation weights can be considered to maximize their advantageous functions for protecting biodiversity, providing good living environment and leisure space for urban residents and driving regional economic development.

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Chapter 6

A FRAMEWORK STUDY ON THE ECOLOGICAL PLANNING AND DESIGN OF URBAN WETLAND LANDSCAPES BASED ON BIODIVERSITY

CHAPTER SIX: A FRAMEWORK STUDY ON THE ECOLOGICAL PLANNING AND DESIGN OF URBAN WETLAND LANDSCAPES BASED ON BIODIVERSITY

6.1 Theoretical foundations

Urban wetland landscapes provide a good living environment and open space close to nature for urban residents, promoting a harmonious relationship between people and nature, and their special environmental conditions also determine the important biodiversity conservation function of urban wetlands, which is also considered to be the core function of wetland ecosystems. Urban wetlands not only provide habitat for flora and fauna, but also provide a beautiful habitat for humans. Urban wetland landscapes have both ecological and aesthetic properties, and the landscape planning and design must satisfy both human needs in creating an aesthetic environment and biological survival needs, and have a more prominent natural and ecological value than other types of urban green space. When rapid urban development leads to rapid loss of biodiversity, scientifically rational urban wetland landscape design strategies and methods need to be established to conserve wetland biodiversity and provide good wetland landscapes.

Although more attention is currently being paid to biodiversity conservation in urban wetland landscape planning and design, however, there are sometimes contradictions between biodiversity conservation and human landscape needs and aesthetic experience. Some ecologically valuable wetland landscapes have not been protected due to their visual unattractiveness[1], and many native species and ecologically valuable landscapes may be poorly protected because they are not aesthetically pleasing to people[2], and artificial landscapes that fit the traditional aesthetic evaluation criteria for landscapes may also be planned and managed to the detriment of biodiversity and ecosystem conservation[3]. In design practice, landscape designers also tend to consider more from the perspective of aesthetics and landscape art, while the concept of biodiversity conservation is still inadequate; the use of ecological technology is not appropriate; the design approach takes more into account the current landscape factors and lacks long-term biodiversity conservation sustainability ideas; the subsequent biodiversity conservation effect management is insufficient, etc., resulting in the actual wetland landscape planning and design is not ideal for local biodiversity conservation. Conflicts between 'design-ecology-aesthetics' in the planning and design of urban wetlands still occur from time to time, resulting in planning principles and implementation strategies that are not always fully aligned with the ecological and aesthetic orientation of the objectives.

Landscape ecological planning is the application of the principles of landscape ecology and the knowledge of other related subjects, through the study of landscape patterns and ecological processes, as well as the interaction between human activities and the landscape, on the basis of landscape ecological analysis, synthesis and evaluation, to propose the optimal use of the landscape and countermeasures and recommendations, so that the landscape not only conforms to the principles of ecology, but also to the combination of art and science. It focuses on the resource and environmental characteristics of the landscape, emphasizing people as part of the landscape and the effect of human disturbance on the landscape[4]. Landscape ecological design is based on landscape ecological planning, through the development of visual imagination and the application of innovative techniques to present the most appropriate materials, locations, ecological processes, localities and landscape ecological design forms. Landscape ecological planning focuses on the distillation and mastery of ecological laws, while landscape ecological design focuses on the innovation and creation of landscapes based on ecological laws[5].

Based on the theory of landscape ecological planning and design, urban wetland landscape ecological planning and design can be an important way to solve the "design-ecology-aesthetic" conflict in wetland design and to realize the combination of ecological value, aesthetic value and economic value, taking urban wetlands as the object (Figure 6-1). This study takes the relationship between biodiversity conservation and human needs in urban wetland landscape environments as the starting point, fully considers the relationship between wetland environment design, biodiversity conservation design and combines their design characteristics to propose a framework for urban wetland biodiversity landscape planning and design, with a view to achieving urban wetland biodiversity conservation and landscape quality improvement through rational planning and design, multidisciplinary division of labor and cooperation, scientific assessment and monitoring.

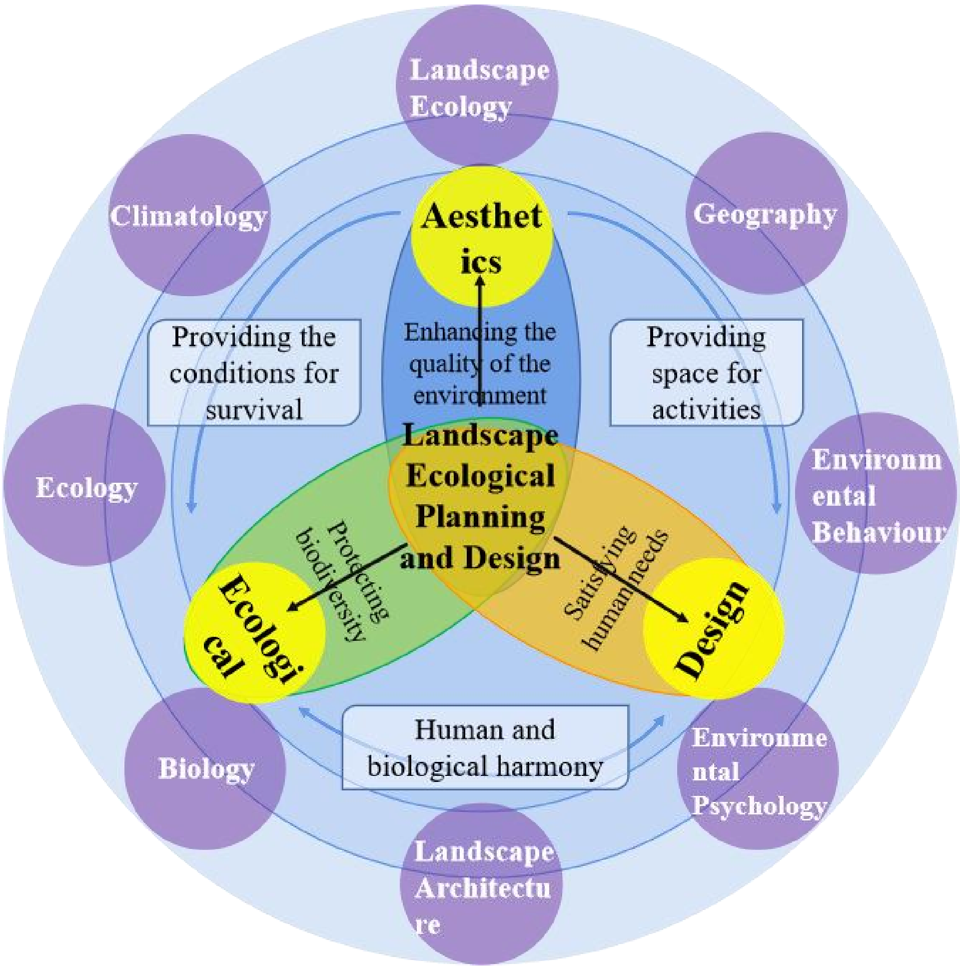

Fig. 6-1 Reconciling design, ecology and aesthetics through landscape ecological planning

6.2 Analysis of a landscape design framework for achieving biodiversity in urban wetlands

6.2.1 Biodiversity Sensitive Urban Design (BSUD)

Biodiversity Sensitive Urban Design (BSUD), which was constructed by Professor Georgia E. Garrard's team at RMIT University in Australia. Five principles of Biodiversity Sensitive Urban Design (BSUD) are proposed and a framework for incorporating BSUD into urban development decisions is described[6].

1) Documenting ecological values. An assessment of the ecological values on the site identifies what needs to be preserved and protected and sets biodiversity targets for its location, taking into account the site and landscape context.

2) Define biodiversity targets. Examples of biodiversity targets include increasing the likelihood that threatened species will persist on site, or reintroducing viable populations of locally extinct native species.

3) Define the development objectives of the site. This includes settlement objectives,

infrastructure requirements, and other environmental objectives (for example, energy consumption or water quality standards).

4) BSUD Action. Biodiversity sensitive design action plans are defined from the site development stage. The action plan is divided into 3 main parts: design, construction and management.

5) BSUD Assessment. An improved Delphi expert scoring method was used to assess its ability to meet all specific objectives, a process that encouraged creativity in identifying potential actions.

6) Decisions. Decisions on what action to take are informed by the costs of implementation and the benefits actually gained from biodiversity conservation and enhancement, advising on planning design and seeking to promote active management through thoughtful design to achieve biodiversity objectives.

6.2.2 The Landscape Biodiversity Planning & Design System (LBPDS)

The Landscape Biodiversity Planning and Design System, introduced by AECOM in 2013 to protect biodiversity, is a framework system that focuses on sustainable practices that guide landscape designers, planners, and other stakeholders to protect ecosystems and enhance our biomes, such as climate regulation, carbon storage, and flood control, as well as continuing to provide benefits to us. The AECOM Landscape Biodiversity Planning and Design System has developed the Landscape Biodiversity Index (LBI) as a more specific indicator to guide landscape practice as a means of enhancing biodiversity, ecosystem services and achieving area-specific conservation, to assess local biodiversity-related performance and to guide the application of landscape biodiversity planning and design systems, allowing designers to quantitatively assess urban landscapes in a detailed and comprehensive manner[7]. In terms of site design, LBI can help prioritize specific plant species, landscape patterns, or structural design features needed to achieve habitat and biodiversity goals in landscape design, considering all types of landscapes from natural to man-made to achieve habitat and biodiversity goals in landscape design[8]. The LBI primarily uses a combination of Excel and GIS-based calculations to develop measures of landscape structure and pattern characteristics to assess the LBI score. The indicators measured, the weights of the indicators, performance thresholds, and scoring criteria are defined by the planning team and calibrated for each project context and local ecology.

The LBPDS is applied in seven specific steps 1) site assessment; 2) LBI model calibration; 3) existing conditions LBI baseline measurement; 4) creation of alternatives based on planned LBI scores; 5) parcel/land use category LBI score targets and guidelines; 6) detailed measurement of landscape plan design options; and 7) implementation and validation.

The system and its LBI evaluation system are led by biodiversity conservation, using LBI assessments to guide landscape planning and design with an emphasis on native ecology and priority conservation matters; plant community design and landscape creation are key to conserving and enhancing biodiversity and habitat connectivity through different development strategies to achieve co-prosperity between people and nature.

6.2.3 Planning and Design Framework for Better Cities under the Concept of Ecological Civilization

Yu Kongjian uses the ecological design principles proposed by Simon van Di Rijn and Stuart Cowen (1996) as a framework, combines the principles of human ecosystem design and regenerative design proposed by John Lyle et al. and the principles of sustainable landscape and visual ecology and ecological cities proposed by Robert Thayer et al. and furthermore in the light of international developments in landscape and urban design[9], four approaches to the harmonious coexistence of cities and nature are proposed, guided by the concept of ecological civilization.

1) The "Inverse Planning" approach. Through a reverse planning approach, an ecological priority is given to the reconstruction of a spatial pattern that is in harmony with nature and guarantees the ecological security of the city[10]. "Inverse Planning" is an approach to landscape planning that emphasizes ecological priorities, and is essentially a methodology that emphasizes urban spatial planning by optimizing the control of unbuilt areas, with the preservation of ecological services as a prerequisite for the layout of urban space[11].

2) Designing ecological approaches. Through the Design Ecology Approach, nature-based ecosystem services are used to restore the continuity and integrity of the living community of landscape, forests, fields, lakes, and grasses, to improve ecological infrastructure, and to repair and rebuild damaged ecosystems so that nature in cities can produce clean air, water and food, regulate urban flooding and degrade pollution, mitigate heat islands and haze, and host a diversity of organisms while providing high-quality ecological rest and aesthetic opportunities for residents[10].

3) The Way of Nature. Improve the functional layout and form of the city through urban design and urban repair, build environmentally friendly municipal infrastructure, and reduce its damage to the natural ecosystem[10]. Nature in the city is presented as a vibrant and beautiful ecological landscape through continuous and complete ecological processes of urban ecological restoration and reconstruction.

4) Reduce disturbance to the environment and maintain a natural environment with blue water and fish by promoting a circular economy and practicing a green production and lifestyle[10].

Yu Kongjian has been committed to the organic integration of ecological theory and landscape planning and design, and has promoted the sustainable development of China's urban ecological landscape through many excellent design cases in practice. In terms of urban wetlands, its real-life application value has been proven in projects such as the Liupanshui Minghu Wetland Park and the Harbin Qunli National Urban Wetland Park.

6.2.4 Summary of three typical frameworks

The BSUD framework focuses on biodiversity and proposes specific actions in three areas: design, construction and management, and its approach is mostly focused on the needs of biodiversity conservation, without considering the needs of people in urban design.

All three classic design frameworks describe design processes based on biodiversity conservation, emphasizing the important role of interdisciplinary teams and scientific assessment (Figure 6-2).

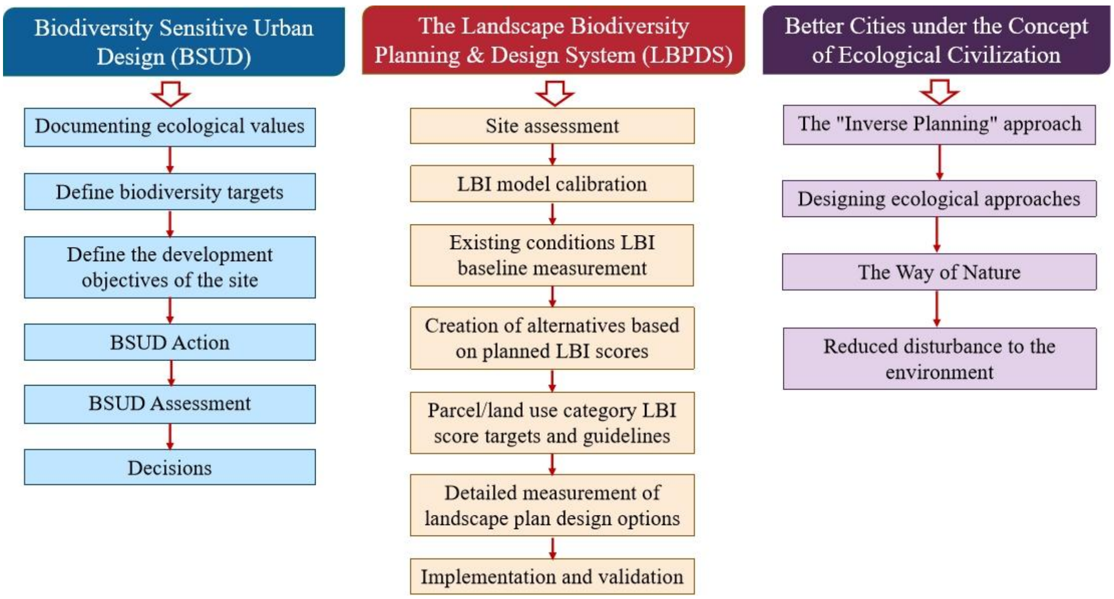

Fig. 6-2 Three classic design frameworks describe design processes

6.3 Framework for biodiversity-based urban wetland landscape planning and design

By analyzing and optimizing the above three classical landscape frameworks and establishing a multi-objective decision framework model between the complex relationship of "design-ecology-aesthetics", a framework for urban wetland biodiversity landscape design (UWBLD) has been developed (Figure 6-3). The landscape ecology of urban wetlands consists of landscape ecological assessment, landscape ecological planning, landscape ecological design, and landscape ecological management, which is an applied study of landscape ecology combined with practice and an effective way to achieve sustainable development of urban wetlands[4]. The UWBLD framework implementation path consists of the following seven steps.

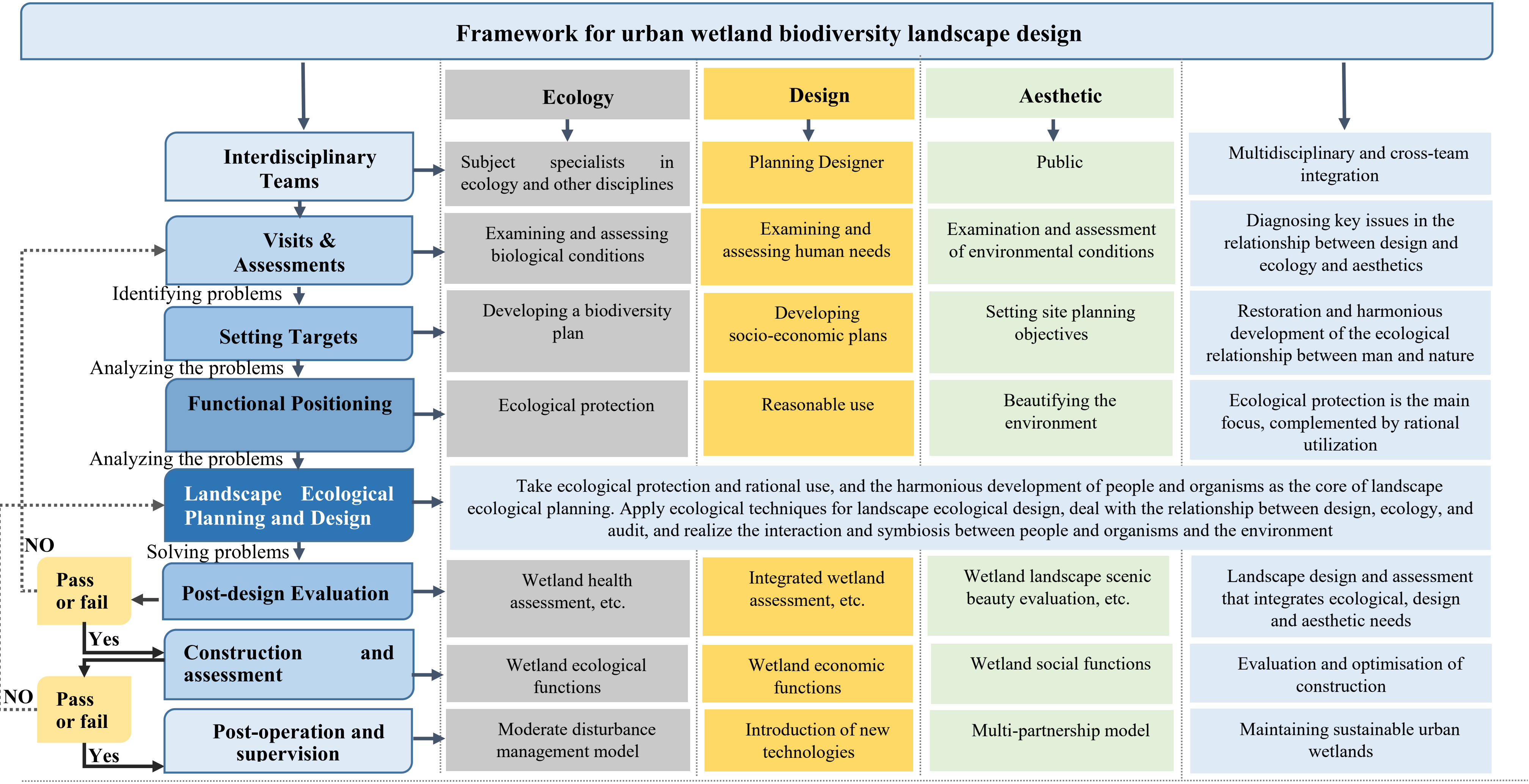

Fig. 6-3 Framework for urban wetland biodiversity landscape design (UWBLD)

6.3.1 Forming multi-disciplinary project teams

An interdisciplinary approach. Collaboration between scientists, professionals (landscape planners, architects, horticulturists, nurserymen, engineers, builders), stakeholders (citizens) and decision-makers (administrators, politicians). A top-down to bottom-up approach that involves people in the planning, design and implementation of new biodiversity landscape designs. Involving non-professionals in wetland conservation or restoration projects in wetland aesthetic perception studies can increase public consensus on the environmental value of wetlands[1].

6.3.2 Visits & Assessments

The visits and assessment of urban wetlands mainly include:

1) Examination of the environmental conditions of the wetland, including the basic conditions of the topography, distribution of water bodies, soil and climate, and assessment of the content and quality of water bodies and soil;

2) Examining local socio-ecological issues such as environmental disasters, confined lists caused by urban problems, and assessing ecological suitability;

3) Examination and assessment of the numbers, species, distribution, and spatial patterns of biological populations and ecosystems; examination and assessment of the species, numbers, and distribution of native and invasive plants;

4) Examining and assessing human needs such as ecological safety, quality habitat, recreation, science, and education.

Through examination and assessment to diagnose key issues in the relationship between human and nature ecology, parametric landscape analysis and design system models are used to conduct comprehensive analysis and evaluation of the existing resource categories, advantages, conservation values, existing contradictions and constraints in wetlands, so as to guide plant selection and wetland design, coordinate the relationship between wetland biodiversity conservation and planning and design objectives, and enhance the scientific nature of planning and design.

6.3.3 Setting Targets

After examination and assessment, the biodiversity conservation objectives are determined and the overall objectives for the ecological conservation and use of wetlands are set, based on the strengths and problems of wetland resources and the integration of biological and human development needs.

1) Development of biodiversity action plans: including species conservation, habitat structure, landscape pattern construction, restoration and design of water bodies and soils, habitat protection and creation, biodiversity allocation plans, etc.

2) Formulation of rational use plans: including functional positioning of wetlands, landscape and ecological planning and design plans, social cooperation plans, management and maintenance plans, etc.

6.3.4 Functional Positioning

The primary function of urban wetlands is the protection and restoration of the ecological environment, and the second is the rational use function. Depending on the ecological background conditions and regional needs, urban wetlands present multiple functional characteristics in terms of rational use. Different wetlands have leading functions to guide the development of urban wetlands in their multiple functions, such as tourism, recreation, water landscape improvement, water containment, and other different functions.

6.3.5 Pathways to implementation of landscape ecological planning and design

1) Landscape Ecological Planning

With the ecological protection and rational use of urban wetlands and the harmonious development of human and biodiversity as the core of the landscape ecological planning, it focuses on the ecological reconstruction, ecological restoration and ecological conservation of urban wetlands, as well as the needs of human viewing and recreation.

A: Biological Landscape Planning - Habitat Design

Using ecological theories, the habitat patches of plants and animals that need to be protected or newly created within the site and corridors conducive to species migration and gene exchange are identified, and the area, density and heterogeneity of the patches of urban wetland green space are enhanced. Roads, rivers and woodlands are integrated and protective green belts are planned to enhance the protection of wetland ecology. Plan for different habitat types such as grassland, mudflat, rocky beach, swamp, woodland, scrub, and water to increase the biodiversity of the wetland ecosystem.

B: Environmental landscape planning

Water system planning: Rational planning of the overall spatial layout of the water system, connecting different size patches of water bodies, forming a systematic water system, and planning the water circulation and purification system. A variety of wetland water types such as lakes, streams, ponds, waterfalls, and marshes are created to control the width of the water surface, depth of the water body, velocity of the water flow, and variation in water level to ensure the integrity of the wetland water system, maintain the diversity of the wetland system, create a variety of habitats for fish, shrimps, and mollusks, and provide a variety of water viewing experiences for residents.

Layout structure: Improve the ecological landscape pattern of urban wetlands, delineate ecological control zones and maintain the ecological background of wetlands; strictly regulate no-build, restricted and suitable zones, and establish more nature reserves or areas off-limits to human activities to reduce human interference and enable them to give full play to their ecological functions, especially to support biodiversity; optimise ecological corridors, establish green networks and increase connectivity.

Topographical transformation: Overall planning and design according to the natural form of the original wetland system and the distribution pattern of biological systems, increasing the topographical slope of the water and land over spaces, creating conditions for the design of rain gardens; considering the differences in geomorphology and geomorphological combinations, designing ponds, rivers, streams, islands, long embankments, shallow beaches, sandbars, deep pools and other rich and diverse topographical and geomorphological features of urban wetlands.

Vertical design: Highly heterogeneous spaces are designed through elevation control, slope control and water level control to create suitable habitats conducive to the growth and reproduction of wetland plants.

Functional zoning: With wetland protection and rational use as the core, under the overall layout structure of the wetland, reasonable functional zoning is carried out according to the original conditions and resources of the wetland, which should take into account the integrity of biological habitats and wetland-related humanistic units, highlighting the ecological protection characteristics and recreational function role of urban wetlands.

Road planning: Rely on the existing traffic conditions of the wetland, develop appropriately, and minimize the impact on the natural environment of the wetland; road system grading, reasonable planning of the slow walking system, and tour route planning should link up recreation nodes in series and avoid animal habitats as far as possible.

C: Event Landscape Planning

Reasonable planning of recreational functions and landscape node distribution to improve the service range and radius of wetlands and increase the participation of all types of people in wetland park recreation. Landscape facilities should be set up in the most easily accessible areas along the roads in the park, leaving most of the wetland area as a habitat for plants and animals. Focus on preserving history and culture, perpetuating folk culture, bringing into play wetland recreation and science education, and highlighting the social functions of urban wetlands. Focus on the role of wetlands in enhancing the visibility of the city and regional development, and establish linkages with the surrounding area to highlight the economic benefits of urban wetlands.

2) Landscape Ecological Designing

Apply ecological techniques for landscape ecological design, deal with the relationship between design and ecology, ecology and aesthetics, design and aesthetics, and realize the interaction and symbiosis between people and organisms and the environment.

A: Biological Landscape Designing

Planting design: In terms of biodiversity, focus on a reasonable mix of native-dominated, site-appropriate, and multifunctional species to provide adequate food and shelter space for organisms and to create and enhance native micro- and macrofauna habitats. A diverse mix of native and exotic species and the introduction of endangered plants with good landscape effects for conservation and sustainable design[12] can also contribute to biodiversity, resilience, and resilience, and avoid over-design and invasive exotic plants. In terms of landscape quality, pay attention to the harmony of colors and proportions created by plant species, planting methods, collocation, and seasonality, enhance the landscape value of key plants, and reduce the area of urban lawns under intensive management.

Habitat design: In terms of biodiversity conservation, design heterogeneous habitats to provide more possibilities for species diversity, design habitat types preferred by organisms and sufficiently large hiding spaces[13], and provide and enhance the layout and camping of habitats, foraging areas, etc. for organisms. In terms of landscape quality, there should not be too many habitat types; an excess of habitats can affect public satisfaction with the quality of the wetland landscape.

B: Environmental landscape designing

Water quality purification design: In terms of biodiversity, it can be enhanced by topographically designing plunging water with height differences, adopting technologies such as aeration and oxygenation, artificial floating island technology and rain gardens, and choosing suitable wetland plants to purify the water. In terms of landscape quality, ecological materials such as permeable paving are used, and attention is paid to the harmonious matching of materials, proportions, and scales; aeration and oxygenation can be designed in conjunction with human activities to increase the interest in the experience.

Rain garden design: design rain gardens of a certain scale and size such as recessed green areas and grassed ditches, giving priority to native plants with strong adsorption and purification capacity, and which are resistant to flooding, drought and adversity for short periods of time[14] to collect and purify surface runoff rainwater. In terms of landscape quality, pay attention to the overall aesthetics of the plant mix.

Road design: in terms of biodiversity, slow systems and elevated paths are designed to retain access for animal movements; permeable paving is used for paths with low loads such as walking. In terms of landscape quality, the road paving is designed through an artistic approach to material form combinations and color matching, etc. The materials are preferable to wood and natural stone, and the colors are harmoniously matched to the principles.

Barge design: In terms of biodiversity, natural forms of ecological barges are designed to promote the improvement of the water environment, create shallow habitats conducive to the growth of aquatic and wet plants, and design ecological buffer zones. In terms of landscape quality, ornamental water and wet plants are planted in the shallow areas where the waterfront meets, avoiding bare shallows.

C: Event Landscape Designing

Landscape node design: To create green open spaces and enhance the possibilities for human and biological interaction. For example, the design of observation points, paths or stepping stones, bridges, etc., which allow people to observe the daily life of animals such as birds, butterflies, and fish, and to feel the beauty of coexistence between humans and nature while taking a rest. The focus is on the convenience and comfort of space use, on resolving conflicts between function and safety, and between animal and human needs. For example, designing seasonal public spaces that are primarily ornamental in winter to reduce human disturbance, while opening up to public spaces shared with animals in other seasons[15] .

Design of supporting facilities: In terms of biodiversity, the distribution of facilities should be far from the biological protection areas, and the design of facilities such as buildings, landscape structures, and water-friendly platforms should be carried out using bottom elevation, ecological materials, and ecological construction techniques. In terms of landscape quality, ecological and environmentally friendly materials are used, with simple, light colors dominating. The design of the landscape facilities in terms of shape, style, style, proportional scale, material, and color should be kept in harmony with the wetland environment, reflecting the original landscape features of the wetland. Design museums, cognitive gardens, experience areas, and other wetland science education and propaganda functions, combined with digital and network information technology, multi-level and comprehensive science education, and propaganda.

Cultural landscape design: extracting the cultural characteristics of the city, region, or wetland and designing the landscape with patterns, symbols, materials, and colors are conducive to enhancing the quality of the wetland landscape beauty degree.

When using ecological design techniques and ecological technologies for landscape ecological design, appropriate ecological design techniques should be used depending on the distance of the wetland from the built-up area and the functional positioning of the wetland. The ecological design practices that can be used for urban wetlands in different regional locations are detailed in Table 6-1. The content of the services that can be laid out in each area is detailed in Table 6-2.

Table 6-1 List of applicable ecological design approaches for urban wetlands in different areas

Landscape Ecological Designing	Ecological Design Approach	Urban Core Area	Urban Fringe Area	Urban Suburban Area
Design factors for water quality protection	Degree of variation in inlet topography	●	○	○
	Natural purification	●	●	○
	Artificial wetland purification systems	●	●	○
	Ecological floating islands	○	○	○
	Aeration and oxygenation	●	○	-
	Change in terrain slope	●	○	○
	Rainwater garden	●	○	○
	Permeable paving	●	●	●
Design factors for shoreline maintenance	Natural form shoreline	●	●	●
	Ecological barges	●	●	●
Design factors for Ecological facility	Ecological materials	●	●	●
	Slow moving system	●	●	●
	Overhead paths	●	●	●
	Ecological Education Promotion	●	○	○
	Organic composting	-	○	○

	Waste reuse	○	○	-
	Renewable energy use	○	○	-
	Water saving measures	○	○	○
	Temperature control, cooling, noise reduction and sound-dampening measures	●	○	○
	Public water-friendly spaces	●	●	●
	Eco-building	●	○	-
	Type and intensity of artificial disturbance	●	○	○
Design factors for Plant diversity	Plant diversity	●	●	●
	Vegetation area	●	●	●
	Plant community structure	●	●	●
	Habitat diversity	●	●	●
	Plant adaptations	●	●	●
	Artificial plant species	●	○	-
	Native plant species	●	●	●
	Water-wet plant species	●	●	●
	Invasive alien plant species	●	○	○
	Artificially simulated natural habitat	●	○	○
	Ecological conservation measures	●	○	○
	Ecological buffer zone	●	●	●

Remarks: ●Must be set ○Can be set - Not required

Table 6-2 List of urban wetland supporting facilities in different areas

Type of supporting facilities	Basic items	Urban Core Area	Urban Fringe Area	Urban Suburban Area
Management Services Facilities	Facility for rainwater control and utilization	●	○	○
	Emergency evacuation facilities	●	○	○
	Management Centre	●	●	○
	Visitor Centre	○	○	○
Recreational facilities	Event Venue	●	●	●
	Resting platform	●	●	●
	Fitness venues	○	-	-
	Children's recreational facilities	○	-	-
	Cruise Terminal	○	○	○
	Camping sites	○	○	○
	Landscape Structures	●	●	○
	Seating	●	●	●
Ancillary service facilities	Restaurant building	○	○	○
	Building for sale	●	○	-
	Bicycle rental points	-	○	○
Science and	Exhibition or Science	○	○	-

education facilities	Museum			
	Science Gallery	●	○	○
	Signage and information boards	●	●	●
	Bird watching house	-	○	○
	Field awareness and education base	-	○	○
	Research Observatory	○	○	-
	Science Lab	○	○	-
Transport facilities	Public parking	●	●	●
	Bicycle parking	●	○	○
	Eco-friendly Electric Vehicle Interchange	○	○	○
Environmental sanitation facilities	Waste treatment facilities	●	●	●
	Restrooms	●	●	●
Safety and security facilities	Safe guarding facilities	●	●	●
	Monitoring facilities	●	●	○
	Barrier-free facilities	●	●	○
	Law and Order Fire Point	●	○	○
	Medical Emergency Point	●	○	○

Remarks: ●Must be set ○Can be set - Not required

6.3.6 Comprehensive and holistic assessment

Landscape design and assessment that integrates ecological, social and economic needs[16]. Such as pre-assessment of wetland ecological effects, pre-assessment of biodiversity effects, pre-assessment of wetland purification capacity, pre-assessment of ecological landscape carbon sequestration capacity, pre-assessment of wetland health, pre-assessment of wetland landscape beauty, pre-assessment of wetland comprehensive value, etc.

Urban wetlands can bring greater ecological value in the future by comparing the ecological effects of the wetlands before and after planning and design, and guiding the optimization of the scheme.

6.3.7 Post-operation and supervision

Long-term regulation is key to biodiversity conservation action[17] and can provide strong data to support future planning and design.

1) Continuous follow-up on project construction and restoration;

2) Introduce new technologies and build a "smart wetland" system to achieve all-around monitoring from wetland management and visitor services to ecological restoration, scientific research and monitoring, science popularization and education, and wetland cultural tourism and creativity;

3) Emphasis on adaptive dynamic management, such as the active introduction of endangered species and the creation of their corresponding habitat environments;

4) Permanent cooperation with scientific and educational organizations, constant updating of research methods, and regular research activities.

Understanding public perceptions of wetlands and their ecological value is a key component of developing sustainable wetland management plans[1]. Promote positive public perceptions and values of wetlands through science education campaigns, so that the public has a better understanding of wetlands and that wetland ecosystems are managed sustainably and effectively[18][19].

6.4 An empirical study of the Urban Wetland Biodiversity in Landscape Design (UWBLD) framework in different regions

6.4.1 The Urban Core Area - Singapore Jurong Lakeside Wetland Gardens

Jurong Lakeside Gardens in Singapore is a typical urban core wetland covering $53hm^2$ (Figure 6-4). Based on the principle of bio-friendly design, it restores urban wetlands damaged by industrialization through effective ecological restoration design, emphasizing the overall natural environment and biological habitat of the wetlands, while incorporating people's intrinsic needs and natural functions to provide the public with recreational functions such as water-friendly parks, wildlife parks, and ecological trails.

Fig. 6-4 Location Map of Jurong Lakeside Gardens, Singapore (Image credit: Author's extract from Baidu Maps)

1) Interdisciplinary Team. The design team worked with horticultural experts, wetland scientists, residents of the surrounding community, and horticulturists to test and developed soil mixes and plant species color schemes before project implementation to ensure the visual quality of the plant landscape. Feedback from residents of the surrounding community, municipal administrators, etc. was collected during the design phase and then integrated into the design for scheme refinement.

2) Scientific Assessment. protection of the ecological background of the site: over 3,000 existing trees in the wetland have been preserved and over 200 transplanted, providing an ecological corridor for wildlife and creatures. From 2014 to the end of 2019, wetland flora and fauna diversity are surveyed before planning and design, during construction, and after completion of construction, and appropriate mitigation measures are taken to minimize human disturbance. According to the post-construction biodiversity report, seven species of odonates were found, indicating the success of the planning and design.

3) Ecological Priority. Zoning control of wetlands, subdividing key habitats based on current biodiversity hotspots. The control area is designed to reduce roads and seating to provide refuge areas for wildlife.

4) Landscape design-led implementation pathways.

Rain Garden Design. Introducing elements of Water Sensitive Urban Design (WSUD), the three concrete drains were transformed into fully naturalized streams, with detailed modeling simulations, analysis, and assessment of flow velocity and capacity, cutting off sections and designing bio-engineered embankments to provide new activity spaces for organisms and communities along the route, enriching wetland biodiversity.

Ecological Buffer Zone Design. Creating ecological staggered zones and creating overstretches to provide refuge areas and nesting sites for migrating and resident birds.

Planting Design. Trees and shrubs that attract birds, butterflies, and dragonflies were chosen for the planting design, providing them with a food source and nesting opportunities; well-developed respiratory root plants such as sugar gum trees were used to resist the tide, and over 50 species of deep-rooted shrubs and ground covers adapted to the changing tides were used to stabilize the base shore.

Event Design. The design of the water park, wildlife park, eco-trail, and healing garden meet the current needs of the public for living, learning, and fitness.

Design of Facilities. The design of landscape facilities under human and biological sharing, all landscape facilities and activities are designed around biodiversity, on the one hand providing science education through recreation, and on the other distinguishing it from other urban public open spaces. For example, the bionic design is used to create an adventure space for children that mimics the movements of animals and provides a variety of unique play experiences for children; a water playground that mimics the tidal pattern.

Recycled Design. Roads, shelters, viewing platforms, and other designs using recyclable materials, fallen logs, and stones from the site.

5) Operations & Regulation. Events such as tree planting and public exhibitions are held to establish links with community residents and integrate their feedback on the wetland into later operation and supervision.

6.4.2 Urban Fringe - Biodiversity Planning and Design for the Crosswind Marsh Wetland, USA

The Crosswind Marsh Wetland, located in Sumter Township, Michigan, USA, is a 566hm^2 urban wetland in an urban fringe area (Figure 6-5). Established to accommodate the disturbing effects of the Detroit Airport runway expansion on wetlands, restoring over 1,000 acres of wetland ecosystems from former agricultural and residential land, reestablishing ecosystems for hundreds of native plant and animal species, and providing a public resource with environmental education and recreational space for Wayne County residents. It has become one of the largest self-sustaining wetland projects in the United States, reducing maintenance costs.

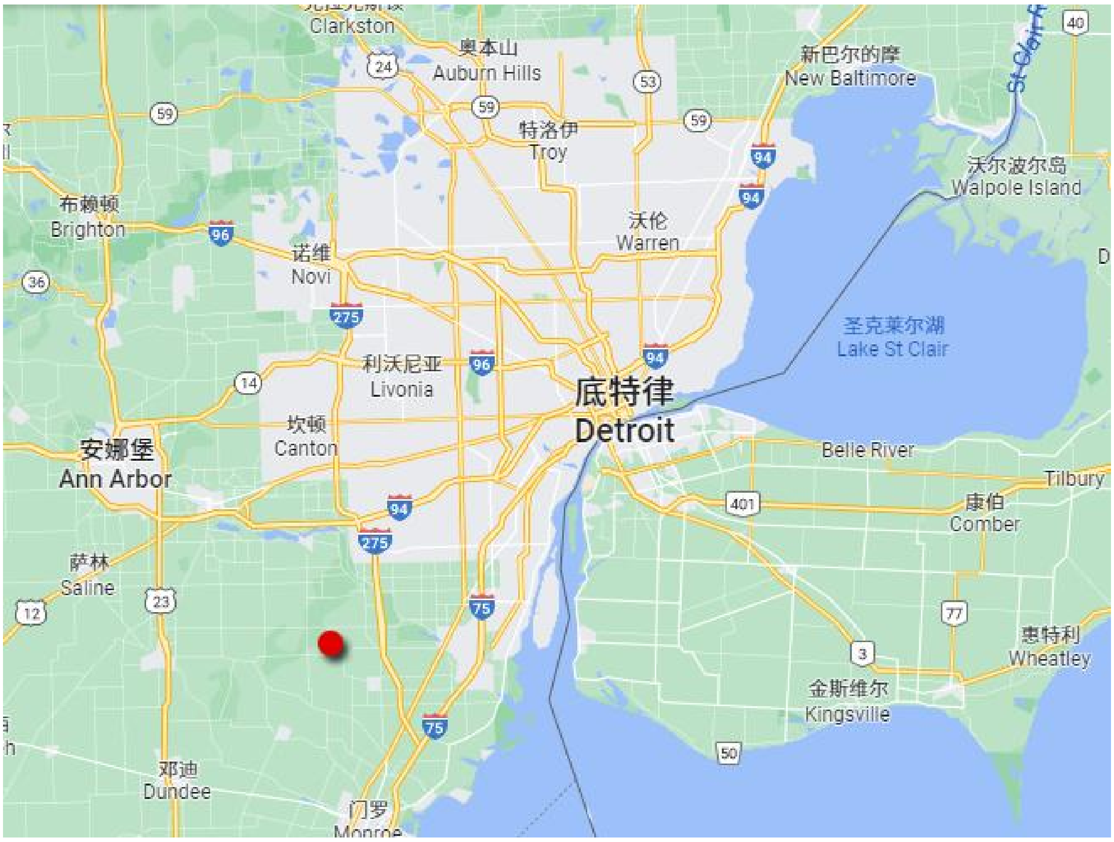

Fig. 6-5 Location Map of the Crosswind Marsh Wetland area, USA (Image credit: Author's extract from Baidu Maps)

1) Interdisciplinary Team. The interdisciplinary team, led by landscape architects, also includes civil engineers, wetland scientists, aquatic and fisheries biologists, botanists, and recreational planners, as well as public participation from residents of the surrounding community.

2) Scientific Assessment. Planning and design staff first investigated and researched adjacent wetlands and historical information, obtained a list of current wetland habitats and plants from historical maps and information, provided a list of pioneer plants and carried out the scientific analysis, conducted plant and soil experiments, and studied habitat design options. A systematic survey of ecological processes, flora and fauna, and hydrology is also carried out. Computer modeling was used to calculate the hydrology of the wetland, extensive agricultural drainage systems were removed and dykes and spillway berms were constructed to improve flooding problems. Active seeding and planting programs are developed by planning sites according to habitat types.

3) Ecological Priority. The restoration of reconstructed habitats, the development of wetland protection plans at different stages through the grading of hydrological conditions, the formation of a system of wetlands of various water depth types, the introduction of 244 species of birds, 30 species of mammals, 20 species of fish, 21 species of reptiles and amphibians, and 70 species of butterflies and dragonflies.

4) Landscape design-led implementation pathways.

Planting Design. Over 300,000 species of native aquatic plants, 10,000 seedlings, and 300 acres of wetland seed were planted to create natural habitat structures and nesting platforms; and three rare plants found on the site were transplanted into the wetlands on 20 acres for propagation and re-establishment.

Event Design. Planning and design of low-impact recreational activities such as hiking, bird watching, horse riding, boating, nature education, festivals, and viewing of natural scenery.

Design of Facilities. Boardwalks, wood chip paths, and grassy walkways are designed using recyclable, ecological materials. The landscape facilities are located in the most accessible areas of the park along the roads and most of the area has been preserved as a wildlife habitat.

5) Operations & Regulation. It provides a valuable educational resource for the public, school groups, and civic organizations, offering a variety of science and education courses, and realizing the social and economic value of the wetlands through media dissemination. The Michigan State University research team conducts regular visits and studies of the Crosswind wetlands, providing scientific monitoring and research data to guide sustainable conservation and use of the wetlands, and careful monitoring and ongoing management keep invasive species under control.

6.4.3 Urban Suburban - Dutch Marken Lake · Wadden Sea Project

The Marker Lake • Wadden Sea project originated from the Dutch South Sea Polder project, which was completed in 1932 with the completion of the Avrudek Dam, making the South Sea an enclosed lake area, which was then divided into the Marker and IJssel lakes by the Hautrib Dam in 1976. Long-term isolation has resulted in Marker Lake forming a freshwater lake wetland, where water quality and ecosystems have been compromised and biodiversity has been drastically reduced. The objective of the Marker Lake • Wadden Sea project is to create a lake wetland of spatial and ecological value, featuring bird watching and a combination of experience and recreation (Figure 6-6).

Fig. 6-6 Location Map of the Dutch Marken Lake · Wadden Sea, Netherlands (Image credit: Author's extract from Baidu Maps)

1) Interdisciplinary Team. The project team was formed by a consortium of the Dutch public and private sectors, and after consultation between 17 stakeholders, a team consisting of Boskalis Maritime, Arcadis Design Consultants, Witteveen+Bos Engineering Consultants, and Vista Landscape and Urban Planning was selected to design, construct and manage the project.

2) Scientific Assessment. The interdisciplinary team held several consultation meetings to integrate and analyze the available data, indicators, references, analytical methods, and range of objectives involving the project. The assessment of its policy objectives was divided into three main sections: the ecosystem improvement assessment, the bird haven creation assessment, and the dissemination of knowledge, education, and innovation assessment. The assessment of research objectives is divided into five main sections: Silt Kinetics, Silt Construction, Spatial Quality, Ecological Processes, Governance, and Application.

3) Ecological Priority. The project is a modification of the traditional Dutch 'polder model' of water management, where silt is removed and sediment is dredged and piled on top of a sand dam, providing shelter from the waves by creating a 'dune + side dam' habitat. It also combines rock dams to create sheltered lakes, gradually forming islands scattered throughout the wetlands, creating diverse habitats such as swamps, mud pools, freshwater lakes, streams, and puddles, providing a large number of different scales of shelter and shallow water for birds. Seven natural islands are planned and isolated to maximize the 'island effect' and to avoid ground predators. Human activity zones are designated around the harbor area to avoid the disturbance of birds by visitors.

4) Landscape design-led implementation pathways.

Planting Design. The introduction of reeds and other plants has accelerated soil maturation, allowing the nutrient-rich clay and silt to be fully utilized and providing a food supply for birds.

Design of Facilities. The harbor area provides a visitor center and resting places for visitors, with a walkway and boardwalk to the marsh area, linking different types of viewing huts and a variety of entertaining landscape facilities, such as bird-watching facilities at different heights and from different viewing angles. The project also provides a concentrated water sports area with beach recreation, kite flying, and surfing activities.

5) Operations & Regulation. The project is under the permanent supervision of KIMA and includes the organization of field trials and discussion sessions on three research topics: "Ecosystems", "Silt and Clay Construction Methods" and "Adaptive Management".

6.5 Ecological design paradigms for urban wetland landscapes in different regions

Compared to natural wetlands, urban wetlands can be artificially created to provide a more suitable environment for organisms due to the high operability of habitat construction and management. Therefore, in the process of conservation and utilization, urban wetlands differ in their functional positioning and wetland characteristics, depending on their regional location, ecological background conditions, and service targets.

The term "paradigm" was coined by the American philosopher of science Thomas Kuhn[20] (Kuhn, 2012) and refers to a set of basic ideas, theories and methods that have been developed in a professional field under a common belief[21]. Yue et al.[22] studied the paradigm evolution of landscape planning theories in terms of both substantive and procedural theories, suggesting that there is a tendency for substantive and procedural theories to intermingle, with the 'pattern-process-design' paradigm and the 'experimental design' paradigm becoming effective ways to foster substantive interdisciplinary collaboration between ecologists and planners. Through landscape design, planners achieve the goal of reconciling the health of ecosystems with the needs of society, while ecologists gain access to experimental data and the testing of scientific theories. Luan et al.[23] established a resilient design paradigm for urban green infrastructure based on an adaptive approach, proposing a dynamic cycle model for the whole process: "identification and diagnosis - design decision - construction and implementation - operation monitoring - evaluation and analysis - information feedback", providing methodological support for the dynamic and optimal configuration of urban green infrastructure.

Based on the Urban Wetland Biodiversity Landscape Design (UWBLD) framework proposed in 6.3 of this chapter, and combined with the empirical analysis of urban wetland biodiversity conservation and use in different regions in 6.4, a paradigm of "Interdisciplinary Team - Visits & Assessments - Ecological Priority - Functional Orientation - Landscape Design-led - Operations & Regulation" was proposed for the ecological planning and design of urban wetland landscapes. The paradigm emphasizes the whole process of monitoring, assessment, feedback, design, and operational supervision, which is conducive to the two-way optimization of science and practice, and thus promotes the sustainable development of urban wetland landscapes. It is expected to provide a reference for the conservation and rational use of urban wetlands in China.

Based on the findings of the research on plant diversity, application of ecological design practices, evaluation of landscape beauty, evaluation of wetland health, and comprehensive evaluation of wetlands in different areas along the urban gradient, a landscape ecological planning and design paradigm for different areas of urban wetlands along the urban gradient is proposed. Through landscape ecological planning and design to highlight the characteristics of different regional wetlands, the implementation of wetland plant diversity conservation and differentiated wetland use is expected to provide a reference for the conservation and utilisation of urban wetlands.

6.5.1 Wetland characteristics and landscape ecological design paradigms in urban core area

1) Wetland characteristics

Wetlands in urban core areas are generally scattered at multiple points and are surrounded by urban built-up land, making them easily accessible and usable by urban residents as public open spaces. Therefore, wetlands in urban core areas are often planned and designed as wetland parks, riverfront greenways, and special water features. While protecting the ecology of the wetlands, they provide leisure, recreation, education, and science education for urban residents.

The positioning of wetlands in urban core areas varies according to the type of wetland, area, ecological background conditions, and service targets. Wetlands in urban core areas with larger areas and better ecological background conditions tend to have ecological protection as their main function, as well as multiple functions such as recreation, entertainment and science education, etc. The service targets are generally foreign tourists and local residents, highlighting the natural scenic features of wetlands. Wetlands with moderate size and average ecological background conditions in the core area are mostly utilized in a rational way. For example, wetlands with good accessibility serve the surrounding residents, with more emphasis on daily activities such as recreation, entertainment, and fitness, and more supporting facilities; wetlands with poor accessibility have more emphasis on ecological protection and ornamental functions, with fewer supporting facilities. Wetlands in the core areas, which are smaller in size and have poorer ecological background conditions, are mostly used for recreation and entertainment as their main functions, and through planning and design become open spaces for viewing, recreation, and fitness for the surrounding residents.

In addition to the threats posed by the fragmentation of the ecological base as a result of urban expansion, wetlands in the urban core areas face direct competition from other high-premium land construction targets, as well as the need to balance the function of providing urban green space for the daily recreation of urban residents. Therefore, it is neither possible to achieve ecological conservation in the urban core through the designation of large protected areas, nor is it possible to compensate for pristine wetlands by creating new wetlands in the peripheral areas of a high premium[24]. Wetlands in urban core areas show an overall high degree of conservation and use, a long history of the establishment, a wealth of functional types, a predominantly artificial landscape, many artificially planted plants, a high intensity of anthropogenic disturbance [25], and severe fragmentation of wetland habitats.

2) Design Paradigm

The key point in the ecological planning and design of wetland landscapes in urban core areas is to fully exploit the wetland resources and locational advantages of the core areas, with a focus on restoring wetland ecosystems, increasing the environmental holding capacity of wetlands, and improving their resilience. A zoning approach is adopted to restore damaged habitats with natural forces as the mainstay, supplemented by artificial forces and the creation of multiple habitat types, which will contribute to the enhancement of biodiversity[24]. According to the type of land around the wetland and the needs of the people, planning, and design of a variety of types of recreational functions to meet the diverse needs of urban residents; strengthening science education to guide the ecological awareness of tourists and citizens[26]. In terms of post-operation and maintenance, a dedicated management body, a healthy public-private partnership and emerging smart technologies will provide a sustainable and continuous impetus for the restoration of wetland systems in urban core areas[24]. To fully exploit the integrated value of wetlands in terms of ecological, economic, and social functions, and to realize the ecological protection and rational use of wetland landscapes in urban core areas. The design paradigm for wetlands in the urban core area is detailed in Framework Figure 6-7.

Interdisciplinary Team		The project focuses more on the participation and feedback from the residents of the surrounding community, consulting them at the beginning of the design process, listening to their suggestions afterward to improve the scheme, and interacting with them in the later stages of operation and supervision for continuous optimization.
⇩		
Visits & Assessments		The population is mainly urban residents and tourists, with emphasis on examining the needs of the population, accessibility, and distribution of basic services and facilities, exploring the cultural characteristics of the city, and assessing the environmental carrying capacity of the wetlands.
⇩		
Ecological Priority	Ecological Objectives	Improving the urban environment, protecting and restoring urban biodiversity, and reducing wetland destruction.
⇩	Social Objectives	Improving supporting facilities to meet the needs of tourists' sightseeing and surrounding residents' daily recreation and entertainment; achieving cooperation in wetland scientific research and popularisation of science education; and promoting the city's culture.
	Economic Objectives	Promoting the surrounding regional economy through tourism development.
Functional Orientation		Wetland tourism is the main function, with a focus on urban stormwater management. Highlighting the semi-natural, semi-artificial integrated beauty of the wetlands and the artistic beauty of the man-made.
⇩		
Landscape Design-led	Vertical	Design micro-topography to increase the degree of variation in inlet topography and avoid urban

	Design	Surface runoff pollutants from flowing into the wetland through elevation control.
	Water System Design	More attention is paid to the design of rain gardens to collect and purify surface runoff rainwater from areas such as coastal municipal roads through stormwater management.
	Planting Design	More emphasis is placed on the design of artificial ornamental plants, with species chosen as native as possible to simulate the natural community structure of plants.
⇩		Choose plants with more developed root systems, strong resistance, strong metabolic growth, long growth cycles, better removal of nitrogen, ammonia nitrogen, and total phosphorus from water bodies, and with a certain ornamental or economic value, so that they can absorb pollutants from water bodies and better purify the water while reflecting the ornamental value.
	Road Design	Consideration should be given to the interface with urban transport, a graded design, a well-developed road network, a reasonably planned slow-moving system, and barrier-free facilities designed to facilitate activities such as walking, sightseeing, and viewing by visitors.
	Ancillary Facilities Design	Fully designed with supporting facilities.

Operations & Regulation	To achieve a full range of monitoring from wetland management and visitor services to ecological restoration, scientific research and monitoring, science popularisation and education, wetland cultural tourism, and cultural creation, such as the adoption of a moderate disturbance management model, so that the overall appearance of the plant landscape maintains its natural wild beauty and creates good conditions for increasing species richness. Using nature education as a medium to bring together multiple players to form a multi-polar development model[24].

Fig. 6-7 The design paradigm for wetlands in the urban core area

6.5.2 Wetland characteristics and landscape ecological design paradigms in urban fringe area

1) Wetland characteristics

The urban fringe wetlands are usually located in the border area between urban and rural areas. With the urbanization process, the construction land in the urban fringe area is gradually expanding and the number of urban residents is also gradually increasing, influenced by the human living environment, whose main disturbing factor is the damage to the water quality of the wetlands caused by the discharge of domestic sewage. As a transition zone between the city and the countryside, wetlands such as lakes and marshes in the fringe areas are gradually being protected and utilized to prevent erosion by urban development. Through initiatives such as ecological restoration, construction of flood control and drainage facilities, improvement of the water environment, and landscape enhancement, they are planned and designed to function as urban wetland parks and riverfront greenways, providing open spaces for leisure and recreation for the surrounding residents while protecting the ecology of the wetlands.

Wetlands in the urban fringe act as a green barrier and ecological substrate for the built-up area of the city and drive the surrounding urban development through spillover values[27]. The positioning of the functions varies according to the type of wetland, ecological background conditions, and accessibility. Wetlands with good ecological background conditions tend to have ecological protection as their main function; wetlands with good ecological background conditions and high accessibility tend to have rational use as their main function, incorporating education and science, flower viewing, camping and picnicking, and other special functions; wetlands with average ecological background conditions and good accessibility to the surrounding residents tend to develop daily recreational functions such as leisure, entertainment, and fitness.

Wetlands in urban fringe areas as a whole exhibit characteristics such as diverse ecological substrate resources, multiple functions, fragile edge interfaces, complex hydrological conditions, extensive land space, and dynamic changes in land use.

Wetlands in urban fringe areas as a whole exhibit characteristics such as diverse ecological substrate resources, multiple functions, fragile edge interfaces, complex hydrological conditions, extensive land space, and dynamic changes in land use.

2) Design Paradigm

Wetlands in urban fringe areas have good natural landscapes and idyllic scenery and can provide healthy and natural spaces for urban residents to relax and unwind. The main point of the landscape ecological planning and design is to fully exploit the natural resources of the fringe wetlands and the advantages of the surrounding resources, focusing on the restoration of the wetland ecosystem, based on water ecology and water environment improvement, enhancing the water quality and improving the wetland environment through flood prevention and mitigation, ecological restoration and other means, using the ecological background conditions of the wetlands to design and build diverse habitats, enriching the spatial heterogeneity of the wetlands and thus enhancing biological Diversity. At the same time, the development is integrated with the resources around the wetland, relying on the characteristics of the wetland to plan and design open space science resources suitable for camping, picnicking, and viewing beautiful scenery, to improve tourism functions and enhance the value of the land. Focus on its economic function and improve the social function, so as to enhance the overall value of the wetland and achieve ecological protection and rational use of the wetland landscape in the urban fringe area. The design paradigm for wetlands in the urban fringe area is detailed in Framework Figure 6-8.

Interdisciplinary Team	A more focused collaboration of experts in ecology, biology, and wetland science, as well as government officials.	

⇩

Visits & Assessments	The population is mainly urban residents, focusing on the ecological background conditions of the wetland and the nature of the surrounding land, and exploring the cultural characteristics of the wetland.	

⇩

Ecological Priority	Ecological Objectives	Restoration of wetland areas to protect and restore urban biodiversity.
	Social Objectives	Create a characteristic landscape to meet the needs of tourists' sightseeing and urban residents' leisure and holiday; achieve cooperation in wetland scientific research and popularisation of science education.
	Economic Objectives	Enhancing the urban landscape of the region, driving economic development and land appreciation in the surrounding areas.

⇩

Functional Orientation	The main function is recreation and excursions, with a focus on water landscape improvements. Highlight the semi-natural, semi-man-made integrated beauty of the wetlands.

Landscape Design-led	Vertical Design	Install protective measures such as retaining walls to prevent landslides and soil erosion in areas where the slope is greater than the soil resting angle.
	Water System Design	More attention is paid to the restoration of the overall water system, water purification, and the creation of the water landscape, with particular attention to the impact of changes in water levels on the landscape.
	Planting Design	Appropriately introduce artificially cultivated plants and choose native species; for new wetlands, increase the variety of artificial plants and ecological conservation measures to enhance habitat diversity and create conditions for increased plant diversity.
		Increase the variety of wet and water plants and select "amphibians" that are adapted to terrestrial conditions and can be grown under submerged conditions.
	Road Design	Reduce mesh interweaving and avoid crossing ecologically sensitive areas such as habitats.
	Ancillary Facilities Design	The focus is on the installation of recreational services, ancillary services, science education, and other facilities.

Operations & Regulation	A wide range of science education courses and special recreational activities are offered, long-term cooperation with scientific and educational organizations is established, research methods are constantly updated and regular research activities are carried out.

Fig. 6-8 The design paradigm for wetlands in the urban fringe area

6.5.3 Wetland characteristics and landscape ecological design paradigms in urban suburban area

1) Wetland characteristics

The urban countryside has a good ecological pattern and is rich in natural resources, most of which are in an underdeveloped and underutilised state[28]. Wetlands are mostly lakes, reservoirs and marshes with good ecological background conditions and relatively weak artificial disturbance, and they play an important role in the urban environment in terms of water conservation and providing habitat for wildlife[29]. Because of the distance from the city center and the low accessibility, most of the wetlands are not protected and utilized. Reservoirs and lakes, with their large surface waters and the advantages and characteristics of beautiful landscape nature, are gradually being valued and planned, and designed as leisure and holiday spaces for foreign visitors and city dwellers.

The main function of wetlands in the urban countryside is ecological conservation, restoring wetland ecosystems, establishing nature reserves, and maintaining and enhancing the biodiversity of urban wetlands. In terms of development and utilization, it mainly relies on the natural resource characteristics of the wetlands to create an attractive landscape with special features. For example, the Qingshan Lake Wetland in Hangzhou, using the large area of water and beautiful natural scenery around the lake, planning and designing a cycling greenway around the lake, becoming the only place for Hangzhou citizens to experience cycling around the lake on weekends and holidays; at the same time, creating a water forest park business card, using a large area of pond fir forest formed by the theme of plant landscape features, becoming a popular place for the public and tourist crowds to visit.

Wetlands in the urban suburban area as a whole are characterized by a low degree of protection and utilization, a single functional type, a predominantly natural landscape, beautiful natural scenery, less artificial landscape, a more stable plant community structure, and biodiversity, a weak intensity of human interference, few supporting service facilities and few management and maintenance measures.

2) Design Paradigm

The planning and design of wetlands in urban suburban areas should focus on preserving the stability of their natural communities and pay more attention to the application of native plants to create a stable plant community. In addition, there is relatively little shoreline maintenance and management in countryside wetlands, and rainfall scouring due to natural rainfall is an important factor affecting wetland shoreline damage and erosion, so enhancing the inlet topography and reducing erosion should also be a key concern in the design of suburban wetlands. In terms of rational utilization, relying on the ecological resource advantages of wetlands, the development area is distinguished from the core and fringe wetlands by its distinctive recreational functions, forming an urban wetland landscape characterized by a high-quality ecological environment and beautiful natural scenery. By giving priority to its ecological functions and using the ecological features to drive the economic and social functions of the wetlands, the sustainable development and sustainable use of the wetland landscape in the countryside will be achieved. The design paradigm for wetlands in the urban suburban area is detailed in Framework Figure 6-9.

Interdisciplinary Team		An interdisciplinary team led by a landscape architect, overseeing experts in ecology, biology, wetland science, and government officials.
⇩		
Visits & Assessments		The people are mainly urban residents, focusing on the ecological background conditions of the wetland and the surrounding resources, and exploring the characteristic resources of the wetland.
⇩		
Ecological Priority	Ecological Objectives	Protecting and restoring wetland biodiversity and conserving water.
	Social Objectives	Create a characteristic landscape to meet the needs of urban residents for leisure and outdoor sports; achieve cooperation in wetland scientific research and popularisation of science education.
⇩	Economic Objectives	Tourism-led ecological conservation and management of wetlands.
Functional Orientation		The main function is outdoor sports and recreation, with a focus on water conservation. The natural beauty of the wetland's natural scenery and the harmony between man and creatures are highlighted.
⇩		
Landscape Design-led	Vertical Design	Take advantage of the topography of the countryside to create highly heterogeneous

		countryside habitats that meet the survival needs of a diverse range of biological species.
	Water System Design	Greater focus on water conservation.
	Planting Design	Make full use of the countryside's rich natural resources to create wildflower meadow plant communities and reduce artificial plant species and ecological conservation measures.
⇩		Choose plants with more developed stems and leaves to reduce the erosion of sediment at the bank edge by water currents; increase the variety of water and wet plants to create a rich plant community structure.
	Road Design	Roads should be kept to a minimum and avoid crossing ecologically sensitive areas such as habitats.
	Ancillary Facilities Design	The number of ancillary facilities along the perimeter of the road should not be excessive.
Operations & Regulation		Permanent cooperation with scientific and educational organizations, constant updating of research methods, and regular research activities.

Fig. 6-9 The design paradigm for wetlands in the urban suburban area

6.6 Summary

This section introduces the theory of landscape ecology and landscape ecological planning, and constructs a theoretical system that coordinates the complex relationship of "design-ecology-aesthetics". Through the analysis and optimization of the classical landscape framework, an Urban Wetland Biodiversity Landscape Design (UWBLD) framework is proposed, which consists of seven steps: interdisciplinary team, survey and assessment, goal setting, functional positioning, landscape ecological planning and design, comprehensive evaluation, and post-operation and supervision. After analyzing the characteristics of urban wetlands in different regions, a paradigm for landscape ecological planning and design of urban wetlands in different regions is proposed. The aim is to provide a reference for the conservation and rational use of urban wetland biodiversity in China by means of an integrated landscape approach.

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Chapter 7

AN EMPIRICAL STUDY: URBAN WETLANDS AS A POTENTIAL HABITAT FOR AN ENDANGERED AQUATIC PLANT, ISOETES SINENSIS

CHAPTER SEVEN: AN EMPIRICAL STUDY: URBAN WETLANDS AS A POTENTIAL HABITAT FOR AN ENDANGERED AQUATIC PLANT, *ISOETES SINENSIS*

CHAPTER 7: AN EMPIRICAL STUDY: URBAN WETLANDS AS A POTENTIAL HABITAT FOR AN ENDANGERED AQUATIC PLANT, *ISOETES SINENSIS*

7.1 Introduction

Conservation of endangered plants is a key priority in biodiversity conservation that has always been appreciated by conservation biologists[1][2]. Endangered plants are one of the most easily lost biological resources. If not well protected, the loss of biological and genetic values contained in endangered plants will have an immeasurably negative impact on both the ecosystem and human society[3]. Due to the unique habitat requirements and narrow ecological amplitude of endangered plants, in-situ conservation is an essential aspect of endangered plant conservation[4]. This is most often achieved by protecting their original populations and maintaining their natural habitats[5][6]. However, studies have shown that the populations of some protected plants within an area do not increase following conservation efforts, suggesting that the effect of the conservation program is not significant, even though the in-situ conservation area has existed for some time[7]-[9]. On this basis, in recent years, researchers have focused on exploring multi-channel management mechanisms to protect endangered plants as well as promoting the establishment of protected areas and in-situ conservation[10]-[13].

Urban wetlands are urban open spaces that are an essential component of the urban ecological environment[14]. They provide not only beautiful views and recreational opportunities, but also suitable habitats for aquatic animals and plants, all the while increasing urban biodiversity and mitigating the urban heat island effect[15]-[17]. With the construction and expansion of cities, urban wetlands have disappeared at a relatively high rate[18][19]. At the same time, urban environments are also severely affecting the water quality and hydrological process line of urban wetlands[20]. These detrimental changes have promoted the restoration, protection, management, education and assessment of urban wetlands[21]-[24]. Subsequently, wetland plant community structures have been stabilized, wetland habitats are more diverse and heterogeneous, and public awareness of wetland conservation has been raised. It is now the case that the protected ecosystem of urban wetlands provides a better habitat for aquatic plants as the biodiversity within the wetlands has greatly improved[14].

Isoetes sinensis is an endangered aquatic plant that grows in shallow waters or marshes which have low water velocity and good water quality[25]-[27] and is listed as a tier I nationally protected species in China[28]. Its survival is easily affected by changes in the water environment [29]-[31]. Therefore, *I. sinensis* is a good indicator of the state a water environment is in[32]. The existing studies on *I. sinensis* mainly focus on resource collection, physiological research, and reproduction technology[30][31][33][34]. Notably, sporogenesis has addressed *I. sinensis*′s reproduction problem[35]. However, there is still a lack of research on the ex-situ conservation of artificially reproduced *I. sinensis* and returning it to native habitats to rejuvenate populations. The improvement of water quality and the high degree of heterogeneity of urban wetlands have created an opportunity to introduce *I. sinensis* into urban wetlands. Following the successful introduction, ex-situ conservation of *I. sinensis* can be better achieved and the biodiversity of the area can be greatly enhanced. In addition, the urban water quality could be monitor through regular observing the growth of the *I. sinensis* which as an indicator plant for the water environment. To date, studies on the introduction of endangered plants into urban areas have mainly focused on trees, shrubs, and land herbs[36]-[38]. For instance, some endangered tree species have been successfully introduced into urban areas[39], yet the successful introduction of endangered aquatic plants has not been reported.

This study conducts the community survey of *I. sinensis*, an urban green space water habitat survey, a controlled homogeneous garden test, and urban wetland remote sensing. Hangzhou is taken as an example to achieve the following: 1) determine the physiological and functional characteristics of *I. sinensis*, reflecting its preference for environmental factors and then determining its ecological niche; 2) evaluate the spatial distribution of potential *I. sinensis* habitats in urban wetlands; 3) develop management strategies for the introduction of *I. sinensis* into urban wetlands.

7.2 Research areas and methodology

7.2.1 Introduction of research areas

In China, *I. sinensis* is mainly natural distributed in the middle and lower reaches of the Yangtze River. Specifically, Zhejiang Province is the area with the largest number of *I. sinensis* populations. This study investigates the populations of *I. sinensis* in Hangzhou, Ningbo, and Shaoxing in Zhejiang province (Fig. 7-1). These three cities have subtropical monsoon climates and rich wetland resources. In 2019, the average annual temperature in Hangzhou was 18.1 ℃ with an average annual rainfall of around 1647.7 mm; the average annual temperature in Ningbo was 17.8 ℃ with an average annual rainfall of around 1840.8 mm; the average annual temperature in Shaoxing was 18.4 ℃ with an average annual rainfall of around 1686.6 mm[40]. Hangzhou (29◦11’–30◦33’ N, 118◦21’–120◦30’ E) is selected as an urban research area because it is home to a dense water network and various kinds of urban wetlands. In recent years, effective measures have been taken to protect the water environment in Hangzhou and the water quality were improved obviously from 2017 to 2020[41] In 2020, the proportion of I–III surface water in the city was 98.1%, 3.8% higher than in 2019[42]. On this basis, it provides an ideal research area for the introduction of *I. sinensis* into urban wetlands.

Fig. 7-1 The location and habitat status of field survey sites of *Isoetes sinensis*

7.2.2 Methodology

1) Field study

Field research was conducted on six wild populations in the three regions detailed above. The quantity, distribution area, density, plant height, type of common plants, soil types, distance from roads, major disturbance factors, water depths in the distribution area, and water velocity are recorded. Water samples are also collected for water quality analysis.

2) Urban wetland investigation

According to the Hangzhou Urban Wetland Classification System[43], the wetlands in the study area can be categorized into permanent rivers, coastal freshwater lakes and constructed wetlands. Constructed wetlands can be further categorized into reservoirs, canals and aqueducts, urban constructed water landscapes and entertainment, and aquatic farms. The wetlands within the study area are categorized using a combination of remote sensing and ground surveys. Regarding remote sensing, Arcmap 9.3[44] is used to visually analyze the high-resolution satellite imagery within the area to determine wetland categories and their respective sizes. Based on the remote sensing observations, a specific water area (no less than 5%) is selected from the remote sensing results and field surveys will be conducted from August to October 2021 to verify the wetland types and confirm the accuracy of the remote sensing. Meanwhile, water samples are collected and a portable Doppler flow velocity and water level detector (DPL-LS12) is applied to record the water's depth and velocity.

3) Physiological ecology experiment

Water level variation experiment. In March 2021, similarly sized artificially grown *I. sinensis* (about 10 cm tall) were selected for potted cultivation. The cultivation substrate was a mixture of loess and peat soil at a ratio of 2:1 to simulate the major soil types in natural. Three water levels were set in the water level variation experiment: high water level (15–30 cm), medium water level (5–15 cm), and low water level (0–5 cm). For each level, three pots were planted with 3 plants per pot. In total, there were 27 plants. To simulate the changes in water depth caused by rain and sunshine in the natural environment, the plants are watered when the water level dropped to 15 cm, 5 cm, and 0 cm in the three water levels, respectively, to bring the water level back to the highest point. In July 2021, the LI-6400 portable steady porometer (Li-Cor, Lincoln, USA) was used to measure the photosynthetic rate of the plants grown in different water levels. The number of leaves, leaf length, and leaf diameter of the plants were also measured. To obtain the light response curve, the net photosynthetic rate of the plants was measured at luminous flux densities of 0, 10, 20, 40, 60, 80, 100, 200, 400, 600, 800, 1000, 1200, 1400, 1600, 1800 and 2000 μmol m − 2 s− 1. The light compensation point and light saturation point was determined by fitting the measured light response curve using modified rectangular hyperbola model by Photosynthesis Calculation Soft[45].

Nitrogen variation experiment. In June 2021, the period of rapidly growth[30], an experiment investigating changes in water nutrients was conducted at a water depth of 5 cm. The ammonia-nitrogen concentration of I-IV surface water[46] was taken as the standard and urea was employed as a solvent. Solutions were prepared with ammonia-nitrogen concentrations of 0.15 mg/L (N0.15), 0.5 mg/L (N0.5), 1.0 mg/L (N1.0), and 1.5 mg/L (N1.5). Meanwhile, water was used to conduct the control experiment. Plants of a similar size were selected and their leaf lengths and number of leaves were recorded. A potted cultivation experiment was carried out using fine sand as a substrate. For each solution, three pots were cultivated with three plants per pot. In total, there were 45 plants. The solution was changed every 10 days and the entire experiment lasted for 30 days. In July 2021, at the end of the experiment, the leaf length, the number of leaves, and the number of newly germinated leaves were recorded.

4) Calculation and analysis

Considering the key environmental factors limiting *I. sinensis* survival, the following suitable habitat module of *I. sinensis* in urban wetlands is established:

$$A = \begin{cases} D \mid D \in (0,a) \\ V \mid V \in (0,b) \\ N \mid N \in (0,c) \end{cases} \quad (1)$$

A refers to the suitable habitat of *I. sinensis*; a, b, and c refer to the maximum water depth, water velocity, and ammonia-nitrogen content suitable for *I. sinensis* survival.

The proportion of suitable wetland of each type of wetland (Fi) is calculated as:

$$Fi = \frac{\mathrm{AR}i}{\mathrm{ARt}} \quad (2)$$

ARi refers to the suitable area in type i wetland; ARt refers to the total area of type i wetland.

In urban wetlands, the total potential suitable habitat area (At) is calculated as:

$$At = \sum_{i=1}^{n} (Fi \times \mathrm{Ai}) \quad (3)$$

Ai refers to the total area of type i wetland; n refers to the number of wetland types.

The data were statistically analyzed using Excel 2010 software subjected to difference significance analysis using SPSS17.0 software[47].

7.3 Results

7.3.1 Community features of *I. sinensis*

In the field, *I. sinensis* is usually distributed in ponds, streams, swamps and abandoned farmlands where there is low water velocity. Water depth ranges from 0 to 30 cm, whilst water velocity is between 0.01 and 0.04 m/s. The light environment of *I. sinensis* were from full light to shade. Most of wild populations were grew in habitats with sufficient light in our survey. However, the population in Huanghu (site2), Zhejiang was grow in almost completely shaded habitat where there were Metasequoia glyptostroboides, a tall tree species, in the upper layer and Bidens frondosa, a tall and dense herb with a height of 150 cm, in the lower layer of community.

The most common plants associated with *I. sinensis* are Oenanthe javanica, Cardamine hirsuta, Lysimachia fortune, Callitriche palustris, B. frondosa, Alisma plantago-aquatica, Commelina purpurea, Microstegium vimineum and Ranunculus japonicas, etc. The distance between populations and roads varies between 0.5 and 20 m. Cultivation and maintenance of the forests are the main human-induced disturbance factors. Growth density typically falls within the range of 3–25 plants/m2. It is worth noting that the Wangjialu population is extremely densely distributed, which is highly unusual (Table 7-1).

Table 7-1 *Isoetes sinensis* community habitat features

Location	Light condition	Density (plant/m^2)	Habitat and soil types	Velocity (m/s)	Depth (cm)	Ammonium-nitrogen concentrations (mg/L)	Main common plants	Away from road (m)	Man-made interference factors
Jingshan, Hangzhou	60% full light	25	Pond under forest, yellow loam, humus	0.02	5	0.41	*O. javanica*, *L. fortunei*, *C. hirsuta*, *Hedyotis auricularia*, *Viola lactiflora*, *C. palustris*	2	Forest tending
Huanghu (site1), Hangzhou	full light	3	Pond, fertile, humus	0.02	30	0.38	*Typha angustifolia*, *Juncus setchuensis*, *Myriophyllum verticillatum*	4	None
Huanghu (site2), Hangzhou	10% full light	4	Floodplain under forest, yellow loam	0.04	2	0.15	*R. ternatus*, *L. heterogenea*, *Polygonum pubescens*, *L. fortunei*, *Bidens frondosa*	20	Forest tending
Qiantanghu, Ningbo	full light	6	Swamp, yellow loam, humus	0.03	3.5	0.28	*Zizania latifolia*, *O. javanica*, *C. hirsuta*, *L. fortunei*, *Glechoma longituba*, *Alternanthera philoxeroides*	1.5	Vegetable plantation
Wangjialu, Ningbo	full light	>1000	Wasted farmland, yellow loam	0.01	0.4	0.56	*C. palustris*	0.5	Seedling plantation
Zhuji, Shaoxing	30% full light	15	Swamp under forest, yellow loam, humus	0.03	4	0.27	*A. plantago-aquatica*, *R. japonicus*, *B. frondosa*, *C. communis*	5	None

7.3.2 Photosynthetic rate and growth features of *I. sinensis* in different water levels

The light response curve shows that the light compensation point of *I. sinensis* is relatively low (20 μmol m^{-2} s^{-1}) whilst its light saturation point is high (1550 μmol m^{-2} s^{-1}) (Fig. 7-2). This indicates that *I. sinensis* is a plant with a broad light ecological amplitude that can adapt to both weak and strong light. These results are consistent with those derived from studies on communities.

Photosynthetic rates increase as water depth decreases. The photosynthetic rates of the middle and low water levels differ very little, although they are much higher than those observed at high water levels. The number of leaves and leaf length are largest at low water levels and smallest at high water levels. Meanwhile, leaf diameter shows the opposite trend. This could be due to the fact that at high water levels, the leaves require a more developed aeration system to carry out gas exchange. At medium water levels, leaf length and leaf width are significantly different from those at low water levels, although they are not significantly different from those at high water levels. There are significant differences in the number of leaves across the three levels (Fig. 7-3).

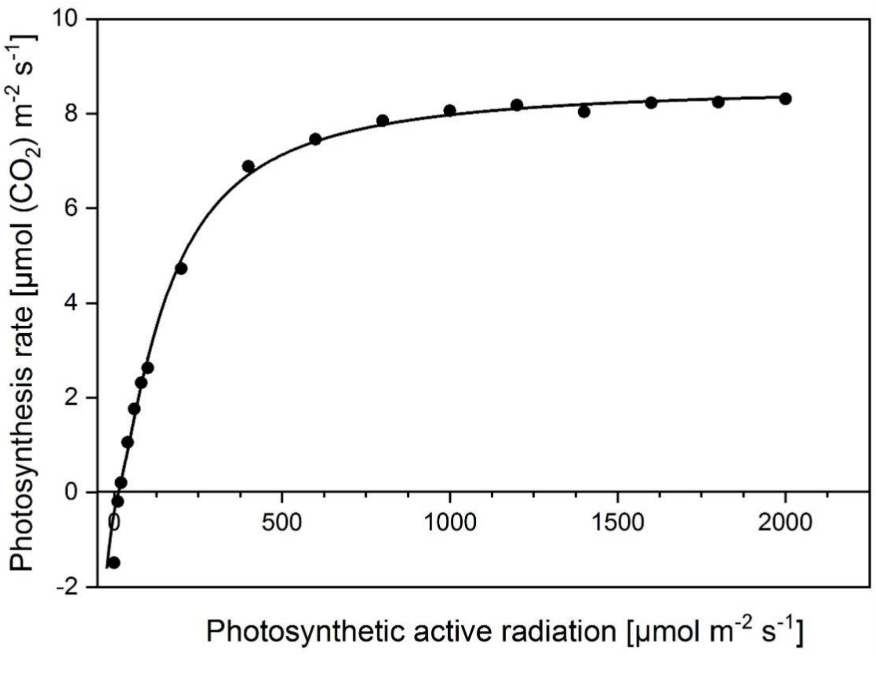

Fig. 7-2 The light response curve of I.sinensis

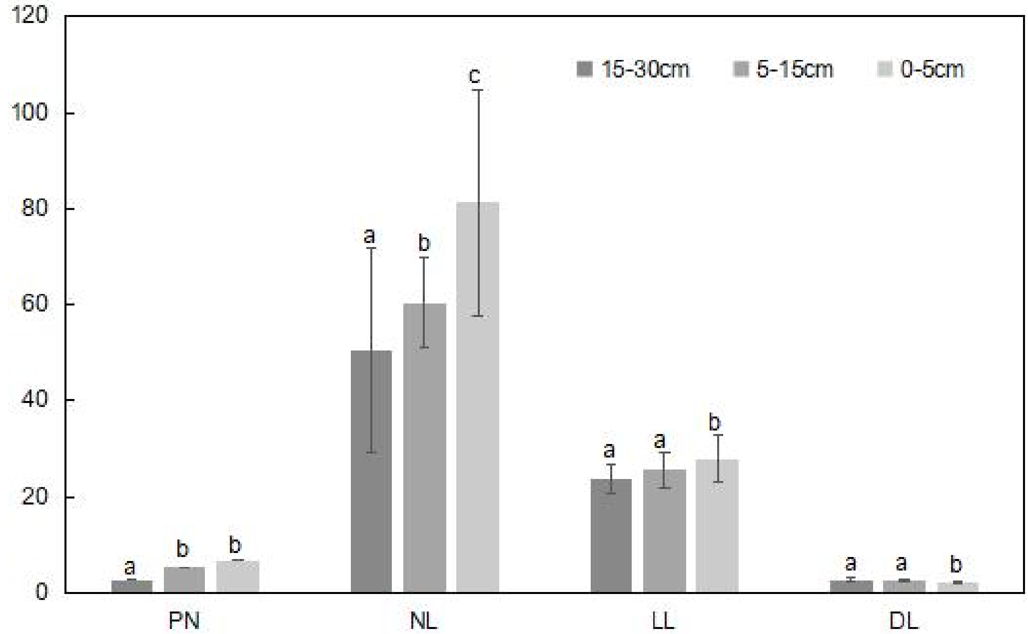

Fig. 7-3 The Photosynthetic rate and leaf features of *I. sinensis* in different water levels. PN: Net photosynthetic rate (μmol ($CO2$) m^{-2} s^{-1}), NL: Number of leaves, LL: Length of Leaves (cm), DL: Diameter of leaves (cm).Data are presented as mean ± standard error, and statistical significance was determined at α = 0.05. Different letters express significantly different between water depth treatments

7.3.3 Growth features of *I. sinensis* in different ammonium-nitrogen concentrations

At N0.15 treatment, both the length and number of leaves of *I. sinensis* had increased by the end of the experiment, and the number of leaves had increased significantly. At N0.5 treatment, the length and number of leaves did not change significantly. At N1.0 and N1.5 treatments, both the length and number of leaves were significantly reduced. From these results, it can be seen that an ammoniumnitrogen concentration either too high or too low can inhibit the growth of *I. sinensis*. Meanwhile, the number of newly germinated leaves was significantly different under all ammonium-nitrogen conditions. The number of newly germinated leaves was the greatest at N0.15 treatment. As ammonium-nitrogen concentration increases, the number of newly germinated leaves gradually decreased. Except at N1.0 and N1.5 treatments, where the differences between the different ammonium-nitrogen concentrations were significant (Table 7-2).

Table 7-2 Leaf features in different ammonium-nitrogen concentrations

Stage	Treatments	Leaf length (cm)	Number of leaves	Number of new leaves
the begin of the experiment	CK	13.00±2.24a/A	16.83±4.33a/A	-
	$N_{0.15}$	13.17±0.83a/A	17.17±4.64a/A	-
	$N_{0.5}$	13.33±1.53a/A	17.50±6.82a/A	-
	$N_{1.0}$	13.17±2.25a/A	17.17±6.24a/A	-
	$N_{1.5}$	13.67±2.13a/A	16.67±3.73a/A	-
the end of the experiment	CK	12.33±0.97b/A	14.33±6.05c/B	1.50±0.59b
	$N_{0.15}$	13.33±2.18a/A	19.33±4.89a/B	2.17±0.53a
	$N_{0.5}$	13.00±1.61a/A	17.17±3.71b/A	1.27±0.29b
	$N_{1.0}$	12.17±0.83b/B	14.83±3.42c/B	0.83±0.53c
	$N_{1.5}$	11.50±1.99c/B	14.67±4.71c/B	0.67±0.57c

The $N_{0.15}$, $N_{0.5}$, $N_{1.0}$, $N_{1.5}$ represent the initial ammonium-nitrogen concentrations of 0.15mg/L, 0.5mg/L, 1.0mg/L, 1.5mg/L, respectively. Data are presented as mean ± standard error, and statistical significance was determined at α =0.05. Different letters in each column express significantly different results between ammonium-nitrogen concentrations treatments in the same experimental stage (a, b, c) or between different experimental stages under the same ammonium-nitrogen concentration treatment (A, B).

7.3.4 Potential habitats for *I. sinensis* in urban wetlands

1) Types of wetlands in the Hangzhou urban area

According to the investigation, the wetlands in the study area can be divided into 3 major categories and 6 minor categories (Fig. 7-4, Table 7-3). Amongst all the categories, permanent rivers account for the largest proportion. This is mainly because the Qiantang River flows through the area and accounts for a large proportion of the water area in the region. Following the permanent rivers are the urban constructed water landscapes and entertainment, which result from the improvements made to the water environment in Hangzhou in recent years. Reservoirs and aquatic farms account for a relatively small proportion, at less than 1%. This is due to the gradual transformation of productive water into waterscapes through the urban development process.

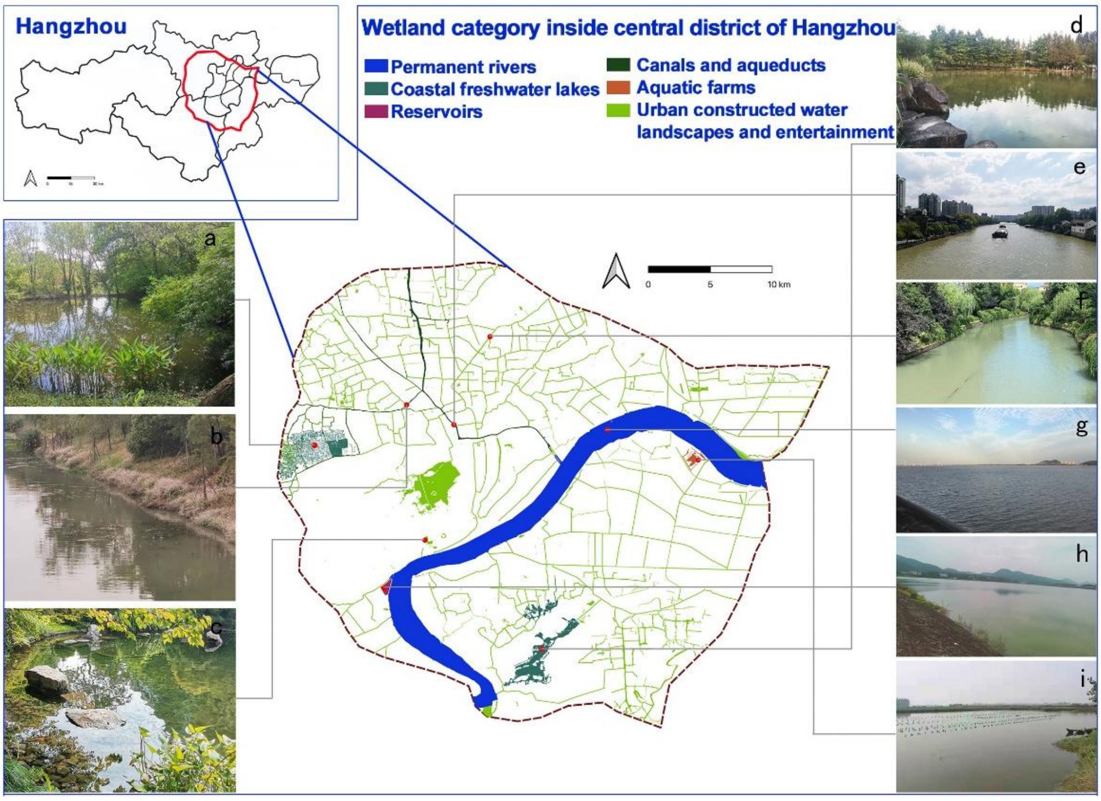

Fig. 7-4 Types and appearances of different unban wetlands of study area. Some suitable habitations (a–c) and unsuitable habitations (d–i) for *I. sinensis* were showed

Table 7-3 Types of urban wetland and suitable habitat area in Hangzhou

Major category	Minor category	Area (ha)	Proportion to total water area	Suitable area(ha)	Proportion of suitable area
River wetland	Permanent river	5417.9	58.57%	0	0%
Lake wetland	Costal freshwater lake	1037.9	11.22%	26.47	2.55%
Constructed wetland	Reservoir	39.6	0.43%	0	0%
	Canal and aqueduct	322.3	3.49%	4.06	1.22%
	Constructed water landscapes and entertainment	2382.7	25.76%	114.85	4.82%
	Aquatic farm	49.2	0.53%	0	0%
Total		9249.6	100%	145.38	1.57%

2) Calculation of potential habitat

Among the water bodies studied, permanent rivers, reservoirs, and aquatic farms are not suitable habitats for *I. sinensis* due to their high water velocity, hardening of water quality along the shoreline, and excessively high ammonia-nitrogen concentration, respectively. In contrast, the permanent freshwater lakes and urban artificial water landscapes and entertainment areas offer some suitable habitats (Fig. 7-5). As shown in Table 3, the total area of suitable wetland habitat in the region is 145.38 ha, of which the suitable area from urban artificial water landscapes and entertainment accounts for the highest of 79%, reaching 114.85 ha. Meanwhile, the suitable area of canals and aqueducts accounts for the smallest proportion (2.79%), at just 4.06 ha.

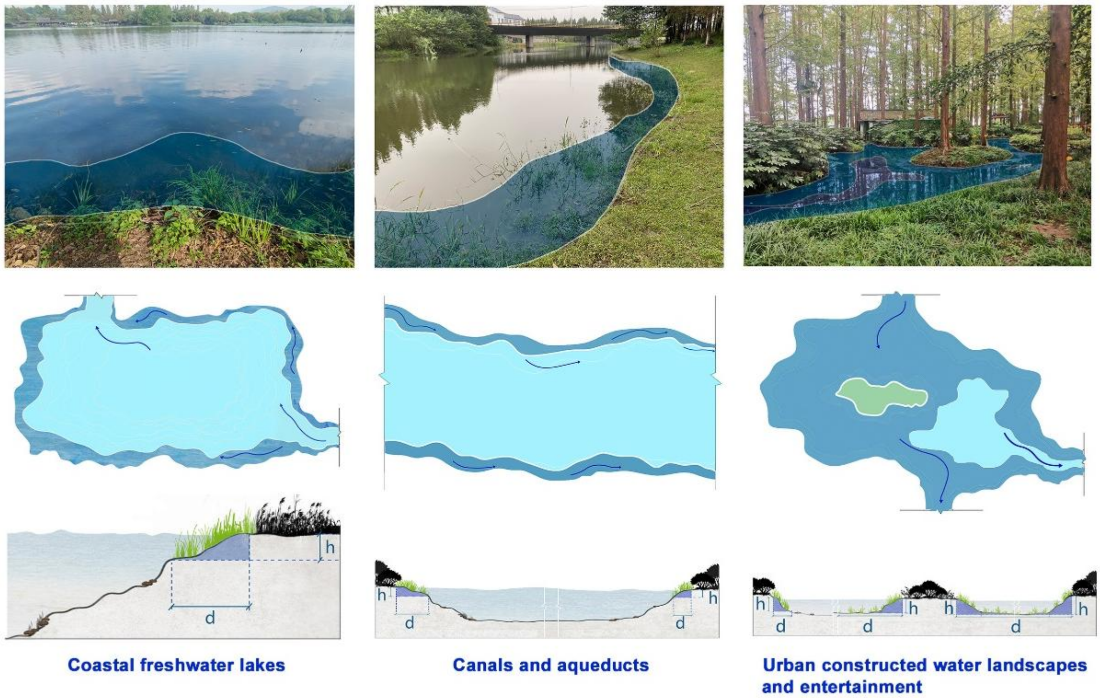

Fig. 7-5 The suitable habitats for *I. sinensis* in different urban wetlands. Rows represents three different urban wetlands respectively and columns indicate the appearance, plan and cross-sectional view of each urban wetland, respectively. The dark blue represents the suitable habitations. The arrows represent the direction of water flow. The letter h represents the suitable water depth and the letter d represents the distance from the farthest end of the suitable habitations to the shore

7.4 Discussion

7.4.1 Aquatic habitat preference of *I. sinensis*

The main factors affecting the growth of aquatic plants are water depth, water quality, flow velocity, and temperature[47]-[50]. Changes in the aquatic environment significantly affect the growth and spread of *I. sinensis*[26]. In this study, *I. sinensis* is found to have better growth potential at lower water levels. This is consistent with the fact that, in its natural habitat, *I. sinensis* is typically found in shallow waters and very rarely in deep waters. Thissuggests that *I. sinensis* prefers aquatic habitats with lower water levels. In the field survey, the water velocity recorded in *I. sinensis* habitats was very low, at less than 0.04 m/s. Notably, *I. sinensis* is not found in neighboring areas where the velocity is higher. Previous studies have shown that the leaves of submerged plants growing in water with a faster water velocity will become soft[51]. The leaves of I.sinensis are fragile and may damage easily in habitats with faster water velocity. In addition, the instability of the soil matrix and poor soil nutrition in the habitats with fast water velocity will also affect the survival of I.sinensis[30]. The size of microspores of I.sinensis are relatively small (23−32 μm) [52][53], which is very difficult to stay for a long time in fast water velocity. The maturation time of the macrospores and the microspores also may not be exactly the same[54]. It will reduce the chances of successful fertilization of megaspores and microspores. In some examples among endangered seed plants such as Carpinus putoensis[55] and Parrotia subaequalis[56], the pistil and the stamen during the flowering period have different maturity periods, resulting in a low seed setting rate, which is one of the major reasons for endangerment. Therefore, the habitats with low water velocity may be more suitable for the growth and expansion of *I. sinensis* than fast water velocity. Flow velocity also exerts some influence on the physiology and growth of aquatic plants. Within the tolerance range, at a low velocity (0–0.01 m/s), an increase in velocity can promote the photosynthetic rate of aquatic plants, whilst a reasonable water velocity can enhance the uptake of nutrients, inorganic carbon sources, and oxygen by the leaves of submergent plants[57]. Meanwhile, higher water velocity hinders the growth of aquatic plants and reduces the growth rate of submergent plants[58]. When carrying out investigations, chlorophyll is an important indicator that can reflect photosynthetic efficiency[50]. The study of the correlation between chlorophyll content of spores of Sargassum integerrimum (an aquatic plant) and water velocity revealed that chlorophyll content is highest when the velocity is between 0.01 and 0.04 cm/s[59]. Therefore, within the appropriate velocity range of *I. sinensis*, controlling and reducing the water velocity may benefit the growth and protection of this species. Furthermore, different aquatic plants tolerate nutrient salt concentrations to varying degrees. When the nutrient salt concentration reaches a certain level, aquatic plants will gradually die[60][61]. The increase in nitrogen content is the main factor leading to the eutrophication of water and an increase in nutrient salt concentration. In a simulated fertilization experiment, it was found that when exposed to the usual nitrogen concentration, the leaf respiration rate and net photosynthesis rate of *I. sinensis* in the vegetative growth stage decreased significantly. The possible reason for this is that chemical fertilizers hinder amino acid synthesis in leaves[62]. A comparative study on the growth of *I. sinensis* under three different nutrient concentrations found that the growth potential is better at low ammonia-nitrogen concentrations (0.5 mg/L), which is consistent with our conclusion. However, when the ammonia-nitrogen concentration exceeds 1.2 mg/L, the normal photosynthetic activities of *I. sinensis* are inhibited[31]. This finding is not entirely consistent with our conclusion that *I. sinensis* growth is affected when the ammonia-nitrogen concentration exceeds 0.5 mg/L. This could be related to the different designs of the gradient stage.

Moreover, nitrogen deposition has become one of the key contributors to urban pollution in the course of urbanization[63]. The increase in ammonia-nitrogen concentration in water negatively affects the growth of *I. sinensis*. In recent years, water quality in Hangzhou's urban wetlands has improved significantly. In 2018, the average ammonia-nitrogen concentration of urban rivers in Hangzhou was 1.14 mg/L, a marked decrease from the 1.28 mg/L measured in 2017. Additionally, the proportion of Class I-II surface waters with ammonia-nitrogen concentrations less than 0.5 mg/L had increased from 2.13% in 2011 to 17.23% in 2018[64]. If Hangzhou can continue to make further improvements in water quality, the city and its water spaces have the potential to provide greater habitats for *I. sinensis*.

7.4.2 Potential of introducing *I. sinensis* into urban wetlands

The protection of endangered species in urban areas is considered as an additional approach that can be employed to bolster in-situ conservation[65][66]. In recent decades, urbanization has accelerated worldwide[67], leading to the extinction of some endangered species. However, as these urban areas were previously where many endangered species were distrusted, their climates resemble the natural habitats of the endangered plants[36]. Therefore, the likelihood of successfully introducing new species and protecting them in these areas is high. In the 1960 s, *I. sinensis* was discovered in Jiuxi and Yunqi, both of which are located in the research region of the present study. In the following decades, *I. sinensis* was never rediscovered due to habitat changes. However, in recent years, as Hangzhou began to implement wetland protection programs, many wetland ecosystems have recovered. These programs have increased the area of wetlands and significantly improved the water quality, providing a prime opportunity to reintroduce *I. sinensis* to the area. Based on the proportion of suitable aquatic habitats in the different categories of wetlands, it can be calculated that 145.38 ha of water area is suitable for *I. sinensis* growth (Table 3). As urban areas continue to expand, a large number of wetlands have come to be included in urban areas, making wetlands one of the most common habitat types within urban areas. It is important to note that the habitat of urban wetlands is quite different from natural wetlands. As an important living area for humans, some environmental factors in urban wetlands can be easily controlled. This is useful as it allows humans to tailor the wetland environment to see the needs of introduced species. In this way, humans can create better habitat conditions for *I. sinensis* through appropriate interventions. Field studies have shown that light conditions have no influence on the distribution of *I. sinensis*, although some studies have shown that *I. sinensis* exhibits its highest carbon assimilation ability under 70% light conditions, which can promote the accumulation of photosynthetic products[34]. By controlling the light environment, we can provide a more suitable habitat for *I. sinensis*. As a typical r-strategist, *I. sinensis* produces a large number of spores to increase its reproduction rate. However, due to the influence of the water environment, the germination rate of *I. sinensis* is not high. Even those spores that do develop successfully, it often grow weakly due to their lack of competitive ability in the community while the surrounding common plants grow vigorously[26]. Usually, the weakly competitive species often cannot occupy the most advantageous niche in the community[68][69]. It may be one of the major reasons why the wild population of this species is difficult to expand[70].

Urban wetlands is under intensive managed in generally, that can provide suitable habitats and increase the survival rate of *I. sinensis* in urban wetlands by artificially creating, improving the water environment and purposeful plant cleaning to reduce interspecies competition. Urban landscape water bodies are generally maintained by the city management department. The routine maintenance included the planting and management of aquatic plants. Therefore, the introduction of endangered plants into urban wetland will not increase the extra cost. The main additional cost is the technical training for workers.

Although the wetlands in Hangzhou can provide *I. sinensis* with a considerable habitat area, they only account for a relatively small portion of the total wetlands in the city. Especially in the large urban waterscapes, the hardened shorelines might not provide suitable habitats for aquatic plants. On this basis, landscape designers should increase the proportion of natural shorelines in the management of urban wetlands to provide more natural habitats that are suitable for aquatic plant growth.

7.4.3 Significance of maintaining urban wetland biodiversity

Conservation programs for endangered species are governed by the principle of ’in-situ conservation: protecting the original habitat protects the species’. Implementation of in-situ conservation is a top priority. It is also readily apparent that the introduction of endangered plants into the city cannot replace in-situ habitat protection. Based on the unique characteristics of the urban environment, appropriate conservation methods for given endangered species should be explored as a complementary measure to in-situ habitat protection. Studies have shown that the introduction of endangered plants in urban areas can increase the abundance and evenness of urban plants[71], enhance the entertainment value of ecosystem services [72], realize social and cultural goals, such as landscape aesthetics and educational value[73], and promote public awareness of biodiversity conservation.

Based on *I. sinensis*’s preferred aquatic environment, we selected a suitable habitat (water depth 8 cm, velocity 0.02 m/s, and ammonia-nitrogen concentration 0.22 mg/L) in Hangzhou Botanical Garden to plant *I. sinensis* and the poster for public education have been set up beside the site where the plants of *I. sinensis* was planted. The public can obtain corresponding knowledge on biodiversity conservation while visit here. As observed, the *I. sinensis* grew well (Fig. 7-6). This research approach provides a new opportunity to protect other endangered aquatic plants and identify ecological refuges. Many cities in China such as Beijing, Shanghai, Nanjing, Hangzhou, Wuhan, and Guangzhou have introduced *I. sinensis* in their botanical gardens. By monitoring the status and dynamics of *I. sinensis* in urban wetlands, we can provide scientific evidence to assist with the future return of *I. sinensis* to natural wetlands. In addition, the goal of this study is to establish a method that uses urban habitats to protect endangered plants. This method is not only used to protect *I. sinensis* and only implement endangered plant protection in Hangzhou. We also hope that the results can provide theoretical support for the conservation of different endangered plants in other cities in the world.

Fig. 7-6 A suitable habitat of *I. sinensis* in Hangzhou Botanical Garden

7.4.4 Uncertainties of introducing *I. sinensis* to urban wetlands

Although urban wetland habitats provide sufficient potential habitats for *I. sinensis*, there are also some uncertainties that are present in the introduction process. First, aquatic plants introduced to urban wetlands are usually species with strong vigor that are highly valued for their visual appeal. However, as an indicator of the aquatic environment, the entertainment value of *I. sinensis* is not high and its growth vigor is relatively weak[32][26]. If there are no appropriate management and education measures implemented by the city government, these plants are very likely to be regarded as weeds and will subsequently be eradicated. Second, *I. sinensis* is sensitive to pollution. Chemical pesticides, even at low concentrations, can be used in maintenance to kill pests or control weeds[74]. The residues of these chemicals can make their way into the water and easily damage the plant. In addition, land use changes due to urban development alter wetland habitats, with the resulting nitrogen deposition in urban areas leading to high ammonium-nitrogen concentrations in water[75]. All of these factors can affect *I. sinensis* living conditions in urban wetlands. These negative impacts need to be investigated and addressed through further research and regulation. Fortunately, the reproduction problem of *I. sinensis* has been addressed by sporogenesis. This makes it feasible to carry out the study on the conservation of *I. sinensis* in urban wetlands by using artificially bred seedlings, instead of using plants directly introduced from the wild. This will be beneficial to protect the wild resources of *I. sinensis*. Overall, the scope of the present case study is relatively narrow, in that it exclusively aims to demonstrate that urban wetlands have the potential to provide habitats for *I. sinensis*. Successful implementation will require further empirical research to provide more data and observations.

7.5 Summary

Combining field research, physio-ecological experiments and remote sensing, this study analyzes *I. sinensis*'s preference for the water environments and the general conditions found in the wetlands of Hangzhou. The present research puts forward an effective method for the introduction of *I. sinensis* into the urban wetlands of Hangzhou. The potential wetland area in Hangzhou for *I. sinensis* introduction is also analyzed. The study showed that *I. sinensis* prefers shallow water, with a low velocity and low ammonia-nitrogen concentration environment. Hangzhou urban wetlands can be divided into 3 major categories and 6 minor categories. The total area of wetlands in Hangzhou is 9249.6 ha, of which 145.38 ha are suitable for *I. sinensis* planting. As the water environments in urban areas continue to improve, urban wetlands will have a greater potential to protect endangered plants in the future. Planting *I. sinensis* in urban wetlands is an effective step to assist in the protection of this species. Although the possibility and potential of introducing *I. sinensis* in urban wetlands are great, the characteristics of the plant and the city pose uncertainties to its protection. Therefore, appropriate regulations and standards should be designed and implemented to guide management and avoid any adverse impacts. Locating a suitable habitat is the initial step in protecting *I. sinensis* in urban wetlands. Further attention should be paid to the introduced plants' growth status and population dynamics following introduction to provide more data for their return to nature, which is also an important research topic.

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Chapter 8

CONCLUSION AND PROSPECT

CHAPTER EIGHT: CONCLUSION AND PROSPECT

8.1 Conclusion

Biodiversity is an important support for human survival and the basis for sustainable economic and social development. It is also an important evaluation index for the ecological health of human settlements, which is of great significance to the ecological balance and sustainable development of cities. Rapid urbanization has made a large number of natural wetlands classified into urban built-up areas and become an important part of urban ecosystems. Urban wetlands not only provide important ecological service functions for the city, but also create an aesthetically attractive space providing recreational opportunities for urban residents, which plays an increasingly important role in the urban ecosystem. Therefore, when the rapid development of cities leads to the rapid loss of biodiversity, it is necessary to establish scientific and reasonable urban wetland landscape designing strategies and methods to protect urban biodiversity. However, although more attention has been paid on the current urban wetland landscape planning and designing of biodiversity conservation, in practice, landscape designers often consider more from the perspectives of aesthetics and landscape art, while the awareness of biodiversity conservation is still lacking; the design methods consider more current landscape factors and lack long-term sustainability of biodiversity conservation; and subsequent management of biodiversity conservation is insufficient, etc. All of them result in the fact that realistic wetland landscape planning and designing of local biodiversity conservation is not ideal.

Based on the investigation of plant diversity, this study takes Hangzhou as the research object. Through the comparative analysis of plant diversity and ecological design techniques in three typical areas: Xixi Wetland, Tongjian Lake Wetland and Qingshan Lake Wetland respectively in urban core, urban fringe and urban suburban, this thesis explores the impact of ecological design on the health of wetlands, analyzes the internal relationship and influence pathways of urban wetland landscape ecological design in how to affect wetland plant diversity and human aesthetics. Thus, the theoretical framework of urban wetland landscape design based on biodiversity is established, and the paradigm of urban wetland landscape design in different regions is explored further, which provide scientific references for urban wetland landscape planning and designing.

The main work and results can be summarized as follows:

Chapter 1: REASEARCH BACKGROUND AND PURPOSE OF THE STUDY. The present situation of urban wetlands is investigated, and the significance of urban wetland to urban biodiversity protection is put forward. Through the analysis of the definition of both domestic and foreign urban wetlands, the research progress of urban wetland ecological restoration, the research progress of urban wetland plant diversity and wetland health, the research progress of urban wetland ecological design, and the research progress of urban wetland landscape evaluation, the shortcomings and prospects of the existing research progress are summarized, the research and methods of data analysis that can be used for urban wetlands are confirmed, and the main research contents, technical routes and innovations of this research are proposed.

Chapter 2: STUDY AREA AND METHODOLOGY. This chapter first introduces the overviews of Hangzhou, including geographical environment, climate, local resources and economy. Then, based on the urban transport circle, the research scope of urban core, urban fringe and urban suburban is divided, and the typical wetland cases in each area are described. The ecological environment foundation, protection and planning strategies, tourism development situation of three typical urban wetlands are expounded, and the advantages and existing problems of each urban wetland are pointed out. Finally, the methodology of the study is described, including data collection methods and data analysis methods.

Chapter 3: CHANGES IN PLANT DIVERSITY IN URBAN WETLANDS ALONG URBAN-RURAL GRADIENT IN HANGZHOU. This chapter analyzes the changes of plant diversity in urban wetlands in different regions and their influencing factors. Xixi Wetland has the most species of autophytes, and Tongjian Lake Wetland has the most species of cultivated plants. The cultivated plants introduced artificially affect the distance attenuation effect of Phytocommunity, which also leads to a certain convergence of plant diversity in the three urban wetlands. The introduction of exotic scenic species in Xixi Wetland and the management model which is tolerant to autogenous plants have created good conditions for improving species richness. It can become a model for urban wetlands to improve plant diversity. In terms of biodiversity conservation, the number of endangered plants protected in Xixi Wetland, located in the urban core, is as many as eight species. Utilizing urban wetlands to protect endangered plant is a good attempt to protect biodiversity. Influenced by the factors: the distance between wetland and urban built-up area, functional orientation of wetlands, the intensity of artificial disturbance and management mode, etc, the plant diversity of Xixi Wetland, Tongjian Lake Wetland and Qingshan Lake Wetland shows some differences.

Chapter 4: IMPACT OF ECOLOGICAL DESIGN ON PLANT DIVERSITY IN URBAN WETLANDS IN DIFFERENT REGIONS. This chapter uses the structural equation model to analyze the relevant factors and influencing pathways of how landscape ecological design techniques affect plant diversity in urban wetlands in three different regions. Affected by the distance between wetlands and urban built-up areas, the service function of wetlands and other factors, the ecological design techniques of Xixi Wetland, Tongjian Lake Wetland and Qingshan Lake Wetland show certain differences. The number of ecological design techniques applied in Xixi Wetland is significantly higher than that in Qingshan Lake Wetland and Tongjian Lake Wetland. Ecological design methods of three urban wetlands have had a significant impact on plant diversity. There are 10 ecological design factors in Qingshan Lake Wetland that have an important impact on plant diversity, while in Xixi Wetland and Tongjian Lake Wetland, there are 5 ecological design factors that do. There are 12 factors that have a significant impact: ecological conservation measures, degree of variation in inlet topography, change in terrain slope, permeable paving, rainwater garden, habitat diversity, plant community structure, plant adaptations, artificial plant species, water-wet plant species, invasive alien plant species, type and intensity of artificial disturbance. In the planning and designing of urban wetlands, special attention should be paid to adopting appropriate ecological design for wetlands with different urban areas and different service functions.

Chapter 5: URBAN WETLAND EVALUATION INDICATOR ESTABLISHMENT. This chapter evaluates three urban wetlands in estimation of the scenic beauty in wetlands, assessment of the health of wetlands, and comprehensive evaluation of wetlands. The results of estimation of the scenic beauty method show that the public's evaluation of the three urban wetland landscapes is consistent. SBE models of the three wetlands find that having high plant richness, harmonious color, sufficient cultural expression, and coordinated landscape elements helps to improve the scenic beauty in wetlands. While too many types of habitats may have a negative impact on the scenic beauty of the wetlands. Scientific and rational ecological design can not only improve scenic beauty of urban wetlands, but also enhance the diversity of plants in urban wetlands. The results of the comprehensively evaluating urban wetlands finds that the ecological function of the urban wetland landscapes is the most important factor in the comprehensive evaluation. Wetland parks in different regions show differences in their comprehensive evaluation ratings due to their geographical location, functional positioning, and planning and designing. Wetlands in urban core areas should give full play to the integrated value of ecological, economic and social functions; wetlands in urban fringe areas can focus on their economic functions, improve social functions and enhance the overall value of wetlands; and wetlands in urban countryside areas can give priority to their ecological functions in order to drive the development of economic and social functions with their ecological features.

Chapter 6: A FRAMEWORK STUDY ON THE ECOLOGICAL PLANNING AND DESIGN OF URBAN WETLAND LANDSCAPES BASED ON BIODIVERSITY. This section introduces the theory of landscape ecology and landscape ecological planning, and constructs a theoretical system that coordinates the complex relationship of "design-ecology-aesthetic". Through the analysis and optimization of the classical landscape framework, an Urban Wetland Biodiversity Landscape Design (UWBLD) framework is proposed, which consists of seven steps: interdisciplinary team, survey and assessment, goal setting, functional positioning, landscape ecological planning and design, comprehensive evaluation, and post-operation and supervision. After analyzing the characteristics of urban wetlands in different regions, a paradigm for landscape ecological planning and design of urban wetlands in different regions is proposed.

Chapter 7: AN EMPIRICAL STUDY: URBAN WETLANDS AS A POTENTIAL HABITAT

FOR AN ENDANGERED AQUATIC PLANT, *ISOETES SINENSIS*. This chapter takes *Isoetes sinensis* as a case study to explore the feasibility of introducing endangered plants into urban wetlands to identify potential habitats through field studies, eco-physiological experiments, and urban wetland surveys in the central district of Hangzhou, China. The water environmental preferences of *I. sinensis* and urban wetlands in Hangzhou are counted, and the potential of wetland areas that can be introduced is analyzed. The study demonstrates that *I. sinensis* can survive in habitats with a water depth less than 15 cm, a water velocity less than 0.04 m/s, and an ammonium-nitrogen content in water less than 0.5 mg/L. On this basis, 1.75% of the wetland (145.38 ha) in the central district in Hangzhou can serve as wetland habitats for *I. sinensis.* It provides an effective method for endangered *I. sinensis.* to introduce into Hangzhou urban wetland habitats. Empirical studies have shown that the improvement of urban wetlands in Hangzhou provides more ways the protection of urban biodiversity. With the management of urban water environments, urban wetland habitats will have a greater potential for protection in the future.

Chapter 8: CONCLUSION AND PROSPECT. The conclusion of the whole paper is clarified, and the future protection and utilization of urban wetlands are put forward.

To sum up, through the investigation and analysis of three typical wetlands in Hangzhou's urban core, urban fringe and urban suburban, this study finds that due to factors, such as the distance between the wetlands and the urban built-up area, the functional positioning of wetlands, the intensity of artificial disturbance and the management model, the plant diversity, ecological design, scenic beauty, wetland health, and comprehensive evaluation of wetlands in different regions are all different. What's more, ecological design will have a significant impact on plant diversity, scenic beauty, and wetland health. Based on the research conclusions above, an urban wetland landscape planning and designing framework about biodiversity protection-based is proposed, and the landscape ecological planning and designing paradigm of urban wetlands in different regions is proposed, in order to provide scientific references for urban wetland landscape protection and planning and designing.

8.2 Prospect

In this study, Hangzhou is used as an example. Three typical urban wetlands in different regions of the city are selected as the research objects. In the study of ecological design techniques, due to the limited number of samples, the factors that is not in the final model do not mean that they have no significant impact on plant diversity of urban wetlands. In further research, typical wetland cases can be added, and the research on the relationship between biodiversity factors can be expanded to more comprehensively explore the relationship between ecological design techniques and urban wetland biodiversity.

In the study of the scenic beauty estimation (SBE), the quantitative analysis of multiple influencing factors of landscape elements in the SBE subjective evaluation process should be added for different urban wetland types in the future, so as to find more factors that influence landscape vision, especially specific factors based on ecological design practices, and facilitate more targeted improvement of landscape visual quality from the planning and design perspective.

In the wetland evaluation, only the scenic beauty estimation (SBE) of the wetland landscape and the comprehensive evaluation of wetlands have been done. In further research, studies on the evaluation of wetland health and wetland ecosystem services can be added to assess the differences between urban wetlands in different regions in a more comprehensive way.

In the future, what needs further research and consideration are how to highlight the characteristics of wetlands in different regions through landscape ecological planning and designing, protect wetland plant diversity and differentiatedly utilize wetlands, which provide targeted scientific references for urban wetland landscape protection and planning and designing. In addition, locating a suitable habitat is the initial step in protecting endangered aquatic plant in urban wetlands. Further attention should be paid to the introduced plants' growth status and population dynamics following introduction to provide more data for their return to nature, which is also an important research topic.