基于生态安全格局理论的中国生态基础设施规划实践综述（1997~2019年）

Review of Ecological Infrastructure Planning Practices Based on the Ecological Security Pattern Theory in China (1997 ~ 2019)

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摘要

本研究梳理了北大景观和土人设计团队20余年来在生态安全格局理论指导下的生态基础设施规划设计项目，探索了生态安全格局理论在各生态类型区和特殊生境中，以及各种生态过程分析方法在实践中的应用及拓展。由于本研究涉及的近百个实践项目所处生态类型区不同，因此在将生态安全格局理论应用于生态问题时存在一定的地域性差异。然而，类似生境内的项目需要应对的重点生态问题存在共性。目前，该理论已从最初的面向生物栖息地保护的“试验性”理论，发展到包含所有重要生态过程及其子过程的庞大理论体系。本文重点关注生态安全格局理论在区域和城市尺度上的实践，试图梳理：1）当该理论应用至更广泛的生态类型区后，生态基础设施规划如何能够针对性地解决地方性生态问题，以及该理论在不同生态类型区中应用情况的异同；2）针对典型生境的规划，利用该理论来协调人地关系、寻求协同发展的方法；3）该理论在空间广度上的拓展对理解生态过程、建立生态安全子格局，以及更新分析技术的影响。本研究通过实证分析表明，不论是就方法论还是实践应用而言，生态安全格局理论均为我国生态文明建设做出了贡献，为国土空间规划提供了宝贵的技术支持和理论依据。

关键词

生态安全格局；生态基础设施；生态区划；生态问题；生物栖息地；中国生态文明建设

ABSTRACT

This paper reviews the ecological infrastructure planning practices by LA PKU and Turenscape over the past two decades, discussing the application and development of the ecological security pattern theory in different types of ecoregions and typical habitats, and that of ecological process analysis methods in practice. Nearly 100 studied projects employed this theory to address different local ecological problems. But similarities could be found regarding the key ecological issues among similar habitats. Far from mainly addressing habitat protection issues at its early stage, the ESP theory by now has expanded its application to all important ecological processes and sub-processes. This paper focuses on related application at urban and regional scales, attempting to summarize 1) approaches to solving local ecological problems via ecological infrastructure planning in a wider geographic range, and differences concerning the application modes in varied ecoregions; 2) ways to harmonize man–land relations and to achieve synergic development in typical habitats; and 3) influence brought by the wider spatial range to the application on the understanding of ecological processes, the establishment of sub-security-patterns, and the renewal of analysis techniques. The empirical analysis in this study suggests that both the methodology and application of the ESP theory contribute to China's ecological civilization construction, providing valuable technical support and theoretical basis for territorial spatial planning.

KEYWORDS

Ecological Security Pattern; Ecological Infrastructure; Ecological Zoning; Ecological Problems; Habitats; China's Ecological Civilization

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1 引言

“生态基础设施”（Ecological Infrastructure）概念诞生于20世纪下半叶由联合国教科文组织提出的“人与生物圈计划”，出发点在于促进生态的可持续性和城市的协同发展。[1]这一概念最早应用于荷兰的农业和渔业规划管理上，而后被推广至区域、国家和洲际尺度的更多领域。[2]与之类似的概念包括由美国学者提出的“绿色基础设施”（Green Infrastructure）。在区域及城市尺度上，绿色基础设施指可以“提供栖息地、防洪、清洁空气和水体的自然区域”；而在社区或场地尺度上，绿色基础设施则指“模拟自然的雨水管理系统”[3]。相关实践在美国马里兰州、明尼苏达州，以及芝加哥、波特兰等地区开展[4]。此后，一些学者仅在城市规划的语境中使用“绿色基础设施”一词[5]。欧盟则融合生态基础设施的视角，将绿色基础设施概念的延伸为“由自然和半自然区域及其他环境特征组成的战略规划网络，旨在提供广泛的生态系统服务”[6]。2020年2月，世界自然保护联盟发布“基于自然的解决方案”（Nature-based Solutions）[7]，对全球开展生态基础设施规划给予了指导[8]。

伴随着中国近几十年来的飞速发展，高强度的开发活动和不恰当的土地利用方式使脆弱的城市生态环境面临着巨大压力[9]。作为中国首位提倡建立城市生态基础设施的学者，俞孔坚将“生态基础设施”定义为“城市所依赖的自然生态系统，是城市及其居民能持续地获得自然服务的基础”[10]。基于需要将重要生态资源作为国土生命支持系统的关键性格局进行规划建设的基本共识，以及中国生态系统亟需有效保护的时代背景，中国陆续开展了一系列关于生态安全格局和生态基础设施建设的理论研究及实践。

1995年，俞孔坚首次提出“生态安全格局”（Ecological Security Pattern，ESP）理论，并引入此前生态规划途径中常被忽略的水平生态过程分析作为景观规划的支撑[11]。生态安全格局以保护整个生态系统而非个别要素为出发点，与当时国际上对于生态基础设施网络建设的普遍认知相契合。在2005年浙江台州的生态基础设施规划中，ESP理论被首次用于系统性的生态基础设施规划[12]，在洪水、生物、文化遗产和游憩4个景观子系统，以及宏观、中观、微观三个景观尺度中均充分展现了巨大的实践应用潜力[13]。此后，通过在北京、武夷山等地实施的生态基础设施规划，ESP理论得到了进一步实践和论证[14][15]，逐渐成为系统性的方法论，迄今已直接指导了北大景观①和土人设计团队在国内的近百个生态规划实践。

① “北大景观”是对1997年成立的北京大学景观规划设计中心、2003年在中心基础上成立的北京大学景观设计学研究院，以及2010年在研究院基础上成立的北京大学建筑与景观设计学院研究团队的简称。北大景观与土人设计在景观规划与设计实践中长期保持密切合作。

① "LA PKU" is a collective name short for the research team of the College of Architecture and Landscape of Peking University founded in 2010, which was developed from the Center for Landscape Architecture and Planning of Peking University established in 1997 and then the Graduate School of Landscape Architecture of Peking University founded in 2003. LA PKU has a long-term and close collaboration with Turenscape in landscape planning and design practice.

1 Introduction

The concept “ecological infrastructure” (EI) is part of the Man and the Biosphere Programme proposed by UNESCO in the second half of the 20th Century, aiming to propel ecological sustainability and synergic urban development.[1] It was first applied in agriculture and fishery planning and management in the Netherlands, and then promoted across scales, from regional, national to intercontinental.[2] A similar concept is “green infrastructure” (GI) proposed by American scholars—at urban and regional scales, GI refers to natural areas that provide diverse habitats, flood protection, and clean air and water; at the community or site level, it refers to the rainwater harvesting system that stimulates the nature[3]. Related practices have conducted in Maryland and Minnesota, as well as Chicago and Portland in the USA[4]. Afterwards, the term of GI has only been discussed in the field of urban planning in academia[5]. More specifically, European Union defines GI based on the concept EI as “a strategic planning network composed of natural and semi-natural areas and other environmental features, aiming to provide ecosystem services at all spatial scales.”[6] In February 2020, the International Union for Conservation of Nature launched standards for Nature-based Solutions[7], offering guidelines on worldwide ecological infrastructure planning[8].

In China, intensive land development and improper land use in the past several decades pose much pressure to the fragile urban ecological environment[9]. Yu Kongjian, the first scholar who advocated the promotion of EI construction in cities in China, defines EI as a natural ecosystem that supports a city’s operation and the source of natural services continuously provided for the city and urban residents[10]. Upon the consensus that key ecological resources are pivotal patterns for the life supporting system at territorial scale, and that China’s ecosystems have seen a critical deterioration, China launches a series of research and practice of ecological security pattern planning and EI construction.

In 1995, Yu first proposed the concept of Ecological Security Patterns (ESP) and introduced the analyses of horizontal ecological process that was often overlooked in traditional ecological planning, as the basis for landscape planning[11]. The ESP theory emphasizes ecosystem conservation from a holistic perspective instead of individual ecological factors, coinciding with the international conventional understanding on EI network construction. In 2005, EPS theory was first applied in the systematic EI planning of Taizhou, Zhejiang Province in China[12], which consisted of four sub-systems of landscape (flood, biological, cultural and heritage, and recreational), and demonstrated the potential of EPS at macro-, meso-, and micro-scales[13]. More practice cases in Beijing, Wuyishan of Fujian Province, and other Chinese cities have further validated the EPS theory[14][15] and developed systematic approaches, including the nearly 100 ecological planning projects practiced by LA PKU① and Turenscape.

2006年，俞孔坚向国务院总理提出构建国土生态安全格局的建议[16]，并得到批复，由国家环境保护部主导的国土生态安全格局的规划研究和此后的生态保护红线划定工作自此开始[17]。2012年，中共十八大报告陈述了国土空间开发格局在生态文明建设中的意义[18]，提出“加快实施主体功能区战略，推动各地区严格按照主体功能定位发展，构建科学合理的城市化格局、农业发展格局、生态安全格局”的发展战略[19]。2013年，中共十八届三中全会提出了“划定生态保护红线”的具体要求[20]，并肯定了生态安全格局在生态基础设施和国土安全研究方面所具有的重要意义，国土空间规划工作自此逐步展开。2017年，中共十九大报告指出，应坚持人与自然和谐共生，建设生态文明是中华民族永续发展的千年大计[21]。为了进一步解决自然资源管理不到位、空间规划重叠等问题，2018年国务院机构改革成立自然资源部以统筹相关工作，自此中国进入了生态文明全面建设阶段。ESP理论中的生态系统格局—过程耦合原理为国土空间规划中的垂直评价工作提供了水平生态过程的科学补充，与之对应的源地—廊道—战略点空间组织原则[22]为全过程统筹工作提供了系统性流程和重点工作内容指引，被广泛应用于国土空间规划中的生态系统治理和生态保护修复工程[23][24]。

20余年来，基于ESP理论的生态基础设施规划实践所覆盖的生态类型区种类、生态过程的多样性，以及理论本身等都有所拓展，影响了政策的顶层设计。尽管如此，相关实践的梳理和总结仍然较为匮乏。本文将首先概览ESP理论指导下的生态基础设施实践项目，然后从不同角度解读在不同地理区域中ESP理论的应用，随后分类介绍ESP理论实践对特定生态过程的拓展和方法探索，最后进行总结和展望。

2 生态安全格局理论指导下的生态基础设施规划实践应用概述

在生态安全格局理论形成及应用的过程中，北大景观和土人设计团队积累了大量的实践经验。本文筛选取其中自1997年至2019年主动应用ESP理论并具备较完整ESP理论应用框架的城市及区域尺度项目（以下简称“ESP项目”）为研究对象。其中，约93%的项目面积超过10km²，半数以上面积超过100km²（这已属城市总体规划范畴）；面积不足10km²的项目一般为重点河道、绿道区域规划，属于城市总体规划特别专题的范畴（图1）。

项目实践覆盖了中国广大地区，从东部沿海地区到西部的乌鲁木齐，从南端的珠三角地区到北部的内蒙古自治区及东北地区。上述ESP项目在浙江、安徽、山西、北京、辽宁等省市分布较多。此外，在市级

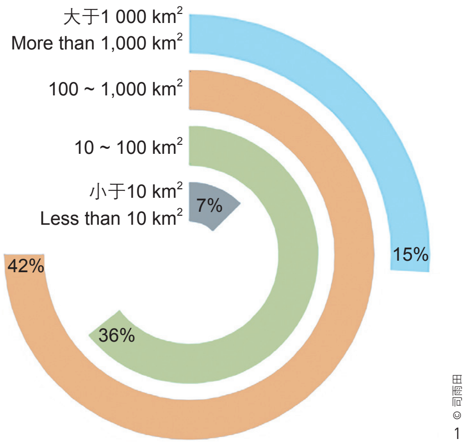
In 2006, the Prime Minister of the State Council of PRC approved Yu's proposal on the construction of national ecological security patterns[16], planning research on national ecological security patterns and ecological conservation redline delimitation led by former Ministry of Environmental Protection of China were launched[17]. In 2012, the Report to the Eighteenth National Congress of the CPC stated the significance of geographical space development in setting up a system for ecological progress[18], proposing to “ensure the speedy implementation of the functional zoning strategy and require all regions to pursue development in strict accordance with this strategy, and advance urbanization, agricultural development and ecological security in a scientific and balanced way”[19]. In 2013, the Third Plenary Session of the 18th Central Committee of the CPC put forward the specific requirements in delimiting the ecological conservation redline[20] and highlighted the significance of ESP to the research on EI and territorial security, signifying the beginning of territorial spatial planning. In 2017, the Report to the Nineteenth National Congress of the CPC pointed out that humans should develop in harmony with nature and building an ecological civilization is vital to sustain the Chinese nation's development[21]. Later in 2018, China's Ministry of Natural Resources was established to cope with the issues of inadequate natural resource management and overlapped spatial planning, propelling the nationwide ecological civilization construction. Upon the ESP theory, the ecosystem pattern–process coupling principle provides a horizontal-ecological-process perspective for territorial spatial planning, and the source-corridor-point spatial organization principle[22] helps guide the whole-process workflow and key tasks in ecological protection practice. These principles now have been widely applied in ecosystem protection and ecological conservation projects[23][24].

ESP-based EI planning projects over the past two decades cover a wide range of ecological area types and processes. As the theory improves, it has influenced the top-down policymaking. Since there is little research that reviews on related practice, this paper sorts out the EI planning projects guided by ESP theory, examines its application in different geographic regions, and discusses how practice of varied types enrich the exploration from methods to the mechanism of ecological processes. Summary and prospects in the very field are made as well.

2 Review on EI Planning Practice Guided by ESP Theory

During the development and application of ESP theory, LA PKU and Turenscape have gained much experience from their years of practice. This paper studies the projects completed during 1997 to 2019 (ESP projects hereafter) which initiatively applied ESP theory and utilized a relatively complete framework at urban or regional scales. About 93% of the projects cover an area of over 10 km², and half of them over 100 km² (as urban master planning cases); and projects of less than 10 km² are often key river corridor or greenway planning (as specific master planning cases) (Fig. 1).

The studied ESP projects distribute across the country, from eastern coastal areas to Urumchi in the west, and from the Pearl River Delta in the south to Inner



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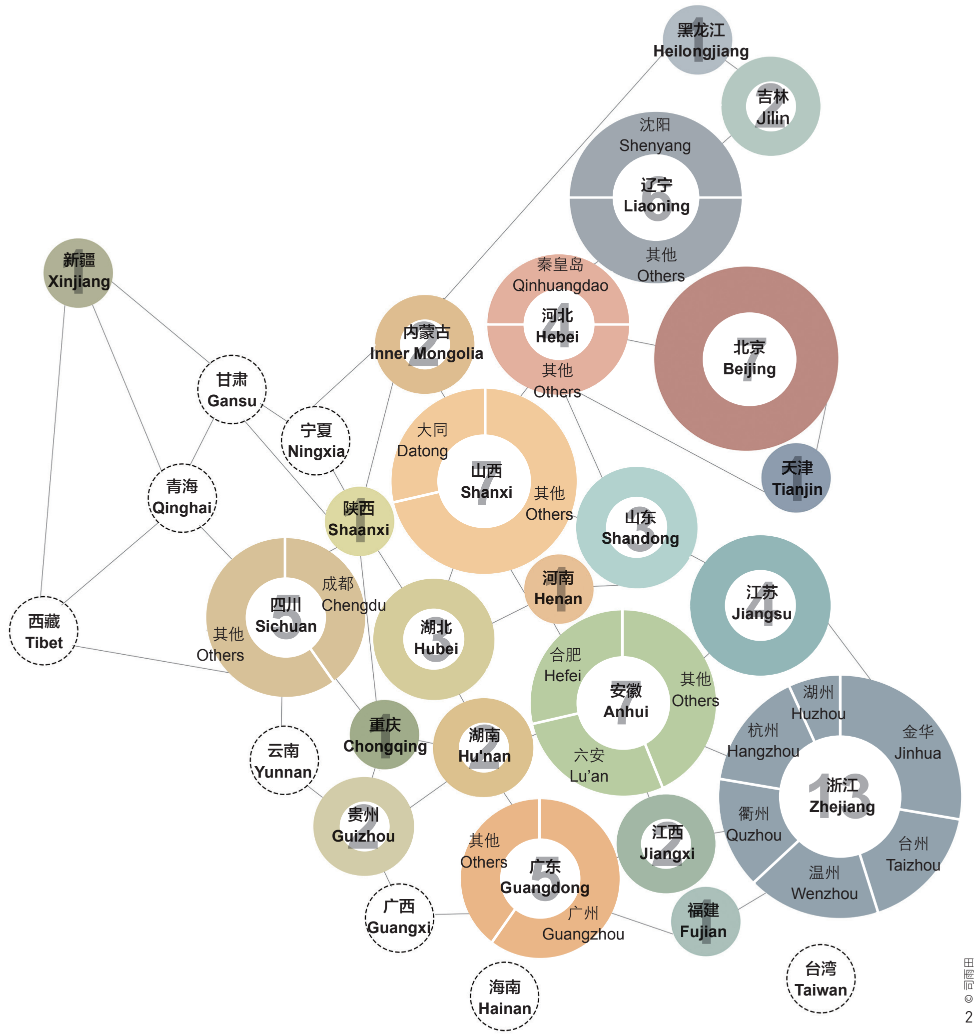

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1. ESP项目面积占比图示
2. ESP项目的市域分布图（图中仅展示项目数量为1以上的城市）

1. Proportional diagram of ESP project areas
2. City-level distribution map of ESP projects
(cities shown in the image are those with more than one ESP projects)

范围内，金华市、沈阳市和广州市拥有较多ESP项目（图2）。总体来看，东部地区的项目明显多于中西部地区，体现出显著的经济发展需求牵引特征。

3 生态基础设施规划项目覆盖的生态系统类型、主要生态问题及解决方案

景观ESP理论虽然在提出之初仅以广东省丹霞山这一特定案例为研究对象，但其应用已经拓展到更广泛的生态地理地带[25]。然而，不同生态地区的自然地理基础、主导生态过程，以及人类活动压力类型和水平存在差异，它们各自的主要生态问题必然各不相同，因此需要提出针对性的解决方案。鉴于傅伯杰等人[26]提出的中国综合生态区划在自然区域划分的基础上重点考虑了人类活动的影响，而且与生态基础设施规划的目标相契合，因此本文参考这一区划进行归类分析（表1）。本文选取的项目覆盖了中国过半的生态区划类型。

Mongolia and northeastern China, with clusters in Zhejiang, Anhui, Shanxi, Beijing, and Liaoning. At the city level, Jinhua, Shenyang, and Guangzhou have a greater amount of ESP projects (Fig. 2). Overall, more ESP projects were implemented in eastern China than in central and western China, reflecting the close influence by regional economic development needs.

3 Ecosystem Types, Main Ecological Problems and Solutions Concluded From ESP Projects

Although ESP theory was first developed during the research of Danxia Mountain in Guangdong Province, it has been employed in other ecoregions seeing a wider geographic range[25]. Each ecoregion is special in respect of physiographic condition, dominant ecological process, and type and intensity of human activities, thus faces with varied main ecological problems that require different solutions. This research employed the ecological zoning from *Study on Ecological Regionalization in China* proposed by Fu Bojie et al.[26] to make an overall review of the natural conditions, human intervention, and EI planning goals of the ESP projects in each ecoregion (Table 1). The studied ESP projects roughly cover over half of the ecoregions in China.

表1：ESP项目所涉及生态区划信息统计

Table 1: Ecological zone information involved in the ESP Projects

生态区划 Ecological zone		年均降水量（mm） Mean annual precipitation (mm)	区内海拔（km） Elevation in the region/district (km)	主要生态问题 Main ecological problem								主要生态子格局 Main ecological sub-security-pattern				
生态地区 Ecoregion	生态子区 Ecodistrict	0 500 1000 1500 2000	0 1 2 3 4 5	洪涝灾害 Floods	水质污染 Water pollution	水资源短缺 Water shortage	地质及自然灾害 Geological and natural disasters	水土流失 Soil and water loss	风沙、土地沙化 Sandstorm and land desertification	土壤盐渍化 Soil salinization	生物栖息地减少 Biological habitat loss	水安全格局 Water	生物安全格局 Biological	文化游憩安全格局 Cultural and recreational	视觉安全格局 Visual	地质灾害安全格局 Geological disaster
温带湿润针阔混交林生态地区 Temperate Humid Mixed Coniferous and Broad-Leaved Forest Ecoregion	长白山针阔混交林生态区（1a） Ecodistrict of Changbai Mountains Mixed Coniferous and Broad-Leaved Forest (1a)			□	□	□	□	□	□	□	□	◐	◐	◐	○	◐
	东北平原东部农业生态区（1b） Eastern Agricultural Ecodistrict of Northeast Plain (1b)			□	□	□	□	□	■	■	□	●	◐	◐	◐	◐
暖温带湿润、半湿润落叶阔叶林生态地区 Warm Temperate Humid and Semi-Humid Deciduous Broad-Leaved Forest Ecoregion	环渤海城镇及城郊农业生态区（2a） Agricultural Ecodistrict of Urban and Suburban Area around the Bohai Sea (2a)			□	■	■	□	□	□	□	□	●	●	●	◐	◐
	华北山地落叶阔叶林生态区（2b） Ecodistrict of Deciduous Broad-Leaved Forest in North China (2b)			□	□	□	□	■	□	□	□	◐	◐	◐	●	●
	黄淮海平原农业生态区（2c） Agricultural Ecodistrict of North China Plain (2c)			■	□	■	□	□	□	□	□	◐	◐	◐	○	◐
	胶东半岛落叶阔叶林生态区（2d） Ecodistrict of Deciduous Broad-Leaved Forest in Jiaodong Peninsula (2d)			□	□	□	□	□	□	■	□	●	●	●	◐	○
	汾渭河谷农业生态区（2e） Agricultural Ecodistrict of Fenhe River–Weihe River Valley (2e)			□	□	□	□	□	■	■	□	◐	●	●	○	◐
	黄土高原水土流失敏感区（2f） Sensitive Area of Soil and Water Loss in Loess Plateau (2f)			□	□	■	□	■	■	□	□	●	●	○	○	●
亚热带湿润常绿阔叶林生态地区 Subtropical Moist Evergreen Broad-Leaved Forest Ecoregion	秦巴山地常绿－落叶阔叶林生态区（3a） Ecodistrict of Evergreen–Deciduous Broad-Leaved Forest in Qinling Mountains and Ta-pa Mountain (3a)			□	□	□	□	■	□	□	□	●	●	●	●	●
	成都平原农业生态区（3b） Agricultural Ecodistrict of Chengdu Plain (3b)			□	■	□	□	■	□	□	□	●	●	●	◐	◐
	三峡库区敏感生态区（3c） Sensitive Eecodistrict of the Three Gorges Reservoir (3c)			□	□	□	■	■	□	□	■	●	●	●	○	●
	长江中游平原农业湿地生态区（3d） Agricultural Wetland Ecodistrict in the Plain of Mid-Yangtze River (3d)			■	■	□	□	□	□	□	■	●	●	◐	○	○
	大别山、天目山常绿阔叶林生态区（3e） Ecodistrict of Evergreen Broad-Leaved Forest in Dabie Mountains and Tianmu Mountain (3e)			□	□	□	□	■	□	□	□	●	●	◐	○	○

续表见下页 / Continued

表1：ESP项目所涉及生态区划信息统计

Table 1: Ecological zone information involved in the ESP Projects

生态区划 Ecological zone		年均降水量（mm） Mean annual precipitation (mm)	区内海拔（km） Elevation in the region/district (km)	主要生态问题 Main ecological problem								主要生态子格局 Main ecological sub-security-pattern				
生态地区 Ecoregion	生态子区 Ecodistrict	0 500 1000 1500 2000	0 1 2 3 4 5	洪涝灾害 Floods	水质污染 Water pollution	水资源短缺 Water shortage	地质及自然灾害 Geological and natural disasters	水土流失 Soil and water loss	风沙、土地沙化 Sandstorm and land desertification	土壤盐渍化 Soil salinization	生物栖息地减少 Biological habitat loss	水安全格局 Water	生物安全格局 Biological	文化游憩安全格局 Cultural and recreational	视觉安全格局 Visual	地质灾害安全格局 Geological disaster
亚热带湿润常绿阔叶林生态地区 Subtropical Moist Evergreen Broad-Leaved Forest Ecoregion	长江三角洲城镇及城郊农业生态区（3f） Agricultural Ecodistrict of Urban and Suburban Areas in the Yangtze River Delta (3f)			□	■	□	□	□	□	□	□	●	●	●	◐	○
	浙闽山地常绿阔叶林生态区（3g） Ecodistrict of Zhejiang-Fujian Evergreen Broad-Leaved Forest in Mountainous Areas (3g)			□	■	□	■	■	□	□	□	●	◐	◐	◐	◐
	湘赣丘陵农业生态区（3h） Hu'nan-Jiangxi Hilly Agricultural Ecodistrict (3h)			□	□	□	□	■	□	□	■	●	●	◐	○	○
	黔桂喀斯特脆弱生态区（3i） Vulnerable Ecodistrict of Guizhou-Guangxi Karst (3i)			□	□	□	□	■	□	□	□	◐	◐	◐	○	◐
	珠江三角洲城镇及城郊农业生态区（3j） Agricultural Ecodistrict of Urban and Suburban Areas in Pearl River Delta (3j)			■	■	□	□	□	□	□	□	●	◐	◐	○	○
半干旱荒漠草原生态地区 Semi-Arid Desert Grassland Ecoregion	鄂尔多斯高原荒漠草原生态区（4a） Desert Grassland Ecodistrict of Ordos Plateau (4a)			□	□	□	□	□	■	■	□	●	●	●	○	○
	毛乌素沙地荒漠生态区（4b） Mu Us Desert Ecodistrict (4b)			□	□	■	□	□	■	□	□	●	●	○	○	●
半干旱草原生态地区 Semi-Arid Grassland Ecoregion	内蒙古高原东南缘农牧交错脆弱生态区（5a） Vulnerable Agro-Pastoral Ecodistrict in Southeastern Edge of Inner Mongolia Plateau (5a)			□	□	■	□	□	■	□	□	●	●	○	◐	●
干旱荒漠生态地区 Arid Desert Ecoregion	准噶尔盆地荒漠生态区（6a） Desert Ecodistrict of Junggar Basin (6a)			□	□	■	□	□	■	□	□	●	●	○	○	○
青藏高原森林、高寒草甸生态地区 Forest and Alpine Meadow Ecoregion in Qinghai-Tibet Plateau	青藏高原东部暗针叶林–高寒草甸生态区（7a） Ecodistrict of Dark Coniferous Forest-Alpine Meadow in Eastern Qinghai-Tibet Plateau (7a)			□	□	□	□	■	□	□	■	○	●	○	○	○

注

● 表示该子区内所有ESP项目均涉及某一子格局；
◐ 表示该子区内部分ESP项目涉及某一子格局；
○ 表示该子区内无ESP项目涉及某一子格局。

NOTES

● means all the ESP projects in the given ecodistrict include the specific sub-security-pattern;
◐ means part of the ESP projects in the given ecodistrict include the specific sub-security-pattern;
○ means no ESP project in the given ecodistrict includes the specific sub-security-pattern.

3.1 温带湿润针阔混交林生态地区

该地区的西界为大兴安岭的西坡，东部抵达国界线，是中国的丰水地区之一。长白山针阔混交林生态区（1a）降水丰沛、整体生境条件较为优越，但存在局部敏感生境。吉林省延吉市依据“一山两河一区”规划设计项目对布尔哈通河历史河道生态潜能的论证结果，拆除了在建橡胶坝，最大程度地恢复了历史河道的自然形态。而东北平原东部农业生态区（1b）开发较早，是中国主要的粮食生产基地，长期的垦荒和耕作使得土地质量严重下降。区内土地沙化、土壤盐渍化等现象日益严重[26]。沈阳棋盘山国际风景旅游开发区土地开发利用规划项目根据生态效益的评估，对保护用地内的具体构成进行协调，将山地上的耕地和园地恢复为林地。

3.2 暖温带湿润、半湿润落叶阔叶林生态地区

该生态区内的地貌类型包括黄淮海平原和辽河平原、辽东半岛和山东丘陵、西部和北部山地。除了胶东半岛落叶阔叶林生态区（2d）具有明显的海洋性气候特征外，其他子生态区——环渤海城镇及城郊农业生态区（2a）、华北山地落叶阔叶林生态区（2b），以及黄淮海平原农业生态区（2c）——属于黄河下游区域，大陆性气候特征显著，人口密度较大，地下水超采问题严重。

北京是2a子区内的重点城市，其城市发展对于京津冀城市群乃至全国都有重大意义，城市本身面临多种生态问题且生境敏感性较高。北京生态安全格局战略研究项目提供了具有多种生态系统服务的生态功能网络以全面解决北京的生态问题，该战略研究将“底线安全格局”作为城市空间发展的前提，并对未来可能出现的多种情境下的城镇空间扩张格局进行了综合协调模拟[27]。门头沟区位于北京城区西部山区，行政区划隶属于北京市，生态区划属于2b子区。其分区规划生态安全与空间管控专题针对地下水回补专门构建了地下水保护安全格局，同时还综合崩塌敏感性分析、泥石流敏感性分析、水土流失敏感性分析，回应了该区内突出的地质灾害问题。

山东省菏泽市城市绿地水系规划项目（2c）对涉及菏泽的黄河下游决口区进行了风险评价，发现该地区不仅面临上游洪水威胁，还可能由于超引黄河水造成黄河断流。最终，规划方案建立了水安全格局以保护和恢复城市河道和湿地坑塘水系的连续性及完整性[28]。胶东半岛落叶阔叶林生态区（2d）地势较低，常出现海水倒灌情况。威海城市景观风貌

3.1 Temperate Humid Mixed Coniferous and Broad-Leaved Forest Ecoregion

This ecoregion is ample of water resources, bordering from the west of Greater Khingan Mountains to China’s east end. Specifically, the Ecodistrict of Changbai Mountains Mixed Coniferous and Broad-leaved Forest (1a) is characterized with high precipitation and sound habitat conditions, but includes some habitats of high eco-sensitivity. In the “One Mountain–Two Rivers–One District” Planning project, an ecological potential research on the historic Buerhatong River in Yanji City, Jilin Province denied the on-going construction of the local rubber dam, which was then demolished to restore the natural river flow. The Eastern Agricultural Ecodistrict of Northeast Plain (1b) in this ecoregion suffers from soil impoverishment due to long-term land reclamation and farming, as well as severe land desertification and soil salinization[26]. The ESP project in this ecodistrict, i.e. the Planning for Land Development and Utilization in Qipan Mountain International Tourism Scenic Area in Shenyang, coordinated the land use in reserved areas by restoring forests from farmlands and orchards in the mountainous areas.

3.2 Warm Temperate Humid and Semi-Humid Deciduous Broad-leaved Forest Ecoregion

This ecoregion covers a variety of landforms from North China Plain, Liao River Plain, Liaodong Peninsula, Shandong Hills to western and northern mountains. Most of the ecodistricts within this ecoregion, for instance the Agricultural Ecodistrict of Urban and Suburban Area around the Bohai Sea (2a), the Ecodistrict of Deciduous Broad-Leaved Forest in North China (2b), and the Agricultural Ecodistrict of North China Plain (2c)—except for the Ecodistrict of Deciduous Broad-leaved Forest in Jiaodong Peninsula (2d) with marine climate—are located at the lower reaches of the Yellow River, having continental climate, with large population density and severe overexploitation of groundwater.

Beijing (mostly in 2a), the capital of the country and the leading city to the development of Beijing–Tianjin–Hebei Urban Agglomeration, suffers from multiple ecological problems and high habitat sensitivity. The project of Strategic Research on Beijing’s Ecological Security Pattern proposed an eco-function network to ensure the multiple ecosystem services, setting a “bottom-line security pattern” for urban development, while simulating the comprehensive coordination of the network under varied scenarios of urban growth[27]. Mentougou District in the western mountainous area of Beijing in 2b was confronted with high risk of geological disasters. The Special Subject of Ecological Security and Space Control for the district planning project established a groundwater security pattern to help recharge groundwater and to analyze collapse sensitivity, debris flow sensitivity, and soil and water loss sensitivity.

The Urban Green Space and River System Planning for Heze City of Shandong Province in Ecodistrict 2c assessed the river burst risk of the designated area in the lower reaches of the Yellow River and found that this area was threatened both by flood from the upper reach and flow cutoff caused by excessive water diversion from the Yellow River. The final planning proposed to form a water security pattern to protect and restore the continuity and integrity of river courses, wetlands,

研究项目对海潮淹没情况进行了模拟，并辨别出了最有利于缓解海潮威胁的湿地位置[29]。

而位于该生态地区内中西部的汾渭河谷农业生态区（2e）和黄土高原水土流失敏感区（2f）都是风沙侵蚀较严重的区域。山西省霍州市由于山地矿产开采，植被破坏和山地石漠化问题突出。山西省霍州市城区生态基础设施规划设计项目（2e）除了开展基础的生态安全格局分析外，还研究了场地的风环境，模拟出了市域主要风廊，这些区域应增加植被覆盖以减少风沙侵袭。

总体来说，基于ESP理论的实践几乎遍布了暖温带湿润、半湿润落叶阔叶林生态地区，并针对每个生态子区的核心生态问题给出了较好的回应。

3.3 亚热带湿润常绿阔叶林生态地区

该生态地区面积最大且包含最多的行政区。区内经济发展不平衡，气候多样，地貌类型复杂，山地、丘陵、盆地、高原，以及平原均有分布。山地丘陵区主要面临水土流失和地质灾害问题；沿海区台风及海潮问题突出；而平原区城市内涝及水污染问题频发。

这一地区内的山地丘陵生态子区较多，大都存在水土流失问题，但气候条件和下垫面的差异使得各生态子区内水土流失程度不同，面临的其他生态问题亦不相同。大别山、天目山常绿阔叶林生态区（3e）和湘赣丘陵农业生态区（3h）以低山丘陵盆地为主，雨量丰沛、自然环境良好。这两个子区中内的ESP项目并未过多关注水土流失和地质问题，而是将重点放在水生态过程分析上。秦巴山地常绿—落叶阔叶林生态区（3a）内的秦岭山脉是中国亚热带和暖温带的天然分界线，生态基底良好，是长江最大支流汉江的发源地。子区内的湖北郧县休闲农业观光园概念性规划项目为了保护汉江水生态，通过识别水源区，利用缓冲法建立了水源安全格局，以期为汉江水生态健康提供空间保护依据。三峡库区敏感生态区（3c）和黔桂喀斯特脆弱生态区（3i）内的地形起伏较为明显。喀斯特地貌特有的皱褶地表，使得子区内地质灾害和水土流失问题较为严重。重庆市江津区北部新城城市设计项目（3c）场地中存在大量陡坎，项目综合地质灾害防治安全格局、防洪安全格局、山林地保护

and ponds[28]. In the low-lying Ecodistrict 2d where is threatened by seawater encroachment, the ESP project on Urban Landscape Research of Weihai City in Shandong Province stimulated scenarios of tide floods and identified the best locations of wetlands that could reduce the impact of tide flood[29].

The Agricultural Ecodistrict of Fenhe River–Weihe River Valley (2e) and the Sensitive Area of Soil and Water Loss in Loess Plateau (2f), located in the central and western area of this ecoregion, are typical dust bowls. For instance, Huozhou City of Shanxi Province in Ecodistrict 2e sees heavy vegetation deterioration and stony desertification in mountainous areas caused by mineral exploration. In response, the Urban Ecological Infrastructure Planning and Design Project in Huozhou conducted research on local wind environment which simulated and identified main wind corridors where the vegetation coverage should be increased to mitigate sandstorms.

ESP projects have roughly been implended in each ecodistrict in the Warm Temperate Humid and Semi-Humid Deciduous Broad-Leaved Forest Ecoregion, and provided solutions responding to the challenging ecological problems correspondingly.

3.3 Subtropical Moist Evergreen Broad-Leaved Forest Ecoregion

This ecoregion covers the most administrative districts in China of uneven economic development levels, and has diverse climates and varied landforms (e.g., mountains, hills, basins, highlands, plains). Mountainous and hilly areas in this ecoregion are usually confronted with problems of water and soil loss, while coastal areas suffer from devastating typhoons and sea tides, and urban plain areas from frequent waterlogging and water pollution.

Within this ecoregion, the problem of soil and water loss, though commonly found in mountainous and hilly areas, varied in each ecodistrict due to the differences of climatic conditions and underlying surfaces. The same to other ecological problems. For instance, the Ecodistrict of Evergreen Broad-Leaved Forest in Dabie Mountains and Tianmu Mountain (3e) and Hu'nan–Jiangxi Hilly Agricultural Ecodistrict (3h) mainly cover hilly and basin areas, with abundant rainfall and sound natural environment. The ESP projects in these two ecodistricts focused mainly on water ecological process analyses, instead of soil and water loss or geological hazards. In the Ecodistrict of Evergreen–Deciduous Broad-Leaved Forest in Qinling Mountains and Ta-pa Mountains (3a), Qinling Mountains act not only as the natural boundary between China's subtropical and warm temperate zones, but also as ecological sources to maintain the basin's health. To protect the water ecology of Hanjiang River—the largest tributary of the Yangtze River originating from Qinling Mountains—the Concept Planning of Agritourism Park in Yun County of Hubei Province in Ecodistrict 3a established a water source security pattern by identifying the headwater and constructing ecological buffers. Another two ecodistricts—the Sensitive Ecodistrict of the Three Gorges Reservoir (3c) and the Vulnerable Ecodistrict of Guizhou–Guangxi Karst (3i)—are featured with accidented terrain. The unique wrinkled surface of Karst landform exacerbates the risk of geological disasters and soil and water loss. Once example of the ESP projects in Ecodistrict 3c is the Urban Design of the Northern New Town in Jiangjin District, Chongqing, where there were a large number of steep

安全格局构建了自然非生物安全格局，以最大程度地减少山崩、塌方、泥石流等自然灾害的发生。浙闽山地常绿阔叶林生态区（3g）内中西部多为海拔500m以上的山地，因此子区内的项目主要关注当地的地质灾害问题。该子区东部沿海地区还受到台风影响，在项目的水过程分析中主要考虑暴雨淹没模拟，并对水过程中的水质、洪水、水源涵养等功能进行了回应。

相较于山地丘陵生态子区，平原生态子区——成都平原农业生态区（3b）、长江中游平原农业湿地生态区（3d）、长江三角洲城镇及城郊农业生态区（3f）、珠江三角洲城镇及城郊农业生态区（3j）——水网稠密，易出现洪涝问题。另外平原内发达的工农业生产催生了密集型人类活动，而水上交通的便利进一步加剧了水质污染问题。3d子区由于农业化肥的使用，水生态系统非点源污染严重。在该子区内，武汉五里界生态城规划项目通过对场地进行现状污染风险等级划分、迁移途径的格局控制，得出现状水质安全格局，随后再与控制性规划进行耦合以得出现状地表覆被情况（包括水塘、水稻田和次生林地），最后建立了层级管理系统以优化与控制性规划耦合后的现状水质安全格局。该规划既回应了子区内普遍存在的非点源污染水质问题，也进一步保护了候鸟主要越冬栖息湿地。在水质提升方面，合肥高新区霍邱现代产业园生态基础设施规划项目（3f）结合场地特征考虑了饮用水水源保护格局。虽然3f子区和3j子区内水污染问题严峻，但其主要原因是工业"三废"的大量排放，此类环境污染问题无法通过规划手段进行防治，因而严格执行源头治理是更为有效的解决办法。这两个位于大江下游入海口的生态区需要借助生态规划来解决的主要危机是因地势低而造成的洪涝问题。3f和3j子区内的ESP项目都强调通过对水系网络的整体保护来恢复水系的生态功能，同时依靠合理布局和分级调蓄来提升水环境健康。

3.4 半干旱及干旱荒漠草原生态地区②

毛乌素沙地荒漠生态区（4b）和内蒙古高原东南缘农牧交错脆弱生态区（5a）都属于半干旱生态地区，风沙和水土流失防治是主要任务。陕西省榆林市生态园林城市建设规划项目（4b）分别构建了地质灾害安全格局和水土流失安全格局，对现状水土流失易发地带进行保护区域划分，重点控制地质敏感区域，同时建立了水土流失防护带与沙地生态恢复区。山西省大同市十里河生态廊道规划项目（5a）除了建立土壤侵蚀

② 考虑到半干旱荒漠草原生态地区、半干旱草原生态地区和干旱荒漠生态地区所存在的生态问题较为类似，且上述地区在地理位置上较为相近，故将其归并在一起讨论。

② The ecoregions of Semi-Arid Desert Grassland Ecoregion, Semi-Arid Grassland Ecoregion, and Arid Desert Ecoregion are geographically close and face with similar ecological problems, which are discussed as a whole in this section.

slopes. The project established a natural abiotic factors security pattern by integrating with the geological disaster prevention and control security pattern, flood control security pattern, and mountain and forest protection security pattern, to reduce natural disaster risks (landslides, mudslides, etc.). The central and western of the Ecodistrict of Zhejiang–Fujian Evergreen Broad-Leaved Forest in Mountainous Areas (3g) are mountains over 500 meters in altitude. ESP projects in Ecodistrict 3g focused on strategy development responding to local geological disasters. To withstand typhoons in the eastern coastal areas in this ecodistrict, these ESP projects employed water process analyses to simulate the inundation scenarios of rainstorms by assessing indicators related to water quality, flooding, and water conservation.

Compared with mountainous and hilly ecodistricts, plain ecodistricts—the Agricultural Ecodistrict of Chengdu Plain (3b), Agricultural Wetland Ecodistrict in the Plain of Mid-Yangtze River (3d), Agricultural Ecodistrict of Urban and Suburban Areas in the Yangtze River Delta (3f), and Agricultural Ecodistrict of Urban and Suburban Areas in the Pearl River Delta (3j) —have denser water networks, making them prone to floods. Humans' intensive industrial and agricultural activities, as well as the increase of water transportation, have exacerbated the water pollution. For instance, Ecodistrict 3d suffered from serious non-point source pollution due to the overuse of agricultural fertilizers. The Wuhan Wulijie Eco-City Planning Project first established a water quality security pattern via risk rating of existing polluted level and the control pattern of contaminant mobility, which was then integrated with the regulatory plan to identify existing land cover such as ponds, paddy fields, and secondary forests. Finally, the water quality security pattern was optimized with a management hierarchy system. This project also proposed habitat protection strategies for wintering migratory birds. Another project aiming at water quality improvement in Ecodistrict 3f—the EI planning for Huoqiu Modern Industrial Park in Hefei Hi-tech Zone—proposed to establish a drinking water source security pattern for the site. However, not all water pollution problems can be resolved by planning approaches. For the Agricultural Ecodistricts of Urban and Suburban Areas in both the Yangtze River Delta (3f) and Pearl River Delta (3j), rigid pollutant source control might be effective to reduce industrial pollution. Moreover, since the biggest threat to these two low-lying ecodistricts located at the estuary of large rivers is floods, the ESP projects in Ecodistricts 3f and 3j stressed on restoring the ecological functions of water systems through holistic protection strategies and improved local water ecosystems through spatial optimization and stepped regulation/storage of water resources.

3.4 Semi-Arid and Arid Desert Grassland Ecoregions②

For Mu Us Desert Ecodistrict (4b) and Vulnerable Agro-Pastoral Ecodistrict in the Southeastern Edge of Inner Mongolia Plateau (5a), both in semi-arid ecoregions, the main task of ESP projects is to prevent and control sandstorms and soil and water loss. The Ecological Garden City Construction Planning Project (4b) of Yulin City, Shaanxi Province established a geological disaster security pattern and a soil and water loss security pattern, which delineate protected zones, identify geologically

安全格局，还将河流廊道安全格局和湿地安全格局叠加为水生态安全格局，以应对境内山区性河流造成的洪涝灾害。这两个项目最终都根据生态安全格局构建了城市防护绿地系统。

新疆石河子市所处的准噶尔盆地荒漠生态区（6a）为干旱荒漠生态地区，更加干旱少雨，可支配的水资源极其有限。而石河子作为军垦名城，农垦用水量大。石河子绿网及水网景观系统综合规划设计项目分析研究了当地的自然生态过程，为城市发展划定刚性控制生态线，保护了石河子的农田生态安全，保障了水资源的合理分配。

3.5 青藏高原森林、高寒草甸生态地区

该生态地区位于青藏高原东部及东南部。青藏高原东部暗针叶林—高寒草甸生态区（7a）内牧场面积较大，但由于过度放牧，草场退化日趋严重。在这一子区中，四川卧龙国家级自然保护区内的居民放牧活动导致高山植被和草场退化，影响了大熊猫等野生动物的生境。四川卧龙国家级自然保护区总体规划项目主要通过生物保护安全格局的构建明晰了人类活动和大熊猫保护的冲突区域，优化了功能分区，并在大熊猫迁移概率较高的地点设置了生态廊道。

通过上述分析可得，20余年来，基于ESP理论的生态基础设施规划项目较好地回应了地方性生态问题。通过追踪典型案例发现，基于ESP理论构建的生态基础设施能够切实解决实际生态问题[30]。而ESP实践项目的环境、经济和社会效益的量化评估也在有序开展中。

4 ESP理论在代表性生境类型下的应用

除生态分区外，研究代表性生境类型中的生态问题是应用ESP理论的另一个维度。本章以海岸带、遗产保护区、自然保护区和采矿迹地生态严重破坏区的典型案例为例，对比分析ESP项目实践中对重点生境下典型生态问题的应对方案。

4.1 海岸带地区

海岸带地区由于地势较低且临海，受海潮影响较大。这类地区降水分布不均，极易因台风突发暴雨和风暴潮等极端天气。这类生态问题爆发期短且集中，易对当地造成严重威胁。

威海城市景观风貌研究利用数字高程模型对不同潮位的淹没范围进行模拟，通过对洼地与径流的分析建立起多层次海潮安全格局，辨别

sensitive areas, and construct buffer belts and restoration zones to protect deserts. In Ecodistrict 5a, the Shili River Ecological Corridor Planning Project of Datong City, Shanxi Province, established a soil and water loss security pattern together with a water ecological security pattern (an overlap of the river corridor security pattern and wetland security pattern), to cope with mountain floods within the city. Both of these projects eventually built green buffer systems based on their ecological security patterns.

The Desert Ecodistrict of Junggar Basin (6a) in Shihezi City of Xinjiang is located in the Arid Desert Grassland Ecoregion, where water resource is scarce. Shihezi, a famous military reclamation city, however, consumes a large amount of water for agricultural development. Given this, the Shihezi Green Space and Water Network Landscape System Comprehensive Planning and Design Project delineated a rigid ecological control line for urban development based on the analyses of local natural ecological processes, so as to ensure the ecological safety of farmlands and improve the distribution of water resources.

3.5 Forest and Alpine Meadow Ecoregion in Qinghai–Tibet Plateau

This ecoregion is located in the east and southeast of the Qinghai–Tibet Plateau. The Ecodistrict of Dark Coniferous Forest–Alpine Meadow in Eastern Qinghai–Tibet Plateau (7a) covers a comparatively large area of pasture that undergoes severe grassland degradation due to overgrazing. Similar problems in Wolong National Nature Reserve, Sichuan Province has threatened the habitat of wild animals such as giant pandas. The master planning for this reserve created a biological conservation security pattern, optimized the site's function zoning by identifying the conflicting areas between human activities and giant panda protection, and set up ecological corridors in key locations for giant panda migration.

Over the last two decades, the ESP projects have succeeded in offering EI-planning solutions to local ecological problems. The implementation of the planning cases is proving the effectivity of the ESP theory in addressing China's ecological issues[30]. Further quantitative assessment on the environmental, economic, and social benefits of more ESP projects is already in progress.

4 ESP Theory Application in Typical Habitat Types

ESP theory can also be applied in addressing ecological problems in typical habitat types. In this section, ESP projects in coastal zones, heritage protection areas, nature reserves, and mined sites that suffer from serious ecological damages were examined to summarize related experience.

4.1 Coastal Zones

With uneven precipitation, low-lying coastal zones are highly prone to typhoons and storm surges, which often intensively occur in a short period of time and cause huge casualties or property losses.

In the Landscape Research of Weihai City, a multi-layered sea tide security pattern

出对缓解海潮威胁最有效的湿地位置[29]。台州市位于浙江省中部沿海地区，境内河流纵横，湿地广布，属亚热带季风气候区，受台风影响较大。为了应对潮汐和洪水，台州市城市开放空间规划编制项目中提出的台州水安全格局从整个流域出发，预留出可供调、滞、蓄洪的湿地和河道缓冲区，为洪水自然宣泄提供空间。项目通过明确潜在调洪湿地范围，计算可调蓄洪水规模，最终确定了不同安全水平的湿地规模和格局，进而形成了区域洪泛湿地规划、区域河道格局调整规划、区域水库及湖泊调整规划。

由于海岸带的滨海泥质沼泽、河流湿地及水田是多种水禽的越冬地和珍稀候鸟迁徙地及停息地，因此相关ESP项目的另一个重要目标是保护候鸟。台州市城市开放空间规划编制、山东省青岛红岛经济区水系综合规划两个ESP项目均通过现状分析，建立了改变模型，得到最终的生物安全格局。以此为基础，规划方案建议当地首先建立栖息地核心区、缓冲区，其次在栖息地之间建立廊道，最后在重要位置设置生态战略点。

4.2 遗产保护区

武夷山市位于福建省北部山区，境内的武夷山于1999年作为世界文化与自然双重遗产被正式列入《世界遗产名录》。武夷山市采取了诸多措施严格控制自然保护区开发，遗产地管理成效斐然。但是仅对武夷山风景区核心景区（面积为70km²）进行静态封闭保护已难以适应城乡统筹发展和真实完整的遗产保护要求：武夷山风景区周边的土地开发加剧了景观破碎化程度，景观多样性下降[15]；核心景区内承受着超负荷的旅游开发，而核心景区外的自然和文化遗产也得不到有效的保护和管理，旅游经济对老城区和乡村发展的带动作用渐弱。

武夷山市生态基础设施暨开放空间规划项目首先打破了原有遗产保护工作只聚焦于核心景区的思路，将保护范围扩展至整个武夷山市（面积约为2 800km²）。其次，基于ESP理论的动态视角，从自然、生物和人文过程出发，构建生物保护、防洪[31]、视觉、文化遗产保护和游憩体验五大安全格局，在将其叠加后获得武夷山市域的生态基础设施总体网络。运用该网络引导城市发展，不但可以实现对武夷山遗产区域内自然与人文景观的整体保护[32]，也将促进整个武夷山市的资源联动。不同于单纯以生态要素布局为主的生态基础设施规划，该生态基础设施总体网络是在更完整的区域中，基于动态过程形成网络联动生态基础设施，为进一步的中微观尺度的规划和景观设计提供参照。

4.3 自然保护区

四川省卧龙国家级自然保护区是中国野生大熊猫栖息地的核心区域之一，对于保护大熊猫等濒危珍稀物种及其栖息地和高山森林生态系统具有重要意义。然而，当地居民点周边长期的放牧和耕作等活动和生活用能方式[33]对自然景观结构产生了持久的、中等强度的影响[34]，造成高山植被退化，破坏了大熊猫和其他野生动物的栖息地。四川卧龙国家级自然保护区总体规划着力解决人类活动与大熊猫保护的冲突问题。通过大熊猫栖息地适宜性评价，重新调整了大熊猫国家公园方案的功能分区

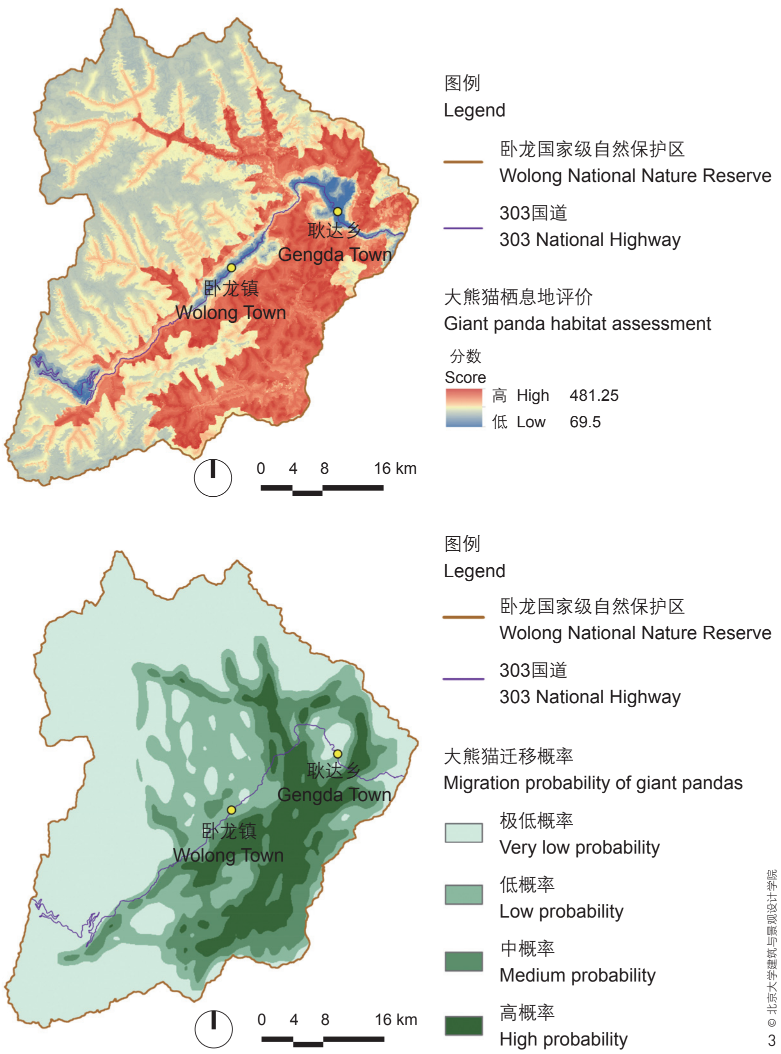
was established on the basis of low-lying land and runoff analyses that utilized the Digital Elevation Model to simulate the inundation scenarios by varied tide heights. The best locations for wetlands that could alleviate tide threats were then identified[29]. Another example is the Urban Open Space Planning for Taizhou in the central part of Zhejiang Province. Taizhou is a coastal city with plentiful river systems and wetlands and largely impacted typhoons in subtropical monsoons. To reduce the hazards of tides and floods, this project proposed a water security pattern at the basin scale and reserve room for flood regulation, detention, and storage via wetlands and channel buffers, allowing for natural flood drainage. By identifying the locations for flood regulation and the estimation of flood storage capacity of the site, wetlands of varied sizes and security levels were determined to support the development of regional floodable wetland plan, regional river pattern adjustment plan, and regional reservoir and lake adjustment plan.

Coastal zones with muddy swamps, riverine wetlands, and paddy fields serve as key habitats for a variety of migratory water birds in winters. Thus protecting migratory birds is another primary goal of coastal ESP projects. Both the Urban Open Space Planning project for Taizhou and the Water System Planning project for Hongdao Economic Zone in Qingdao of Shandong Province established biology security patterns via change models on the basis of status quo analyses. The plans first proposed to build core areas and buffers in the habitats then the corridors connecting the habitats, and finally identified ecological strategic points at key nodes within the security pattern.

4.2 Heritage Protection Areas

Mount Wuyi, located in Wuyishan City in the north of Fujian Province, was officially included in the World Heritage List in 1999 for its outstanding cultural and natural resources. Adopting measures to place strict control over the development within the natural reserve, Wuyishan City has made remarkable achievements on heritage management. However, a higher level of coordinated urban and rural development, as well as intact natural heritage protection, required wiser strategies instead of static protection of the 70-square-kilometer core scenic area in Mount Wuyi Scenic Area. Worse, land development around the scenic area further fragmented the landscapes and undermined landscape diversity[15]; the core scenic area saw a deterioration risk by the over-loaded tourism visits, while the natural and cultural heritages in other areas lacked effective protection and management; and the tourism economics was waning in driving of Wuyishan's urban-rural development.

The EI and Open Space Planning for Wuyishan City took the whole city area as the heritage protection territory (approximately 2,800 km²). Guided by the dynamism concepts in ESP theory, biological protection, flood control[31], visual aesthetics, cultural heritage protection, and recreational security patterns were established, which were then overlaid to form an EI network master plan for the city, to ensure the holistic protection of the natural and cultural landscapes in the heritage area[32] and to enhance the city's resource integration and distribution.



3-1. 大熊猫栖息地适宜性评价
3-2. 大熊猫迁移概率分布

3-1. Giant panda habitat suitability assessment
3-2. Giant panda migration probability distribution

（包括核心区、缓冲区和实验区三部分）。总体规划同时基于最小累积阻力模型对大熊猫迁移概率的识别，形成了维持大熊猫种群联系的生态廊道建设方案（图3）。

4.4 采矿迹地

长平井田地处黄土高原太行山南段西侧，沁水盆地东缘。该地在开发矿区前委托北大景观和土人设计团队进行了山西长平矿区生态建设可行性研究。此研究不仅深入探讨了采矿作业对生态环境的影响，还进一步探究了矿区的社会经济问题。

研究区地处黄土丘陵区，属于中度侵蚀地区。水土保持是该区域生态建设的重点之一。团队通过对植被覆盖度、土壤类型、地表坡度、土地利用进行敏感性评价，对采矿可能引发的地表水水位下降、水土流失等问题进行评估，再对雨洪、水土流失、生物保护、乡土文化景观、视觉等安全格局进行叠加，最终建立起以山体为基底、以丹河水系为核心的生态基础设施网络。该网络保护了采矿潜在影响区域，并最大程度地架构起了稳定的矿区生态系统。

Rather than simply centering on ecological element configuration, the EI network in Wuyishan was built at a larger scale, within which the dynamic process may better connect EI, providing a reference for meso- and micro-scale landscape planning and design.

4.3 Nature Reserves

The Wolong National Nature Reserve in Sichuan Province is one of the core habitats for wild giant pandas in China and plays a significant role in protecting endangered and rare species, their habitats, and alpine forest ecosystems. However, local longtime intensive grazing and farming activities and energy use[33] have had a lasting and moderate impact on the natural landscape structure[34], degrading the alpine vegetation and the habitats for wild animals including giant pandas. The Master Plan of Wolong National Nature Reserve project was launched to rebalance human activities with giant panda protection by improving the functional zoning of the Giant Panda National Park (a core zone, a buffer zone, and an experimental zone) based on a suitability assessment of giant pandas' habitats. The master plan also identified the migration probability of giant pandas with minimum cumulative resistance modeling and developed an ecological corridor construction plan to maintain giant pandas' gene flows (Fig. 3).

4.4 Mined Sites

An example of ESP projects concerning mined sites is the EI planning case for Changping Mining Area located along the west side of the southern Taihang Mountains on the Loess Plateau and along the eastern edge of Qinshui Basin. Before the master planning of the mining area, LA PKU and Turenscape were commissioned to conduct a feasibility research on ecological conservation of the Changping mining area, which studied both the impact of mining on local ecosystem and the socio-economic issues existed in the mining area.

Sitting at the loess hilly area, the study site underwent moderate soil erosion. Soil and water conservation thus is a key task to local ecological protection. The research team proposed an EI network centering on mountains and the Danhe River system according to baseline analyses, including 1) the sensitivity assessment on vegetation coverage, soil type, surface slope, and land use, 2) the simulation of surface water level drop and soil and water loss by mining activities, and 3) the overlay of rainfall and floods, soil and water loss, biological protection, vernacular cultural landscapes, and visual security patterns. The network was able to protect areas subject to the underlying impact of mining activities and to improve the stability of the mining area ecosystem to the best.

除了上述生态分析，此研究还考虑了可能受全井田开采影响的村民的意愿。调研访谈结果显示，村民对现有居住条件满意度较低，缺水问题也制约着农业生产发展。同时，超过半数的村民对于煤矿产业可能带来的污染问题和土地置换问题心存疑虑。研究建议，首先要协同考虑矿区周边的基础设施建设，改善村民居住条件，提高道路运力，促进周边旅游业、观光农业的发展；其次要对采矿产生的废料进行资源再利用，在减少环境污染的同时为村民提供相关产业就业机会。例如，利用矸石充填山沟造地，扩大耕地面积；其余的煤矸石可以用来制砖，形成新的产业。该研究建议在保证矿产资源的开采与利用的前提下，通过生态基础设施合理规划避免或减轻矿区环境污染来提升生态环境质量，带动周边农村地区的经济发展。

5 ESP理论中生态过程及子格局的拓展

随着应用地域范围的扩展，不同项目运用ESP理论的深度和灵活度也在增强。本章将讨论ESP理论覆盖的生态过程及对应的生态子格局在应用中的拓展和方法进展。常见的生态安全格局包括水安全格局、生物安全格局、地质灾害安全格局、文化游憩安全格局、视觉安全格局等，它们又各自拥有较多子格局。

水是生态环境的重要基底，面临各类水问题（如水资源短缺、洪涝灾害、水质污染）的不同生态区均需基于水安全格局进行规划保护和优化，因而几乎所有ESP项目都将水安全格局分析放在首要位置，以识别各生态要素，理顺基础生态功能。生物安全格局也是绝大部分项目都涉及的子格局，不仅因为它能够体现ESP理论中物种水平扩散的精髓[35]，更因为通过指示物种的选择，可以凸显每个项目的地方性特征，并通过生物栖息地的恢复来提升整体生境质量。其他子格局相对而言并非必须，主要依据每个项目所在地的重点生态问题和发展诉求来权衡。例如，在高差大、山地较多的地区往往会构建地质灾害安全格局，以应对水土流失、山体滑坡、崩塌等问题；在文化遗产资源丰富、保护要求较高的地区，进行文化游憩安全格局分析，在此基础上需要进行综合旅游开发、城市风貌规划的地区还会考虑视觉安全格局分析。最终，规划人员根据生态问题的重要性对各个生态安全子格局

In addition to the baseline analyses, this research also collected opinions from local villagers who have been and might be affected by mining activities in the entire mine area. Interview results revealed that villagers were not satisfied with their current living conditions and agricultural production were restricted by water shortage. Moreover, over half of the villagers worried about mining pollution and land replacement. Accordingly, the research coordinated the development of both the mining area and its peripheries, including infrastructure construction to improve villagers' living conditions and local transport capacity to promote both traditional tourism and new agri-tourism. The research also focused on mining waste recycling not only to reduce pollution but also to create more job opportunities for villagers. For example, waste rocks can be used to refill valleys to expand arable land area, and coal gangues can be used for brickmaking that would foster new industries. To sum up, the research suggested to avoid or reduce environmental pollution through proper EI planning without scarifying the exploitation and utilization of mineral resources, while propelling rural economic development.

5 The Exploration of Ecological Processes and Sub-security-patterns of ESP Theory

As the geographic regions of practice enriches, the depth and flexibility of applying ESP theory have also increased. This section displays the methodological efforts of related application in exploring ecological processes and the corresponding ecological sub-security-patterns. Primary ecological security patterns include water security pattern, biological security pattern, geological disaster security pattern, cultural and recreational security patterns, and visual security pattern, each of which has several sub-security-patterns.

Water is vital to an ecosystem. Ecological areas that suffer from different water problems (such as water shortage, floods, water pollution) are in great need of protection or restoration planning of water safety patterns, which is prioritized in almost all ESP projects. Various ecological elements are identified through analysis of water security pattern so as to optimize basic ecological functions. The biological security pattern is also critical to most projects, because not only it matters species horizontal spread—the essential idea of ESP theory[35]—but also it helps protect the local characteristics though the selection of indicator species and improve the overall habitat quality through ecological restoration. Analyses of other sub-security-patterns can be introduced to address specific ecological problems and development demands. For example, in areas with large elevation differences or mountainous terrains, geological disaster security patterns are often emphasized to deal with soil and water loss, landslides, collapses, etc.; in areas with rich cultural heritages or high protection requirements, cultural and recreational security patterns should be highlighted; visual security patterns would be considered in regional overall tourism development planning and urban landscape planning. In the end, planners overlay each ecological sub-security-pattern according to the importance of ecological issues to obtain an overall ecological security pattern. Based on this, a comprehensive spatial adjustment

进行叠加，获得综合生态安全格局。以此为依据，还可进行相较传统规划内容更为综合的空间调整和细化的实施途径规划。

5.1 水安全格局

中国大部地区属于季风气候区，水资源时空分布上的高度不均衡。因此，中国区域和城市的水生态问题往往异常复杂，水资源短缺和洪涝问题并存，水质问题严峻、地下水位下降等系统性水问题对水安全格局建设提出了挑战。[36]

雨季内涝严重、洪水风险增大，不仅直接威胁城市安全，亦会造成巨大的经济损失。雨洪安全格局针对的正是此类生态问题，可分为水系保护安全格局及暴雨淹没安全格局。水系保护安全格局主要对暴雨潜在径流、坑塘、水渠等分别进行缓冲分析，叠加后确定高、中、低安全格局。暴雨淹没安全格局需要收集当地地表径流系数、土地利用类型，以及历史上不同历时、不同强度的降雨量信息。通过计算某一流域内不同降雨历时情况下的径流累积量，利用填挖方工具进行反复验算，直至径流累积量与填挖方数保持一致，再对不同的降水强度进行模拟，可以确定池塘和湿地系统的面积和类型，以使尽可能多的雨水保留在原地，并下渗、补充地下水。[29]完善的水系网络和多层次的滞洪湿地系统的建设可避免对下水道、排水管等灰色基础设施的过度依赖。菏泽市城市绿地水系规划借鉴了当地传统的雨洪管理经验，利用围堰和环城（村）河、蓄水坑塘等方式进行水系规划。武汉五里界生态城由于引入了多层级、分散控制的雨洪过程调节系统设施，在2016年洪涝灾害中经受住了考验[37]。

雨水资源管理与利用已成为中国一切涉水工程的根本策略，也决定了中国建设滞蓄和调节系统的必要性[28]。雨水利用安全格局的建立需通过雨水下渗适宜性分析、地下水超采区分析和山区水土流失分析，综合确定市域雨水利用的关键性空间格局（如山前冲积扇等），并根据不同土地利用类型制定雨洪管理措施和地下水回补措施。由于中国华北地区地下水超采问题严重，北京市部分ESP项目在洪水安全格局和雨水安全格局的基础上，考虑地表和地下水源保护及地下水补给，叠加形成综合水安全格局，保障了北京市水系统的健康[9]。北京市门头沟分区规划生态安全与空间管控专题通过地下水补给适宜性分析、地下水超采分析，恢复天然水循环过程，利用雨水回补地下水。

and detailed implementation roadmap can be carried out, compared with traditional planning methods.

5.1 Water Security Pattern

Most areas of China are in the monsoon climate zone, and the temporal and spatial distribution of water resources is sharply uneven. Therefore, China's regions and cities often suffer from extremely complex water ecological problems: for example, many cities encounter both water shortage and floods, water quality deterioration, drop in groundwater level, or other severe water problems which pose challenges to water security patterns.[36]

Severe waterlogging in rainy seasons and increased flood risk directly threaten a city's safety and would cause huge economic losses. In practice, analyses of stormwater security pattern consists of water system protection security pattern and flooding security pattern. The former focuses on buffer analyses on possible runoffs and pond/canal flows to determine the higher, moderate, and lower security patterns. The later requires data collection of local surface runoff coefficients, land use, and historical rainfall information of different durations and recurrence periods. By calculating the cumulative runoff amount within a certain watershed in different storm scenarios, testing with cut-and-fill tools to make sure that the total runoff amount is consistent with the cut-and-fill amount, and through scenario simulations, the area and type of pond and wetland systems can be determined, so that to retain as much rainwater as possible in place and facilitate infiltration and groundwater recharge.[29] The construction of a complete water system network and multi-level flood detention wetland systems can avoid the overuse of gray infrastructure such as sewers and drainage pipes. For example, the Urban Green Space and Water System Planning of Heze City drew on the local wisdom in traditional stormwater management and employed cofferdams, rivers around the city/village, and water storage pits. In the Wuhan Wulijie Eco-City case, multi-level and decentralized control facilities for the adjustment of rain and flood process were introduced that withstood the floods in 2016[37].

Rainwater management and utilization now has been a fundamental strategy for all water projects in China that determines the necessity to build rainwater detention and regulation systems[28]. Rainwater utilization security pattern is established through analyses of rainwater infiltration suitability, groundwater overexploitation area, and montanic soil and water loss, so that to determine the key spatial pattern of rainwater utilization in the city (such as piedmont alluvial fans), and formulate measures to stormwater management and groundwater recharge according to specific land use types. Due to the severe overexploitation of groundwater in North China, a number of ESP projects in Beijing emphasized surface and groundwater source protection as well as groundwater recharge in the comprehensive planning of flood and stormwater security patterns, which would guarantee the health of Beijing's water system[9]. Such ideas and methods were implemented in the planning project of ecological security and spatial control in Mentougou District of Beijing, which proposed to restore the natural water cycle process and utilize rainwater for groundwater recharge.

另外，中国的地表和地下水水质污染严重。官方数据表明，截至2016年，75%的地表水都出现了不同程度的污染，这也会带来用水安全问题[30]。水源保护安全格局的目标就是涵养水源。通过在研究范围内地表主要取水点、主要径流周围建立水源保护缓冲区，使区域内的水量得以维系、水生态系统功能得到保护。例如，浙江省金华山旅游经济区总体规划项目依据国家对水源地保护及水库保护的要求，为场地内的水库建立了100~300m的防污染缓冲带，形成水质保护安全格局。武汉五里界生态城规划根据用地类型、开发强度和水体敏感度将非点源污染分为三个处理等级，通过识别污染物的迁移途径，将其与现状安全格局进行耦合后确定了污染物控制的关键点和控制廊道，在水质保护安全格局的基础上通过层级管理系统实现进一步调控。

水安全格局是对水生态系统结构和功能进行调节和优化的有效途径，而针对水安全格局所带来效益的评估也是当前ESP理论框架中的一个重要研究方向。

5.2 生物安全格局

在ESP理论提出之前，一般的生物保护规划多把物种局限性地作为被动对象保护在特定地域和现存景观元素中[38]。ESP理论的基本出发点之一是将生物对景观（自然）资源的利用视作具有能动性的生态过程。在这种假设下，可以通过识别关键性的局部景观和空间联系，利用物种自身对空间的探索和侵占能力来保护生物多样性[35]。对物种运动的思考也逐渐促使其他安全格局以水平方向的生态过程为基本出发点，在动态视角下不断发展。

建立生物安全格局的一般方法为：首先确定指示物种，根据其生态习性，判别出物种的核心栖息地，以作为物种空间运动的“源”；而后根据土地利用、海拔、坡度等因素对物种运动的影响建立景观阻力面，并进行空间分析，判别出缓冲区、源间连接、辐射道及战略点；最后将不同指示物种得到的安全格局相叠加，构建生物安全格局，并划分低、中、高三种安全水平。

其中，指示物种的选择至关重要，一般的理论原则为：1）具有稀有或特有性，如濒危物种；2）对维护整体生态平衡具有关键作用；3）具有进化意义[39]，同时应避免选取在食物链上具有直接邻近关系的物种组合，如猫头鹰和田鼠。然而在实践中，类似于卧龙国家级自然保护区这种具有明确焦点物种（大熊猫）的情况并不常见于区域与城市环境中。因此，出于最大保护原则，对于无特殊保护物种的地区，需逐步确立以具有生境代表性的常见物种为指示物种的方法。通常选取一种鸟类、一种哺乳类、一种两栖类动物，它们各自占有某种空间类型，对其水平运动过程的分析可指示其所代表的栖息地类型，叠加后基本可以指示大部分具有典型意义的生境。保护了这些生境，通常也就实现了对珍惜物种的保护，同时也最大化地保护了生境中的其他生态要素，从而保

Overall, China’s surface and groundwater are heavily polluted. Statistics reported that by 2016, 75% of surface water was polluted to varying extent, threatening water security[30]. The primary goal of establishing water source protection security pattern is water conservation. By identifying water source buffers around the main water intake points and headwaters, the water volume in the watershed and the functions of water ecosystem can be maintained. For example, according to the national requirements for headwater and reservoir protection, the overall planning for Jinhua Mountain Tourism Economic Zone in Zhejiang Province established the water quality security pattern based on a buffer (100 to 300 meters in width) for the reservoirs on the mountain. The planning for Wuhan Wulijie Eco-City identified three treatment levels of non-point pollution sources according to land use types, and development intensity and water sensitivity extents. By identifying the contaminant mobility and overlapping them onto the security pattern, the key points and corridors for pollutant control were determined, which can be adjusted in a multi-level management system.

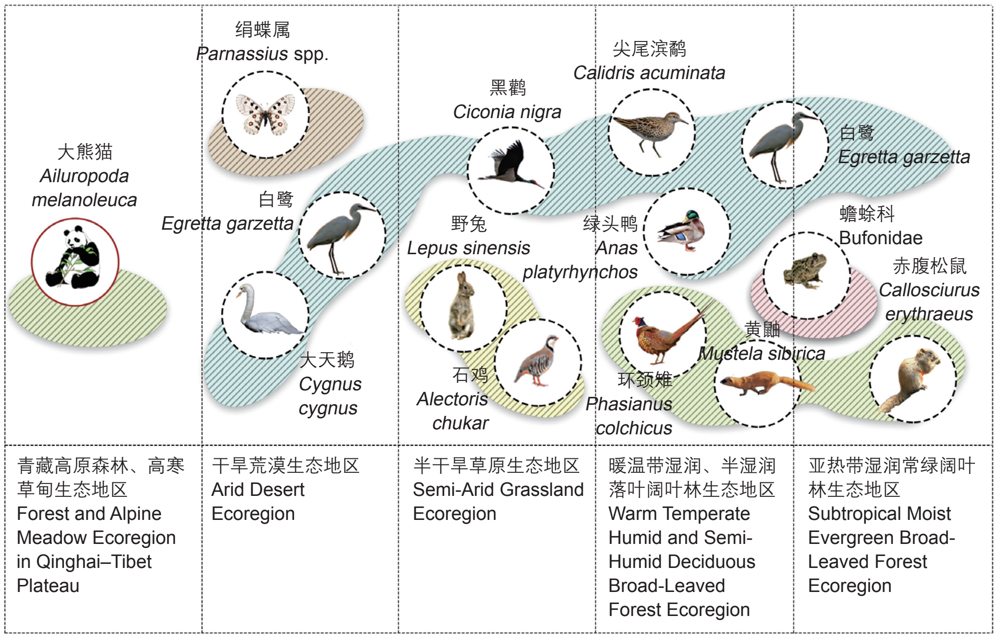
The establishment of water security pattern is an effective approach to adjust and optimize the structure and functions of water ecosystems, and the evaluation of outcome benefits is also an important research topic to the ESP theory.

5.2 Biological Security Pattern

In traditional biological protection planning, animal and plant species are passively protected in a certain area with existing landscape elements[38]. Essentially ESP theory aims to regard the biological interactions/flows in the landscape (the nature) as an active ecological process, which protects biodiversity by identifying key local landscape and spatial connections, and facilitating the species’ natural succession[35]. This idea that emphasizes the mobility of species also inspires the development of other security patterns to work on horizontal ecological processes with a dynamic perspective.

Generally, a biological security pattern can be established by three steps: first, to determine the indicator species and identify corresponding core habitats as the “source” of the species’ mobility; secondly, to identity buffers, source connections, radiation corridors, and key points to the species’ mobility through analyses of landscape resistance on factors such as land use, altitude, and slope grade; and finally, the lower, moderate, and higher security patterns can be obtained by overlapping the analyses of different indicator species.

The selection of indicator species is crucial to the establishment of biological security pattern. Usually, indicator species should be: 1) rare or endemic, such as endangered species; 2) key to maintaining overall balance of the ecosystem; and 3) of evolutionary significance[39]—direct predator–prey species (e.g. owls vs. voles) should be avoided. Since targeted species protection cases (e.g. Wolong National Nature Reserve for giant pandas) are not common in regional or urban planning, the general indicator species selection, for a maximum protection, should include avian, mammal, and amphibian species for each that is representative in its habitat environmental requirements. The analysis of their horizontal mobility processes can indicate the corresponding habitat type, so the overlapping analysis can basically indicate most local habitats. Protecting these habitats means the protection of both the rare species and other habitat



注
图中相同颜色的底纹表示相似的生境。

NOTE
Each shading represents habitats with similar environmental requirements.

4 © 司雨田

4. 各生态区中的代表性指示物种示意图
4. Representative indicator species in each ecoregion

障了生态系统的整体质量。图4展示了ESP项目所涉及生态区内的代表性指示物种。实践的丰富积累已经形成了可靠的数据库，可作为今后生物保护工作的参考。

除了大部分项目都会涉及的动物安全格局外，一些项目也利用详细的土地利用资料或归一化植被指数数据建立了植物安全格局。这两类基础数据可以分别对植被情况进行评级计算，也可叠加计算。

5.3 地质灾害安全格局

地质灾害安全格局是指针对水土流失、泥石流、滑坡、矿山地面塌陷、地面沉降等地质灾害，先确定潜在发生源，再通过对各类型地质灾害的诱因和易发区内土地利用格局的分析，确定能够起关键防护作用的空间联系，并据此划定地质灾害安全格局的低、中、高安全水平。在规划中可以根据安全格局水平提出相应的限制建设要求和灾害防治措施[9]。

在实际项目中，要根据场地地形条件确定影响地质灾害的因子。其中，坡度、土壤性质、植被覆盖度、土地利用性质为常见的评价因子。再查阅相关文献，确定这些因子的具体影响如何在当地进行量化评价。例如，重庆江津区北部新城规划区内分布有大量陡坎，容易造成山崩、塌方和泥石流。研究选取区域内坡度在35° 以上、面积大于800m^{2}的陡坎区域作为源，通过设定不同的缓冲距离，构建了地质灾害安全格局。

components, thus ensuring the entire quality of the ecosystem. Figure 4 shows a few of representative indicator species in varied ecological zones used in the studied ESP projects. Such databases would provide a reference for future biological protection projects.

In addition to animal security patterns established in most of the ESP projects, some projects also use detailed land use data or Normalized Difference Vegetation Index to establish plant security patterns. These two types of data can be used to grade and calculate the vegetation conditions separately or in an overlaid way.

5.3 Geological Disaster Security Pattern

The establishment of geological disaster security pattern is first to locate the potential source of geological disasters such as soil and water loss, debris flow, landslides, mine subsidence, and ground subsidence; and then analyze causes of each type of geological disaster and the land use pattern in corresponding prone areas to identify the key spatial connections to disaster prevention, which determine the lower, moderate, and higher security patterns of geological disasters. According to the level of the security pattern, formulate corresponding construction standards and requirements and disaster prevention measures can be put forward in the planning[9].

In practice, causal factors of geological disasters (i.e., slope grade, soil properties, vegetation coverage, land uses) should be carefully considered according to the specific topographical conditions; Though relevant literature review to determine how specific impact of these factors in different ecoregions can be quantitatively evaluated. For example, there are a large number of steep slopes in the northern Jiangjin District of Chongqing, resulting in a high risk of landslides and mudslides. In its new town master planning, by identifying steep slope areas of a gradient above 35° with an area larger than 800 m^2 as the sources and delimiting different buffer distances, a geological disaster security pattern was formed.

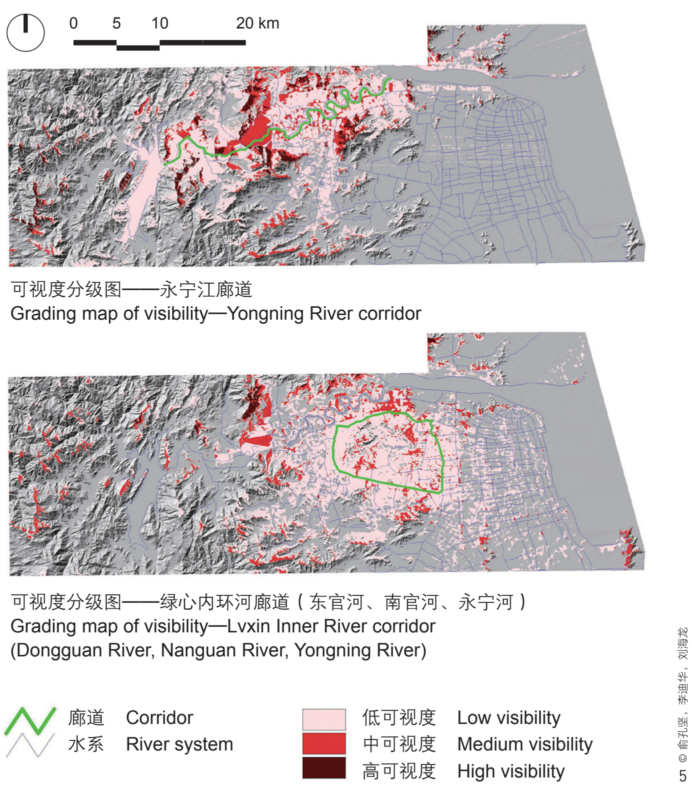
5.4 文化游憩安全格局

游憩是人在景观中的主动体验过程，游憩行为在ESP理论中也可被视为一种在空间上水平扩张的过程。文化游憩安全格局是指识别和建立对景观游憩体验过程的质量具有关键性意义的景观元素和空间联系。在文化游憩安全格局中，诸如乡土遗产点、寺庙等遗产实物都可以作为“源”。潜在的连接这些节点的景观元素（如水系、绿道等）都可基于与遗产休闲活动的兼容性进行阻力系数赋值。最终通过阻力面分析得到适宜性评价，以此进行文化游憩网络的规划。

在文化游憩资源的选定上，公众和专家的意见都要纳入考虑。公众作为游憩的主体，其意见更要广泛吸收。菏泽市城市绿地水系规划基于公众问卷调查对遗产进行了认同度评价和综合价值评价，同时在评价中采用认知地图明确了乡土遗产的价值。而专家更擅长挖掘具有潜在价值和文化影响的遗产廊道和遗产景观网络，以及建立线性文化线路。例如，武夷山市生态基础设施暨开放空间规划基于朱熹生平的理学游历线路和茶文化的遗产分布，有效推动了可突出武夷山特色的非物质线性遗产点的保护和乡土景观的利用。

5.5 视觉安全格局

视觉安全格局在20世纪90年代的丹霞山风景区规划中已显现雏形，是ESP理论中最早使用定量方法进行规划的子格局。景观设计学科最初基于“风景”概念的视觉美学意义而建立，从20世纪60年代中期开始，以美国为中心开展的景观评价研究也主要聚焦于景观的视觉美学意义[40]。而视觉审美安全格局的出发点是保护视觉审美过程，重点在于维护能够促进景观视觉感知的特色景观元素及空间联系，以保持视觉感知



5.4 Cultural and Recreational Security Pattern

People's recreational behavior in landscapes is an active experiencing process, which is also a process of horizontal spatial expansion in ESP theory. Cultural and recreational security patterns are established by identifying and emphasizing landscape elements and spatial connections that are critical to the quality of people's experiencing process in the landscape. Local heritages such as rural historic sites, temples can all be regarded as “sources,” which can be linked up with potential landscape elements (e.g., water systems, greenways) that are valued by resistance coefficients according to their compatibility with recreational activities. Finally, a suitability assessment can be obtained through the resistance surface analysis, which would inform the planning of cultural and recreational networks.

In the identification and selection of cultural and recreational resources, the opinions of both the public and experts must be taken into consideration. As the users of recreational sites, the public's opinions should be widely collected. In the Urban Green Space and Water System Planning of Heze City, evaluations on the identity and comprehensive value of local heritages were conducted through public questionnaire surveys with aid of perception maps. Experts' advices are helpful in identifying the heritage corridors and landscape networks of valuable cultural significance and the planning of cultural tourism routes. For example, by studying Zhu Xi's Neo-Confucianism travel experiences in his whole life and the distribution of tea-culture heritage sites, the ecological infrastructure and open space planning for the Wuyishan City has effectively promoted the protection of intangible linear cultural heritages and the revitalization of rural landscapes that highlight local cultural characteristics.

5.5 Visual Security Pattern

One of the earliest cases using the quantitative planning methods in ESP theory for the establishment of sub-security-pattern was the Visual Security Pattern Planning for the Danxia Mountain Scenic Area in the 1990s. The discipline of Landscape Architecture was originally established based on the visual aesthetic significance of the landscape. Since the mid-1960s, landscape assessment research carried out mainly in the United States has also focused on the visual aesthetics of landscapes[40]. The establishment of visual security patterns is to protect the visual aesthetic process by maintaining the unique landscape elements and spatial connections that can promote the visual perception of the landscape ensuring the continuity of visual perception process. In addition to the traditional landscape aesthetic quality evaluation, quantitative analyses of visual points, visual corridors/viewsheds, and sight blocking are also introduced through field surveys to scrutinize landscape threshold and sensitivity[41], so as to delimit visually sensitive zones. Related factors include relative slope gradient, relative distance, occurrence

5. 台州生态基础设施规划项目中基于不同视觉廊道的可视性分析（参见参考文献[12]）
5. Visibility analysis based on different visual corridors in Taizhou EI planning project (Source: Ref. [12])

过程的完整性。除了传统的景观美学质量评价外，还可根据实际场地观察中的视线穿插、物体遮挡关系等增加景观阈值和景观敏感度的量化维度[41]。视觉安全格局主要针对所确定的视觉点和视觉廊道进行可视性分析，确定视域范围内的景观敏感区域。相关影响因素包括景观的相对坡度、景观的相对距离、景观出现机率和景观的醒目程度。最后对视觉敏感区域进行控制，建立景观视觉安全分级和分区。

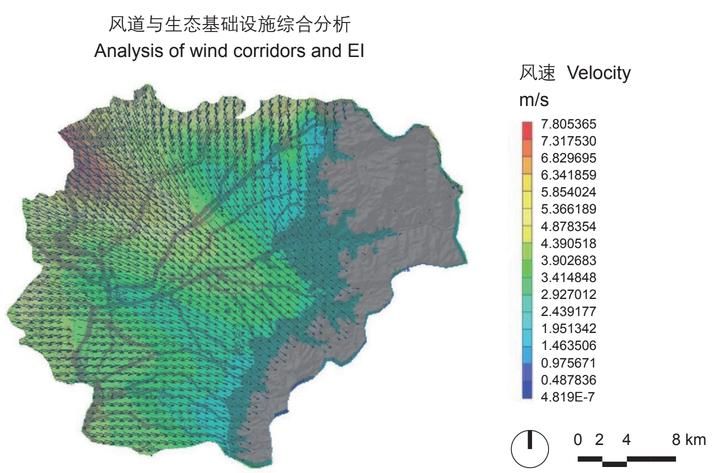
在台州市城市开放空间规划编制的项目中，九峰山丫髻岩、大白云山、太湖山及黄岩区的其他南北山体都是重要的视觉焦点。在宏观尺度上，通过对永宁江休闲廊道、西江历史文化遗产廊道、洪家场浦休闲廊道、绿心内环河廊道进行可视性分析（图5），建立了视觉安全格局；在中观尺度上，此项目还进行了基于山脊线保护的椒江两岸城市天际线规划。

5.6 其他生态子格局

就其他生态子格局而言，江苏省淮安市白马湖国家公园（国家生态公园）规划设计和南京高淳国际慢城规划研究都建立了农田保护安全格局。针对基本农田保护问题，对现状耕地分布和基本农田用地类型进行叠加，构建农田保护安全格局。北京南部产业新区地处北京风沙源之一，自然基础条件差。北京南部产业新区规划项目以研究范围内的砂土质区域为源，以土壤表土质地、植被覆盖、土地利用要素作为阻力面计算因子，划分低、中、高安全水平的风沙防治安全格局。山西省霍州市城区生态基础设施规划设计项目通过风道模拟，分析了影响市域的主要风通道。此风环境研究可以结合生态基础设施利用风力资源或减弱风对城市的影响。通过分析确定西北—东南方为市域主要风道，北部为主要风力区，应在北部（尤其是西北部）增加植被覆盖，减少风沙侵袭（图6）。

6 结论与展望

本文对北大景观和土人设计团队20余年来项目的研究发现，基于ESP理论的生态基础设施规划在中国已形成了从理论到实践的成熟体系。无论是在应用范围、方法体系还是技术路线上，ESP理论都在不断



6 © 土人设计

6. 霍州市风道分析

6. Wind corridor analysis of Huozhou

probability, and the eye-catching degree of the landscape. Finally, visually sensitive zones can be managed by establishing visual security classification and zoning.

In the preparation project for the Urban Open Space Planning of Taizhou City, the Yajiyan Cliff on Jiufeng Mountain, the Dabaiyun Mountain, the Taihu Mountain, and other north-south mountains in Huangyan District are regional focal landscapes. At the macro-scale, the visual security pattern was established through visual analyses of the Yongning River Recreational Corridor, the Xijiang Historical and Cultural Heritage Corridor, the Hongjiachangpu Recreational Corridor, and the Lvxin Inner River Corridor (Fig. 5). At the meso-scale, this project also carried out urban skyline planning for the Jiaojiang River banks based on ridgeline protection boundaries.

5.6 Other Ecological Sub-security-patterns

In terms of other ecological sub-security-patterns, the planning and design of the Baima Lake National Park (National Ecological Park) in Huai'an City, Jiangsu Province, as well as the planning and research project of the Nanjing Gaochun International Slow City, have established farmland security patterns by overlaying the distribution and types of existing farmlands to address the primary problems in farmland protection. The new industrial zone in southern Beijing is located in one of the main windstorm origins to the city. By taking the sandy soil zone within the study area as the source, and analyzing related factors such as topsoil type, vegetation coverage, and land use as the resistance surfaces, the Planning Project for the New Industrial Zone developed lower, moderate, and higher security patterns for sandstorm prevention and control. The urban EI planning and design project of Huozhou City, Shanxi Province analyzed the main wind channels of the city through simulation modeling. This wind environment study can further guide EI planning and design to utilize wind resource and reduce the negative impact of windstorm. Analyses reveal that the northwest-southeast direction is the main wind corridor to the city and the northern part is the most affected area. Strategies were proposed that the northern (especially the northwest) part of the city should increase vegetation coverage to alleviate sandstorm invasion (Fig. 6).

6 Conclusions and Prospects

The practice by LA PKU and Turenscape over the past two decades demonstrates that ESP-based EI planning has established a mature system in China that can guide applications at varied scales with diverse methodologies and technical routes. Far from mainly addressing habitat protection issues at its early stage, the ESP theory now has been used in almost all kinds of ecological processes and geographic regions in China, covering major ecoregions and representative

拓展其边界：已从最初的面向生物栖息地保护这一生态过程的“试验性”理论发展到几乎包含全部主要生态过程、覆盖中国几乎全部生态区划类型的庞大理论体系。在研究对象上，从丹霞山这一探索性案例，发展到覆盖中国主要生态区划类型和特色生境的规划实践；在分析技术上，从探索性的单一阻力面方法发展到针对各种生态过程、使用具有不同适应性的方法进行机制分析；在实践效率和质量上，短短20余年间，研究发展到近百个项目，ESP理论的研究成果可直接指导城乡空间布局和生态建设，在综合生态系统服务的基础上，探索了保护与发展的协调可能，ESP理论及生态基础设施规划实践为中国生态文明建设做出了重要贡献。

自ESP理论框架提出以来，中国其他学者在ESP构建研究的细分方向上进行了完善。例如，在对生态源地的定量识别中，指标的筛选从最初只考虑生态用地斑块自身的功能属性[42]，发展到逐步关注其动态变化趋势[43]，再到强调其在整个景观格局中的重要连通作用等[44][45]。另外，在阻力面设置的技术层面，已有学者尝试引入不透水表面指数[46]和夜间灯光[47]等多源数据对不同土地覆被类型生态阻力系数进行修正，为原有方法中基于土地覆被类型的均一化赋值提供了新的思路。既有的ESP理论框架也因此具有了更丰富的内涵和更深入的技术推进，从而被更广泛地应用于生态规划、空间管制、功能区识别与保护等场景中。

目前，全球生态环境问题依然不容乐观，极端天气和自然灾害频发，人为因素导致的生态危机已危及全人类生存，因此推动关于ESP和生态基础设施的研究仍然具有重要意义。在未来的研究中，值得从以下方向深入讨论：

1）生态基础设施研究的一个普遍观点是将自然带回人类社会，实现以生态为中心和以人类为中心的平衡[48]。生态系统服务的相关研究也从最初主要考虑供给层面，逐渐发展到重视与人类福祉相关的生态系统服务[49]。ESP项目实施后，除了可以为当地带来生态绩效之外，还可以带来一定的社会文化影响。与使用者相关的身心健康等影响亟待进行更多的评估，ESP理论也应在保障生态安全的基础上，寻求更多维的价值和人类福祉。

2）ESP理论的初衷是在宏观、中观和微观尺度上自上而下逐步建立完整的生态基础设施，除了本文提到的项目，ESP方法也在其他规划项目中逐渐主流化，但在实践中ESP理论容易被简化为忽略空间尺度和地域性的范式套用。事实上，规划设计人员在实际应用ESP理论的过程中需要更深入地结合当地情况理解方法论。无论是技术性的指标体系构建，还是从宏观格局到微观落地的具体规划方法，都存在灵活运用的空间。

3）ESP理论虽然已经积累了诸多实践，但在中国的实施效力却难以得到真正的保障。“生态文明”相关要求已被写入《中华人民共和国宪法》，但国土空间规划需要更专业、更系统的顶层设计，唯有通过出台专项法律法规及操作标准，才能保障实施。LAF

habitats. In terms of analysis techniques, ESP theory has developed a wide range of highly adaptive approaches to different ecological processes. Witnessing an increasingly large number of practice projects in the past twenty years, ESP theory are readily applicable to urban and rural spatial planning and ecological construction, exploring to synergize protection and development for maximum ecosystem services. ESP theory and EI planning practice have made significant contributions to China's ecological civilization construction.

In addition to the basic theoretical framework of ESP, Chinese scholars have been refining the research subjects. For example, in the quantitative identification of ecological sources, indicators are no longer selected only by the functions of ecological land patches[42], but upon the holistic dynamic trend[43] and the connection roles in landscape pattern[44][45]. In terms of resistance surface setting, multi-source data such as impervious surface index[46] and nighttime light[47] are introduced to correct the ecological resistance coefficients of different land cover types, providing an alternative to the normalized evaluation of ecological resistance surface based on land cover types. The ESP theoretical framework therefore gains richer connotations and technical advance and sees a wider promotion in ecological planning, spatial regulation, functional area identification and protection, etc.

The global ecological and environmental issues are still challenging. Frequent extreme weather events, natural disasters, and man-made ecological crises are endangering the survival of all human beings. It is of great significance to promote the research on ESP and EI in the following aspects:

1) A shared goal of EI research is to harmonize the man-land relationship by finding a fit between people and nature[48]. The focus of research on ecosystem services has shifted from service provision towards ecosystem services linking to human well-being[49]. ESP projects can bring about both ecological and cultural benefits. The influence of ecosystem services on human physical and mental health are in urgent need to be further evaluated. In addition to securing ecosystem security, ESP theory is expected to play a part in multidimensional values which stand for a higher level of human well-being.

2) The primary goal of ESP theory is to establish a complete top-down EI system at macro-, meso-, and micro-scales. Yet as the ESP methods get popular in other planning, they are often applied with insufficient consideration on the spatial scale and local conditions. Planners and designers should utilize the theory based on local conditions, exploring flexibility both in technical indicator system construction and approaches from macro planning to micro implementation.

And 3) the implement efficacy of associated practice needs to be improved. Although ecological civilization construction has been a constitutional agenda in China, territorial spatial planning requires a more professional and systematic top-level design. The implementation of such design relies on legislation and regulations as well as relevant norms and standards. LAF

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