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Spatial Mechanism for Opening the "Black Box": A Translational Pathway From Landscape Ecological Research to Landscape Ecological Planning and Design Practice

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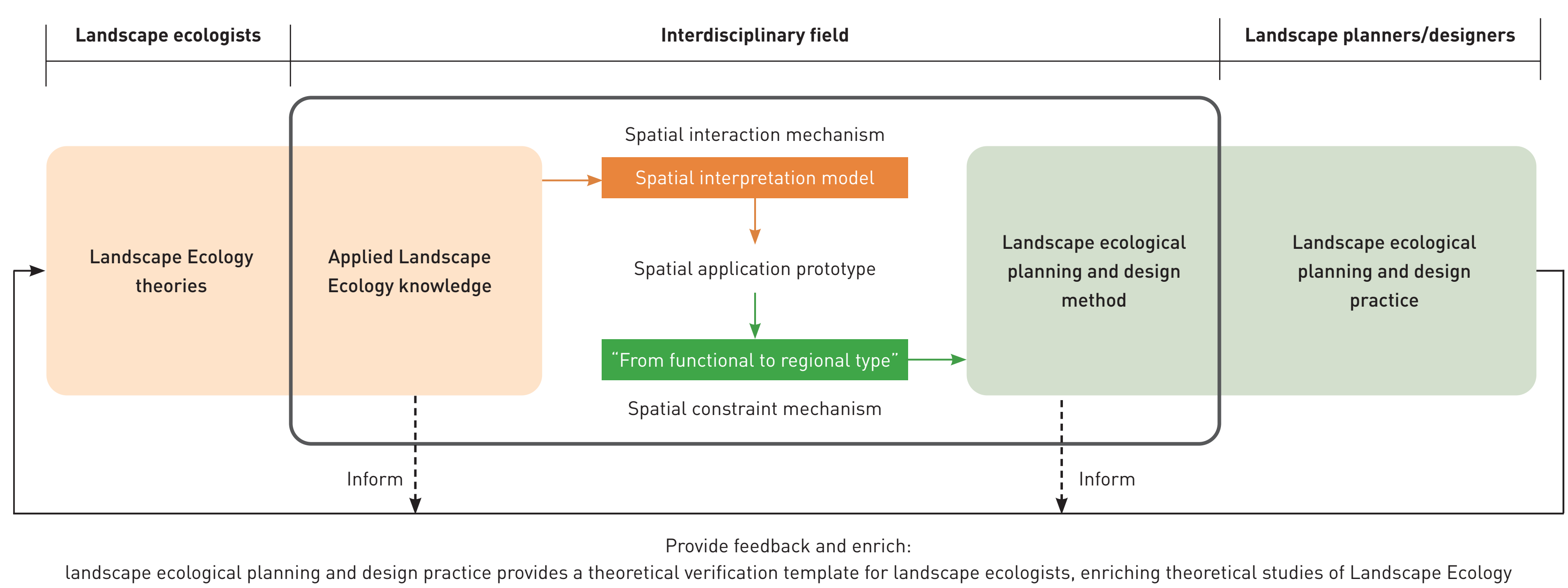
GRAPHICAL ABSTRACT



ABSTRACT

In the field of Landscape Ecology, due to the excessive parallel development of landscape ecological science research and landscape ecological planning and design practice, the knowledge produced by landscape ecological research cannot effectively guide landscape ecological planning and design practice. This theory–practice gap has been widely concerned by landscape ecologists and landscape ecological planning designers. Although many scholars have made useful contributions to bridging the gap, a systematic translational pathway has not yet been formed. In this context, this study first reviews the development history of landscape ecological research and landscape ecological planning and design practice, as well as the evolutionary characteristics of their integration. Second, based on the internal relationship between the two, a three-level research system linking up research to planning and design practice is constructed. Third, the spatial mechanism analysis framework is further proposed to open the "black box" in the transformation from research to planning and design practice, and to bridge the theory–practice gap. The landscape ecological planning and design procedure through synergic analyses of spatial interaction mechanism and spatial constraint mechanism is constructed correspondingly. Finally, taking the Sanya Mangrove Ecological Park project in China as an example, the effectiveness of the procedure is verified.

KEYWORDS

Spatial Mechanism; Landscape Ecological Research; Landscape Ecological Planning and Design Practice; Theory–practice Gap; Translational Pathway; Knowledge Production; Black Box

HIGHLIGHTS

- Proposes a three-level research system linking up landscape ecological research and planning and design practice
- The analysis of spatial mechanisms opens the "black box" between research and practice
- Proposes a landscape ecological planning and design procedure through synergic analyses of spatial mechanisms

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1 Introduction

1.1 The Disconnection and Misalignment Between Landscape Ecology Research and Landscape Ecological Planning and Design Practice

Landscape Ecology is an interdisciplinary science that studies landscape structure, function, and change, providing theoretical basis and method guidance for landscape ecological planning and design practice[1]~[3]. Over the past few decades, great progress has been made in the research on Landscape Ecology, forming a series of concepts, principles, and models[4][5], such as landscape pattern and process[1], landscape scale[2], sustainable landscape pattern[6], and landscape ecological security pattern[7]. These research achievements promote the development and innovation of landscape ecological planning and design practice. However, there is a lack of effective connection between scientific ecological knowledge addressing a single problem (or involving individual elements) and ecological practice addressing complicated problems (or involving multiple elements)[8]~[11]. Applying local, time-sensitive, and generic ecological knowledge into the overall practice of specific scenarios would result in the disconnection between research and planning and design practice[12], and problems such as ecological knowledge not recognized or generally practiced by planning designers[10], the stereotype application of spatial models in planning and design practice[13], and the "shallow forms" caused by passive planning and design following the current process[14]. Zhifang Wang defined such problems as the dislocation between traditional scientific research disciplines and applied practice disciplines[12]; Chundi Chen et al.[15] and Weining Xiang et al.[16] introduced the "Pasteur's quadrant" paradigm to characterize the disconnection between landscape ecological research and planning and design practice. Among the reasons, one is the essential difference between scientific research and practical application: the knowledge from scientific research is objective, verifiable, and professional, while the planning and design practice is subjective, experience-based, and of historicity and sociology. The gap between scientific research and practice is also known as the "knowing–doing gap"[17][18], "research–implementation gap"[18], or "theory–practice gap"[17].

1.2 Review of Research Progress and Problem Definition

In order to bridge the gap between landscape ecological research and landscape ecological planning and design practice, scholars have explored from the theory-dominated and practice-dominated perspectives. Among the studies of the former, Forster Ndubisi reviewed the development of landscape ecological research and landscape ecological planning and design practice by analyzing their interactions through the lenses of historical relationship, and put forward the concept of transition with the focus shifting from the principle to the practice[19]. Wenche Dramstad put forward 55 rules and concepts about landscape ecological planning, as well as the conceptual schema of ecological design about patches, boundaries (edges), corridors (connectivity), and mosaics[20]. Joan Nassauer and Paul Opdam viewed spatial design in planning procedure as a bridge the theory–practice gap, proposing the "pattern–process–design" paradigm that integrates research and design[21]; Bangrui Yue put forward the "theory–pattern–case" model as a logical translation channel from research to planning and design practice[22]. Yuncai Wang proposed the "landscape space pattern language" which provides a path for the planning and design of the organic overall landscape[23]. Among the practice-dominated studies, Xiang proposed the concept of "ecological wisdom" as a bridge between ecological theory and ecological practice, addressing the limitation of existing scientific knowledge and the failure of current ecological practice[24]. Zhifang Wang further suggested that "actionable ecological knowledge" is an important part for effectively linking ecological research and ecological practice[25]. Kongjian Yu made efforts from both perspectives: on the one hand, he proposed the "ecological security pattern" approach[7][26] to bridge Landscape Ecology theory and spatial planning, which has already been used in the systematic planning of ecological infrastructure; on the other hand, he conducted research based on the practice of Turenscape[27] that applies spatial language patterns in planning and design and proposed the paradigms of "practice research" and "prototype study"[13].

Both landscape ecological research and landscape ecological planning and design practice are interdisciplinary fields[19]. Although many scholars have made valuable contributions to bridging the gap between the two, most current research remains confined to single fields, focusing on the production of "intermediate knowledge" such as spatial patterns or spatial prototypes between research and practice. There is still a lack of discussion on this disconnection within a unified framework, and a systematic transformation pathway has yet to be established.

In summary, this paper attempts to answer the following questions: 1) How can landscape ecological research be truly connected to landscape ecological planning and design practice? 2) How can the variables of pattern, process, and function in Landscape Ecology be translated into operable spatial pattern language? 3) How can the spatial pattern language help generate specific planning and design schemes? The universally applicable landscape ecological planning and design procedure proposed in this paper is then further explored and verified through a case study.

2 Review of Landscape Ecological Research and Landscape Ecological Planning and Design Practice

2.1 Development of Landscape Ecological Research

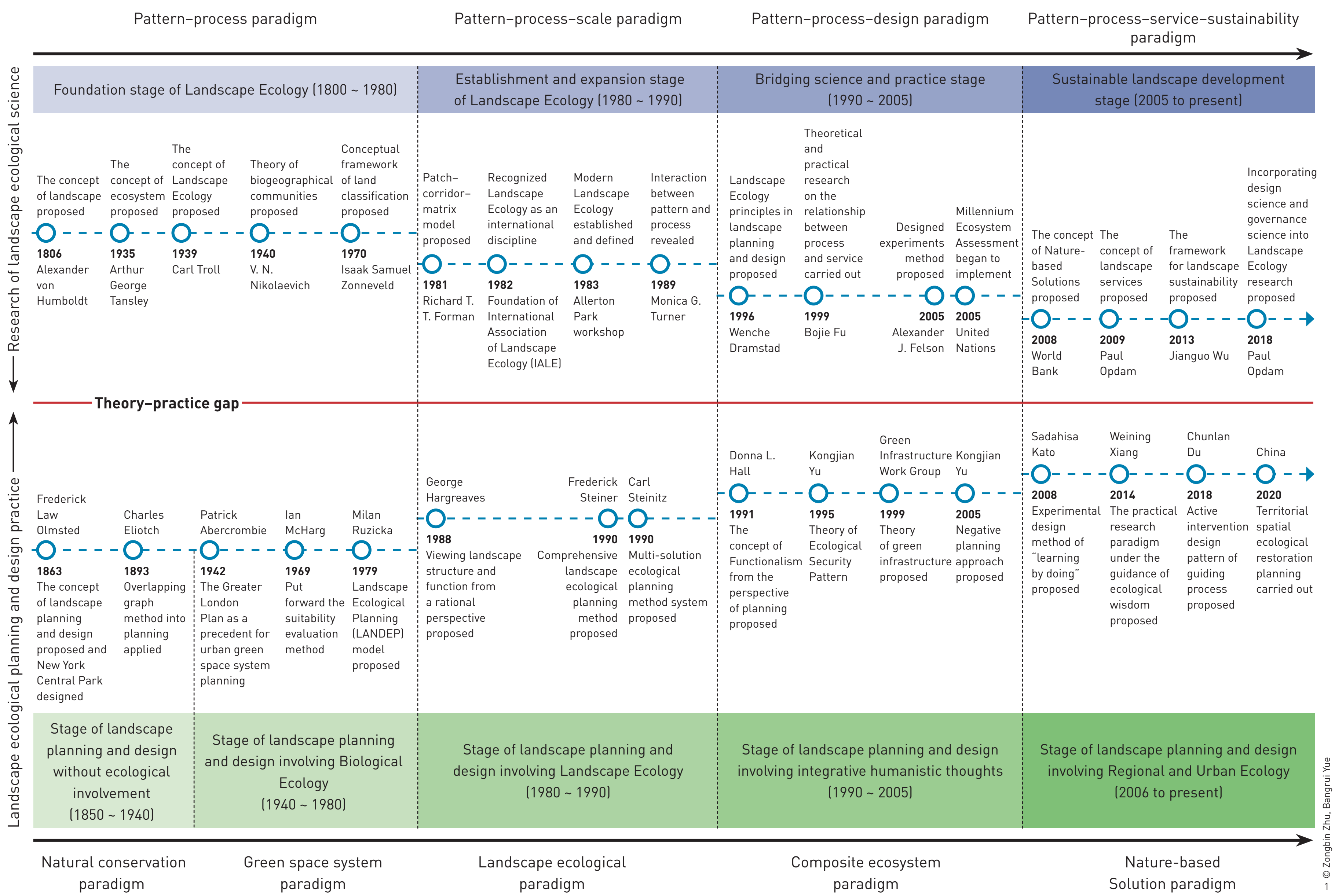
Landscape Ecology focuses on the interactions between the Earth's surface materials, energy, information transmission with biotic and abiotic elements, aiming to optimize, utilize, and protect landscape patterns[3]. It seeks to address the spatial relationship between humans and nature, achieving harmony in human–environment interactions by interpreting and understanding of landscape patterns and processes[2]. Based on the evolution of the pattern–process paradigm and spatial planning, the development of landscape ecological research can be roughly divided into four stages[2][4][28]~[30] (Fig. 1).

1) Foundation stage of Landscape Ecology (1800 ~ 1980). During this period, Ecology and Geography developed independently, laying the groundwork for the birth of Landscape Ecology through the introduction of concepts like landscape and ecosystem. After the 1930s, influenced by disciplines of Ecology and Geography and driven by the theory of geographical communities[2], the exploration of basic landscape issues and their relationships with spatial planning began[4].

2) Establishment and expansion stage of Landscape Ecology (1980 ~ 1990). The establishment of the International Association of Landscape Ecology marks that Landscape Ecology has become an international discipline. Landscape Ecology has gradually established and expanded to the pattern–process–scale paradigm[31], emphasizing the importance of spatial scale and spatial heterogeneity to ecosystem functions. The patch–corridor–matrix model provides a systematic conceptual framework for the study of pattern and process, opening the integration of landscape planning and Landscape Ecology[22][32]. Efforts at this stage discussed how to apply landscape ecological planning theories to land use and protection practices[4].

3) Bridging science and practice stage (1990 ~ 2005). Landscape Ecology continues to expand its applied fields. Landscape Ecology principles[20], the "aggregate-with-outliers" model[33], and the designed experiment method[34] in landscape planning have promoted the expansion of Landscape Ecology to the pattern–process–design paradigm, narrowing the gap between research and practice[4][30].

4) Sustainable landscape development stage (2006 to present). Accompanied by the implementation of the Millennium Ecosystem Assessment[35] and the emergence of the "Nature-based Solution" concept[36], Landscape Ecology has gradually moved from theoretical exploration to decision-making practice, emphasizing the symbiosis of ecology, human well-being, and social mechanisms, thereby promoting sustainable landscape planning and development[37][38]. Landscape services, linking with ecological science and sustainable development, have further developed the "pattern–process–service–sustainability" paradigm[39] in Landscape Ecology. Incorporating design science and governance science to achieve



1. Development history of landscape ecological research and landscape ecological planning and design practice.

sustainability solutions has become a current trend in Landscape Ecology[4][38].

2.2 Development of Landscape Ecological Planning and Design Practice

Landscape ecological planning and design refers to the spatial planning and design at various scales, following broad ecological principles, with the goal of harmonizing human–nature relationships[2][22]. The review on the development history of Ecology helps reveal the five progress stages of landscape ecological planning and design practice[22][40]~[44] (Fig. 1).

1) Stage of landscape planning and design practice without ecological involvement (1850 ~ 1940). In earlier years, landscape planning and design developed independently of Ecology, and were guided by the idea of nature conservation and usually defined by landscape designers' individual ecological concepts. The construction of Central Park in New York marked the emergence of ecological thoughts in Western planning and design. The application of the map-overlay method to landscape planning in the 1890s signaled the beginning of the integration of Ecology and landscape planning[8][22].

2) Stage of landscape planning and design practice involving Biological Ecology (1940 ~ 1980). Landscape planning and design began to merge with Ecology, marking the entry into an era of

Ecology-based landscape planning. The introduction of suitability evaluation methods and the LANDEP (landscape ecological planning) model based on suitability evaluation translated ecological language into spatial factors that could be practically applied, representing the emergence of landscape ecological planning methods.

3) Stage of landscape planning and design practice involving Landscape Ecology (1980 ~ 1990). Landscape Ecology was integrated with landscape planning and design, leading to the era of Landscape Ecology-based planning and design[22]. Research on the relationship between patterns and processes and the introduction of the "patch–corridor–matrix" model contributed to the improvement of landscape ecological planning and design theories and methods[28][32]. The comprehensive landscape ecological planning method and the multi-solution ecological planning method system further broaden the territory of landscape ecological planning and design practice[44].

4) Stage of landscape planning and design practice involving integrative humanistic thoughts (1990 ~ 2005). Landscape Ecology began to incorporate holistic and humanistic thinking, transforming landscape ecological planning and design into a composite ecosystem paradigm[22][42]. Theoretical approaches such as ecological security patterns, green infrastructure, and concepts like functionalism, resilience, and "negative-planning approach" integrated landscape with society and ecology, enabling the co-evolution of the geosphere, biosphere, and technosphere[22].

5) Stage of landscape planning and design practice involving Regional and Urban Ecology (2006 to present). With the proposal of the "Nature-based Solutions" concept and the rise of landscape services, sustainability has gradually been underscored in landscape ecological planning and design[37][38]. This stage has seen a transition from focusing solely on natural spaces and biological habitats to multi-objective optimization that comprehensively considers human–nature relationships. The introduction of methods such as "learning by doing" experimental design[45] has refined planning and design procedures, making landscape planning decisions more scientific. The concurrent development of ecological planning and design practices guided by ecological wisdom, as well as Regional and Urban Ecology, has become a prevailing trend[46].

2.3 Evolutionary Characteristics of the Integration Between Landscape Ecological Research and Landscape Ecological Planning and Design

As shown in Fig. 1, the landscape ecological research has gone through four paradigm stages, namely "pattern–process," "pattern–process–scale," "pattern–process–design," and "pattern–process–service–sustainability." Simultaneously, the landscape ecological planning and design practice has also witnessed a five-stage development from natural conservation paradigm to green space system paradigm, ecological landscape paradigm, composite ecosystem paradigm, and Nature-based Solution paradigm[43]. In the integration process of the two fields, the theoretical framework of Landscape Ecology informs landscape planning and design, while the design principles and processes provide feedback and enrich the theoretical framework of Landscape Ecology. Landscape ecological planning and design practice has changed from experience-based planning and design to evidence-based planning and design.

3 Landscape Ecological Planning and Design Research System

Based on the review of the development history of landscape ecological research and landscape ecological planning and design practice, and the authors' previous research results[47][48], this paper proposes a three-level research system to link up research and planning and design practice (Fig. 2).

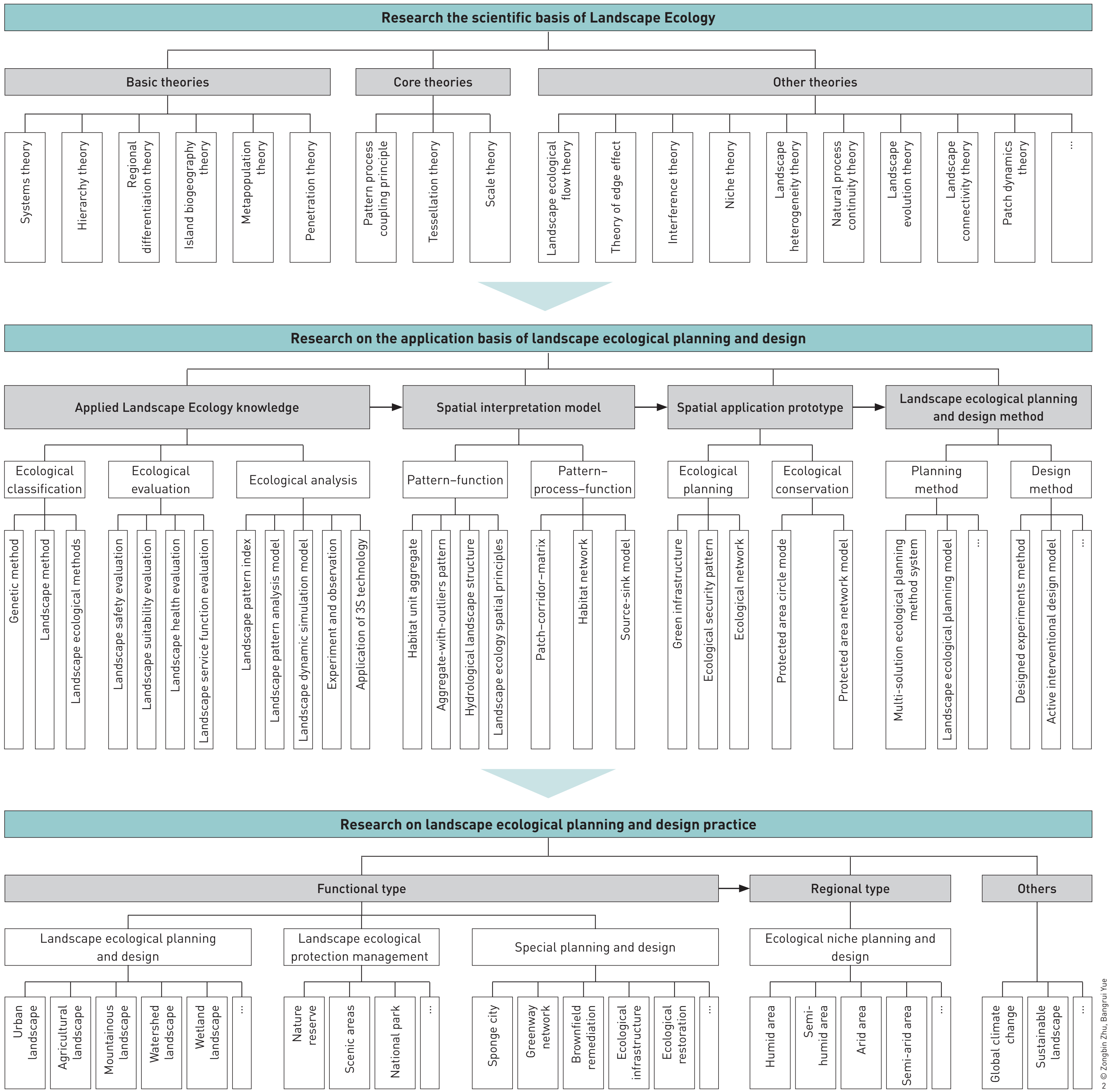
1) Research on the scientific basis of Landscape Ecology. It is composed of basic theories, core theories, and other theories of Landscape Ecology, providing a scientific basis for the basic research and application research of landscape ecological planning and design.

2) Research on the application basis of landscape ecological planning and design. It is composed of applied Landscape Ecology knowledge, spatial interpretation models, spatial application prototypes, and planning and design methods. The theoretical knowledge in research needs to be combined with specific ecological classification, ecological evaluation, and ecological analysis, so as to transform into planning and design practice. Related theories, technologies, models, methods, and strategies in this combination process can be called the application basis of landscape ecological planning and design.

3) Research on landscape ecological planning and design practice. It refers to the specific planning and design practice for multiple functional types, regional types, and other types (e.g., global climate change).

4 Spatial Mechanism: A Link Between Landscape Ecological Research and Landscape Ecological Planning and Design Practice

According to the above research, this paper argues that bridging the theory–practice gap requires the research on the application



2. Three-level research system linking up landscape ecological research and planning and design practice.

basis of landscape ecological planning and design. However, how to transform the variables of pattern, process, and functions in Landscape Ecology into drawable pattern language① for planning and design practice, and how to transform the drawable pattern language into specific spatial schemes in planning and design practice still remain "black boxes."

In the field of Philosophy, "mechanism" is a tool to open the "black box" inside the system and explain the interconnections and interactions within the system[49]. Therefore, this paper introduces the concept of "spatial mechanism"[50][51] and proposes two types of spatial mechanism—spatial interaction mechanism and spatial constraint mechanism (Fig. 3). These two mechanism types link up the three-level research system discussed above, which aims to open the "black box" from Landscape Ecology theories to spatial application prototypes (spatial pattern language), and the "black box" from spatial application prototypes to specific planning and design schemes. The analyses of these two spatial mechanisms can effectively help transform Landscape Ecology theories and knowledge into specific design and planning strategies.

4.1 From Landscape Ecology Theories to Spatial Application Prototypes: Spatial Interaction Mechanism

4.1.1 Analysis of Spatial Interaction Mechanism

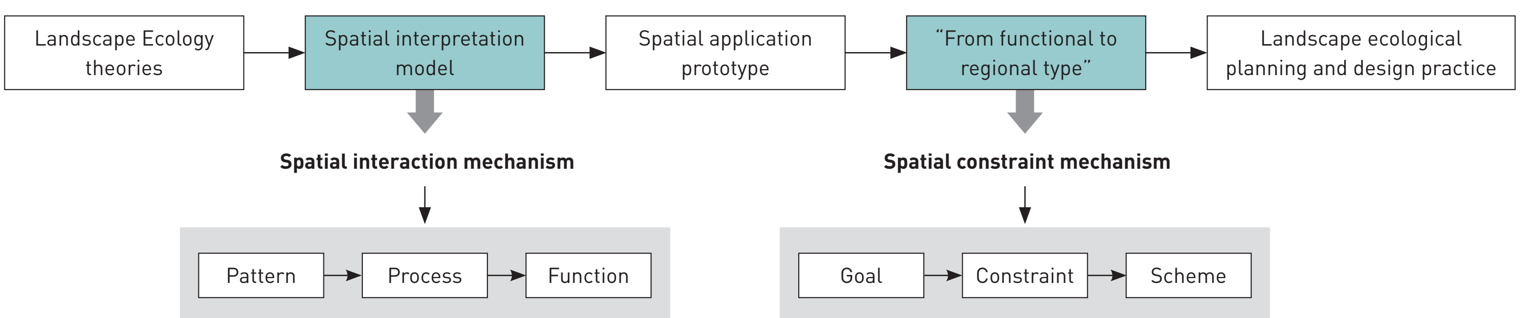
In landscape ecological planning and design practice, the relationship between spatial form and function has always been a controversial issue for planning designers, which has led to discussions such as "ecological–aesthetic disjuncture"[52], "deep forms," and "shallow forms"[14]. Although the exploration of the relationship is indispensable, planners'/designers' efforts most stay at the collision of different ideas, lacking the research on knowledge rationality and reductionism based on natural science, which makes the scientific nature of planning and design practice questioned[53]. The spatial interaction mechanism proposed in this paper refers to the causal relationship between a specific spatial pattern and a specific ecological function in a given site. The planning and design process is the realization process of obtaining a specific function (result) by shaping the spatial pattern (cause). The analysis of spatial interaction mechanism is to figure out the causal relationship between the pattern and the function, through two analysis paths—causal mapping and causal chain[50].

Causal mapping is a simplified path for causal relationship analysis. Previous studies have revealed the process of how Landscape Ecology theories are transformed into spatial application prototypes. The most representative one is "Diamond Principe"[54]: Based on the "species–area" theory and the "equilibrium" theory, Jared Diamond further revealed the causal mapping mechanism (spatial interpretation model) between patch structure (spatial form) and species abundance (function). Finally, through the combination of the six principles, spatial application prototypes, such as the circle model and network model for nature reserve planning and design, was formed[22].

In the real world of landscape ecological planning and design practice, the essence of the relationship between spatial form and function cannot be simply represented through causal mapping. Fortunately, the research on landscape process in Landscape Ecology has successfully opened the "black box" between spatial form and function via the analysis path of "pattern–process–function" causal chain. The most representative one is the "patch–corridor–matrix" model proposed by Richard T. T. Forman[28][33], which provides a popular, concise, and simple spatial language for distinguishing landscape structure and analyzing the causal chain mechanism (spatial interpretation model) between spatial form and function. Then the spatial application prototypes, such as ecological security pattern model, ecological network model, and green infrastructure model, are deduced[22][43].

In summary, landscape planning and design practice only

① The authors believe that the essence of planning and design scheme generation is drawing, so this paper emphasizes the attribute of spatial mapping and drawing of the planning and design discipline.



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3. Spatial mechanisms that link up the three-level research system.

focused on the form–function relationship at the beginning, until the research on landscape process in Landscape Ecology opened the pattern–function "black box." Therefore, the following paragraphs focus on interpreting the spatial mechanism of "pattern–process–function" causal chain.

4.1.2 Actionable Knowledge of Spatial Interaction Mechanism

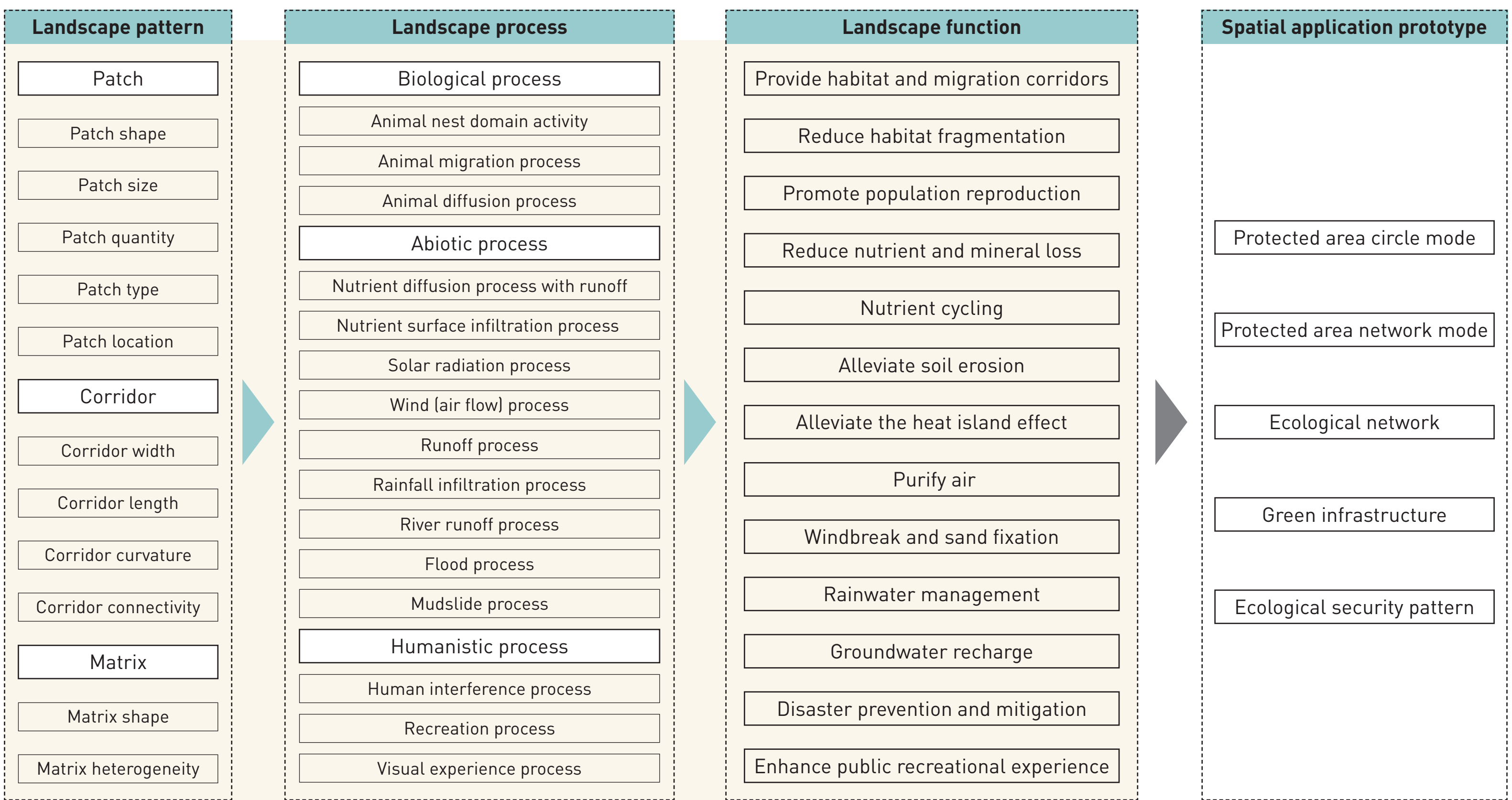
Via the analysis path of "pattern–process–function" causal chain, this paper translates the variables of pattern, process, and function in Landscape Ecology into actionable knowledge for planners/designers (Fig. 4), demonstrating with a case of river corridor (green infrastructure) ecological planning and design (Fig. 5). Firstly, the ideal landscape function (flood regulation) of river corridors is clarified; secondly, the affecting landscape process (river runoff process) is analyzed, and the affecting key structural characteristics (curvature and width) are analyzed; finally, it evolves the longitudinal, horizontal, and vertical landscape structure of river corridors that can be actionable knowledge. That is, obtaining the ideal pattern through the analysis of spatial interaction mechanism. Here, only the causal chain analysis of the ideal process and function is carried out. The analysis of the existing "pattern–process–function" and the ideal "pattern–process–function" is detailed in the following case study.

4.2 From Spatial Application Prototype to Landscape Planning and Design Practice: Spatial Constraint Mechanism

4.2.1 Analysis of Spatial Constraint Mechanism

Landscape ecological research provides a set of efficient and systematic methods to define the ideal pattern with the help of computer and GIS[14]. Many planners/designers also realize that landscape ecological planning and design is to connect landscape spatial patterns and functions by following ecological processes[7][55]. However, most of the previous studies are often limited to simply adhering to scientific research thinking of Landscape Ecology[56], dogmatic use of landscape prototypes[13], and passive planning and design using the existing landscape processes as design constraints[55]. This makes the final solution become the "dystopia" of research[57], and what is obtained is only the "ideal forms" in the context of scientific research, rather than the "deep forms."

Thus, how to transform the abstract spatial application prototypes into specific schemes in planning and design practice? The spatial constraint mechanism proposed in this paper refers to the causal relationship between the goals and schemes of landscape ecological planning and design for a given site (Fig. 3). Different from the knowledge rationality and reductionism emphasized in the analysis of spatial interaction mechanism, the spatial constraint mechanism pays more attention to the site-oriented



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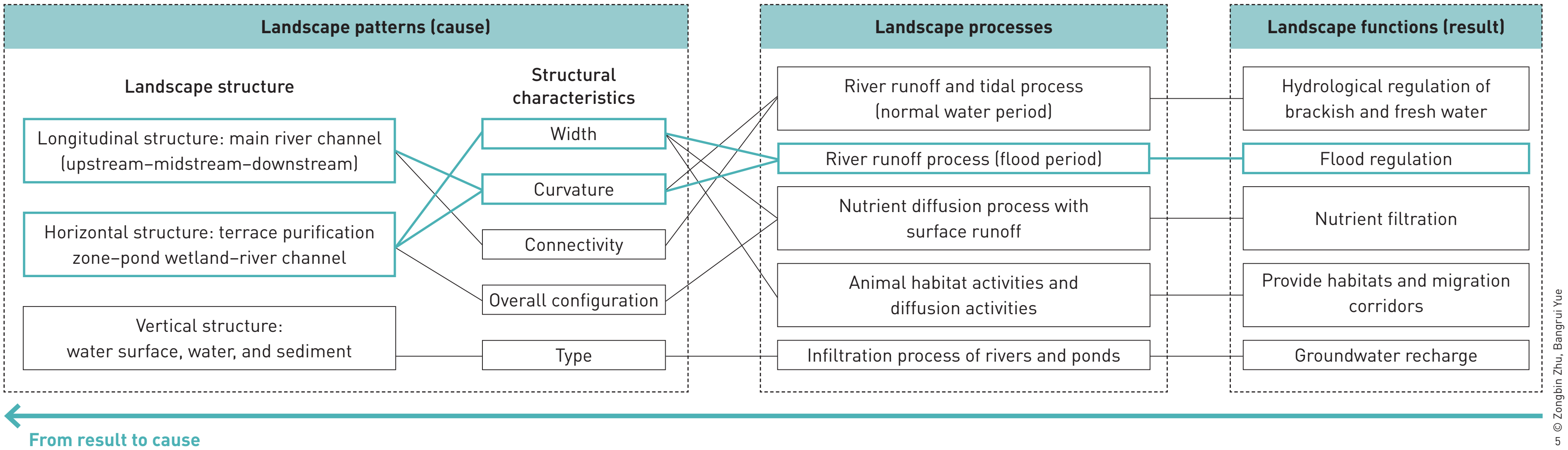
4. Actionable knowledge framework of spatial interaction mechanism.



5. Analysis of the "pattern–process–function" causal chain mechanism for river corridors planning and design.

practice-dominated and holism[13][56]. Based on the research on landscape ecological planning and design practice[58][59], and the considerations of specific site conditions, this paper proposes to take the approach of "from functional type to regional type" as the key to open the "black box" between spatial application prototypes and schemes. The analysis of various spatial constraints[9][25] covers the identification and response of functional constraints (e.g., planners'/designers' knowledge structure and creative ability, and functional requirements of stakeholders), geographical constraints (e.g., climatic conditions, geological and geomorphological conditions), and site constraints (e.g., site terrain and site hydrological conditions)[25]. From the spatial application prototype with universality and versatility (e.g., green infrastructure that emphasizes versatility), to a specific functional type (e.g., "sponge city" green infrastructure that emphasizes stormwater management), and then to a regional type with complex design constraints (e.g., "sponge city" green infrastructure in arid and semi-arid areas of Northwest China[60] that emphasizes regional climate characteristics), a planning/design scheme tailored to the site is concretized step-by-step.

Constraints would not hinder designers' creativity, but can stimulate their potential and promote the active planning and design instead of the passive planning and design prevalent nowadays.

4.2.2 Actionable Knowledge of Spatial Constraint Mechanism

Via the analysis path of the "goal–constraint–scheme" causal chain, this paper translates the approach of "from functional type to regional type" into actionable knowledge (Fig. 6), demonstrating with ecological planning and design of green infrastructure in sponge cities in the arid and semi-arid regions of Northwest China[60] (Fig. 7). First, clarify landscape goals (e.g., stormwater regulation) were clarified; second, analyze spatial constraints to the landscape goals (e.g., strong permeability and poor water holding capacity of soil); at last, propose specific landscape approach (e.g., increasing water source and reducing water loss) and landscape strategies (e.g., optimization of water condition distribution, micro topography, sunken green space, etc.).

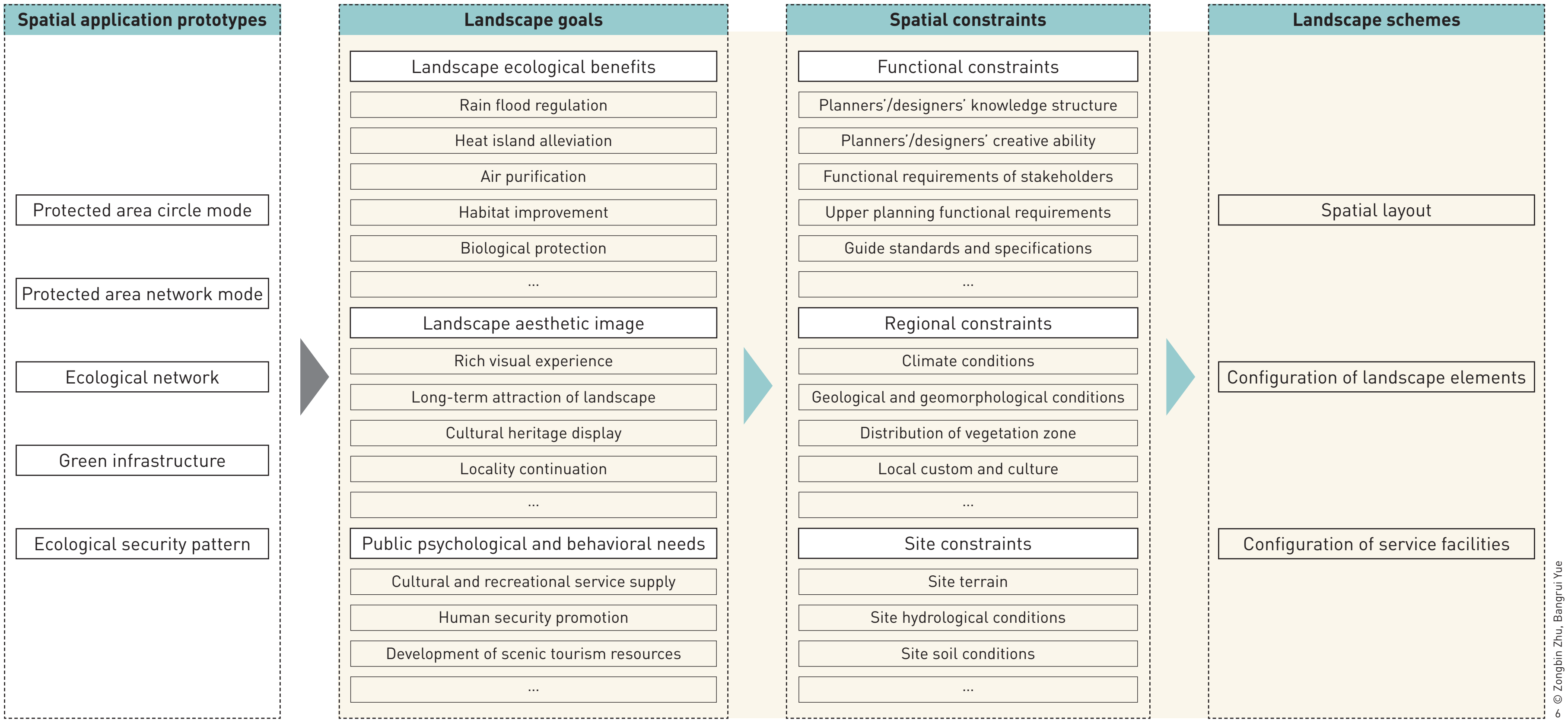
5 Landscape Ecological Planning and Design Procedure Through Synergic Analyses of Spatial Interaction Mechanism and Spatial Constraint Mechanism

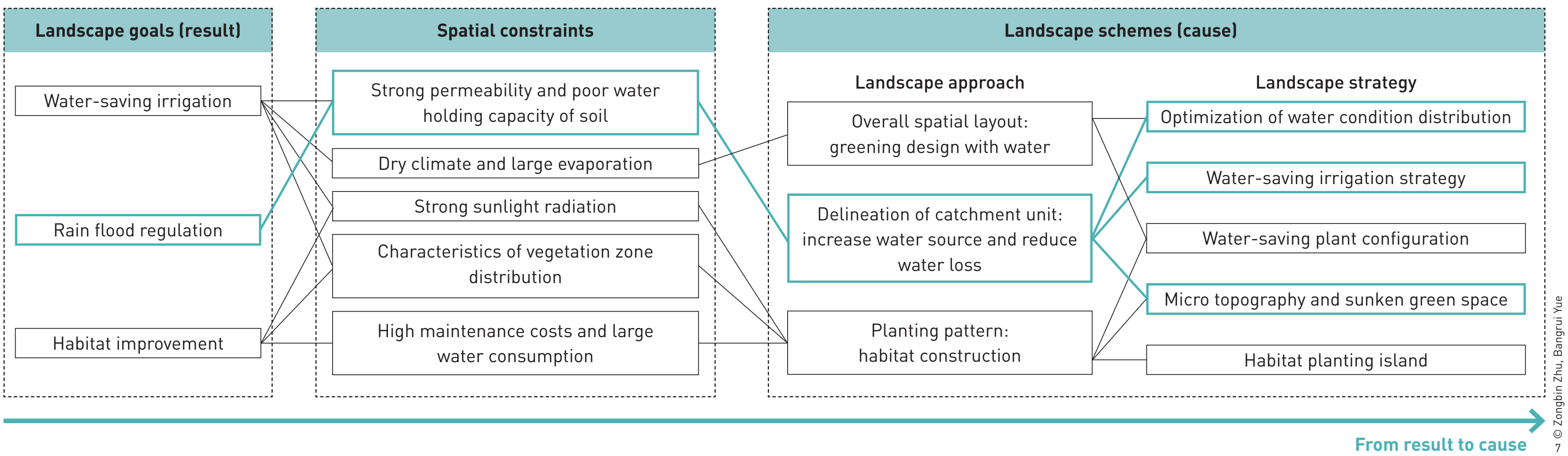
In order to make the spatial mechanism analysis practical and operable, this paper proposes a landscape ecological planning and design procedure based on the synergic analyses of spatial mechanisms (Fig. 8).

5.1 Analysis of Spatial Interaction Mechanism of the Existing Landscape

The spatial mechanism analysis based on the pattern–process–function causal chain is mainly divided into three steps: landscape pattern expression, landscape process analysis, and landscape function evaluation.

1) Landscape pattern expression: based on the spatial interpretation model (mainly the "patch–corridor–matrix" model), establish the expression system of the existing landscape, including





6. Actionable knowledge framework of spatial constraint mechanism.
7. Analysis of the "goal–constraint–scheme" causal chain mechanism for sponge city planning and design in an arid region.

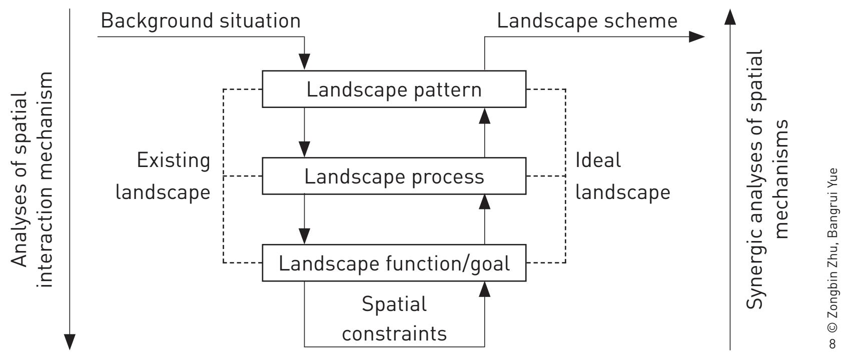
meteorology, topography, hydrology, and land use status.

2) Landscape process analysis: analyze the existing landscape from three aspects, namely biological process, non-biological process, and humanistic process.

3) Landscape function evaluation: evaluate the health and safety of the ecosystem and the status of ecosystem services, analyze the interests of the existing landscape pattern on the landscape process (i.e., to promote or hinder the occurrence of the process), so as to assess whether the existing landscape is functioning well.

5.2 Synergic Analyses of Spatial Interaction Mechanism and Spatial Constraint Mechanism of Ideal Landscape

The synergic analyses of spatial interaction mechanism based



8. Landscape ecological planning and design procedure through synergic analyses of spatial mechanisms.

on goal–constraint–scheme causal chain and the spatial constraint mechanism based on "goal–constraint–scheme" causal chain are mainly divided into three steps: landscape goal determination, landscape process analysis, and landscape pattern optimization.

1) Landscape goal determination: based on the existing landscape function, combined with spatial constraints to determine the landscape goal (i.e., the ideal landscape function).

2) Landscape process analysis: the corresponding ideal landscape process is derived based on the landscape goal.

3) Landscape pattern optimization: improve the landscape pattern that affects a specific landscape process, and propose a planning/design scheme.

6 From Ideal Forms to Deep Forms: Case Study of Sanya Mangrove Ecological Park

This paper here takes the Sanya Mangrove Ecological Park in China as an example to verify the effectiveness of the landscape ecological planning and design procedure based on the synergic analyses of spatial mechanisms in landscape planning and design practice.

Sanya Mangrove Ecological Park is located on the east bank of the Sanya River, where seawater and freshwater meet. Seasonal uneven water flow volume leads to water shortage in the dry season. A large amount of urban development has encroached on the original pit and pond system. The concrete flood control wall constructed has seriously damaged the mangrove and floodplain ecosystem, blocked the connection between seawater and upstream urban rainwater, and caused serious urban flooding.

The process of developing the landscape optimization scheme in a branch shape through the synergic analyses of spatial mechanisms was displayed as Table 1 and Figs. 9 and 10. The specific strategies include:

1) Water quality improvement strategy. The design follows the

Table 1: Analysis of spatial constraint mechanism

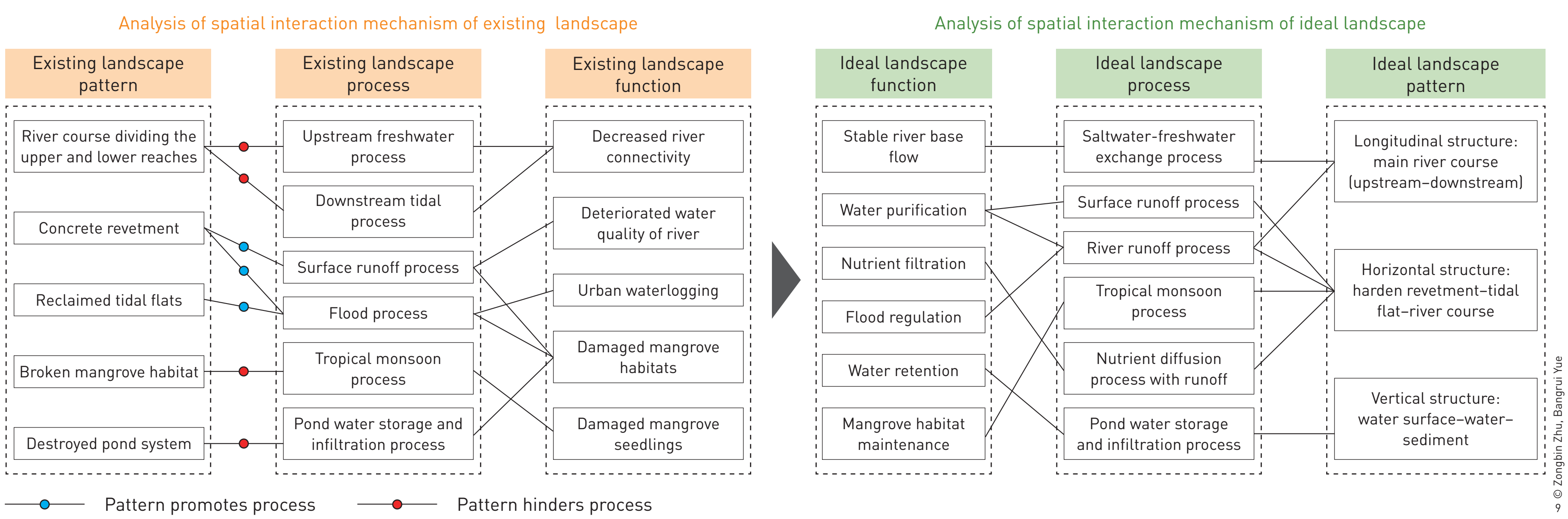
Spatial constraint		Content
Functional constraint	Planners'/designers' knowledge structure	Professional knowledge about mangrove ecosystems, environmental engineering, and sustainable design to scientifically assess and respond to pollution problems
	Planners'/designers' creative ability	Innovatively apply ecological design principles and put forward solutions with both functional and aesthetic values
	Functional requirements of stakeholders	Balance and maximize the benefits of various stakeholders, including local governments, environmental organizations, and communities
	Functional requirements of upper plans	Guided by relevant national and local environmental regulations and planning documents to ensure the schemes meeting environmental protection standards
	Specifications, guidelines, and standards	Follow relevant landscape design specifications, guidelines, and industry standards
Regional constraints	Climatic conditions	Consider climate adaptability factors such as climate change and seasonal precipitation that impact the growth and water quality management of mangroves
	Geological conditions	Consider geological conditions that impact the flow and deposition of pollutants, and improve the geological stability to prevent the diffusion of pollutants

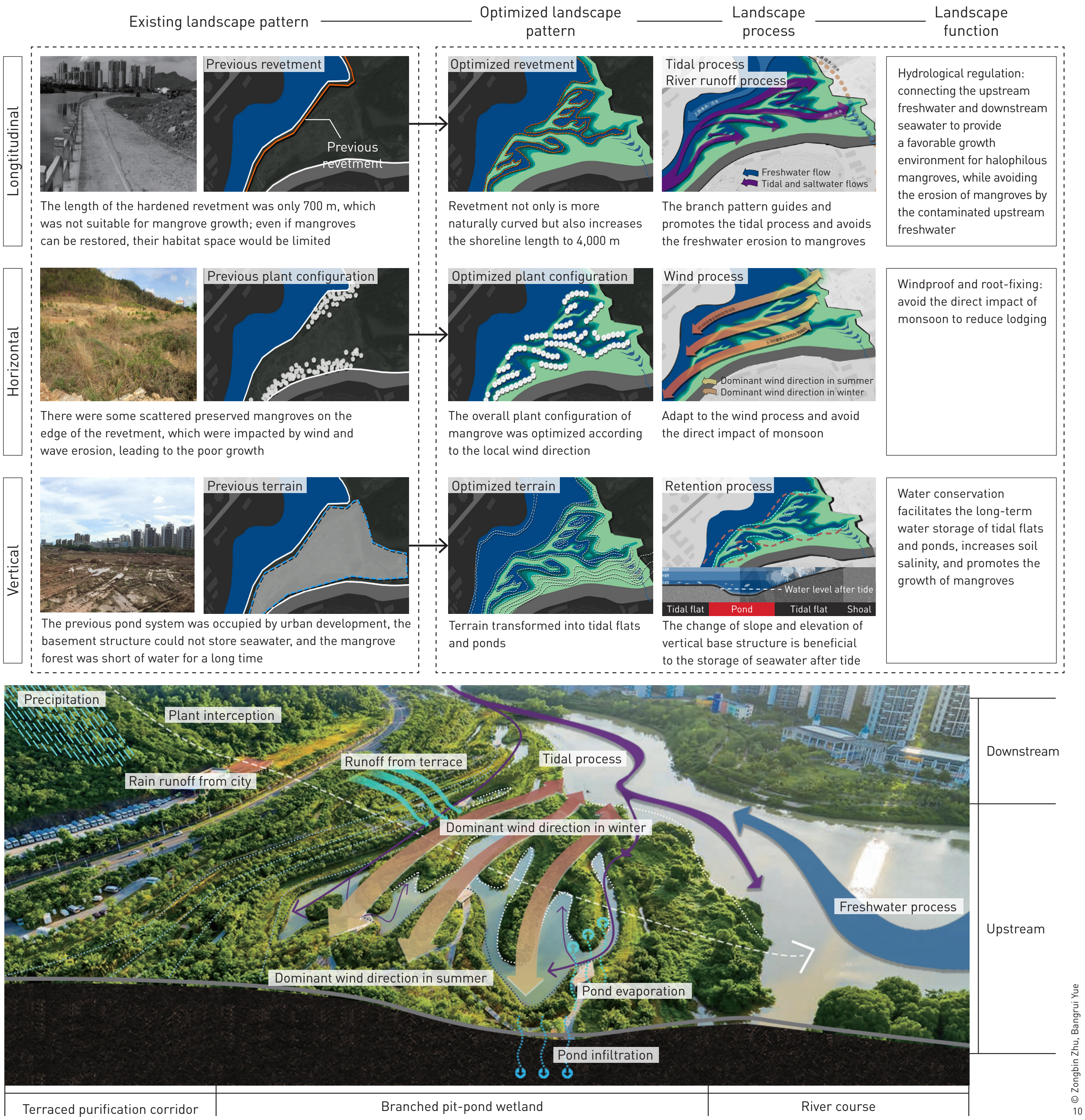
(Continued)

Table 1: Analysis of spatial constraint mechanism (Continued)

Spatial constraint		Content
Regional constraints	Distribution of vegetation zone	Mangroves, as a unique evergreen shrub (or small tree) community in tropical and subtropical bays and estuarine mudflats, are often distributed in the intertidal zone between the high tide line and the low tide line
	Local custom and culture	Consider the traditions and culture of local residents that will affect the acceptance and implementation effect of the design
Site constraints	Topographical conditions	Arrange appropriate drainage and filtration systems based on the slope and undulation of the site that define the distribution of water flow and pollutants
	Hydrological conditions	Consider water level changes caused by tide that mangroves rely on, and the purification and management of water bodies to prevent pollutants from entering rivers and wetlands
	Soil conditions	Consider soil type and fertility that determine the growth of mangroves, and the soil improvement and pollutant filtration
	Salinity conditions of mangrove habitats	Mangroves, as halophilous plants, require the salt content of seawater in the outer edge usually of 3.2% ~ 3.4%, and 2.0% ~ 2.2% for the inner edge
	Wind direction conditions of mangrove habitats	Protect mangroves from long-term wind and wave erosion that impact the survival rate and growth rate of mangroves
	Temperature conditions of mangrove habitats	Mangroves require the air temperature no lower than 9.3 °C and the water temperature no lower than 10.6 °C
	Tidal flat conditions of mangrove habitats	Tidal flats provide an ideal habitat for mangroves, where the wading depth not only impacts the species selection of mangroves, but also is an important factor for their growth height
	Species niche conditions of mangrove habitats	Protect and restore niche and protect biodiversity due to the species relationship in mangrove ecosystem is complex

9. Analysis of spatial interaction mechanism.





10. Analysis of the landscape optimization strategies for Sanya Mangrove Ecological Park.

site's existing hydrological process. By changing the horizontal structure of the river course, the water purification pattern of the cascaded wetland purification ring was formed by introducing terraces, ponds, and wetlands, so that rain runoff in the city can be purified and discharged into the river course.

2) Habitat restoration strategy. According to the characteristics of mangroves (halophilous, easy to lodge), by analyzing the impact of the landscape process on the growth of mangroves, a branched wetland pattern was proposed, and by changing the horizontal and vertical landscape structure of river corridors and revetments, a

suitable living environment for mangrove growth was created.

3) Leisure and recreation strategy. Build a multi-dimensional transportation system, link external slow lanes with local slow traffic, extend landscape trails into the edge of the wetland, set landscape boardwalks within mangrove wetlands, forming various recreational experiences.

7 Conclusions

Based on the review of landscape ecological research and landscape ecological planning and design practice, this paper constructs a three-level research system for landscape ecological planning and design, and further points out that the analysis of spatial mechanism can open the "black boxes" in the transformation from research to practice, which provides methodological support for ecological research and evidence-based planning and design, and enhances the interpretability of landscape ecological planning and design.

From Landscape Ecology theories to spatial application prototypes and to landscape ecological planning and design practice, it is a process from de-contextualization (context of research) to re-contextualization (context of practice). As the intermediate knowledge between theory and practice, spatial application prototype plays a role between prototype generality and regional particularity, between scientific abstraction and practical specificity, and between existing landscape (now) and ideal landscape (future). Landscape ecological planning and design practice is a holistic and integrated decision-making process. Future research needs to further integrate research and practice. It is necessary to pay attention to both ecological knowledge and form design to create deep forms.

It is necessary to point out that this paper only discusses the disconnection and dislocation between theory and practice simply upon the transformation from research to practice, without exploring ecological wisdom and computer technology methods. The ecological knowledge (experience) summarized from landscape ecological planning and design practice can also be further extracted and refined into spatial application prototypes (for practice)[55][61]. Computer technology, landscape mapping[17], and other methods for large-scale site preview analysis, scenario simulation, and parametric design and design simulation for small-and medium-scale sites are also important media for connecting ecologists and planners/designers[17][62]. In the future, researchers can continue to deepen the studies on spatial mechanisms from the above two aspects and to demonstrate the effectiveness of this landscape planning and design procedure.

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打开“黑箱”的空间机制：从景观生态科学研究到景观生态规划设计实践的转化途径

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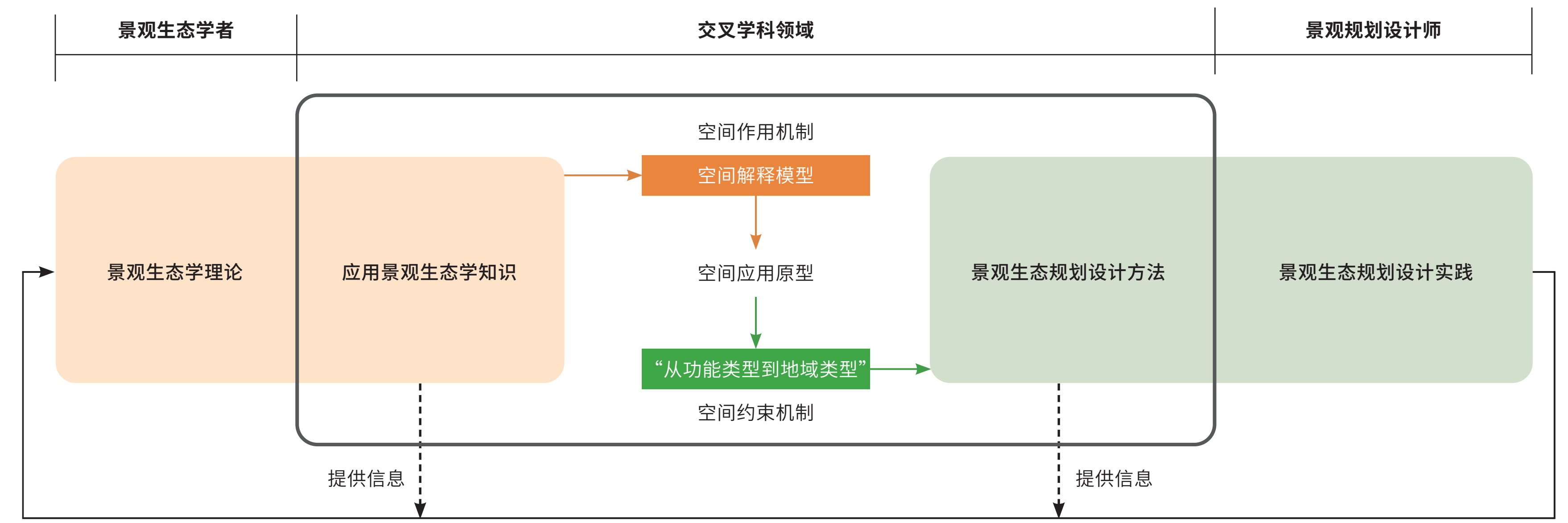
图文摘要



摘要

在景观生态学领域，景观生态科学研究与景观生态规划设计实践的过度并行发展，导致科学研究生产的知识无法有效指引实践应用。这一“理论－实践差距”已受到景观生态学者与景观生态规划设计师的广泛关注。尽管众多学者为弥合差距做出了有益贡献，但目前尚未形成系统性的转化路径。在此背景下，本研究首先对景观生态科学研究与景观生态规划设计实践的发展历程，以及二者的融合演变特征进行了梳理；其次，基于两者之间的内在联系，建构了连接科学研究和规划设计实践的三层级研究体系；再次，提出空间机制分析框架，打开从科学研究到规划设计实践转化途径中的“黑箱”，以缝合理论－实践差距，并建构了空间作用机制与空间约束机制协同分析的景观生态规划设计程序；最后，以中国三亚红树林生态公园项目为例，验证了该规划设计程序的应用有效性。

关键词

空间机制；景观生态科学研究；景观生态规划设计实践；理论－实践差距；转化途径；知识生产；黑箱

文章亮点

- 建构了连接景观生态科学研究和景观生态规划设计实践的三级研究体系
- 空间机制分析打开了科学研究与规划设计实践之间的“黑箱”
- 提出空间作用机制与空间约束机制协同分析的景观生态规划设计程序

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- 陕西省科技厅青年项目“儿童友好城市视角下西安城市街区绿地评价方法及空间优化策略研究”（编号：2024JC-YBQN-0602）

编辑 田乐，汪默英

1 引言

1.1 景观生态科学研究与景观生态规划设计实践脱节错位

景观生态学是一门研究景观结构、功能和变化的综合性科学，为景观生态规划设计实践提供了理论基础和方法指导[1]-[3]。近几十年来，景观生态学的研究取得了长足进展，形成了一系列概念、原理和模型[4][5]，如景观格局与过程[1]、景观尺度[2]、可持续景观格局[6]、景观生态安全格局等[7]。这些研究成果促进了景观生态规划设计实践的发展和创新。然而，针对单一问题（或单一要素）的生态科学知识与针对复杂综合问题（或多要素）的生态实践之间缺乏有效衔接[8]-[11]，造成将局部的、有时效性的、基于假设条件的一般性生态知识直接应用于具体场景的整体实践中的现状，导致科学研究与规划设计实践脱节[12]，出现了生态知识不被规划设计师承认或普遍实践[10]、规划设计实践中景观生态空间模式套用[13]、遵循现状过程进行被动式规划设计生成“浅陋之形”等问题[14]。王志芳将这类问题定义为传统科研学科与应用实践学科之间的错位[12]，陈春谛等人[15]及象伟宁等人[16]引入“巴斯德象限”范式来表征科学研究与实践应用之间存在的脱节问题。这一问题涉及到的因素是多方面的，其中一个重要因素是科学研究与实践应用之间的本质区别：科学研究的知识具有客观性、可验证性、专业性，而规划设计实践应用具有主观性、经验性、历史性和社会性。由此，科学研究与实践应用之间的差距也被称为“知行差距”[17][18]、“研究—实践差距”[18]或“理论—实践差距”[17]。

1.2 研究进展综述与研究问题界定

为了弥合景观生态科学研究与景观生态规划设计实践之间的差距，众多学者分别基于理论优位与实践优位视角进行了探索。在理论优位研究中，福斯特・恩杜比斯从历史关系角度回顾了景观生态科学研究与景观生态规划设计实践的发展过程，分析了两者之间的相互影响和作用，并提出了从原理转向实践的“过渡概念”[19]；文克・德拉姆施塔德提出了55条景观生态规划的法则、概念，以及生态设计中关于斑块、边界（界线）、廊道（连通性）和镶嵌体的概念性图式[20]；琼・纳索尔和保罗・奥德姆将规划程序中的空间设计当作连接理论与实践的纽带，提出融合科学研究与规划设计实践的“格局—过程—设计”范式[21]；岳邦瑞提出了从科学研究到规划设计实践的逻辑转化通道“理论—格局—案例”模式[22]；王云才提出了“景观空间图式语言”，为规划设计有机的整体景观提供路径[23]。在实践优位研究中，象伟宁基于现有科学知识有限性及现今生态实践未能有效利用已有生态知识的状况反思，提出“生态智慧”作为衔接生态理论与生态实践的桥梁[24]；王志芳进一步提出“可实践生态知识”是有效衔接生态科研与生态实践的重要组成部分[25]。俞孔坚则从理论优位与实践优位两个层面进行了探索，一方面以景观生态学理论方法为基础提出了景观生态学与空间规划的桥梁——生态安全格局途径[7][26]，并用于系统性的生态基础设施规划，另一方面基于土人景观实践[27]进行实践研究，以应对规划设计中的空间模式语言套用问题，并提出了“实践研究”范式、“原型研究”模式等[13]。

景观生态科学研究与景观生态规划设计实践均属于跨学科领域[19]。尽管众多学者为弥合二者之间差距做出了有益贡献，但目前大多数研究仅局限于单一领域，即聚焦于科学研究与实践之间的空间模式或空间原型等“中间知识”的生产，而仍然欠缺将科研—实践脱节这一整体性问题放入统一框架的讨论，且尚未形成系统性的转化路径。

综上，本研究聚焦于以下问题：1）如何弥缝景观生态科学研究与景观生态规划设计实践的差距并真正形成转化？2）如何将景观生态学的格局、过程和功能变量转化为可操作的空间模式语言？3）如何将空间模式语言转化为具体的景观生态规划设计实践方案？并在此基础上，进一步探索具有普适性的景观生态规划设计程序，且在案例中加以验证。

2 景观生态科学研究与景观生态规划设计实践的发展历程

2.1 景观生态科学研究发展历程

景观生态学关注地球表层物质、能量、信息传输和生物、非生物要素的相互作用，追求优化、合理利用和保护景观格局[3]，旨在通过理解景观格局和过程实现人地关系的协调[2]。从“格局—过程”范式演变及空间规划的视角洞察景观生态科学研究的发展历程，大致历经4个阶段[2][4][28]-[30]（图1）。

1）景观生态学奠基阶段（1800~1980年）。早期生态学、地理学独立发展，景观、生态系统等概念的提出为景观生态学的诞生奠定了基础。20世纪30年代之后，受生态学、地理学等学科影响及地理群落学说的推动[2]，景观生态学开始探索景观的基本问题及其与空间规划的关系[4]。

2）景观生态学建立与扩展阶段（1980~1990年）。国际景观生态学会的成立标志着景观生态学成为国际性学科，景观生态学逐步建立并向“格局—过程—尺度”范式[31]扩展，强调空间尺度和空间异质性对生态系统功能的重要作用。“斑块—廊道—基质”模型的提出为格局与过程研究提供了系统的概念架构，标志着景观规划设计与景观生态学开始融合[22][32]。该阶段探讨了如何将景观生态学规划理论应用于土地利用和保护实践中[4]。

3）科研与实践弥合阶段（1990~2005年）。景观生态学向应用领域不断拓展，景观规划中的景观生态学原理[20]、“集聚间有离析”模式[33]、设计实验方法[34]等的提出推动了景观生态学向“格局—过程—设计”范式扩展，进一步弥合了科学研究与实践应用之间的差距[4][30]。

4）可持续景观发展阶段（2006年至今）。伴随着千年生态系统评估计划[35]的实施与“基于自然的解决方案”理念[36]提出，景观生态学从理论认知逐渐走向决策实践，开始强调生态与人类福祉、社会机制共生，促进可持续景观规划与发展[37][38]。景观服务作为生态科学与可持续发展的桥梁，将景观生态学进一步拓展至“格局—过程—服务—可持续性”范式[39]。设计科学和治理科学的纳入以实现可持续性的解决方案成为现今景观生态科学研究的发展趋势[4][38]。

2.2 景观生态规划设计实践发展历程

景观生态规划设计是基于广义生态学原理，以协调人与自然关系为目标的各种尺度空间的规划与设计的总称[2][22]。基于生态学的发展历程洞察景观生态规划设计实践的发展历程，大致历经5个阶段[22][40-44]（图1）。

1）生态学未介入的景观规划设计实践阶段（1850~1940年）。早期，景观规划设计与生态学独立发展，景观规划设计仅以自然保育思想为指引、遵循景观设计师的主观生态思想，直到纽约中央公园建成，标志着西方规划设计开始萌生生态思想。19世纪90年代叠图法应用于景观规划，标志着生态学与景观规划的融合开始萌芽[8][22]。

2）生物生态学介入的景观规划设计实践阶段（1940~1980年）。此阶段景观规划设计与生态学开始交融，景观规划开始进入基于生态学途径的时代。绿地系统规划是该阶段的主要实践类型。适宜性评价方法、立足于适宜性评价的LANDEP模型的提出将生态学语言转化为可被实践应用的空间因子，标志着景观生态规划方法的诞生[22]。

3）景观生态学介入的景观规划设计实践阶段（1980~1990年）。此阶段景观规划设计进入基于景观生态学途径的时代[22]。格局过程关系研究、“斑块—廊道—基质”模型的提出促进了景观生态规划设计理论及方法的完善[28][32]，综合性景观生态规划方法、多解生态规划方法体系等则进一步拓宽了景观生态规划设计实践发展方向[44]。

4）融合整体人文思想的景观生态学介入的景观规划设计实践阶段（1990~2005年）。此阶段景观生态学融入整体论和人文论思想，景观生态规划设计转变为复合生态系统范式[22][42]。生态安全格局、绿色基础设施等理论方法及功能主义、韧性、“反规划”途径等思想使景观、社会、生态之间产生联系，以实现地圈—生物圈—技术圈协同进化[22]。

5）区域、城市生态学介入的景观规划设计实践阶段（2006年至今）。伴随“基于自然的解决方案”理念的提出、景观服务成为热点，景观生态规划设计对于可持续性的注重逐步提升[37][38]，由关注自然空间的生物栖息地强化向人与自然关系综合考量的多目标优化阶段转变。“边学边做”试验性设计[45]等方法的提出使规划设计程序更趋完善、景观规划决策更加科学。生态智慧指引与区域、城市生态学指引的生态规划设计实践协同发展成为当前主要趋势[46]。

2.3 景观生态科学研究与景观生态规划设计实践融合演变特征

由图1可知，景观生态科学研究先后经过了“格局—过程”“格局—过程—尺度”“格局—过程—设计”“格局—过程—服务—可持续”4个范式阶段；景观生态规划设计实践从起初的自然保育范式逐步发展到绿地系统范式、生态景观范式、复合生态系统范式，以及基于自然的解决方案范式[43]。在两个领域的整合过程中，景观生态学的理论框架为景观规划设计提供信息，而设计原则和过程为景观生态学的理论框架提供反馈并进行扩展，景观生态规划设计实践由经验规划设计向循证规划设计转变。

3 景观生态规划设计研究体系

基于对景观生态科学研究与景观生态规划设计实践发展历程的梳理，以及笔者既往研究成果[47][48]，本文提出连接科学研究与规划设计实践的三层级研究体系（图2）。

1）景观生态科学基础研究。由景观生态学的基础理论、核心理论及其他理论构成，为景观生态规划设计应用基础研究与实践应用研究提供了科学基础。

2）景观生态规划设计应用基础研究。由应用景观生态学知识、空间解释模型、空间应用原型和规划设计方法构成。科学研究中的理论知识需要和具体的生态分类、生态评价、生态分析等方法相结合，才具备转化为规划设计实践进行落地的可能性。这一结合过程中的相关理论、技术、模型、方法、策略等都可称为景观生态规划设计应用基础。

3）景观生态规划设计实践应用研究。指面向多个功能类型、地域类型，以及全球气候变化等其他类型的具体规划设计实践操作。

4 空间机制：连接景观生态科学研究与景观生态规划设计实践的桥梁

根据上述研究，本文提出，需通过景观生态规划设计应用基础研究这一纽带来弥合理论实践差距。然而，如何将景观生态学的格局、过程和功能变量转化为规划设计实践中可绘制的模式语言①，以及如何从可绘制的模式语言转化到规划设计实践中具体方案的空间落位，仍是"黑箱"问题。

在科学哲学领域中，"机制"是打开系统内部"黑箱"、解释系统内部联系及相互作用关系的工具[49]。为此，本文引入"空间机制"（spatial mechanism）概念[50][51]，提出两类空间机制：空间作用机制与空间约束机制（图3）。这两类机制联系了"基础理论研究—应用基础研究—实践应用研究"三级体系，分别旨在打开从景观生态学理论到空间应用原型（空间模式语言）的"黑箱"，以及空间应用原型到具体规划设计实践方案的"黑箱"。通过这两类空间机制分析，可以有效地实现景观生态学理论知识向具体设计和规划策略的转化。

4.1 从景观生态学理论到空间应用原型：空间作用机制

4.1.1 空间作用机制分析

在景观生态规划设计实践中，空间形式和功能的关系一直是规划设计师争论不休的问题，引发了诸如"生态—审美冲突"[52]、"深邃之形"与"浅陋之形"[14]等讨论。对于其二者关系的讨论虽极其重要，但规划设计师的探讨仅止步于不同思想观念的碰撞，缺乏基于自然科学的知识理性与还原主义研究，使得规划设计实践的科学性备受质疑[53]。本文提出的空间作用机制指在特定的景观规划设计对象中，特定空间格局与特定生态功能之间的因果关系——规划设计过程就是通过塑造空间格局（因）来获得特定功能（果）的实现过程。空间作用机制分析的目的在于"由果溯因"，找出格局与功能之间的因果关系，包括因果映射式与因果链条式两种空间作用机制分析路径[50]。

因果映射式是一种简化的因果关系分析路径。众多既往研究揭示了景观生态学理论如何转化为空间应用原型的过程，其中最具代表性的是"戴蒙德导则"[54]：基于"物种—面积"理论及"均衡"理论，贾雷德·戴蒙德进一步揭示出斑块结构（空间形式）与物种丰度（功能）之间的因果映射机制（空间解释模型），最后通过组合六大空间导则形成了指向自然保护区规划设计的保护区圈层模式、保护区网模式等空间应用原型[22]。

简单的因果映射关系并不能真实反映景观生态规划设计实践中空间形式与功能之间关系的本质。幸运的是，景观生态学关于景观过程的研究成功打开了二者之间的"黑箱"，形成了"格局—过程—功能"因果链条式的空间作用机制分析路径。最具代表性的是理查德·T. T. 福尔曼提出的"斑块—廊道—基质"模式[28][33]，其为判别景观结构、分析空间形式与功能之间的因果链条机制（空间解释模型）提供了一种通俗、简明、易行的空间语言；进而推演出生态安全格局模式、生态网络模式、绿色基础设施模式等空间应用原型[22][43]。

总而言之，景观规划设计实践一开始仅关注形式—功能关系，直到景观生态学中关于景观过程的研究打开了格局与功能之间的"黑箱"。后文重点展开对"格局—过程—功能"因果链条式空间作用机制的探究。

4.1.2 空间作用机制的可实践知识

本文通过"格局—过程—功能"因果链条分析路径，将景观生态学的格局、过程和功能变量转译为可实践知识（图4），并以河流廊道（绿色基础设施）生态规划设计情境为例，进行因果链条机制简要分析（图5）。首先明确河流廊道的理想景观功能（洪水调节），其次重点分析对其产生影响的景观过程（河川径流过程），分析产生影响的关键结构特征（曲度、宽度），最后指向规划设计师可实践的河流廊道的纵、横、竖向景观结构，即通过空间作用机制分析得到理想格局。此处仅从理想过程与功能角度进行了因果链条分析，对于现状"格局—过程—功能"与理想"格局—过程—功能"的具体分析详见后文案例。

4.2 从空间应用原型到景观规划设计实践：空间约束机制

4.2.1 空间约束机制分析

景观生态科学研究借助计算机、地理信息系统为规划设计师判断理想格局提供了一套高效且系统的方法[14]，众多规划设计师也认识到景观生态规划设计通过遵循生态过程来连接景观空间格局与景观空间功能[7][55]。然而，以往研究大多单一地秉承景观生态科研思维[56]、教条式使用景观原型[13]，把现状景观过程作为设计约束条件，进行被动式规划设计[55]。这使得最终的解决方案出现科学研究"敌托邦"现象[57]，得到的仅仅是科学研究语境下的"理想之形"，而非"深邃之形"。

那么，如何将抽象的空间应用原型转化到具体规划设计方案中的空间落位？本文提出的空间约束机制指在特定的景观规划设计对象中，景观生态规划设计目标与方案之间的因果关系（图3）。不同于空间作用机制分析强调的知识理性与还原主义，空间约束机制更注重场地导向的实践优位与整体主义[13][56]。基于既有景观生态规划设计实践应用研究[58][59]，以及具体场地条件，本文提出将"从功能类型到地域类型"作为空间应用原型与设计方案之间"黑箱"的钥匙。空间约束限制分析[9][25]涵盖规划设计师知识结构、创意能力及利益相关者功能需求等功能约束，气候条件、地质地貌条件等地域约束，以及场地地形、场地水

① 笔者认为，规划设计方案生成的本质是制图，因此此处强调规划设计自身空间制图的学科属性。

文条件等场地约束的识别和应对[25]。从初始的具有普适性和通用性的空间应用原型（如绿色基础设施，强调多功能性），到增加了特定功能属性和需求的功能类型（如“海绵城市”绿色基础设施，强调雨洪调节功能），再到结合具体地域环境及地方性知识、具有复杂设计约束限制的生态规划设计类型（如西北干旱半干旱地区“海绵城市”绿色基础设施[60]，强调地域特征），规划设计方案在这一过程中语境逐渐具体化，最终落位于场地。

场地的约束和限制非但不会阻碍创造力，反而能激发规划设计师的潜能，可促使他们将遵循现状过程的被动式规划设计转变为干预景观过程的主动式规划设计。

4.2.2 空间约束机制的可实践知识

本文通过“目标—约束—方案”因果链条分析路径，将“从功能类型到地域类型”转译为可实践知识（图6），并以西北干旱半干旱区海绵城市绿色基础设施生态规划设计[60]情境为例，进行简要因果链条机制分析（图7）。首先明确了景观目标（雨洪调节），其次分析了影响景观目标的空间约束条件（土壤渗透性强、持水性差），进而提出了景观途径（开源节流）与具体的景观策略（水分条件分布优化、微地形、下凹绿地等）。

5 空间作用机制与空间约束机制协同分析的景观生态规划设计程序

为使空间机制分析具有实践可操作性，本文提出基于空间机制协同分析的景观生态规划设计程序（图8）。

5.1 现状景观空间作用机制分析

基于格局—过程—功能因果链条式的空间作用机制分析阶段主要分为景观格局表述、景观过程分析和景观功能评价三个步骤。

1）景观格局表述：基于空间解释模型（主要为“斑块—廊道—基质”模型），建立现状景观的表述系统，包括气象、地形、水文、土地利用状况等。

2）景观过程分析：从生物过程、非生物过程、人文过程三方面对现状景观进行分析。

3）景观功能评价：对生态系统的健康与安全及生态系统服务的状况进行评价，分析现状景观格局对景观过程的利害（即促进或阻碍过程的发生），从而判断目前景观是否运转良好。

5.2 理想景观空间作用机制与空间约束机制协同分析

基于“格局—过程—功能”因果链条式的空间作用机制与基于“目标—约束—方案”因果链条式的空间约束机制协同分析主要分为景观目标确定、景观过程分析和景观格局优化三个步骤。

1）景观目标确定：基于现状景观功能，结合空间约束确定景观目标（即理想景观功能）。

2）景观过程分析：基于景观目标推导出对应的理想景观过程。

3）景观格局优化：映射到影响特定景观过程的景观格局结构，提出规划设计方案。

6 从理想之形到深邃之形：三亚红树林生态公园案例解析

本节以中国三亚红树林生态公园项目为例，验证基于空间机制分析的景观生态规划设计程序在景观规划设计实践中的有效性。

三亚红树林生态公园位于三亚河东岸，场地恰巧处于海水与淡水交汇的分界位置，季节性的水量不均导致旱季河道缺水。大量城市开发侵占了原有坑塘系统，混凝土防洪墙严重破坏了红树林及河漫滩生态系统，并且阻挡了海水与上游城市雨水的连通，造成了严重的城市内涝。

表1、图9和图10展示了从通过空间机制协同分析到提出枝杈状形态的景观提升方案的过程。具体策略包括：

1）水质提升策略：设计遵循场地现状水文过程，通过改变河道横向结构配置，形成层叠状湿地净化环的净水格局，即增加梯田、坑塘湿地，使城市中的雨水径流净化后排入河道。

2）生境修复策略：根据红树林生物特征（喜盐、易倒伏），分析场地的景观过程对红树林生长的利害关系，提出枝杈状的坑塘湿地格局，即通过改变河流廊道、驳岸等横／竖向景观结构，营造适宜红树林生长的生存环境。

3）休闲游憩策略：构建多维交通系统，外部慢行道串联区域慢行交通，景观步道局部深入湿地边缘，特色栈道穿梭于红树林湿地之间，形成了不同的游憩体验。

7 结语

本研究基于景观生态科学研究与景观生态规划设计实践历程回顾，建构了景观生态规划设计三层级研究体系，进一步指出空间机制分析打开了科学研究到实践应用转化途径中的“黑箱”，为寻解生态科研与循证规划设计提供了方法论支持，增强了景观生态规划设计的可解释性。

从景观生态学理论到空间应用原型，再到景观生态规划设计实践，是去语境化（科学研究语境）到再语境化（实践语境）的过程。空间应用原型作为理论与实践之间的中间知识，其在原型一般性与地域特殊性、科学抽象性与实践具体性之间发挥作用，同时介于现状景观（现在）与理想景观（未来）之间。景观生态规划设计实践是整体性、集成

表 1：空间约束机制分析

空间约束类型		具体内容
功能约束	规划设计师知识结构	具备红树林生态系统、环境工程和可持续设计等方面的专业知识，以科学评估和应对污染问题
	规划设计师创意能力	创新性地应用生态设计原理，提出兼具功能性和美学价值的解决方案
	利益相关者功能需求	需平衡并尽量满足地方政府、环保组织和社区在内的利益相关者的需求和期望
	上位规划功能需求	以国家和地方的环保法规和规划文件为指导，确保设计符合环境保护标准
	规范、指南、标准	设计中需遵循相关的景观设计规范、指南与行业标准
地域约束	气候条件	气候变化和季节性降水量影响红树林的生长和水质管理，需考虑气候适应性
	地质地貌条件	地质条件影响污染物的流动和沉积，需考虑地质稳定性并防止污染物扩散
	植被地带分布	红树林是热带、亚热带海湾、河口泥滩上特有的常绿灌木和小乔木群落，一般分布于高潮线和低潮线之间的潮间带
	地方习俗文化	当地居民的习惯和文化会影响设计的接受度和实施效果，需在设计中充分考虑
场地约束	场地地形	场地地形的坡度和起伏影响水流和污染物的分布，需设计适当的排水和过滤系统
	场地水文条件	红树林依赖潮汐带来的水位变化，需要考虑水体的净化和管理，防止污染物进入河流和湿地
	场地土壤条件	土壤类型和肥力影响红树林的生长，需考虑土壤改良和污染物的过滤
	红树林生境盐度条件	红树林植物是喜盐植物，红树林带外缘的海水含盐量通常为 3.2%~3.4%，内缘的含盐量通常为 2.0%~2.2%
	红树林生境风向条件	长期的风浪侵蚀会影响红树林的成活率和生长速度，所以背风处的红树林长势较好
	红树林生境温度条件	红树林对温度要求较高：最冷月气温为 9.3℃，水温为 10.6℃
	红树林生境滩涂条件	滩涂是红树林理想的生存环境，涉水深度不仅决定红树林的种类，也影响其生长高度
	红树林生境物种生态位条件	红树林生态系统中的物种关系复杂，需要设计保护和恢复生态位的方案，保护生物多样性

性的决策过程，未来研究需进一步整合科学研究与实践应用，既要关注“生态”，也要关注“形态”，方能得到深邃之形。

需要指出的是，本文仅从景观生态科学研究向实践应用转化的单一向度探讨了二者的脱节错位问题，而未探讨生态智慧与计算机技术方法等。生态智慧等总结于实践的生态知识（经验）也可进一步归纳提炼为空间应用原型（实践原型）[55][61]；计算机技术、景观制图[17]等方法针对大尺度场地的预景分析、情景模拟，以及针对中小尺度场地的参数化设计和设计模拟，也是连接生态学家与规划设计师的重要媒介[17][62]。未来研究可从上述两方面继续深化空间机制研究，并论证该转化途径的有效性。

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