REVIEW ARTICLE

Sustainable landscape pattern: a landscape approach to serving spatial planning

Jianquan Dong · Hong Jiang · Tianwei Gu · Yanxu Liu · Jian Peng

Abstract

Context Spatial planning system needs the support of approaches toward achieving sustainability, with sustainable landscape pattern (SLP) for one potential spatial approach. However, the scientific definition of SLP has not been clarified in previous studies, and the support of SLP for spatial planning is also few summarized.

Objectives The scientific definition and conceptual connotation of SLP were proposed, and its application status and development directions of theory and practice in spatial planning were further summarized.

Methods We systematically reviewed the literature on landscape sustainability, urban growth boundary, ecological network, green infrastructure, ecological security pattern, ecological red line and others close to SLP, and qualitatively summarized the key theoretical and practical support of SLP for spatial planning.

Results SLP is defined as a certain combination of composition and configuration of landscape elements that enables social-ecological processes to sustainably provide stable ecosystem services for promoting human well-being in a particular region. SLP effectively supports spatial planning to determine planning targets, analyze spatial patterns, and compare and select schemes by assessing target landscape elements, identifying key spatial areas, and simulating future development scenarios. It is proposed that frontier concepts (i.e. spatial resilience, metacoupling framework and landscape multifunctionality) provide new research perspectives for SLP, and that SLP can also be applied to ecological restoration, urban agglomeration coordinated development, and nature-based solution in the future.

Conclusions Clarifying the scientific connotation of SLP can provide theoretical and methodological support for spatial planning practice and also a spatial approach for sustainable development.

Keywords Sustainable landscape pattern · Spatial planning · Landscape sustainability

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Introduction

The social-ecological systems are facing unprecedented challenges due to global climate change and urbanization. There are also a number of increasingly prominent problems, including the depletion of natural resources, biodiversity losses, frequent urban disasters, and dramatic human health risks (Newbold et al. 2015; Estoque et al. 2020). The World Charter for Nature issued by the United Nations in 1982 clearly pointed out that the sustainable supply capacity of ecosystems need be considered when drawing up long-term plans of economic development in order to avoid irreversible harm to ecosystems. Agenda 21, launched in 1992, established a common action plan to support a global partnership for sustainable development to protect the environment and improve human well-beings. In 2015, the United Nations put forward 17 sustainable development goals (SDGs) and 303 quantitative assessment indicators, and published the progress of each SDG yearly, which gradually makes the concept of sustainable development as a global consensus (Cumming et al. 2017; Pradhan et al. 2017). However, the paths to achieving sustainable development that balance ecological conservation, economic growth, and social equity are still being explored due to the diversity and the complex trade-offs and synergies of SDGs (Gao and Bryan 2017; Fuso Nerini et al. 2018).

Space is an important cognitive perspective of natural process and social activities, as well as sustainability promotion (Peng et al. 2020). Significant regional differences in natural background, social development and their interactions result in spatial heterogeneity among socio-ecological problems, especially the imbalance between the supply and demand of ecosystem services (Maron et al. 2017). Hence, effective spatial governance measures are urgently needed to be proposed to ensure and enhance regional sustainable development. As a process to optimize the spatial patterns of natural and social elements, spatial planning is an important approach that aims to manage natural resources, protect ecosystem and mitigate unbalanced regional development (Gustafsson et al. 2019). Different from other solutions for spatial governance (e.g. landscape planning, geodesign and land system architecture) (Turner et al. 2013; Li and Milbern 2016), spatial planning is a more comprehensive and systematic approach to regulating

social-ecological systems. Different countries have formed multi-level and multi-type spatial planning systems with regional characteristics (Hersperger et al. 2018), such as the current co-existing system including the Five-Year Socio-Economic Development Plans, urban and rural planning, land use planning, and ongoing territorial spatial planning in China (Zhou et al. 2017). The zoning technology is used to establish a comprehensive planning system that includes the Master Plan, the Concept Plan, and 55 Development Guide Plans in Singapore (Wong et al. 2008). In France spatial planning has been formulated at different levels based on spatial policy framework, such as the comprehensive policy, the special policy, and the sectoral policy (Liu 2018).

Although there are differences in the naming and types of regional spatial planning systems, the core cognition of spatial planning in each country have gradually changed from regulating static land use patterns to analyzing the dynamic interactions between ecosystems and social systems (Todes et al. 2010). Based on historical or empirical data, traditional linear or nonlinear forecasting only focuses on the pattern changes in different land use types (e.g., where can be located for urban expansion or for crop planting), and less emphasizes the relationship of natural processes and social activities (e.g., how to strengthen the spatial connectivity among fragmented habitats and ensure the match between the supply and demand for ecosystem services). Current spatial planning aims to achieve multiple sustainable development goals involving regulating urban expansion, improving infrastructure construction, utilizing natural resources efficiently, reducing environmental pollution, and increasing adaption to climate change (Meerow and Newell 2017; Tammi et al. 2017). Therefore, more key theories and techniques based on sustainability science could be proposed for supporting the spatial planning systems to achieve regional sustainable development.

Landscape is spatially association of heterogeneous areas with distinct interactions between natural processes and human activities (Nassauer and Opdam 2008), and is also an effective geographical unit for spatial planning (Chen and Wu 2009). With the deep interdisciplinary studies involving landscape ecology and sustainability science, landscape sustainability science has tended to focus on the ability of specific landscapes to provide long-term and stable ecosystem

services and improve human well-being (Wu 2013). The spatial distribution and arrangement of landscape elements with such capability refers to the topic of sustainable landscape pattern (SLP). SLP is the theoretical application of the extended paradigm of "landscape patterns - ecosystem processes - ecosystem services - human well-being" in landscape ecology and landscape sustainability science (Wu 2021), which also follows the patch-corridor-matrix landscape model (Aminzadeh and Khansefid 2010).

However, the realization of landscape sustainability involves the structure, function, and dynamic processes of different elements in complex social-ecological systems (Zhou et al. 2019), which have resulted in extensive research scope and unclear connotation of SLP. Previous studies have put forward concepts consistent with the core target of SLP with various case studies, such as the ecological network (EN) for biodiversity conservation (Isaac et al. 2018; Beaujean et al. 2021), the urban growth boundary (UGB) to control the disorderly urban expansion (Chakraborti et al. 2018), the green infrastructure (GI) to protect natural landscapes (Meerow and Newell 2017), and the ecological security pattern (ESP) to maintain the ecosystem integrity and ecological security (Peng et al. 2018a; Dong et al. 2021). Such concepts have been clearly defined and widely used in recent years (Fig. 1). The proposal and practice of these concepts based on landscape ecology conform to the key demand of current spatial planning (Opdam et al. 2002; Hersperger et al. 2021), that is, how to balance protection and development. The SLP concept

can provide important theoretical support and technical approach for spatial planning oriented toward regional sustainable development.

This study aimed to clarify the theoretical and practical foundation of SLP by investigating the related concepts and their development processes. Specifically, a scientific definition of SLP was made, with identifying possible SLP classifications. Then it was analyzed for the connotation consistency of concepts proposed by previous studies with SLP, and compared the similarities and differences among various research objectives of these concepts. We further summarized the methods used for SLPs identification and investigated case studies on SLPs that have been applied in spatial planning in order to determine the important role of SLP in different procedures of spatial planning. In the context of global efforts to achieve SDGs, we think that the study on SLP is still in its infancy. More in-depth theoretical and methodological progress is needed due to the insufficient cognition of complex interactions between natural and social systems. Furthermore, the diversity of social and ecological elements involved in spatial planning at different scales or levels will promote a wider practice of SLPs. Therefore, after defining the concept of SLP and its role in spatial planning, we put forward the key research directions for SLPs in the future from the perspectives of theoretical support and practical application.
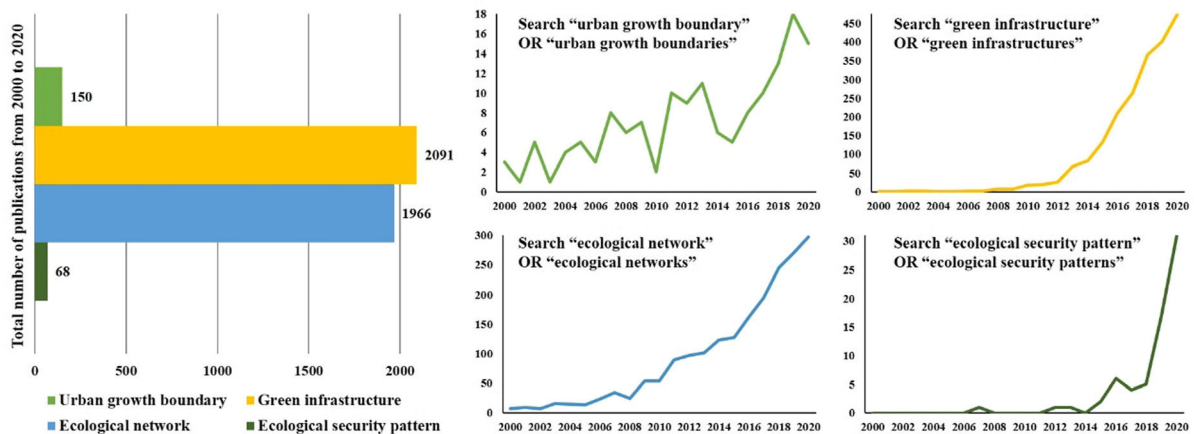

Fig. 1 Number of publications from 2000 to 2020 related to urban growth boundary, green infrastructure, ecological network and ecological security pattern searched in title, abstract and keywords based on the Web of Science Core Collection

Defining sustainable landscape patterns

With the increasingly strong impact of human activities on the natural ecosystem, landscape has become a key spatial unit for assessing regional sustainable development. Since the beginning of the 21st century, the study on landscape sustainability has gradually become an important topic in landscape ecology, physical geography and sustainability science (Chen and Liu 2014), and the concepts of landscape sustainability and sustainable landscape have been proposed (Musacchio 2013). Wu (2013) defined landscape sustainability as "the capacity of a landscape to consistently provide long-term, landscape-specific ecosystem services essential for maintaining and improving human well-being in a regional context and despite environmental and socio-cultural changes". "Landscape-specific" in this concept has two meanings. Firstly, it means that landscape type determines what ecosystem services it can provide (Wu 2013), which can be regarded as "area-specific" in space and be similar to the concept of a sustainable landscape. Secondly, "landscape-specific" emphasizes that landscape pattern affects the spatial heterogeneity of ecosystem service provision (Wu 2013). That is to say, the differences in composition and configuration of landscape elements may enhance or weaken the formation and supply of ecosystem services. Wu (2021) further emphasized the prominent roles of landscape patterns in connecting the ecosystems and social systems. Therefore, the realization of landscape sustainability depends not only on which types of landscape have socio-ecological sustainability, but also on the sustainability effect of such landscapes with different spatial patterns. Based on previous cognition on landscape sustainability and sustainable landscape, SLP can be defined as follows: a certain combination of composition and configuration of landscape elements that enables social-ecological processes to sustainably provide stable ecosystem services for promoting human well-being in a particular region.

The above definition of SLP is a spatial-temporal expression of the interaction between natural processes and social activities at the landscape scale (Fig. 2). Sustainable landscape pattern not only focuses on a particular landscape, but also emphasizes the clusters of various landscape elements and their spatial relations. "Composition" and "configuration"
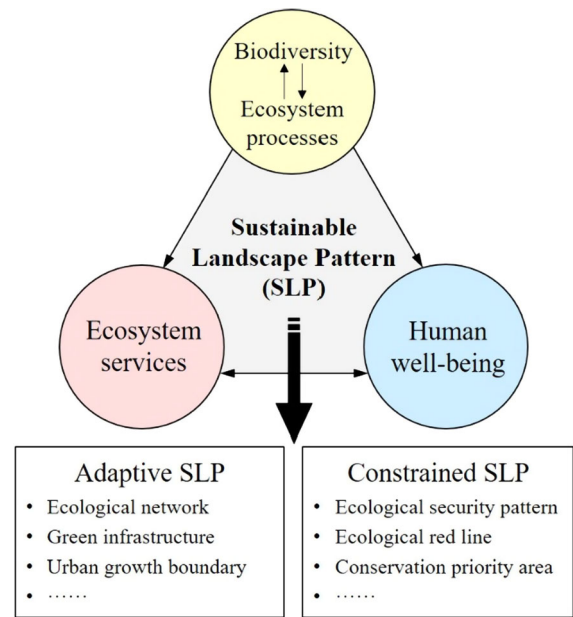
Fig. 2 Theoretical basis of sustainable landscape pattern

express the important dimensions of the spatial pattern of landscape. "Sustainably" and "stable" reflect the temporal dynamic characteristics of landscape sustainability, which can be stated that the sustainability is a long-term process and can be stably maintained by the resilient social-ecological systems when being disturbed. From SLP to landscape sustainability, "ecosystem services" has become the key linkage between the ecosystem and the social system, which means that ecosystem processes and functions provide benefits to human beings, while the access to ecosystem services is related to individual needs. The framework of "landscape pattern - ecosystem processes - ecosystem services - human well-being" has also become an extension of the research paradigm from the relationship between spatial pattern and ecological processes in landscape ecology to the correlation between natural contribution and human benefit in landscape sustainability science. Based on the extended paradigm, ensuring ecosystem processes is the basic premise for SLP (i.e. ecological sustainability), and human well-being reflects the ultimate goal of SLP (i.e. social and economic sustainability). Furthermore, the sustainability across regions can be further realized as far as possible based on the spillover and metacoupling of ecosystem services after balancing local protection and development.

Therefore, the ideal SLP is an effective spatial approach that achieves SDGs with ecological, social and economic aspects.

Previous studies have paid more attentions to SLP identification for specific target related to SDGs, and some relevant concepts proposed in these studies could be considered as SLPs. For example, the first UGB was demarcated in the United States in 1958 (Ding et al. 1999) and has become an effective tool to control the disorderly urban expansion. The land located within the boundary supports essential urban services related to citizens' work and recreational activities, which is aimed to maximally conserve the natural or semi-natural landscapes outside the boundary (Huang et al. 2019). Emerged in Central and Western Europe in the 1980s, the ENs consisting of core areas, buffer zones, corridors and stepping stones can effectively maintain or promote regional biodiversity by guaranteeing spatial and functional connectivity among discrete natural habitats (Hofman et al. 2018; An et al. 2021). GI, composed of various natural or semi-natural elements, forms a network structure that not only supports the integrity and health of ecosystems, but also provides physical basis for the stability of the EN and human welfare (Tzoulas et al. 2007; Wang et al. 2021). The ESP originated in China and is oriented towards specific target of ecological security thresholds. Landscape elements that are of key significance for ensuring regional ecological processes and ecosystem services, such as ecological sources, ecological corridors and strategic points, are all focused in ESPs (Peng et al. 2018b; Gao et al. 2021). In recent years, the ecological red line (ERL) which has been fully applied at the province, city and county scales in China, is a typical practice of integrating SLPs into spatial governance policy. ERL determines the minimum spatial protection boundary by comprehensively considering the regional ecological background and decision-making objectives based on not weakening the ecosystem services (Bai et al. 2016). Apart from the above SLPs, which have been scientifically defined, there are still other informal concepts formed from the perspective of spatial pattern related to sustainable development issues that should also be regarded as important research topics of SLP, such as biodiversity hotspots, conservation priority areas, and multifunctional landscape patterns (Waldhardt et al. 2010; Terrado et al. 2016).

The above definitions and practices of SLPs are put forward based on the natural and socio-economic backgrounds of different countries (Jiang et al. 2021). In the developed regions, such as European countries and the United States, the degradation of ecological land is limited due to the low population density and mature urbanization stage. Therefore, in order to maintain landscape sustainability, it is necessary to sufficiently guarantee the natural landscapes or construct stable network structures to enhance the adaptability of landscape patterns to interference and stress, such as UGB, EN and GI. Such kind of SLP is named as the adaptive sustainable landscape pattern (ASLP) (Fig. 2). On the contrary, most developing countries (e.g. China) are undergoing rapid urbanization with the high intensity of urban expansion and population agglomeration. While the ecological land is severely damaged, the demand for ecosystem services is also increasing sharply. Therefore, how to balance the spatial input and the socio-ecological output is crucial. It is necessary to identify the minimum spatial boundary that can maximize the landscape sustainability based on bottom-line view (Peng et al. 2018a), such as ESP and ERL. In addition, biodiversity hotspots, conservation priorities and multifunctional landscape patterns are also the optimal input-output relationships for ecosystem management. Such kind of SLP is named as the constrained sustainable landscape pattern (CSLP) (Fig. 2).

Although the proposed backgrounds of ASLP and CSLP are different, SLPs are not unique to the region. In highly urbanized countries, extreme ecological problems may also exist, and CSLPs are required to ensure regional sustainable development. For example, when local biodiversity is seriously threatened, it is important to strictly manage biodiversity hotspots in addition to constructing ENs. In rapidly urbanizing regions, although CSLP is an effective spatial approach for sustainable development at the current stage, ASLP will be gradually incorporated into regional sustainable management as the urbanization process levels off and the interaction between ecosystems and social systems becomes dynamically stable.

How SLPs serve spatial planning

The earliest official definition of spatial planning can be traced back to the *Conference Européenne de*

Ministers Responsable pour L'aménagement du Territoire (CEMAT) in Europe in 1983. It is pointed out in the European Charter of Regional/Spatial Planning that "Regional/spatial planning seeks at one and the same time to achieve balanced socio-economic development of the regions, improvement of the quality of life, responsible management of natural resources and protection of the environment, and rational use of land" (Adams et al. 2006). Since then, different countries and regions have gradually formed spatial planning systems with multiple levels (such as national level, regional level, and local level) and multiple types (such as master planning, development planning, and subject planning) (Hersperger et al. 2018). Although different countries differ in their focus and formulation process towards various types of spatial planning, spatial planning is more comprehensive and inclusive on the whole compared to early land use planning. Spatial planning aims to evaluate the needs of economic development and ecological protection by analyzing the spatial patterns of current natural and social elements, and further develop the sustainable management strategies for future social-ecological systems (Todes et al. 2010). The theoretical and methodological frameworks in landscape ecology and landscape sustainability science gradually evolve and are committed to achieve such targets of spatial planning (Milovanović et al. 2020), with SLP for an important approach. According to previous studies on spatial planning, current SLP research has a good fit with the core concept and formulation procedures for spatial planning, i.e. assessing the status of target elements, identifying key spatial areas, and simulating future development scenarios (Table 1).

Assessment serving for planning targets

Assessing the quantitative structure and spatial attributes of landscape elements is a key issue in studies on SLPs, and is also an important part of the spatial planning procedures (Fagerholm et al. 2019). The assessment of key indicators before constructing SLPs helps to clarify the status of target elements and assists in determining the objectives of spatial planning. In addition, dynamic monitoring and evaluating the constructed SLPs helps to assess the effectiveness of spatial planning implementation. For example, assessing biodiversity loss and habitat connectivity is usually concerned in ENs. Magris et al. (2018) used

spatial prioritization methods and population models to assess species distribution and spatial connectivity, which were concluded as the targets of biodiversity conservation in spatial planning for constructing more effective network of protected areas. Studies on GI and ESP emphasize the quantitative assessment of ecosystem services (e.g. food supply, water and air purification, and recreation service), social system vulnerability (e.g. sensitivity, adaptability and resilience), and natural disaster risks (e.g. drought, flooding, and heatwave) (Wang and Pan 2019).

Identification serving for spatial patterns

Because SLP reflects the spatial distributions and arrangements of different landscape elements, identifying the key spatial areas has always been the most basic issue of SLP (Lin et al. 2017). In the process of spatial planning, the natural and social elements are always arranged in a targeted way to help formulate effective spatial governance policies based on the identification of key areas. For instance, ERLs and conservation priority areas focus on the identification of single-type spatial boundary. Bai et al. (2018) adopted the perspectives of stakeholders to identify the ERLs in Shanghai City by integrating the spatial patterns of ecosystem service, as well as biodiversity and ecologically fragile hotspots, which are aimed to balance ecological protection and economic development in the spatial planning. ENs, GI and ESPs emphasize to spatially identify the various functional types of landscape elements. For example, ecological corridors, which are important components of ENs, have been constructed and incorporated into spatial planning in many European countries (Dileo et al. 2017). Ecological pinch points and barrier points are extensions of the ESP paradigm, which have become the important areas of ecological protection and restoration in China's territory spatial planning (Peng et al. 2018b).

Simulation serving for development plans

Spatial planning and SLPs are both aimed at seeking practical approaches to coordinating protection and development based on their current status and future needs, and widely introduced models can provide a possible way by simulating spatial patterns in different future scenarios (Couclelis 2005). Simulating the

Table 1 SLPs serving for spatial planning

Serving for spatial planning	Key points	Related SLP	References
Assessment serving for planning targets	Assessing six potential benefits to analyze the effectiveness of GI projects	GI	Meerow and Newell (2017)
	Assessing the ecosystem services supply and human ecological demand, which is also the basis for some planning targets	ESP	Zhang et al. (2017)
	Assessing the effect of integrating species distribution and connectivity among reserves to determine the performance of species persistence in current planned reserve networks	EN	Magris et al. (2018)
Identification serving for spatial patterns	Identifying potential ecological red line areas to improve the living environment and biodiversity in spatial planning	ERL	Bai et al. (2018)
	Identifying the UGB considering policy factors related to spatial planning	UGB	Huang et al. (2019)
	Identifying key stepping-stone patches for maintaining the connectivity of important habitats, and guiding urban ecological conservation	EN	Luo et al. (2020)
Simulation serving for development plans	Simulating the basic, moderate, and strict-rank ESPs to select the optimal spatial patterns for balancing protection and development	ESP	Su et al. (2016)
	Simulating four conservation scenarios by incorporating unprotected patches into habitat networks, and selecting the optimal scenario	EN	Xun et al. (2017)
	Simulating six ecosystem services within a "business-as-usual" scenario and three scenarios that capture changes in green infrastructure	GI	Paulin et al. (2020)

GI green infrastructure; *ESP* ecological security pattern; *EN* ecological network; *ERL* ecological red line; *UGB* urban growth boundary

changes of spatial patterns of SLPs under different scenarios, such as land use change scenarios, the representative concentration pathways (RCPs) scenarios, and the shared socio-economic pathways (SSPs) scenarios, can help optimize the spatial governance strategies (Su et al. 2016; Fan et al. 2021). In particular, the rapid progress of simulation models on land use change (e.g. CA-Markov model and the CLUE-S model) has promoted more SLPs to be spatially simulated (Mas et al. 2014; Zheng et al. 2015). In addition, taking various spatial planning schemes as development orientations and using the core indicators of SLPs to quantitatively assess the effectiveness of spatial planning schemes can provide references for the comparison and selection of planning schemes. For example, Paulin et al. (2020) selected three implementation schemes related to GI in the Amsterdam spatial planning scheme "Green Quality Impulse" and the "business-as-usual" scenario, and then assessed the changing characteristics of six ecosystem services under different schemes and scenarios to effectively support the construction of GI.

Research directions for SLP

SLP is defined according to the theory of landscape sustainability science in this study, and the related concepts that accord with the targets and connotations of SLPs are summarized. Generally, these concepts are based on the "pattern-process-scale" mutual relationship for landscape ecology, which integrate the landscape structure paradigm of "patch-corridor-matrix". With the deepening of researches on social-ecological system, frontier theories, such as spatial resilience, metacoupling framework and landscape multifunctionality, will further develop the connotation and cognition of SLP. Furthermore, SLP has broader practical directions, such as ecological restoration, urban agglomeration coordinated development, and nature-based solutions, to promote the comprehensiveness and systematicness of spatial planning procedures and targets. Therefore, in the context of global and regional sustainable development, it is crucial to clarify the frontier theories supporting SLP development, and to explore the key practical directions of SLP for spatial planning (Fig. 3).
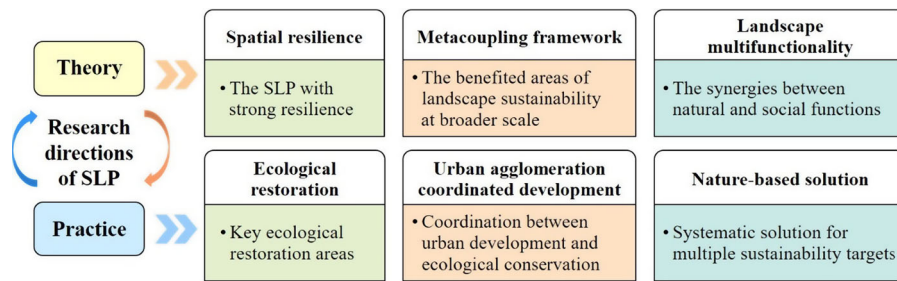
Fig. 3 Research directions for the theoretical support and applicable practice of SLP for spatial planning

Spatial resilience

Spatial resilience is the ability of social-ecological systems to maintain stability in the face of disturbance from a multi-spatial-temporal perspective with landscape as the object (Cumming 2011). The resilience is affected by specific functions, spatial structures and patterns of the internal components within the system, and the resilience also depends on the external matrix conditions and spatial connectivity (Allen et al. 2016). The objectives of SLP are to identify the spatial patterns that sustain regional ecosystem services supply, which is related to the integrity of ecosystem structure and function, and the resilience of ecosystems under stress. The perspective of importance is usually concerned in the current studies on SLPs. For example, ecological source identification mostly focuses on assessing the importance of multiple ecosystem services in the process of constructing ESPs. Ecosystem services may not be provided by ecological sources sustainably when the system is affected by disturbances, if the resilience analysis is ignored. Therefore, how to identify SLPs with strong spatial resilience could be the focus of future researches.

Ecological restoration

Under the guidance of SDGs, except for protecting ecosystem health and sustainable ecosystem service supply, spatial planning also focuses on the restoration of degraded, damaged, or destroyed ecosystems. Ecological restoration is a long-term planning process aimed to recover ecological integrity and human benefits (Jackson and Hobbs 2009; Suding et al. 2015). In 2006 and 2019, the Society for Ecological Restoration published two editions separately of international

principles and standards for ecological restoration that emphasized to pay attention to the key attributes of target ecosystems and use quantifiable indicators to evaluate the progress toward the restoration targets. Supported by the concept of spatial resilience, SLP can provide a viable way for ecological restoration to spatially identify key landscape elements and to assess spatial sustainability in the future. For example, existing studies have identified the key restoration areas in ecological corridors that impede the species movement (Dong et al. 2020), and furthermore simulating the differences between the future and the current patterns of SLP can also help to determine the directions of ecological restoration.

Metacoupling framework

The metacoupling framework is based on analyzing the human-nature relationships within a specific system or among different systems, including intra-coupling (human-nature relationship within the system), peri-coupling (human-nature relationship between adjacent systems), and tele-coupling (human-nature relationship between remote systems) (Liu 2017). The metacoupling framework highly focuses on natural background, socio-economic conditions, and their interaction relationships within the system. Moreover, the spatial flow relationships caused by the potential spillover effects among different systems should be also considered (Schaffer-Smith et al. 2019). Current studies on SLP mainly emphasize how to balance local ecosystem conservation and social development needs, such as local production and consumption of products or services, and the local protection of biodiversity. However, the conservation objects of SLPs usually have interregional output and benefit characteristics, such as the allocation of water

resources between upstream and downstream areas, and the inter-habitat migration of large mammals (Bagstad et al. 2014). Therefore, future studies on SLP could be extended from the local scale to the inter-regional scale and need to determine the benefit areas of landscape sustainability at larger spatial scales based on the metacoupling framework.

Urban agglomeration coordinated development

Urban agglomeration is the outcome of global urbanization, especially the development of metropolitan areas. In addition to the highly close economic ties and population movements between cities, the development of urban agglomeration also shows the spatial expansion from a single city to the connection of multiple cities (Fang and Yu 2017). Urban agglomeration without constraint or function optimization may aggravate the corresponding ecological problems due to unsustainable development, such as the disorderly expansion of construction land, urban heat island effect, natural habitat degradation, and biodiversity loss (Manoli et al. 2019). The construction of SLPs at the scale of urban agglomeration provides a spatial approach for optimizing the functional division of urban space and enhancing ecological protection and restoration at the same time (Zhang et al. 2017). For example, demarcating UGBs and ERLs of urban agglomeration towards future urban development and ecological protection can reduce the occupation and fragmentation of ecological land caused by inter-regional urban expansion. When identification approaches of SLPs are combined with the metacoupling framework mentioned above, the construction of ENs in urban agglomerations will enhance spatial connectivity among inter-regional habitat patches, which will promote inter-city cooperation in protecting ecosystem integrity.

Landscape multifunctionality

Landscape multifunctionality refers to the capacity of a landscape to simultaneously support multiple inter-acted benefits to society (Mastrangelo et al. 2014). The maintenance of landscape multifunctionality is achieved from the multifunctional landscapes (Peng et al. 2019). Constructing and optimizing multifunctional landscape patterns is an important way to synergize various SDGs and thus to enhance human

well-being (Wang et al. 2021), which is consistent with the targets of SLPs. However, currently the identification of SLPs mainly adopts the spatial overlap approach by integrating multiple landscape elements assessment. The approach essentially emphasizes to independently evaluate different landscape elements and then to identify hotspots, but it ignores the trade-offs and synergies among different assessment factors. Taking landscape services as an example (Termorshuizen et al. 2009), studies have shown that there are significant trade-offs between local food production and other regulating services (Gordon et al. 2010), which may make it difficult for the SLPs identified through spatial overlap approach to sustainably ensure food security and ecological security simultaneously. Therefore, it is important to understand the potential relationships of landscape functions, and further to regulate trade-offs and enhance synergies among various landscape services in order to achieve the multiple objectives of SLPs (Turner et al. 2014; García et al. 2020).

Nature-based solutions

As an umbrella term, nature-based solutions refer to "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Xie and Bulkeley 2020). From a spatial perspective, nature-based solution is a systematic approach to responding to the challenges of coordinating conservation and development (Maes and Jacobs 2017). Nature-based solution focuses on the multiple coupling of the ecological, social, and economic functions of various natural or semi-natural landscapes, i.e. multifunctionality of landscapes. SLPs based on landscape multifunctionality assessment can provide nature-based solutions that achieve multi-dimensional SDGs. For example, ESPs identified with the target of integrating water resource security, soil retention, landscape connectivity, and habitat protection can simultaneously guarantee ecosystem service demand and biodiversity maintenance (Zhang et al. 2017). Therefore, it is necessary to develop more effective nature-based solutions, which can achieve multiple spatial planning targets through the synergies among various landscape services.

Conclusions

In this study, we have systematically reviewed the literature closely related to SLPs and proposed that SLP refers to a certain combination of composition and configuration of landscape elements that enables social-ecological processes to sustainably provide stable ecosystem services for promoting human well-being in a paticular region. Sustainable landscape patterns can be divided into ASLPs and CSLPs depending on the research targets and proposed background. As an important way to optimize the spatial pattern of natural and social elements, spatial planning procedures (i.e. determine planning targets, analyze spatial patterns, and compare and select planning schemes) are compatible with assessing target landscape elements, identifying key spatial areas, and simulating future development scenarios in studies on SLPs. Furthermore, frontier concepts (i.e. spatial resilience, metacoupling framework, and landscape multifunctionality) were introduced to provide new research directions for future studies on SLP, and SLPs integrated with these concepts can also be applied to the spatial planning practice of ecological restoration, urban agglomeration coordinated development, and nature-based solutions. The scientific connotation for SLP proposed in this study is the theoretical extension of landscape sustainability science, and summarized practice of SLPs in spatial planning provides a spatial approach for the realization of regional sustainable development.

Declarations

Conflict of interest The authors declare no conflicts of interest.

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