sustainability

Article

A Review of Social–Ecological System Research and Geographical Applications

Fang Liu [1,2], Erfu Dai [1,3,*] and Jun Yin [3,4]

1 Lhasa Plateau Ecosystem Research Station, Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
2 University of Chinese Academy of Sciences, Beijing 100049, China
3 Key Laboratory of Land Surface Pattern and Simulation, Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
4 Lhasa Tibetan Plateau Scientific Research Center, Lhasa 850000, China
* Correspondence: daief@igsnrr.ac.cn

Abstract: This paper reviews the exploration and application of social–ecological systems research perspectives to sustainable development issues such as the areas of coupled human–earth relations, resource management, geographical landscape patterns, system dynamics, and the relationship between ecosystem services and human well-being, and summarizes practical approaches and applied techniques for solving social–ecological system problems in order to understand changes and relationships in complex systems better. The article summarizes the theoretical research on social–ecological systems by domestic and international scholars into six frameworks: system resilience, system cascade, nature's contribution to humans based on ecosystem services, public resource system management, system behavior scenario analysis, and system regime shift. Innovative research and practice oriented to complexity, coupling, and nonlinearity have emerged. However, there are differences between scientific research and applied practice, including their theoretical and methodological orientations. We should be oriented to social–ecological system problems to achieve a transformation from components to relationships, from outcomes to processes, from single to open systems, from general interventions to context sensitivity, and from linear to complex causality to meet what is required from sustainability science and geography.

Keywords: social–ecology system; theoretical framework; sustainable development; complexity; coupling studies; geographical applications

check for updates

Citation: Liu, F.; Dai, E.; Yin, J. A Review of Social–Ecological System Research and Geographical Applications. *Sustainability* **2023**, *15*, 6930. https://doi.org/10.3390/su15086930

Academic Editor: Alejandro Javier Rescia Perazzo

Received: 3 February 2023
Revised: 17 April 2023
Accepted: 18 April 2023
Published: 20 April 2023

1. Introduction

The 21st century has witnessed dramatic changes in both the earth environment and human societies dominated by the Anthropocene [1–3]. Further evidence suggests that these changes have given rise to global-scale processes of human modernization and earth system science, and have unpredictable implications for future human well-being and societal development that deserve greater attention and exploration [2,4]. Increased natural and anthropogenic stresses have threatened the earth's ability to meet growing human demands of food, energy, and water in a sustainable way [5]. Meanwhile, many key global sustainability challenges are closely intertwined [6], such as air pollution, biodiversity loss, climate change, disease spread, species invasion, and resource shortages. These challenges result from the confluence and interaction of multiple, mutually reinforcing social developments and ecological processes at multiple scales [4], where social development includes demographic change, economic development, political dynamics, cultural integration, and technological innovation processes, and ecological processes include material metabolism, energy flow, ecosystem succession, and information feedback among organisms [7]. Moreover, the combined effects of human activities and ecosystem processes have resulted in more complex earth environments, such as climate emergency change and global integration. As a result, the sustainable development challenge facing the human world in the 21st century is therefore to recognize and address the relational, holistic, and intertwined nature of these complex systems [6,8,9].

Facing complex social and environmental issues, the whole range of different expertise and implementing a combination of actions is an important but difficult process [10]. Ecology usually has often viewed socioeconomic status as the external drivers or environment background of the ecosystem dynamics, whereas many economists try to introduce the relevant theories of politics, economics, and sociology to study the ecological resource governance. For example, Hardin introduced the concept of game theory and market action in neoclassical economics for the governance of public resources such as forests and put forward the famous theory of "tragedy of the commons", but economics and other social sciences simply put ecosystems and natural resources as being regarded as the material basis for obtaining economic benefits and providing livelihoods, resulting in many assumptions that are difficult to applicate in complex regional ecosystems. It is no doubt that patterns of production, utilization and well-being develop not only from economic and social relations within and between regions but also depend on the capacity of other regions' ecosystems to sustain them [11,12]. However, the change and progress of human society need to seek the optimal solution of balancing economic benefits and ecological benefits: social–ecological system theory emerged in this context. It systematically points out that society and nature are inevitably interdependent and closely linked.

In recent years, social–ecological systems (SES) theory has become a prominent line of research and thinking in the study of sustainability [13]. There is a two-way interaction between social components and ecological elements, forming a feedback loop [7,14,15]. Therefore, understanding the interconnectedness of complex problems requires an interdisciplinary, multi-scale, paradigm-shifting analytical evaluation assessment methodology that is applied to the solutions of the real-life sustainability problems faced.

2. Perspective for Understanding Social–Ecological Systems

The concept of social–ecological systems has been shown to analyze development issues arising from complex interactions between people and the environment on a regional scale [4,16], and is based on the perspective of "the division between society and natural system is artificial and arbitrary" [17], that is, the relationship between the social system and natural ecosystem can be selectively divided according to the theme, characteristics, intention, and nature of human research.

Social–ecological systems, also known as a "composite human–earth system" or "composite human–nature system" [18,19], refers to the coupling system with complexity, nonlinear, uncertainty, and multilayer nesting characteristics formed by the interaction between human beings and the environment [8,14].

Since then, the study of human and natural systems fosters interdisciplinary dialogue and collaboration in a broader range of fields and practices. Hence, we conducted a review of the SES concept through a large amount of the literature, and many papers analyzed did not provide an accurate definition of the term social–ecological system, which reduces the usefulness of the concept to a certain extent. So, we propose that the understanding of SES needs to be started from the perspective of the research field, guiding problems and essential characteristics, so as to be more meticulous when conducting SES research [20].

2.1. Interdisciplinary Research

In 1998, Berkes and Folke [17] explored the questions of "Are humans' activities condemned to destroy ecosystems?" from an interdisciplinary perspective. They defined the ability of a complex system to blend internal conditions with the external environment in order to build a bridge between the social sciences, which focus on social behaviors and practices, and the natural sciences, which focus on ecosystem endowments and processes.

Early SES research was inspired by the interdependence of human and nature from anthropology, ecology, resource science, and geography. Later research literature involves environmental and social sciences, economics, resource science, geography, and ecology, followed by medicine, psychology, art, and other humanities. Socio-ecosystem research represents a recognized interdisciplinary field of the science of sustainable development [20–22].

Many of the methods used by SES go beyond the traditional humanities, sociology and natural sciences, or other single disciplines [4,13,23]. SES research adjusts methods or implements a series of method combinations in order to jointly capture the key points of social and ecological fields and clarify the relationship between them [13,24] and create more methods, models, and policies for the practical application of SES research [25–27]. SES research is also highly collaborative with practical demonstrations, and a more powerful natural science–social science interface can be developed to guide research, co-create knowledge, and make decisions [23,24,27].

2.2. Complex Adaptive Systems (CAS)

Undoubtedly, the Anthropocene brings new environmental and social problems [16,28], and scientific research is increasingly using practice-oriented approaches to assess the current situation, predict the potential, and develop policies to deepen the understanding of the dynamic nature of human–earth interactions [4].

There is a general consensus in the relevant literature that SES are described as intertwined complex adaptive systems (CAS) [15,25,29]. They consist of interactions between various elements of human and nature. These interactions make up the structure, processes, patterns, and functions of the system and feed back to the elements that generate them. Therefore, we are actively exploring to unravel the mechanisms and patterns of dynamic interactions between human and non-human elements in SES and to explain interesting emergent phenomena [29]. The basic principles of SES research are based on the understanding that linked human and ecosystems are CAS, and that this network of constantly adapting and evolving socio-ecological interactions produces macro- or micro-level SES outcomes, such as land use landscape patterns, and may lead to changes in social systems. Thus, explanations of SES dynamics and phenomena need to focus on micro-level interactions and macro-level outcomes, as they both shape the drivers of system evolution [29].

What is more, some features in CAS, such as critical thresholds, critical points, regime shifts [28,30–33], cross-scale connections, feedback loops, and nonlinearities [34,35] can be used to identify and explain the complex nature of SES behavior and related patterns [25]. The integration of CAS concepts into SES research also reflects the fact that its theoretical framework and conceptual foundation have been developed [21,36]. However, the understanding of CAS is then limited and therefore there are many research gaps in identifying relevant methodologies and practical approaches to study SES.

Through theoretical derivation of SES, Preiser [25] obtained the conceptual definition and organizational principles of SES as a complex adaptive system, which described various characteristics and connotations of SES (Table 1).

2.3. Coupling System

Human–natural systems are more often studied independently [37], such as how the natural environment supports or constrains social development, or how human activities damage and interfere with the natural environment, and a one-way understanding of social–ecological systems hinders a better understanding of the complexity (e.g., feedback, nonlinearity and thresholds, heterogeneity, time lags) in coupled human and natural systems.

Table 1. SES organization principles based on CAS concept.

Rules	Description
Relationships over individuals	The nature and trend of the system as a whole can be better understood by clarifying the relationship between the components than by understanding the idiosyncratic characteristics of the individual components
Adaptability	Many relationships in the system have feedback processes and response mechanisms so that the system can constantly adjust its state to adapt to environmental changes and external forces
Nonlinear correlation	The change of small elements will lead to the large-scale, continuous, and sudden unexpected restructuring of SES structure and function, and ultimately lead to the reform of the whole system
Boundaryless	SES has a profound interaction and connection with the broader environment, and the boundaries of the system often depend on the researcher's purpose, the observer's perspective, and the characteristics of the research problem
Situational dependence	Elements and indicators in the system will assume different roles and functions according to time sequence and context
Complex causal relationship	Causality in SES is not unidirectional or linear but marked by a complex recursive causal path. This leads to SES not always being an accurate thorough understanding, and the property nature of the system is unpredictable

In general, traditional social sciences pay more attention to human actions, preferences, goals, consciousness, and interpersonal relationships and functions, and minimize the function of environmental backgrounds or immobilize environmental influences. Ecological science tends to focus on the elements, patterns, and processes of the environment itself, such as physical, chemical, and biological effects, while human beings are regarded as external and non-dominant parties. However, socio-ecological systems are a new concept that couple human and natural systems. Although there are significant differences in theoretical origins, conceptualization methods, and problem-solving purposes, the emergence properties of coupled systems show that socio-ecological systems have their own unique structure, function, and dynamic mechanism.

The dynamic mechanism of the coupled system originates from both natural and social forces [18]. Coupled social and ecological systems involve relationships between multiple human activities and environmental subsystems, micro-level impacts, changes at the macro-scale, positive effects or negative feedback, and quantitative and qualitative patterns of change. Therefore, their dynamics are very complex [18,38]. Additionally, they also need to take into account the occurrence and contribution of emergence phenomena. These complications make it necessary to conduct coupled systems research and explore the conditions, mechanisms, and rules of whole emergence and sustainability.

As the basic attributes of social–ecological systems, complexity, coupling, and interdisciplinarity reflect the difficulty of research in this field, as well as the major challenges related to the sustainable development of the region. Social–ecological systems research is an intersection of geographic research and sustainable development science, involving numerous disciplinary knowledge at the spatiotemporal scale, and is a focus and difficulty for future scientific research.

3. Social–Ecological Systems Research

As a complex adaptive system and coupling system, SES profoundly influence and shape the development processes and paradigms of sustainability research [25,33,39]. Moreover, the interdisciplinary nature of its research also provides more referential, usable, and improved disciplinary methods, tools, and approaches for exploring the principles, mechanisms, and characteristics of socio-ecological systems. Early SES papers [21,40] mainly used the ideas and principles of environmental science, economics, sociology, and other disciplines to explore the human–environment system interaction from the perspectives of land system change, public resource management, system vulnerability, or natural environment change. As the concept of SES is gradually transformed into the study of the complex and coupled system interwoven between human society and natural ecology [41–43], more and more studies have carried out extensive research. Regarding ecosystem services and human well-being [44], María Mancilla García [43] demonstrated that adopting a philosophical view and focusing on the dynamic relationship of processes provides a new perspective for advancing SES research. Patrick [45] believes that transdisciplinary environmental networks are required to generate knowledge of the dynamics of coupled human–natural systems and to assess societal and policy consequences of complex environmental issues. He tried to establish a sound socio-ecological observatory and collect a large number of relevant environmental coupling data, so as to analyze the characteristics and problem attributes of SES in a more comprehensive and scientific way. Hanqin Tian [5] constructed an integrated simulation model of the food–energy–water (FEW) relationship by coupling ecological, economic, and climatic elements to analyze the interactions and feedback in the ecosystem–human–climate system. Joern Fischer [19] suggested that studies of SES are useful for understanding the interrelated dynamics of environmental and social change. Existing research results have helped facilitate improving the understanding of the dependence of human social systems on ecosystems, promoting cooperation between natural science and sociology. The methodological diversity provided by multi-disciplines improves the understanding of complex systems, and now major policy development and decision-making programs have begun to consider SES interactions. Carena [46] analyzed the complexity of socio-ecological systems in terms of social values and environmental governance, suggesting that multi-level values influence natural resource management and sustainable use and facilitate the development of effective strategies to adapt to global change.

From the existing research literature, we can distill the basic connotations of SES research: (1) social and ecological systems and ecosystems interact and are interdependent from structure to process; (2) these interactions produce emergent outcomes and properties (e.g., resilience and adaptability) that differ in their effects from their individual components; (3) one can study social, ecological, and economic systems of sustainable development to understand their properties and trends and thereby reconstruct a holistic picture of sustainable development outcomes; and (4) SES research provides an integrated view of humans in nature and engages with global sustainable development goals in a more system-wide conscious manner [43].

In order to clarify the main content, guiding issues, methods and methodology of SES research, and to understand the key characteristics, structure, function, adaptation, and other properties of SES, we summarize the comprehensive SES research carried out by current scientists from aspects of frameworks, methods, and tools research, thus providing more practical experience and theoretical guidance for meeting the challenges of sustainable development in the world (Figure 1).

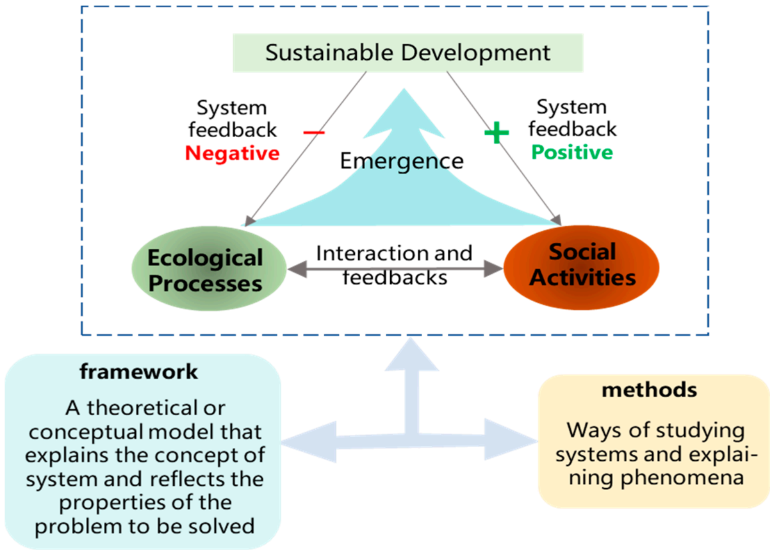

Figure 1. An understanding of SES as complex, interdependent, and coupling systems that influence the analytical framework and methods applied to SES research.

3.1. SES Frameworks

Scientific studies all design top-down or bottom-up research programs and frameworks of thought based on the concepts, connotations, characteristics, and nature of their fields of study. Similarly, the frameworks constructed in numerous SES studies reflect different areas of social–ecological systems, such as adaptive governance, resilience assessment, institutional transformation, and sustainability potential. Various analysis frameworks are linked to the nature of the problem to be solved, the preferences of the researcher, or the particular area of SES research. Moreover, these frameworks have brought more options to system governance pattern-related research by providing a platform to analyze the integrating effects from natural, political, economic, and social factors.

Within the last two decades, significant advances have been made in interdisciplinary research and analytical framework design for social–ecological system coupling. In different studies that explicitly consider the interaction between social systems and ecosystems, most of the various research and analysis frameworks have been designed and constructed based on conceptual understanding, problem attributes, and causal relationships. The main purpose of these frameworks is to identify, categorize, and organize those factors, relationships, processes, and outcomes deemed most relevant to understanding a particular phenomenon [46–48]. This paper focuses on the applied framework designed by social–ecological systems theory for sustainability analysis in the geosciences, and includes (Table 2):

- The Panarchy framework depicting system resilience as an outcome of connected adaptive cycles at different scales (Panarchy) [34,49–53] (Figure 2).
- The conceptual cascade framework of "Pattern–Process–Service–Sustainability" that builds on the understanding the coupled human and natural system (CCF-PPSS) [5,6,18,54,55] (Figure 3).
- A socio-ecological framework for measuring nature's contributions to people (MNCPF) based on ecosystem services [56–59] (Figure 4).
- The diagnostic framework to assess sustainability of the utilization and management of public resources (SESDF) [21,48,60–66] (Figure 5).
- The social–ecological action situation (SE-AS) framework to analyze the emergence of social–ecological phenomena from social–ecological interactions (SEASF) [29,43,67–69] (Figure 6).
- An analytical framework of the regime shifts of social–ecological systems (RSAF) [9,70,71] (Figure 7).

Table 2. The main characteristics of the selected SES frameworks and identified applications.

Types	Concept	Principle	Key Research Questions Appropriate for This Representation	Application in Case
Conceptual descriptive framework	Panarchy	• 4 stages in the evolution of complex systems: exploitation, conservation, release, reorganization • 3 attributes: potential, connectedness, resilience	• Analyze the stage characteristics of social system and ecosystem, and explore the adaptive governance scheme • Assessing the resilience of social–ecosystem systems to stress from external influences and processes	• Assesses resilience and transformation in riverine and wetland social–ecological systems at a variety of scales, levels of development, and degrees of degradation [51] • In residential communities to natural disasters [52] • Dynamic changes of social development and ecological environment sustainability in urban agglomerations [53]
	CCF-PPSS	The framework takes public resource management theory and organizational behavior theory as its social foundation, introduces the condition factors of the ecosystem itself, and constructs a series of core variables such as resource units, resource systems, users, and governance systems, which directly affect the final outcome of the social–ecological system interaction	• Changes in ecological patterns and processes caused by both natural forces and human activities can affect multiple ecosystem services through cascade effects, resulting in trade-off and synergy effects between services	• Analyzes the complexity of coupling human and natural systems in the Loess Plateau region of China, as well as the development traps and sustainable management measures of socio-ecological systems [54]
	MNCPF	Ecosystem services as the nexus between the supply and demand sides of the SES; establishes linkages between ecosystem services and human well-being; introduces factor drivers and feedback loops; takes into account spatial and temporal scales.	• The supply–demand and trade-off relationships that affect ecosystem services through institutions, policies, etc. • To describe the safe operation space and state of SES	• Natural resource management and territorial space governance [57] • Ecosystem services drive urbanization and land use change [58] • Forest ecosystem services are the main source of livelihood for indigenous people in the rainforest [72]
Phenomenological analytical framework	SESDF	The framework is based in common resources pool theory and collective action theory and is a collection of variables characterizing the resource, the resource system, users, and the governance system that have empirically been shown to affect collective action and sustainable common pool resource use	• Focuses on interactions between nature resource users, particularly the factors that enable self-organization for sustainable resource use • Emphasis on the impact of human institutional management and a sense of self-organized learning on ecosystems and natural resources management	• Sustainable development management of island fishery [62,66], lake, and wetland resources [63] • Forest self-governance and forest policy evaluation related research [24,64,65]
	SEASF	This framework is a tool for capturing the dynamic processes that generate socio-ecological phenomena. It extends the concept of action contexts to focus on socio-ecological system interactions and their linkages at various levels, emphasizing specific analysis of specific phenomena	• Focuses on the interpretation of sudden emergent socio-ecological phenomena, providing usable information for field studies, experiments, or mathematical and physical model construction • Act as a boundary object to facilitate the integration of knowledge of key interactions between ecological and social domains into the interpretation of socio-ecological change	• Effective management of lakes should be achieved from three aspects: analysis of lake pollution factors, environmental governance, and improvement of the future ecosystem services [29] • The poverty trap in African countries is a socio-ecological negative feedback phenomenon resulting from the interaction of action scenarios [67,68] • Socio-ecological process scenarios such as at the global level, including trade patterns and climate change, and the regional and local level, including land use change and wetland loss, maintain the potential global pandemic risk [69]
	RSAF	An analytical framework to identify the regime shifts of SES based on changes in the relationships between SES components while also establishing empirical links with their drivers and local and spillover effects with a perspective of processes unfolding over time	• Regime shifts, i.e., large, abrupt, and persistent changes in system structure, function, and feedback, occur across a wide range of SES • Drivers from human activities and climate change determine the social–ecological interactions and then generate both local effects and spillover effects in distant systems	• Analyzing the evolution over the past 1000 years of the SES in China's Loess Plateau, and identifying five evolutionary phases [9] • Urbanization and rural outmigration in China will produce a large but transient carbon sink effect [70]

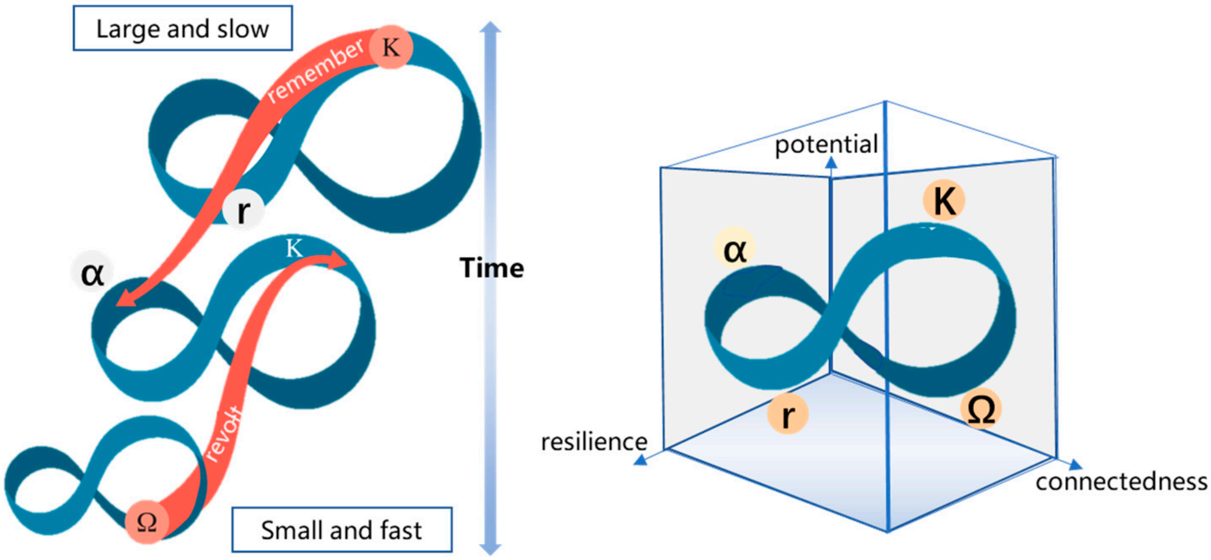

Figure 2. An analytical framework of the regime shifts of SES [9].

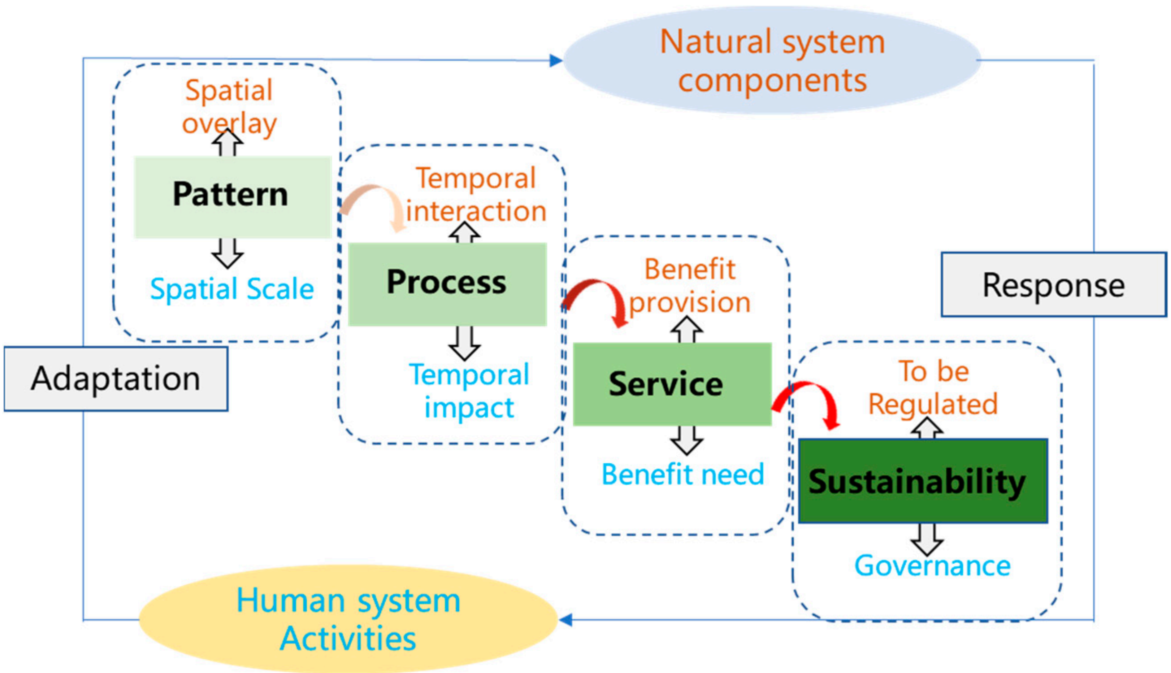

Figure 3. A socio-ecological framework for measuring nature's contributions to people based on ecosystem services [57]. On the supply side, the impact of natural ecosystem elements, structures, processes, and functions on the types, quantities, and spatiotemporal characteristics of ecosystem services are described; on the user side, the use of various ecosystem products and services by the socioeconomic system to meet the needs of different levels of human well-being are described.

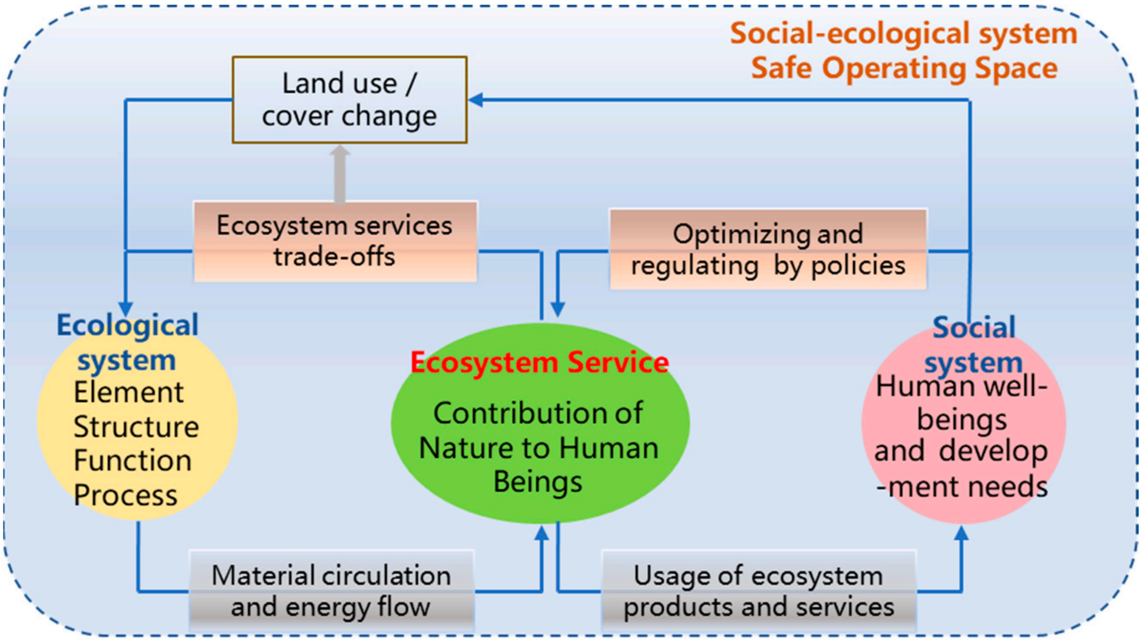

Figure 4. The conceptual cascade framework of "Pattern–Process–Service–Sustainability" [55]. A deep understanding of the framework interactions can help to design policies and measures to enhance the sustainability of complex socio-ecological systems.

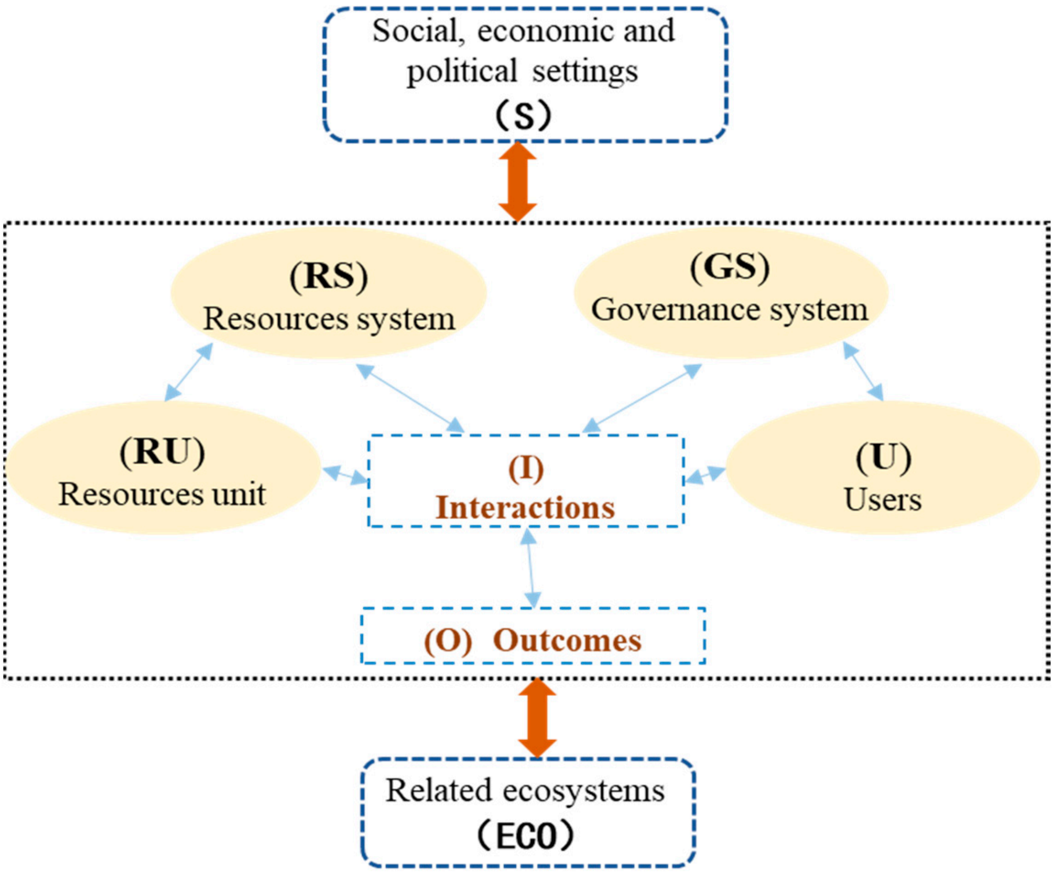

Figure 5. The social–ecological action situation (SE-AS) framework [29].

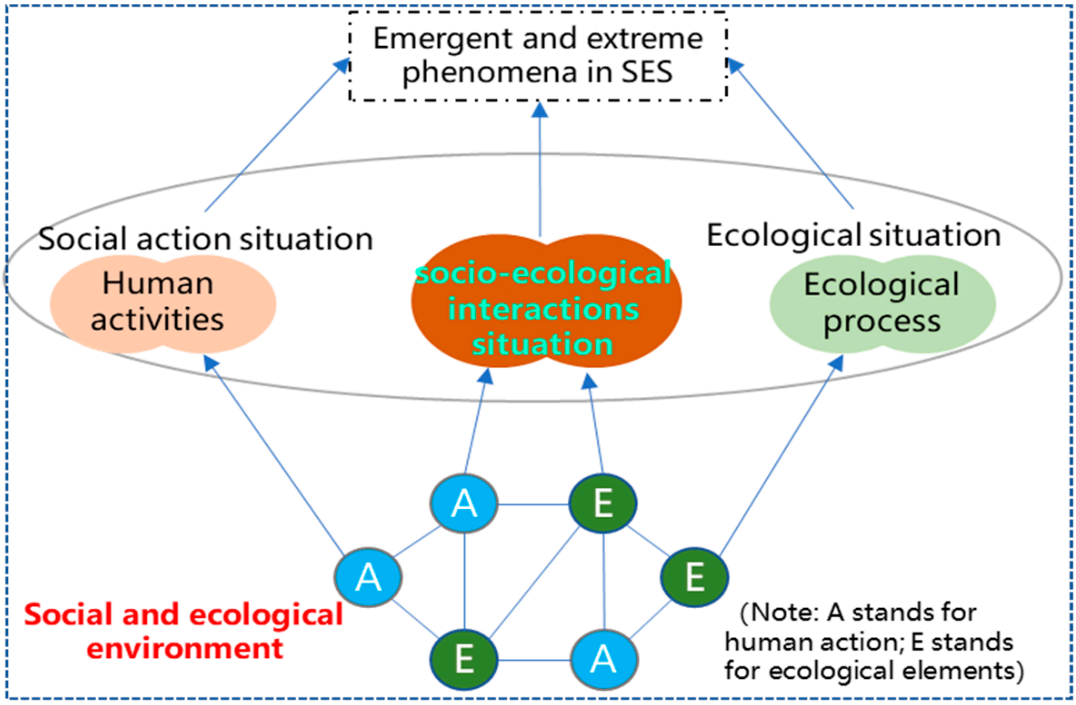

Figure 6. The Panarchy framework [34]. Interaction between elemental components shapes the state of the system. The framework has 3 concerns: recovery time from disturbances and the capacity to absorb them; cross-scale interactions; to build adaptive capacities with experiments and learning.

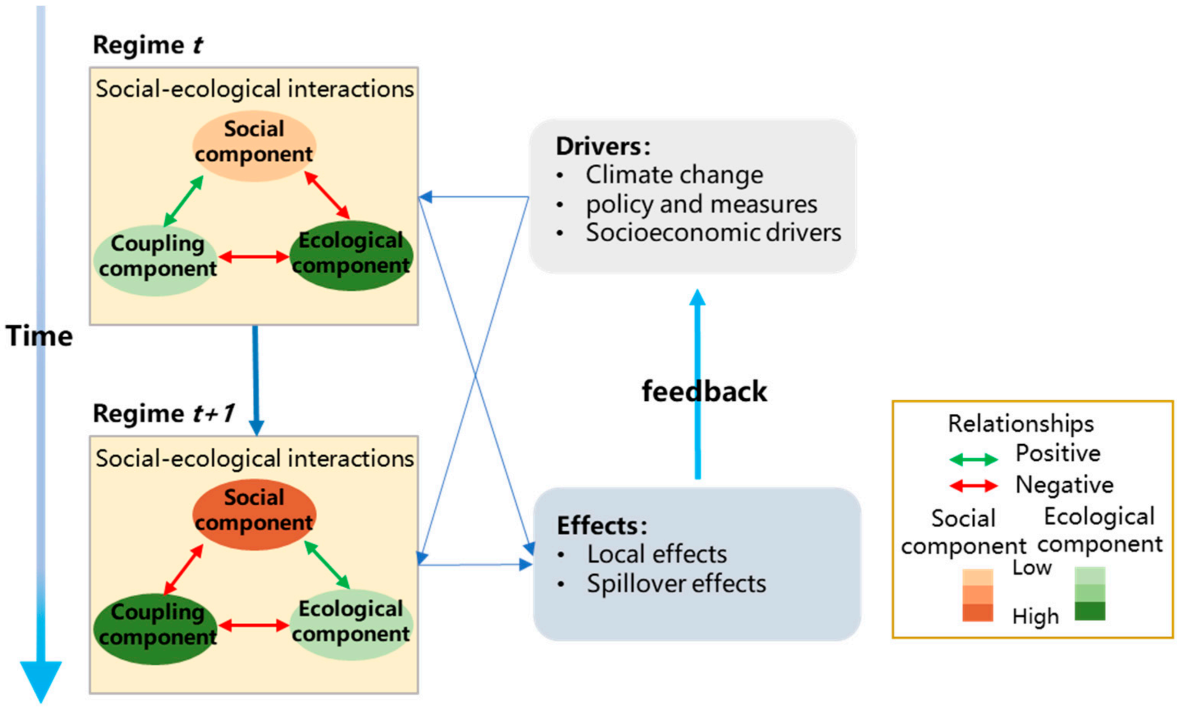

Figure 7. A general diagnostic framework of SES [48].

3.2. Commonalities and Characteristics of Frameworks

These frameworks have emerged from the need for concepts that permit structured, interdisciplinary reasoning about complex problems in social–ecological systems, and are based on the understanding of SES as complex adaptive systems, focusing on the interaction between the elements of the natural ecosystem and socioeconomic system. Therefore, it has universality, and more clearly designed content has selectivity, which is conducive to researchers' selection of applicable frameworks according to the research content, research field, and problem orientation.

The criteria used for summarizing the frameworks in this article are theoretical concepts-oriented or an action analysis-oriented. The former focuses on deducing and summarizing the overall evolution process and comprehensive effect of SES as a coupled system, while the latter focuses on analysis of the interaction mechanism and process model among elements, nodes, variates, and components in the SES.

In terms of research application, these frameworks differ significantly in research objectives, disciplinary backgrounds, time, space, organizational scales involved, and their conceptualization of the social systems and ecosystems as well as their interaction [47], which is manifested in the high diversity of valuable results of different scales.

The data requirements of these frameworks are determined according to the research objectives and selection variables, and the level of detail of the data depends on the nature of the socio-ecological problem being studied.

An overview of SES framework research is difficult to state clearly at this time due to the lack of comparability of results obtained through different frameworks due to differences in application context, scale, and data sources, as described above.

This paper argues that those interesting phenomena and features in SES research arise from social and ecological processes, and that complex feedback loops blur the distinction between causes and effects, making it difficult to accurately quantify the resilience and sustainability of social–ecological systems, so researchers often use frameworks and theories to design their research protocols. Framing research is a theoretical tool for understanding invisible social–ecological systems, building networks of relationships among SES variables, identifying evaluation elements and indicator characteristics, expressing linkages and processes, and embedding external contexts to help explain or predict SES outcomes [1]. However, its theoretical breakthrough does not solve the problem of a lack of methodology, so the actual application of research progress is slow. How to find a general research method that can meet the requirements of natural science and social science, quantify economic, social, and ecological indicators, and finally reflect the relationship between them has become a critical problem in the international academic circle. Those studies should meet the two core requirements of interdisciplinary research: (1) effective integration of different social and natural science theories and hypotheses; (2) quantitative analysis of empirical data in a scientific and efficient way [64]. Meanwhile, the mutual-feed mechanism between social factors and the ecological environment is also a hot spot and a difficulty in current research.

3.3. Research Methods and Tools

To achieve an integrated study of SES, methodological plurality is a necessary condition [19,25]. By applying diverse and innovative methods and tools to make the theorized analytical framework operational, the key components of the dynamics and complexity of system interactions can be better understood, and more hands-on solutions can be proposed.

The resolution of the interconnectedness of complex problems takes an interdisciplinary and cross-disciplinary approach to expertise [73,74]. Many of the methods and instruments used in SES research integrate traditional social and natural science methodologies, including quantitative and qualitative methods such as system dynamics modeling, network analysis, agent-based modeling, multi-criteria analysis/indicator-based aggregation, and integrated assessment/decision support systems (Figure 8). This paper matches SES studies with research methods based on research steps and objectives that are proven effective in obtaining research results and conducive to understanding the dynamics of complex SES interactions, as well as supporting human well-being, livelihoods, and promoting sustainable resource management (Table 3).

Table 3. Summary of methods used in SES research.

Research Objectives	Methods and Tools	Application and References
Data collection and system scoping	Ecological field data collection	The most direct and objective first-hand data can be obtained for understanding the structure and processes of the natural ecological environment and the impact of human activities on disturbance, etc. [75].
	Interviews and surveys	Focuses on the collection of person-related information, generating qualitative data and regular experiences to understand the assessment of long-term social, economic, and cultural changes in SES [62]
	Participatory data collection	Stakeholders in regional socio-ecological systems are themselves part of the problem to be solved, and researchers should focus on co-producing knowledge with them [76]
Analyze SES component variables and relationship	Comparative case study analysis	Qualitative, comparative, empirical meta-analysis will provide a deeper understanding of the complexity of SES [6] Direct comparisons guided by an SES framework [53,59,63]
	Statistical analysis	Processing and application of collected data with mathematical tools, identifying control parameters of social and ecological factors, testing hypothesis problems and forecasting future trends
	Network analysis	Linking society and ecological processes to analyze how patterns of linkage vary among nodes, and how variation in connectedness influences the behavior of network nodes [77]
Explain system phenomena and dynamics changes	Agent-based modeling	One of the key methods to study emergent phenomena of systems: the agents often represent individual or collective actors or biological organisms, the social environment comprises social structures, the biophysical environment represents natural resources or ecosystems that are used or affected by the behavior of the agents [78]
	State-and-transition modeling	Explains the causes and consequences of ecosystem change by simulating the effects of external drivers (such as climate) and human activities (such as management action) [79]
SES governance and informing decision making	Ecosystem service modeling	Integrated valuation of ecosystem services and trade-offs Identify areas for conservation, utilization, or restoration based on the balance between supply and demand of ecosystem services in the region [80]
	Flow and impact analysis	Measuring the relationship between resource flows and human society and monitoring the linkages between ecosystems and human well-being

The interdisciplinary, multi-scale, complex coupled nature of SES research, the need to go beyond the "sum" of social and ecological research, and the need to focus on system dynamics across scales has led to a high degree of methodological diversity [13,81], which needs a variety of data collection methods, data analysis, and deductive methods and models from a variety of disciplines to be combined to solve complex problems of socio-ecological systems. In addition, recent years have also seen the emergence of new research areas of modeling approaches: building social–ecological observatories (SEO) to collect data at multiple spatial scales, resolutions, and knowledge domains [45]; an adaptive social–ecological system management matrix (ASEMM) that is accessible and can be updated periodically to reflect systemic changes in social–ecological management decisions [82]; researchers integrated an assessment model—the Delta Dynamic Integrated Emulator Model (ΔDIEM) [83]—to explore the outcomes of four contrasting adaption trajectories with linkages of the environment, people, and policy choices which can be used to support informed management, development, and adaptation. Such researchers will propose theoretical models or construct method models according to the special SES problems of the region to be solved, and the methods and tools that are more targeted and applicable to the region, but the results obtained from the research and analysis of various methods may not be comparable.

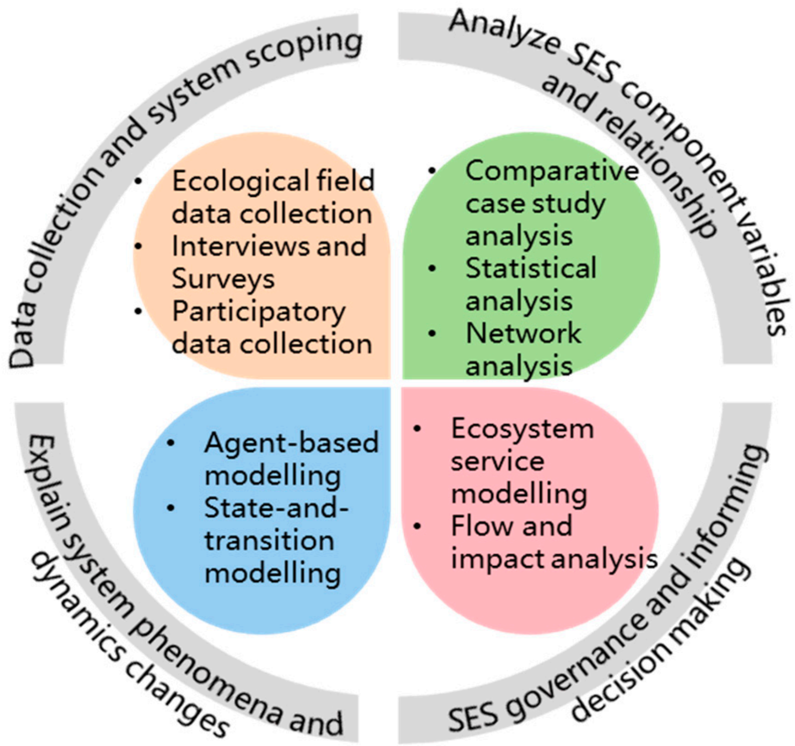

Figure 8. Applicable SES research methods and tools.

However, methodological innovation and diversification remains one of the biggest challenges in SES research [13]. Complex causality is the most difficult problem to be solved by all types of methods. The nonlinearity of causal trajectories, the suddenness of disaster events, and other complex socio-ecological problems require the collection of a large amount of data of a different nature, as well as the accumulation of local experience and scientific methods capable of tracing causal relationships across scales. This is an extremely complex and data-intensive task [84]. In conclusion, it would be interesting to develop new methods to fill the gaps in SES in the future, and innovative methods and approaches that can account for and represent the interactions between various system components are important for analyzing the sustainability of complex socio-ecological systems [14].

4. SES in Geographical Applications

The concept of social–ecological systems is useful for understanding the interlinked dynamics, and the development and evolution processes of environmental and societal change with dynamic, forward-looking, and systematic approaches of the system as a whole. It provides a basic logical framework for the research on the dynamic development of the human–land relationship. The concept has helped facilitate the interpreting of the sustainability of human–land relations: (a) increased recognition of the dependence of humanity on ecosystems; (b) improved collaboration across disciplines, and between science and society; and (c) increased methodological pluralism leading to improved systems understanding [19]. Therefore, it is considered as an important way for science to achieve sustainability of human and natural systems.

Regionalism, comprehensiveness, and complexity are the basic characteristics of geography in the new era. Notably, the concept of social–ecological systems is not rigid, and several different system frameworks and combinations of approaches have been listed to assist in the analysis of complex social–ecological problems and relationships in our article. In view of the regional, comprehensive, and complex characteristics of geography, many applications of geography in the future should be reflected in the following aspects by using social–ecological system theory research and framework analysis.

4.1. Land System and Land Science

The human–earth relationship regional system is the core of geographical research, which is an open and complex giant system composed of the geographical environment and human activities. The social–ecological system is an interpretation of the complex system of human and nature from different disciplinary perspectives, and as the interface between human society and the natural environment, the land system is a typical complex system. Land change science has become an interdisciplinary research direction for understanding human–natural coupling systems. Social-ecological system theory applied to the field of land science can build a coupled social and ecosystem land use trade-off and optimization model, which simulates the state changes of social-ecological systems and the degree of achievement of regional sustainable development goals under different scenarios, and is conducive to optimizing regional land use schemes and coordinating the configuration of regional natural and social demand for land use [85].

4.2. Landscape Pattern and Landscape Management

Land surface distributions of complex and varied landscape patterns, such as riverscapes, mountain landscapes, landscape architecture, etc., are complex, large-scale landscape mosaics of connected resources and land, embedded in different ecological and social economic settings, while social–ecological interactions among stakeholders often complicate resource conservation, landscape exploitation, and biodiversity and pattern management.

The challenges in managing landscapes are diverse, including rapid urban expansion on highly productive agricultural land, increased vulnerability from natural disasters, and biodiversity conservation. Because many of these issues are neither only ecological nor only social in nature, their successful management will require a holistic social–ecological system (SES) science-based approach that includes a thorough understanding of the dynamics of and interactions between their various components.

SES science and networks can improve resource management, better inform socioeconomic development, and suggest proactive responses to potential hazards and chronic risks. Furthermore, these networks provide the capacity to improve community responsiveness to change through the development of resilient infrastructure and promotion of greater security for livelihoods.

4.3. Natural Resource Management and Territorial Space Governance

In terms of natural resource management and territorial space governance, SES research is mainly used to evaluate regional resource and environmental carrying capacity, delineate the boundary line of interaction between human activities and ecological environment. First, SES frameworks can provide boundaries and thresholds for evaluating regional resources and environmental carrying capacity. The goal of green and sustainable development is to control the scale and intensity of human activities within the limits that the natural ecosystem can bear, and the social and economic system within the range of security and justice. Different from the previous work of evaluating resource and environmental carrying capacity based on index systems, the SES framework is used to comprehensively analyze key surface biophysical and socioeconomic processes, and then set the threshold of a safety boundary, so the analysis results are more objective. Secondly, through regulation influencing the safe operation of the space of the earth's limits and social boundaries, and limiting human activities in a certain space range, or quality control, in the protection of the ecological system continuing to supply products and services under the premise, to safeguarding national and regional ecological security and the purpose of the social and economic sustainable development.

5. Conclusions Remarks

Despite many recent advances in sustainability science, the environmental and social challenges we face demand better understanding of the complex and evolving links between ecosystems and human societies. The SES perspective is an interdisciplinary system theory that combines ecological and social sciences to study coupled human and natural systems [6] and has proven to be a theoretical guide and analytical framework to analyze the realization of the ideal of sustainability between humans and nature [19]. The concept has helped facilitate increased recognition of the dependence of humanity on ecosystems, has improved collaboration across disciplines and between science and society, has increased methodological pluralism that has led to improved systems understanding [28,84,86,87], and has manifested in major policy frameworks and initiatives, such as Future Earth, The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) [88], and the Sustainable Development Goals [19,88,89].

This paper focused on the applied framework designed by social–ecological systems theory for sustainability analysis in the geosciences, as well as novel approaches such as model building and mathematical analysis combined with traditional research methods such as field research in geography. We found that provides a basic logical framework for the research on the dynamic development of the human–land relationship. The concept has helped facilitate the interpreting of the sustainability of human–land relations. The classical analytical framework and research methods summarized in this paper are all from the perspective of human–land relations, committed to solving the relationship between geoscientific factors such as land, resources, landscapes, and human activities, and forming a more abundant social ecological system landscape with geographical connotations. We recognize that both social and ecological systems are under increasing dynamic change driven by global change and human activity. Both the initiation of theoretical framework ideas and the development of quantitative model methods should be beneficial to reveal the mutual feedback mechanism between them and become the scientific basis for maintaining and improving the system elasticity and sustainability.

Author Contributions: E.D. conceived the study and provided thoughtful guidance. F.L. constructed the framework of the paper and wrote the manuscript. J.Y. assisted with literature search and information refinement. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Natural Science Foundation Project of Tibet Autonomous Region (Grant NO. XZ202001ZR0042G, XZ2019ZRG-156) and the National Key R&D Program of China (Grant No. 2020YFA0608200).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data created.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Biggs, R.; De Vos, A.; Preiser, R.; Clements, H.; Maciejewski, K.; Schlüter, M. *The Routledge Handbook of Research Methods for Social-Ecological Systems*; Taylor & Francis: Abingdon, UK, 2021.
2. Steffen, W.; Richardson, K.; Rockström, J.; Cornell, S.E.; Fetzer, I.; Bennett, E.M.; Biggs, R.; Carpenter, S.R.; De Vries, W.; De Wit, C.A.; et al. Planetary Boundaries: Guiding Human Development on a Changing Planet. *Science* **2015**, *347*, 1259855. [CrossRef]
3. McGinnis, M.D.; Ostrom, E. Social-ecological system framework: Initial changes and continuing challenges. *Ecol. Soc.* **2014**, *19*, 30. [CrossRef]
4. Folke, C.; Biggs, R.; Norström, A.V.; Reyers, B.; Rockström, J. Social-ecological resilience and biosphere-based sustainability science. *Ecol. Soc.* **2016**, *21*, 41. [CrossRef]

5. Tian, H.; Lu, C.; Pan, S.; Yang, J.; Miao, R.; Ren, W.; Yu, Q.; Fu, B.; Jin, F.-F.; Lu, Y.; et al. Optimizing resource use efficiencies in the food–energy–water nexus for sustainable agriculture: From conceptual model to decision support system. *Curr. Opin. Environ. Sustain.* **2018**, *33*, 104–113. [CrossRef]
6. Liu, J.; Dietz, T.; Carpenter, S.R.; Alberti, M.; Folke, C.; Moran, E.; Pell, A.N.; Deadman, P.; Kratz, T.; Lubchenco, J.; et al. Complexity of Coupled Human and Natural Systems. *Science* **2007**, *347*, 1258832. [CrossRef]
7. Ministry of Environmental Protection, PRC. *Interim Regulations for Ecological Function Zoning*; PRC: Manila, Philippines, 2003.
8. Wang, S.; Fu, B.J.; Wu, X.T.; Wang, Y. Dynamics and sustainability of social-ecological systems in the Loess Plateau. *Resour. Sci.* **2020**, *42*, 96–103. [CrossRef]
9. Wu, X.; Wei, Y.; Fu, B.; Wang, S.; Zhao, Y.; Moran, E.F. Evolution and effects of the social-ecological system over a millennium in China's Loess Plateau. *Sci. Adv.* **2020**, *6*, eabc0276. [CrossRef]
10. Bammer, G.; O'rourke, M.; O'connell, D.; Neuhauser, L.; Midgley, G.; Klein, J.T.; Grigg, N.J.; Gadlin, H.; Elsum, I.R.; Bursztyn, M.; et al. Expertise in research integration and implementation for tackling complex problems: When is it needed, where can it be found and how can it be strengthened? *Palgrave Commun.* **2020**, *6*, 5. [CrossRef]
11. Folke, C. Resilience: The emergence of a perspective for social–ecological systems analyses. *Glob. Environ. Chang.* **2006**, *16*, 253–267. [CrossRef]
12. Arrow, K.; Bolin, B.; Costanza, R.; Dasgupta, P.; Folke, C.; Holling, C.S.; Jansson, B.-O.; Levin, S.; Maler, K.-G.; Perrings, C.; et al. Economic growth, carrying capacity and the environment. *Science* **1995**, *268*, 520–521. [CrossRef]
13. De Vos, A.; Biggs, R.; Preiser, R. Methods for understanding social-ecological systems: A review of place-based studies. *Ecol. Soc.* **2019**, *24*, 16. [CrossRef]
14. Gain, A.K.; Giupponi, C.; Renaud, F.G.; Vafeidis, A.T. Sustainability of complex social-ecological systems: Methods, tools, and approaches. *Reg. Environ. Chang.* **2020**, *20*, 102. [CrossRef]
15. Holling, C.S. Understanding the Complexity of Economic, Ecological, and Social Systems. *Ecosystems* **2001**, *4*, 390–405. [CrossRef]
16. Steffen, W.; Persson, Å.; Deutsch, L.; Zalasiewicz, J.; Williams, M.; Richardson, K.; Crumley, C.; Crutzen, P.; Folke, C.; Gordon, L.; et al. The Anthropocene: From Global Change to Planetary Stewardship. *Ambio* **2011**, *40*, 739–761. [CrossRef]
17. Berkes, F.; Folke, C. (Eds.) *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*; Cambridge University Press: New York, NY, USA, 1998.
18. Wang, S.; Fu, B.; Zhao, W.; Liu, Y.; Wei, F. Structure, function, and dynamic mechanisms of coupled human–natural systems. *Curr. Opin. Environ. Sustain.* **2018**, *33*, 87–91. [CrossRef]
19. Fischer, J.; Gardner, T.A.; Bennett, E.M.; Balvanera, P.; Biggs, R.; Carpenter, S.; Daw, T.; Folke, C.; Hill, R.; Hughes, T.P.; et al. Advancing sustainability through mainstreaming a social–ecological systems perspective. *Curr. Opin. Environ. Sustain.* **2015**, *14*, 144–149. [CrossRef]
20. Colding, J.; Barthel, S. Exploring the social-ecological systems discourse 20 years later. *Ecol. Soc.* **2019**, *24*, 2. [CrossRef]
21. Ostrom, E. A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science* **2009**, *325*, 419–422. [CrossRef] [PubMed]
22. Clark, W.C.; Harley, A.G. Sustainability Science: Toward a Synthesis. *Annu. Rev. Environ. Resour.* **2020**, *45*, 331–386. [CrossRef]
23. Tengö, M.; Brondizio, E.S.; Elmqvist, T.; Malmer, P.; Spierenburg, M. Connecting Diverse Knowledge Systems for Enhanced Ecosystem Governance: The Multiple Evidence Base Approach. *AMBIO* **2014**, *43*, 579–591. [CrossRef]
24. Torralba, M.; Fagerholm, N.; Hartel, T.; Moreno, G.; Plieninger, T. A social-ecological analysis of ecosystem services supply and trade-offs in European wood-pastures. *Sci. Adv.* **2018**, *4*, eaar2176. [CrossRef] [PubMed]
25. Preiser, R.; Biggs, R.; De Vos, A.; Folke, C. Social-ecological systems as complex adaptive systems: Organizing principles for advancing research methods and approaches. *Ecol. Soc.* **2018**, *23*, 46. [CrossRef]
26. Rogers, K.H.; Luton, R.; Biggs, H.; Biggs, R.; Blignaut, S.; Choles, A.G.; Palmer, C.G.; Tangwe, P. Fostering Complexity Thinking in Action Research for Change in Social–Ecological Systems. *Ecol. Soc.* **2013**, *18*, 31. [CrossRef]
27. Reyers, B.; Folke, C.; Moore, M.-L.; Biggs, R.; Galaz, V. Social-Ecological Systems Insights for Navigating the Dynamics of the Anthropocene. *Annu. Rev. Environ. Resour.* **2018**, *43*, 267–289. [CrossRef]
28. Carpenter, S.R.; Mooney, H.A.; Agard, J.; Capistrano, D.; DeFries, R.S.; Diaz, S.; Dietz, T.; Duraiappah, A.K.; Oteng-Yeboah, A.; Pereira, H.M.; et al. Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 1305–1312. [CrossRef] [PubMed]
29. Schlüter, M.; Haider, L.J.; Lade, S.; Lindkvist, E.; Martin, R.; Orach, K.; Wijermans, N.; Folke, C. Capturing emergent phenomena in social-ecological systems: An analytical framework. *Ecol. Soc.* **2019**, *24*, 11. [CrossRef]
30. Westley, F.; Olsson, P.; Folke, C.; Homer-Dixon, T.; Vredenburg, H.; Loorbach, D.; Thompson, J.; Nilsson, M.; Lambin, E.; Sendzimir, J.; et al. Tipping Toward Sustainability: Emerging Pathways of Transformation. *AMBIO* **2011**, *40*, 762–780. [CrossRef]
31. Scheffer, M.; Carpenter, S.R.; Lenton, T.M.; Bascompte, J.; Brock, W.; Dakos, V.; van de Koppel, J.; van de Leemput, I.A.; Levin, S.A.; van Nes, E.H.; et al. Anticipating Critical Transitions. *Science* **2012**, *338*, 344–348. [CrossRef]
32. Hughes, T.P.; Carpenter, S.; Rockström, J.; Scheffer, M.; Walker, B. Multiscale regime shifts and planetary boundaries. *Trends Ecol. Evol.* **2013**, *28*, 389–395. [CrossRef]
33. Lansing, J.S. Complex Adaptive Systems. *Annu. Rev. Anthropol.* **2003**, *32*, 183–204. [CrossRef]
34. Gunderson, L.H.; Holling, C.S. *Panarchy: Understanding Transformations in Human and Natural Systems*; Island Press: Washington, DC, USA, 2002.

35. Biggs, R.; Schlüter, M.; Biggs, D.; Bohensky, E.; BurnSilver, S.; Cundill, G.; Dakos, V.; Daw, T.; Evans, L.; Kotschy, K.; et al. Toward principles for enhancing the resilience of ecosystem services. *Annu. Rev. Environ. Resour.* **2012**, *37*, 421–448. [CrossRef]
36. Biggs, R.; Rhode, C.; Archibald, S.; Kunene, L.M.; Mutanga, S.S.; Nkuna, N.; Ocholla, P.O.; Phadima, L.J. Strategies for managing complex social-ecological systems in the face of uncertainty: Examples from South Africa and beyond. *Ecol. Soc.* **2015**, *20*, 52. [CrossRef]
37. An, L. Modeling human decisions in coupled human and natural systems: Review of agent-based models. *Ecol. Model.* **2012**, *229*, 25–36. [CrossRef]
38. Liu, J.; Mooney, H.; Hull, V.; Davis, S.J.; Gaskell, J.; Hertel, T.; Lubchenco, J.; Seto, K.C.; Gleick, P.; Kremen, C.; et al. Systems integration for global sustainability. *Science* **2015**, *347*, 1258832. [CrossRef]
39. Hertz, T.; Garcia, M.M.; Schlüter, M. From nouns to verbs: How process ontologies enhance our understanding of social-ecological systems understood as complex adaptive systems. *People Nat.* **2020**, *2*, 328–338. [CrossRef]
40. Lambin, E.F.; Turner, B.L.; Geist, H.J.; Agbola, S.B.; Angelsen, A.; Bruce, J.W.; Coomes, O.T.; Dirzo, R.; Fischer, G.; Folke, C.; et al. The causes of land-use and land-cover change: Moving beyond the myths. *Glob. Environ. Chang.* **2001**, *11*, 261–269. [CrossRef]
41. Liu, J.; Yang, W.; Li, S. Framing ecosystem services in the telecoupled Anthropocene. *Front. Ecol. Environ.* **2016**, *14*, 27–36. [CrossRef]
42. Mauser, W.; Klepper, G.; Rice, M.; Schmalzbauer, B.S.; Hackmann, H.; Leemans, R.; Moore, H. Transdisciplinary Global Change Research: The Co-creation of Knowledge for Sustainability. *Curr. Opin. Environ. Sustain.* **2013**, *5*, 420–431. [CrossRef]
43. Reyers, B.; Selig, E.R. Global targets that reveal the social–ecological interdependencies of sustainable development. *Nat. Ecol. Evol.* **2020**, *4*, 1011–1019. [CrossRef]
44. Mancilla García, M.; Hertz, T.; Schlüter, M.; Preiser, R.; Woermann, M. Adopting Process-relational Perspectives to Tackle the Challenges of Social-Ecological Systems Research. *Ecol. Soc.* **2020**, *25*, 29. [CrossRef]
45. Bourgeron, P.; Kliskey, A.; Alessa, L.; Loescher, H.; Krauze, K.; Virapongse, A.; Griffith, D.L. Understanding large- scale, complex, human–environmental processes: A framework for social–ecological observatories. *Front. Ecol. Environ.* **2018**, *16* (Suppl. S1), S52–S66. [CrossRef]
46. Van Riper, C.J.; Thiel, A.; Penker, M.; Braito, M.; Landon, A.C.; Thomsen, J.M.; Tucker, C.M. Incorporating multilevel values into the social-ecological systems framework. *Ecol. Soc.* **2018**, *23*, 25. [CrossRef]
47. Binder, C.R.; Hinkel, J.; Bots, P.W.G.; Pahl-Wostl, C. Comparison of Frameworks for Analyzing Social-ecological Systems. *Ecol. Soc.* **2013**, *18*, 26. [CrossRef]
48. McGinnis, M.D. An Introduction to IAD and the Language of the Ostrom Workshop: A Simple Guide to a Complex Framework. *Policy Stud. J.* **2011**, *39*, 169–183. [CrossRef]
49. Holdschlag, A.; Ratter, B.M.W. Multiscale system dynamics of humans and nature in The Bahamas: Perturbation, knowledge, panarchy and resilience. *Sustain. Sci.* **2013**, *8*, 407–421. [CrossRef]
50. Folke, C.; Carpenter, S.R.; Walker, B.H. Resilience thinking: Integrating resilience, adaptability and transformability. *Ecol. Soc.* **2010**, *15*, 20. [CrossRef]
51. Cosens, B.A.; Gunderson, L.; Chaffin, B.C. Introduction to the Special Feature Practicing Panarchy: Assessing legal flexibility, ecological resilience, and adaptive governance in regional water systems experiencing rapid environmental change. *Ecol. Soc.* **2018**, *23*, 4. [CrossRef]
52. Gunderson, L. Ecological and Human Community Resilience in Response to Natural Disasters. *Ecol. Soc.* **2010**, *15*, 18. [CrossRef]
53. Zhang, L.; Huang, Q.; He, C.; Yue, H.; Zhao, Q. Assessing the dynamics of sustainability for social-ecological systems based on the adaptive cycle framework: A case study in the Beijing-Tianjin-Hebei urban agglomeration. *Sustain. Cities Soc.* **2021**, *70*, 102899. [CrossRef]
54. Fu, B.; Wu, X.; Wang, Z.; Wu, X.; Wang, S. Coupling Human and Natural Systems for Sustainability: Experiences from China's Loess Plateau. *Earth Syst. Dyn.* **2022**, *13*, 795–808. [CrossRef]
55. Fu, B.; Wei, Y. Editorial overview: Keeping fit in the dynamics of coupled natural and human systems. *Curr. Opin. Environ. Sustain.* **2018**, *33*, A1–A4. [CrossRef]
56. MEA. *Ecosystem and Human Well-Being*; Island Press: Washington, DC, USA, 2005; Volume 5.
57. Li, S.C. On How to Measure the Contribution of Nature to Human Beings Scientifically—A Social-ecosystem Analysis Framework based on Ecosystem Services and Its Application. *Frontiers* **2020**, *11*, 28–35.
58. Pan, H.; Page, J.; Cong, C.; Barthel, S.; Kalantari, Z. How ecosystems services drive urban growth: Integrating nature-based solutions. *Anthropocene* **2021**, *35*, 100297. [CrossRef]
59. Díaz, S.; Pascual, U.; Stenseke, M.; Martín-López, B.; Watson, R.T.; Molnár, Z.; Hill, R.; Chan, K.M.; Baste, I.A.; Brauman, K.A.; et al. Assessing Nature's Contributions to People. *Science* **2018**, *359*, 270–272. [CrossRef] [PubMed]
60. Gain, A.K.; Ashik-Ur-Rahman, M.; Vafeidis, A. Exploring human-nature interaction on the coastal floodplain in the Ganges-Brahmaputra delta through the lens of Ostrom's social-ecological systems framework. *Environ. Res. Commun.* **2019**, *1*, 051003. [CrossRef]
61. Carpenter, S.R.; Folke, C.; Norström, A.; Olsson, O.; Schultz, L.; Agarwal, B.; Balvanera, P.; Campbell, B.; Castilla, J.C.; Cramer, W.; et al. Program on Ecosystem Change and Society: An International Research Strategy for In-tegrated Social-Ecological Systems. *Curr. Opin. Environ. Sustain.* **2012**, *4*, 134–138. [CrossRef]

62. Leslie, H.M.; Basurto, X.; Nenadovic, M.; Sievanen, L.; Cavanaugh, K.C.; Cota-Nieto, J.J.; Erisman, B.E.; Finkbeiner, E.; Hinojosa-Arango, G.; Moreno-Báez, M.; et al. Operationalizing the social-ecological systems framework to assess sustainability. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 5979–5984. [CrossRef]
63. Feng, J.; Zhao, Z.; Wen, Y.; Hou, Y. Organically Linking Green Development and Ecological Environment Protection in Poyang Lake, China Using a Social-Ecological System (SES) Framework. *Int. J. Environ. Res. Public Health* **2021**, *18*, 2572. [CrossRef]
64. Schmitt-Harsh, M.L.; Mincey, S.K. Operationalizing the social-ecological system framework to assess residential forest structure: A case study in Bloomington, Indiana. *Ecol. Soc.* **2020**, *25*, 14. [CrossRef]
65. Chong, H.; Panzhu, L. Application and Prospect of Social-ecological System Framework in Worldwide Forest Governance Researches. *World For. Res.* **2021**, *35*, 1–7. [CrossRef]
66. Basurto, X.; Gelcich, S.; Ostrom, E. The social–ecological system framework as a knowledge classificatory system for benthic small-scale fisheries. *Glob. Environ. Chang.* **2013**, *23*, 1366–1380. [CrossRef]
67. Boonstra, W.J.; de Boer, F.W. The Historical Dynamics of Social–Ecological Traps. *Ambio* **2014**, *43*, 260–274. [CrossRef]
68. Enfors, E. Social–ecological traps and transformations in dryland agro-ecosystems: Using water system innovations to change the trajectory of development. *Glob. Environ. Chang.* **2012**, *23*, 51–60. [CrossRef]
69. Bahl, J.; Pham, T.T.; Hill, N.J.; Hussein, I.T.M.; Ma, E.J.; Easterday, B.C.; Halpin, R.A.; Stockwell, T.B.; Wentworth, D.E.; Kayali, G.; et al. Ecosystem Interactions Underlie the Spread of Avian Influenza A Viruses with Pandemic Potential. *PLoS Pathog.* **2016**, *12*, e1005620. [CrossRef] [PubMed]
70. Zhang, X.; Brandt, M.; Tong, X.; Ciais, P.; Yue, Y.; Xiao, X.; Zhang, W.; Wang, K.; Fensholt, R. A large but transient carbon sink from urbanization and rural depopulation in China. *Nat. Sustain.* **2022**, *5*, 321–328. [CrossRef]
71. Yang, D. *Restructuring of Rural Space in Loess Hilly-Gully Region of Northern Shaanxi Based on the Perspective of Social -Ecological System*; Xi'an University of Architecture and Technology: Xi'an, China, 2021.
72. Lhoest, S.; Vermeulen, C.; Fayolle, A.; Jamar, P.; Hette, S.; Nkodo, A.; Maréchal, K.; Dufrêne, M.; Meyfroidt, P. Quantifying the Use of Forest Ecosystem Services by Local Populations in Southeastern Cameroon. *Sustainability* **2020**, *12*, 2505. [CrossRef]
73. Angelstam, P.; Andersson, K.; Annerstedt, M.; Axelsson, R.; Elbakidze, M.; Garrido, P.; Grahn, P.; Jönsson, K.I.; Pedersen, S.; Schlyter, P.; et al. Solving Problems in Social-Ecological Systems: Definition, Practice and Barriers of Transdisciplinary Research. *Ambio* **2013**, *42*, 254–265. [CrossRef]
74. Roux, D.J.; Nel, J.L.; Cundill, G.; O'farrell, P.; Fabricius, C. Transdisciplinary research for systemic change: Who to learn with, what to learn about and how to learn. *Sustain. Sci.* **2017**, *12*, 711–726. [CrossRef]
75. Hand, B.K.; Flint, C.G.; Frissell, C.; Muhlfeld, C.C.; Devlin, S.P.; Kennedy, B.P.; Crabtree, R.L.; McKee, W.A.; Luikart, G.; Stanford, J. A social–ecological perspective for riverscape management in the Columbia River Basin. *Front. Ecol. Environ.* **2018**, *16*, 23–33. [CrossRef]
76. Hossain, S.; Ramirez, J.; Szabo, S.; Eigenbrod, F.; Johnson, F.A.; Speranza, C.I.; Dearing, J. Participatory modelling for conceptualizing social-ecological system dynamics in the Bangladesh delta. *Reg. Environ. Chang.* **2020**, *20*, 28. [CrossRef]
77. Bodin, Ö.; Nohrstedt, D.; Baird, J.; Summers, R.; Plummer, R. Working at the "speed of trust": Pre-existing and emerging social ties in wild-fire responder networks in Sweden and Canada. *Reg. Environ. Chang.* **2019**, *19*, 2353–2364. [CrossRef]
78. Yoon, J.; Klassert, C.; Selby, P.; Lachaut, T.; Knox, S.; Avisse, N.; Harou, J.; Tilmant, A.; Klauer, B.; Mustafa, D.; et al. A coupled human–natural system analysis of freshwater security under climate and population change. *Proc. Natl. Acad. Sci. USA* **2021**, *118*, e2020431118. [CrossRef]
79. Tatiana Filatova, J.; Polhill, G.; van Ewijk, S. Regime shifts in coupled socio-environmental systems: Review of modelling challenges and approaches. *Environ. Model. Softw.* **2016**, *75*, 333–347. [CrossRef]
80. Sun, Y.; Liu, S.; Shi, F.; An, Y.; Li, M.; Liu, Y. Spatio-temporal variations and coupling of human activity intensity andecosystem services based on the four-quadrant model on theQinghai-Tibet Plateau. *Sci. Total Environ.* **2020**, *743*, 140721.
81. Haider, L.J.; Hentati-Sundberg, J.; Giusti, M.; Goodness, J.; Hamann, M.; Masterson, V.; Meacham, M.; Merrie, A.; Ospina, D.; Schill, C.; et al. The undisciplinary journey: Early-career perspectives in sustainability science. *Sustain. Sci.* **2017**, *13*, 191–204. [CrossRef]
82. Uehara, T.; Hidaka, T.; Tsuge, T.; Sakurai, R.; Cordier, M. An adaptive social-ecological system management matrix for guiding ecosystem service improvements. *Ecosyst. Serv.* **2021**, *50*, 101312. [CrossRef]
83. Lázár, A.N.; Nicholls, R.J.; Hall, J.W.; Barbour, E.J.; Haque, A. Contrasting development trajectories for coastal Bangladesh to the end of century. *Reg. Environ. Chang.* **2020**, *20*, 93. [CrossRef]
84. Levin, S.; Xepapadeas, T.; Crépin, A.S.; Norberg, J.; De Zeeuw, A.; Folke, C.; Hughes, T.; Arrow, K.; Barrett, S.; Daily, G.; et al. Social-ecological systems as complex adaptive systems: Modeling and policy implications. *Environ. Dev. Econ.* **2013**, *18*, 111–132. [CrossRef]
85. Deslatte, A.; Szmigiel-Rawska, K.; Tavares, A.F.; Ślawska, J.; Karsznia, I.; Łukomska, J. Land use institutions and social-ecological systems: A spatial analysis of local landscape changes in Poland. *Land Use Policy* **2022**, *114*, 105937. [CrossRef]
86. Partelow, S. A review of the social-ecological systems framework: Applications, methods, modifications, and challenges. *Ecol. Soc.* **2018**, *23*, 36. [CrossRef]
87. Cumming, G.S.; Epstein, G.; Anderies, J.M.; Apetrei, C.I.; Baggio, J.; Bodin, Ö.; Chawla, S.; Clements, H.S.; Cox, M.; Egli, L.; et al. Advancing Understanding of Natural Resource Governance Using the Social Ecological Systems Framework: A Post-Ostrom Research Agenda. *Curr. Opin. Environ. Sustain.* **2020**, *44*, 26–34. [CrossRef]

88. Díaz, S.; Demissew, S.; Carabias, J.; Joly, C.; Lonsdale, M.; Ash, N.; Larigauderie, A.; Adhikari, J.R.; Arico, S.; Báldi, A.; et al. The IPBES Conceptual Framework—Connecting nature and people. *Curr. Opin. Environ. Sustain.* **2014**, *14*, 1–16. [CrossRef]
89. Crona, B.; Van Holt, T.; Petersson, M.; Daw, T.; Buchary, E. Using social–ecological syndromes to understand impacts of international seafood trade on small-scale fisheries. *Glob. Environ. Chang.* **2015**, *35*, 162–175. [CrossRef]