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Landscape Structure and Socio-Ecological Resilience: A Conceptual Framework from Satoyama Landscapes

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Abstract

This study develops a landscape-ecological framework for understanding socio-ecological resilience in Satoyama and analogous socio-ecological production landscapes (SEPL). Although resilience research has extensively examined governance, adaptation, and resource management, the ecological dimension of social-ecological systems (SES) is often represented broadly as a resource system or environmental context, leaving limited attention to how spatial organisation shapes system functioning. This study employed a structured narrative review and conceptual synthesis of literature on Satoyama and related socio-ecological production landscapes, together with foundational scholarship on landscape ecology, SES, and socio-ecological resilience. Literature published up to December 2024, with no predefined lower date limit, was identified through an iterative search and citation-tracing process. Of 45 documents reviewed in full, 21 publications were selected for conceptual synthesis. The analysis examined five interconnected themes: Satoyama as a dynamic social-ecological landscape; landscape-ecological systems; social mechanisms shaping landscape transformation; external drivers; and socio-ecological resilience. The synthesis shows that a Satoyama landscape is conceptualised as a spatially structured SES in which biophysical conditions, ecosystem units, and the landscape mosaic are continuously co-produced through land-use practices, ecological knowledge, institutions, and collective action. Landscape is not merely a passive setting for social and cultural processes. Rather, it constitutes the spatial organisation of the ecological dimension of the SES and shapes habitat availability, hydrological relationships, material flows, and ecosystem functions across scales. Social mechanisms influence these processes through land use, management, and coordination, while ecological conditions and ecosystem services feed back into livelihoods, values, and future decisions. External social, technological, economic, environmental, and political drivers reshape both dimensions. The proposed framework conceptualises resilience as an emergent, multi-scale property of these reciprocal interactions and emphasises adaptive stewardship over preservation of a fixed historical landscape. It provides an analytical basis for empirical research, landscape planning, and management that jointly consider ecological connectivity, landscape heterogeneity, ecosystem functions, and institutional capacity.

Keywords: Social-ecological Systems, Landscape Ecology, Satoyama, Socio-ecological Resilience, Traditional Ecological Knowledge

1. Introduction

Rapid environmental change driven by land-use intensification, urbanisation, globalisation, climate change, and changing patterns of production and consumption has accelerated biodiversity loss and altered ecosystem functioning worldwide (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2019; Millennium Ecosystem Assessment, 2005). These changes affect not only individual ecosystems or species, but also the spatial relationships among forests, agricultural land, waterways, wetlands, settlements, and semi-natural habitats. As landscape mosaics become simplified, fragmented, or disconnected, their capacity to sustain biodiversity, regulate water and nutrient flows, provide ecosystem services, and support human well-being may decline.

Addressing such challenges requires approaches that move beyond the conservation or management of isolated ecosystem units. Ecological functions often depend on relationships among landscape elements, while these relationships are simultaneously shaped by land use, resource management, local institutions, and broader political-economic conditions. Understanding resilience therefore requires attention to both ecological processes and the social arrangements through which landscapes are maintained, transformed, or reorganised over time.

This perspective has gained increasing relevance in international biodiversity policy. At the tenth meeting of the Conference of the Parties to the Convention on Biological Diversity in Nagoya in 2010, the Satoyama Initiative was recognised as an approach for supporting biodiversity and human well-being in human-influenced landscapes (Convention on Biological Diversity, 2010). The International Partnership for the Satoyama Initiative was subsequently established to promote the sustainable use and revitalisation of socio-ecological production landscapes and seascapes (SEPLS) through collaboration among governments, communities, researchers, civil society organisations, and private-sector actors (IPSI Secretariat, 2014).

The Satoyama concept provides an important foundation for this approach. Originally associated with village-adjacent forests and mountains in Japan, Satoyama has developed into a broader concept describing heterogeneous rural landscapes composed of secondary forests, rice paddies, agricultural fields, grasslands, settlements, ponds, streams, irrigation systems, and other natural and human-modified elements (Takeuchi, 2003; Takeuchi et al., 2016). These elements are connected through ecological processes and social practices. Forests, agricultural land, and water systems provide habitat, biomass, food, water regulation, soil protection, and cultural values, while land-use practices, local knowledge, institutions, and collective management influence how these functions are maintained or transformed.

A Satoyama landscape can therefore be understood as a social-ecological system (SES). SES theory highlights reciprocal relationships among ecological conditions, resource systems, actors, institutions, knowledge systems, and governance arrangements (Berkes et al., 2003; Folke, 2006; McGinnis & Ostrom, 2014; Ostrom, 2009). In Satoyama landscapes, people are not external to ecological processes. Land use, forest management, cultivation, irrigation maintenance, biomass use, and collective rule-making are integral processes through which landscape conditions and ecological functions are continuously produced.

However, the ecological dimension of SES is often represented broadly as a resource system, ecosystem, or environmental setting. Although existing SES frameworks recognise ecological systems, they seldom specify how ecological processes are spatially organised across heterogeneous landscapes. This limits conceptual clarity regarding how spatial landscape structure influences habitat availability, ecological connectivity, hydrological relationships, material flows, and ecosystem functioning across scales. Landscape ecology offers a complementary perspective by examining how ecological processes are shaped by the composition, configuration, connectivity, and change of landscape elements (Forman, 1995; Forman & Godron, 1986; Turner, 2005; Wu, 2013).

This study addresses this conceptual gap by proposing a landscape-ecological interpretation of the ecological dimension of SES. At the same time, landscape ecology has not always examined the social mechanisms through which landscape structures are produced and maintained. In Satoyama and similar socio-ecological production landscapes, ecological functions depend on the interaction of biophysical conditions, landscape mosaics, management practices, ecological knowledge, institutions, and collective action. Landscape structure should therefore not be understood solely as a spatial pattern or as an intermediate variable between governance and ecological outcomes. It constitutes the spatial organisation of the ecological dimension of the SES.

This study develops a landscape-ecological SES framework grounded in the Satoyama landscape concept and informed by landscape ecology, cultural ecology, SES theory, and resilience thinking. The study has three objectives:

1) To examine a Satoyama landscape as a spatially structured social-ecological system;
2) To synthesise how landscape-ecological and social-institutional processes interact in shaping landscape change; and
3) To develop a conceptual framework explaining how these interactions contribute to socio-ecological resilience.

By making the ecological dimension of SES more spatially explicit, the study contributes to landscape-based SES analysis and provides an analytical basis for future empirical research, landscape planning, and adaptive stewardship.

2. Methodology

2.1 Review Design and Conceptual Scope

This study employed a structured narrative review and conceptual synthesis to examine a Satoyama landscape as a spatially structured social-ecological system. The purpose was not to conduct a comprehensive systematic review or meta-analysis, but to identify and integrate concepts that explain relationships among landscape structure, ecological processes, social mechanisms, and socio-ecological resilience.

The review combined two bodies of literature. The first included studies on Satoyama landscape and related socio-ecological production landscapes. The second included foundational scholarship on landscape ecology, SES, cultural ecology, and resilience. These bodies of literature were synthesised to develop a framework that makes the ecological dimension of SES more spatially explicit.

For this study, the ecological dimension of SES was conceptualised as a landscape-ecological system comprising biophysical conditions, ecosystem units, and the landscape mosaic. Landscape structure refers to the composition, configuration, and connectivity of elements within the mosaic, while ecological processes interact with and reshape these spatial patterns. The social system included social contexts, knowledge systems, land-use practices, institutions, collective action, and governance mechanisms that influence land use and resource management.

2.2 Literature Identification and Selection

Literature was identified through an iterative citation-based search process rather than a comprehensive database search. The review began with *Satoyama landscape as social-ecological system: Historical changes and future perspective* by Takeuchi et al. (2016), which served as the seed publication because it explicitly connects Satoyama landscapes with social-ecological systems.

Related studies were identified using Connected Papers, followed by backward and forward citation tracing. Additional reports and institutional publications were retrieved, where relevant, from sources including the Institute for Global Environmental Strategies (IGES) and the International Partnership for the Satoyama Initiative (IPSI). Bibliographic databases, including Scopus, ProQuest, and J-STAGE, were used when necessary to locate accessible full-text versions of relevant publications and to verify bibliographic information.

The initial Connected Papers search identified 41 related records. A further 12 potentially relevant documents were identified through backward and forward citation tracing and through references to institutional publications. Of the 53 documents sought for retrieval, eight could not be accessed in full text, leaving 45 documents for full-text assessment.

Publications were included when they addressed at least one of the following areas:

1) landscape-ecological conditions, structures, or processes in Satoyama or comparable socio-ecological production landscapes;
2) social mechanisms influencing land use, resource management, or landscape transformation; or
3) interactions between ecological and social processes relevant to resilience, adaptation, or long-term stewardship.

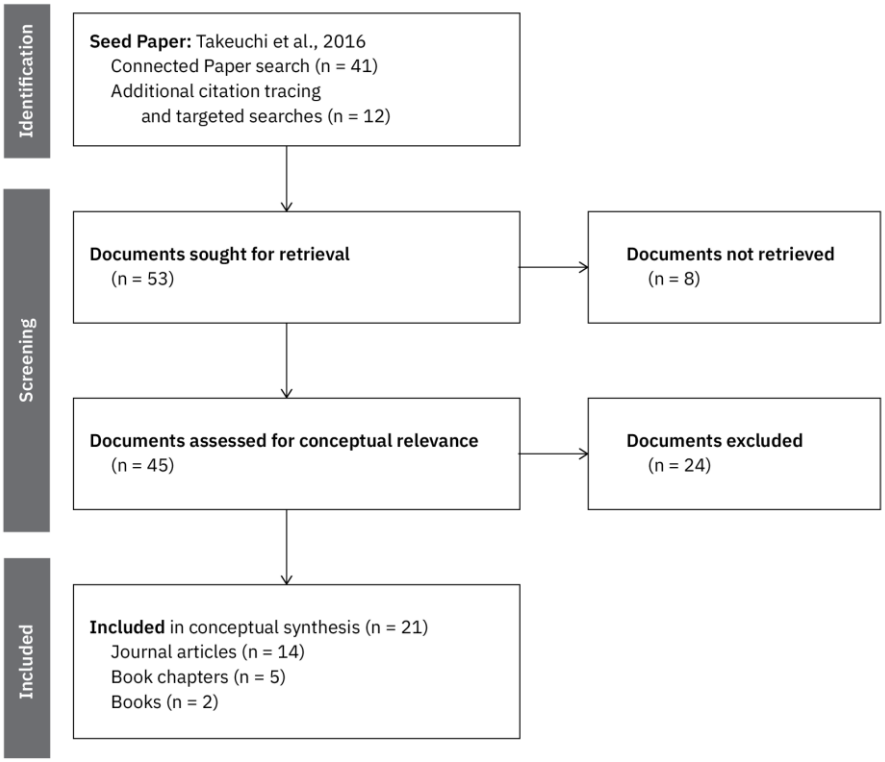

Figure 1 Literature identification and selection process for the structured narrative review.

Only English-language publications with accessible full texts were considered. Among the 45 documents assessed in full, publications were excluded if they consisted primarily of brief descriptive or promotional material, lacked substantive conceptual or empirical content, or had insufficient relevance to the proposed framework. Selection was based on direct conceptual relevance and contribution to one or more analytical themes.

Following full-text assessment, 21 publications were selected for conceptual synthesis. These consisted of 14 peer-reviewed journal articles, five chapters in scholarly edited volumes, and two academic books. These 21 publications comprised the Satoyama- and SEPL-related literature subjected to conceptual synthesis. Foundational works on landscape ecology, SES, cultural ecology, and resilience were used to inform the theoretical interpretation but were not included in this count.

2.3 Data Extraction and Thematic Synthesis

Key information from each selected publication was recorded in an evidence matrix, including study objectives, methods, findings, spatial and social dimensions examined, and relevance to the proposed framework.

The synthesis was organised around five analytical themes:

1) Satoyama as a dynamic landscape-based SES;
2) Landscape-ecological systems as the ecological dimension of SES;
3) Social contexts and mechanisms shaping landscape stewardship;

4) External drivers reshaping local SES conditions; and
5) Socio-ecological resilience as an emergent outcome of interactions among landscape-ecological conditions, social mechanisms, and external drivers.

The framework was then developed by integrating the relationships identified across these themes. Resilience was treated as an emergent property of interactions among landscape-ecological conditions, social mechanisms, and external drivers rather than as a separate component of the system.

3. Result

3.1 Satoyama as a Dynamic Landscape-Based Social-Ecological System

The reviewed literature consistently characterises Satoyama as more than a specific land-cover type, village forest, or preserved cultural landscape. Although the concept originally referred to areas between settlements and mountain forests in Japan, it has evolved into a broader understanding of heterogeneous rural landscapes where forests, agricultural land, grasslands, water systems, settlements, and semi-natural habitats are linked through ecological processes and human practices (Takeuchi, 2003; Takeuchi et al., 2003, 2016).

This interpretation positions Satoyama as a landscape-based SES. Forests, paddy fields, cropland, ponds, streams, irrigation systems, grasslands, and settlements do not function independently. Their ecological roles are shaped by their spatial relationships and by the ways people use, manage, and connect them. Forests may support biomass production, habitat provision, water regulation, and soil protection. Agricultural land and paddy fields may contribute to food production, seasonal habitat, nutrient cycling, and water retention. Waterways and ponds may connect terrestrial and aquatic ecosystems while supporting irrigation, biodiversity, and local livelihoods.

Satoyama landscapes are therefore formed through the long-term interaction between ecological opportunities and constraints and the social arrangements through which people respond to them. Topography, soil, hydrology, vegetation, and climate influence the potential for settlement, cultivation, forest use, and water management. These conditions are interpreted and modified through land-use practices, ecological knowledge, institutions, and collective action.

Importantly, Satoyama should not be treated as a fixed historical landscape. Its composition, land-use patterns, and management arrangements have changed over time in response to demographic shifts, livelihood strategies, technological change, market conditions, and environmental pressures. Its continuity depends not on restoring an idealised historical form, but on sustaining or rebuilding functional relationships between people and landscapes under contemporary conditions (Morimoto, 2011; Yokohari & Bolthouse, 2011).

Accordingly, this study conceptualises Satoyama as a dynamic landscape-based SES in which landscape-ecological and social-institutional processes are continuously co-produced.

3.2 Landscape-Ecological Systems as the Ecological Dimension of SES

Landscape ecology provides the primary basis for making the ecological dimension of Satoyama more spatially explicit. It emphasises that ecological processes are influenced by the composition, configuration, connectivity, and change of landscape elements across multiple scales (Forman, 1995; Forman & Godron, 1986; Turner, 2005; Wu, 2013).

In this study, the ecological dimension of SES is conceptualised as a landscape-ecological system consisting of three connected components: biophysical conditions, ecosystem units, and the landscape mosaic.

Biophysical conditions include topography, soils, hydrology, climate, vegetation, and species distributions. These conditions form the material basis of landscape development and influence where particular ecosystem units can occur. For example, slope, soil characteristics, water availability, and floodplain conditions may affect the suitability of land for cultivation, settlement, wetlands, forests, or other land uses.

Ecosystem units include forests, agricultural fields, paddy systems, grasslands, wetlands, ponds, streams, riparian areas, and settlement-related ecosystems. Each unit may provide particular ecological functions, but their contributions depend on their condition and relationships with other elements. Forests, fields, waterways, and wetlands may together support habitat continuity, hydrological regulation, nutrient cycling, and seasonal resource availability.

The landscape mosaic refers to the interconnected spatial and ecological organisation of ecosystem units across the landscape. Its landscape structure can be characterised through composition, configuration, connectivity, fragmentation, and boundary relationships, while ecological processes continuously interact with and reshape these spatial patterns. Composition concerns the diversity and relative proportion of landscape elements, while configuration concerns their arrangement, adjacency, connectivity, fragmentation, and boundary relationships. These spatial patterns influence ecological processes such as species movement, habitat maintenance, hydrological regulation, material transport, nutrient cycling, disturbance, succession, and primary production.

Ecological processes and land-use practices continuously reshape the landscape mosaic. Recurring low-intensity practices such as coppicing, grassland cutting, paddy cultivation, irrigation maintenance, mowing, and vegetation management may sustain open or semi-natural habitats that would otherwise change through succession. Historical evidence from Japanese Satoyama landscapes shows that the abandonment of such practices can accelerate succession, reduce open-habitat diversity, simplify landscape mosaics, and weaken associated ecological functions. Fragmentation and intensive land use may further disrupt ecological relationships among landscape elements (Iwachido et al., 2020; Jiao et al., 2019; Kamada & Nakagoshi, 1997; Saito & Shibata, 2012; Washitani, 2001).

Ecological processes and functions, including nutrient cycling, hydrological regulation, soil formation and conservation, and habitat maintenance, emerge from interactions among biophysical conditions, ecosystem units, and the landscape mosaic. These processes and functions support ecosystem services, including food and biomass production, water regulation, biodiversity-related benefits, and cultural services.

Landscape heterogeneity and connectivity may strengthen the capacity of Satoyama landscapes to respond to disturbance by providing alternative habitats, ecological pathways, and functional redundancy. However, heterogeneity alone does not guarantee positive ecological outcomes. Its significance depends on the ecological condition, spatial configuration, management, and functional role of individual landscape elements within the mosaic.

3.3 Social Contexts and Mechanisms Shaping Landscape Change

The reviewed literature indicates that landscape change in Satoyama is shaped by both social contexts and social mechanisms. Social contexts influence the capacity of people and institutions to maintain landscape stewardship, while social mechanisms translate knowledge, values, and collective arrangements into direct effects on ecological conditions and landscape structure.

Social contexts, including population structure, ageing, migration, labour availability, livelihood conditions, landholding arrangements, local economies, and cultural values, shape the capacity of communities to sustain landscape stewardship. These conditions influence who can participate in management, whether ecological knowledge is transmitted across generations, and whether collective responsibilities can be maintained. Population ageing, rural outmigration, declining agricultural labour, changing household structures, declining resource value, and fragmented ownership may reduce the continuity of management for paddy fields, forests, irrigation systems, grasslands, ponds, and other semi-natural landscape elements. Underuse should therefore be understood not simply as the absence of management, but as a social-ecological process through which declining stewardship capacity contributes to changes in landscape structure, biodiversity, and ecosystem services (Miyanaga & Shimada, 2018).

These conditions should not be treated simply as external drivers. They are changes within the focal social system, although they may be influenced by wider economic, technological, and political forces. Their importance lies in their direct effect on stewardship capacity. A community may retain ecological knowledge or customary institutions, but lack the labour, economic incentive, or organisational capacity required to sustain management practices.

Within these social contexts, knowledge systems and land-use practices shape how people interact with ecological conditions. Traditional Ecological Knowledge (TEK) may include understanding of seasonal cycles, soil conditions, water availability, vegetation succession, species behaviour, agricultural timing, and resource regeneration. Such knowledge is often embedded in everyday practices, livelihood systems, cultural values, and intergenerational learning rather than existing solely as formalised information (Berkes, 2018; Takeuchi, 2010).

In Satoyama contexts, ecological knowledge has historically informed practices such as coppicing, fuelwood collection, grassland cutting, compost production, paddy cultivation, irrigation management, pond maintenance, rotational resource use, and harvesting of forest products. These practices influence the timing, intensity, and spatial distribution of land use. When aligned with ecological conditions, they may

help maintain secondary forests, agricultural mosaics, open habitats, and water-related ecological functions (Kamada, 2017; Takeuchi et al., 2016).

Landscape stewardship also depends on coordinating mechanisms that extend beyond individual land parcels or households. Forests, irrigation channels, ponds, riparian areas, and common-use resources often require shared rules, collective labour, conflict-resolution mechanisms, and agreed responsibilities. Local institutions may include customary rules, land and water agreements, resource-sharing practices, collective work arrangements, and organisations responsible for common infrastructure or ecological resources.

Contemporary stewardship, however, cannot rely exclusively on traditional village institutions. Changes in energy systems, livelihoods, land ownership, labour availability, and market conditions have reduced the capacity of many communities to maintain historical forms of management. New forms of collective action may involve local governments, civil society organisations, researchers, private-sector actors, volunteers, and regional networks. These actors can contribute financial support, technical knowledge, monitoring, volunteer labour, market opportunities, and platforms for collective learning (Fukamachi, 2020; Hasegawa et al., 2024; Horiuchi et al., 2011). Sustaining stewardship under contemporary conditions may also require management approaches that are socially meaningful and economically viable, together with citizen participation and community-based networks that can complement declining traditional management systems (Fukamachi & Morimoto, 2011).

The case of Iba in Shiga Prefecture illustrates this adaptive form of stewardship. Activities involving residents, farmers, volunteers, specialists, local authorities, and private-sector actors have supported waterway maintenance, aquatic habitat improvement, water-quality monitoring, fish conservation, and environmentally sensitive agricultural practices. Such arrangements help sustain ecological relationships among paddy fields, waterways, lagoons, and aquatic habitats while creating opportunities for knowledge exchange and participation (Fukamachi, 2020, 2022).

Overall, social contexts shape the capacity for stewardship, while social mechanisms determine how ecological knowledge, practices, institutions, and networks influence landscape structure and ecological processes.

3.4 External Drivers Reshaping Local SES Conditions

External drivers are forces originating beyond the boundaries of the focal SES that reshape the conditions under which ecological and social processes interact. Whether a force is classified as external depends on how the analytical boundary of the focal system is defined. These drivers may operate through social, technological, economic, environmental, and political. Examples include urban expansion, infrastructure development, market transformation, climate change, national energy transitions, policy reform, land-use regulation, and tenure arrangements established beyond the authority of local communities (Duraiappah et al., 2012; Takeuchi et al., 2016).

External drivers may affect the landscape-ecological system directly. Infrastructure development can fragment habitats or alter hydrological flows. Climate change can affect water availability, vegetation

dynamics, agricultural productivity, and disturbance regimes. Market demand may encourage agricultural intensification, land conversion, or abandonment of low-profit land uses. Changes in national energy systems may reduce demand for fuelwood or grass, weakening incentives for maintaining secondary forests and grasslands.

Long-term studies of Satoyama landscapes in Kyoto indicate that changes in economic conditions, accessibility, forest use, and agricultural practices can reduce land-use diversity and alter vegetation patterns, while topography continues to influence where particular forms of land use persist or decline (Fukamachi et al., 2001, 2009).

These drivers may also influence landscape conditions indirectly by reshaping the social contexts in which land-use decisions are made. Urban employment opportunities, market restructuring, technological change, and infrastructure expansion may encourage rural outmigration. This may alter population structure, reduce labour availability, weaken collective institutions, and reduce the continuity of land management.

Legal, policy, and tenure conditions are particularly important because they can enable, constrain, or redirect local stewardship. Regulations related to land ownership, zoning, protected areas, water management, agriculture, and resource access shape what communities are able to manage, restore, or transform. These formal conditions differ from local institutions, although both influence land-use decisions. Community rules are negotiated within local systems, whereas laws and regulations may originate at broader administrative or political levels.

External drivers should not be understood solely as sources of degradation. Conservation programmes, regional markets for local products, environmental funding, technical innovation, and partnerships with civil society organisations or research institutions may create opportunities for renewed stewardship. Such conditions can support restoration, alternative livelihoods, ecological monitoring, and new institutional arrangements when historical management systems are no longer viable (Fukamachi, 2020, 2022; Hasegawa et al., 2024).

The effects of external drivers are therefore mediated through local ecological conditions, social contexts, management mechanisms, and institutional arrangements. Similar external pressures may produce different outcomes across places depending on the capacity of local systems to respond, adapt, or reorganise.

3.5 Proposed Landscape-Ecological SES Framework for Satoyama Resilience

The conceptual synthesis indicates that socio-ecological resilience in Satoyama landscapes is an emergent property of reciprocal interactions between landscape-ecological and social-institutional processes (Berkes et al., 2003; Folke, 2006; Holling, 1973). Resilience does not arise from ecological quality, landscape diversity, local knowledge, or institutional capacity in isolation. It depends on whether the relationships among these components continue to sustain essential ecological functions, ecosystem services, and human–nature relationships under changing conditions.

Building on established SES frameworks that distinguish ecological and social-institutional components, the proposed framework identifies two interconnected dimensions of the Satoyama SES: a landscape-ecological dimension and a social-institutional dimension (McGinnis & Ostrom, 2014; Ostrom, 2009). The landscape-ecological dimension is conceptualised as a landscape-ecological system comprising biophysical conditions, ecosystem units, and the landscape mosaic. Within this system, landscape structure refers to the composition, configuration, connectivity, fragmentation, and boundary relationships of ecosystem units, while ecological processes interact with and continuously reshape these spatial patterns. Together, these components provide the spatial and material basis for habitat maintenance, hydrological regulation, biodiversity-related functions, material flows, and ecosystem services.

The social-institutional dimension includes social contexts, individual knowledge and practices, community institutions and collective action, and broader institutional networks. These mechanisms influence the landscape-ecological system through land use, management, restoration, resource allocation, and coordination across land parcels and social groups.

The two dimensions are connected through reciprocal feedbacks. Social actions shape landscape composition, configuration, connectivity, and ecological processes. Ecological conditions and ecosystem services, in turn, influence livelihoods, values, management priorities, and future decisions. Ecosystem services therefore function as an important feedback pathway linking ecological processes with social well-being and institutional capacity.

External drivers affect both dimensions by changing the opportunities and constraints under which social and ecological processes interact. Their influence may lead to degradation when ecological relationships are disrupted or management capacity declines. However, they may also create opportunities for adaptation through new knowledge, partnerships, incentives, technologies, or institutional arrangements.

From this perspective, resilience does not mean preserving a fixed historical Satoyama landscape. It concerns the capacity of the SES to retain or rebuild essential ecological functions, ecosystem services, and stewardship relationships while responding to change (Folke, 2006; Holling, 1973). For analytical purposes, the proposed framework distinguishes three related resilience pathways:

1) Maintenance, where existing landscape structures and stewardship arrangements remain functional;
1) Adaptation, where practices, institutions, or livelihood strategies are adjusted in response to changing conditions; and
2) Reorganisation, where new landscape configurations, governance arrangements, or livelihood relationships emerge because previous arrangements are no longer viable.

Figure 2 presents the analytical decomposition of a Satoyama landscape as an SES. Table 1 summarises the key concepts underpinning each component of the framework.

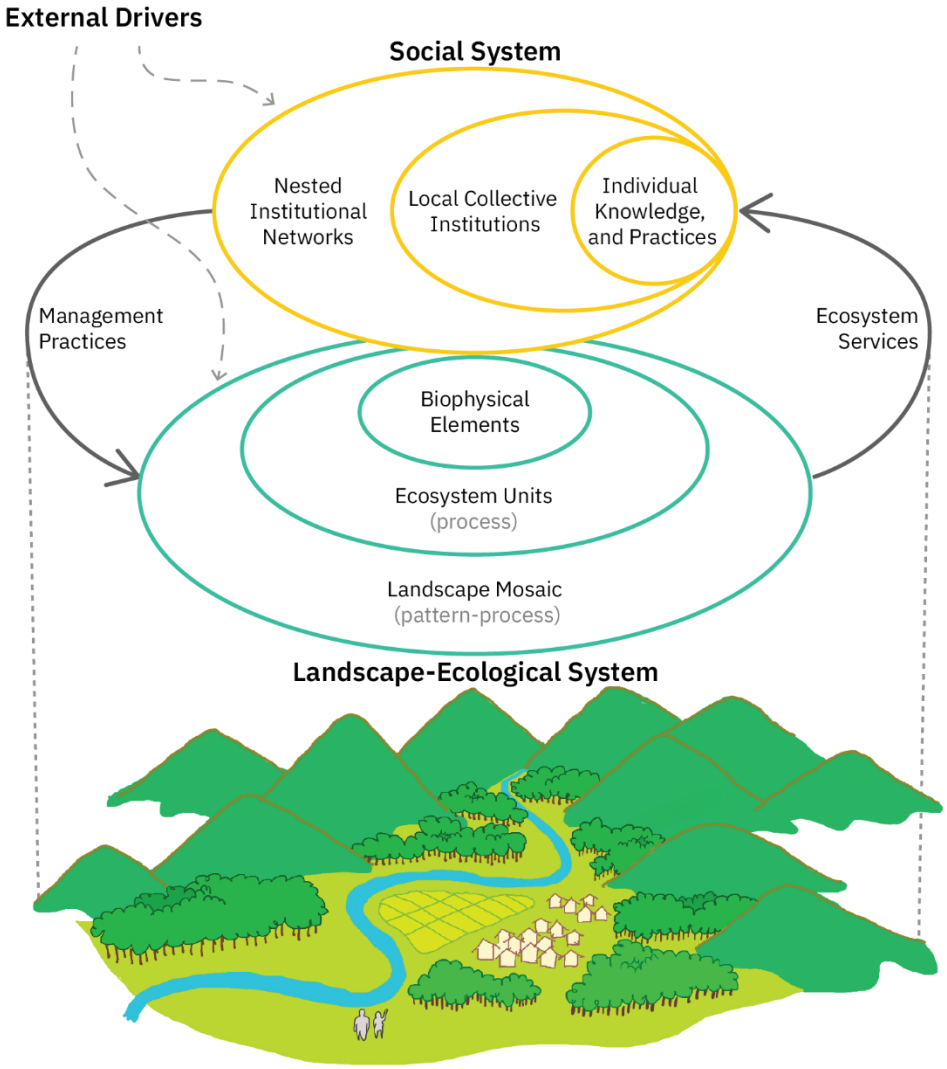

Figure 2 Analytical Decomposition Framework of Satoyama Landscape as a Social-Ecological System (SES).

The framework distinguishes two interconnected dimensions of the Satoyama SES: a landscape-ecological dimension and a social-institutional dimension. The landscape-ecological dimension is conceptualised as a landscape-ecological system comprising biophysical conditions, ecosystem units, and the landscape mosaic. The social-institutional dimension is conceptualised as a social system comprising individual knowledge and practices, community institutions and collective action, broader institutional networks, and the social contexts that shape stewardship capacity. Ecosystem services provide feedback from the landscape-ecological system to livelihoods, values, and management decisions, while management practices link social actions to changes in landscape structure and ecological processes. External drivers reshape the conditions under which the two dimensions interact. Socio-ecological resilience emerges through the maintenance, adaptation, and reorganisation of these relationships.

Table 1 Conceptual synthesis underpinning the proposed landscape-ecological SES framework

Analytical component	Core concepts synthesised from the literature	Expression in Satoyama landscapes	Role in the proposed framework	Key references
Satoyama as a dynamic landscape-based SES	Satoyama is an evolving landscape in which ecological processes, livelihoods, resource use, cultural values, and institutions are interdependent.	Forests, agricultural land, rice paddies, grasslands, waterways, ponds, and settlements are linked through ecological processes and human practices.	Establishes Satoyama as the central unit of analysis: a spatially structured SES in which ecological and social components co-evolve.	Takeuchi, 2003; Takeuchi et al., 2003; Takeuchi, 2010; Takeuchi et al., 2016; Morimoto, 2011; Yokohari & Bolthouse, 2011
Landscape-ecological system	Biophysical conditions and ecosystem units are organised as a landscape mosaic whose structure—expressed through composition, configuration, and connectivity—interacts with ecological processes across scales.	Ecological conditions depend on the arrangement and relationships among forests, paddy fields, cropland, grasslands, wetlands, water systems, and settlements.	Defines the ecological dimension of SES as a spatially structured landscape-ecological system.	Forman & Godron, 1986; Forman, 1995; Turner, 2005; Wu, 2013; Washitani, 2001; Jiao et al., 2019
Social contexts and mechanisms	Social conditions shape stewardship capacity, while knowledge, practices, institutions, collective action, and networks influence landscape management.	Coppicing, paddy cultivation, irrigation maintenance, pond management, collective labour, land and water rules, and multi-stakeholder partnerships.	Explains how social systems directly and indirectly shape landscape structure and ecological processes.	Berkes, 2018; Kamada, 2017; Takeuchi et al., 2016; Horiuchi et al., 2011; Miyanaga & Shimada, 2018; Fukamachi, 2020, 2022; Hasegawa et al., 2024
External drivers	Social, technological, economic, environmental, political, legal, and tenure-related forces reshape local ecological and social conditions.	Agricultural restructuring, changes in biomass demand, infrastructure expansion, climate pressures, policy changes, conservation programmes, and market transformation.	Explains why similar local practices may produce different outcomes across places and periods.	Duraiappah et al., 2012; Takeuchi et al., 2016; Fukamachi, 2020, 2022; Fukamachi et al., 2001, 2009
Socio-ecological resilience	Resilience emerges from interactions among ecological conditions, landscape structure, social mechanisms, and external drivers.	Resilient landscapes retain or rebuild ecological functions, connectivity, stewardship capacity, and adaptive relationships under change.	Positions resilience as an outcome expressed through maintenance, adaptation, and reorganisation.	Holling, 1973; Berkes et al., 2003; Folke, 2006; Ostrom, 2009; McGinnis & Ostrom, 2014

4. Discussion

4.1 Making the Ecological Dimension of SES Spatially Explicit

The primary contribution of this study is to conceptualise the ecological dimension of SES as a landscape-ecological system rather than as a general environmental context or resource base. This distinction is important because ecological conditions are spatially organised. Forests, wetlands, agricultural land, waterways, grasslands, and settlements influence one another through their composition, configuration, connectivity, and ecological interactions.

Landscape structure should therefore not be treated as a passive setting for social action. It represents the spatial organisation through which ecological processes occur and ecosystem functions emerge. Land-use decisions, management practices, and institutions shape this organisation, while ecological conditions and ecosystem services influence livelihoods, values, and future management decisions.

This perspective also clarifies the role of landscape structure within SES analysis. Landscape structure is neither external to the SES nor a separate mediator between governance and ecological outcomes; it forms part of the ecological dimension of the SES itself. Social mechanisms influence landscape structure through land use and management, while changes in landscape structure influence ecological functions and the conditions under which communities make decisions.

The framework consequently shifts attention from individual ecosystem units toward functional relationships across the landscape mosaic. A forest patch, wetland, paddy field, or irrigation channel may have ecological value on its own, but its role in resilience depends on its relationships with surrounding elements. The resilience of the landscape-ecological system may be strengthened when these relationships support habitat continuity, hydrological regulation, material flows, and functional redundancy across scales.

4.2 Implications for Adaptive Landscape Stewardship

The framework highlights that adaptive stewardship depends on more than local ecological knowledge or the persistence of customary institutions. Knowledge systems, practices, institutions, and collective action must remain capable of responding to changing livelihoods, demographic conditions, markets, policies, and environmental pressures.

TEK remains valuable because it provides context-specific understanding of seasonal cycles, resource dynamics, land-use practices, and ecological relationships. However, it should not be viewed as fixed or sufficient in isolation. Contemporary stewardship may require integration of local knowledge with ecological monitoring, scientific research, technical support, new livelihood strategies, and cross-scale institutional collaboration.

The framework also suggests that the central planning question is not whether a landscape should remain unchanged. Rather, it is whether essential ecological functions and stewardship relationships can be maintained or rebuilt under new conditions. In some cases, existing management systems may remain effective. In others, adaptation may require changes in practices, institutional arrangements, or resource-use strategies. Where historical systems are no longer viable, more fundamental reorganisation may be necessary.

For empirical research, the framework supports integrated analysis of landscape-ecological and social-institutional dimensions. Ecological assessment may examine topography, soils, hydrology, ecosystem units, landscape composition, connectivity, ecological processes, and ecosystem services. Social assessment may examine ecological knowledge, land-use practices, livelihoods, local institutions, collective action, and cross-scale governance. These dimensions should be analysed together to identify alignments and mismatches between ecological processes and human activities.

For planning, this integrated perspective helps identify ecological functions requiring protection or restoration, social mechanisms affecting stewardship, and external conditions that enable or constrain adaptation. It supports context-specific responses rather than fixed prescriptions and may be applied to other rural socio-ecological production landscapes when adapted to local ecological, cultural, and institutional conditions.

Table 2 Suggested analytical questions for applying the landscape-ecological SES framework

Framework component	Key analytical questions	Examples of evidence or indicators	Relevance for planning and adaptive stewardship
Biophysical conditions	What are the main topographic, soil, hydrological, climatic, and vegetation conditions of the landscape? What opportunities and constraints do these conditions create for settlement, land use, and resource management?	Elevation and slope; soil properties; floodplain extent; water-flow patterns; seasonal water availability; vegetation cover; climatic conditions	Identifies ecological opportunities, constraints, and areas where present land use may be incompatible with underlying landscape conditions.
Ecosystem units	What ecosystem units are present, and what ecological roles do they perform? How are forests, agricultural land, wetlands, waterways, grasslands, and settlements functionally connected?	Distribution and condition of forests, paddy fields, cropland, wetlands, streams, ponds, riparian areas, and settlement-related ecosystems	Helps identify ecosystem units that require protection, restoration, or coordinated management to maintain ecological functions.
Landscape mosaic	How are landscape elements composed and configured? Are key habitats, water systems, and semi-natural areas connected, fragmented, or simplified?	Land-use and land-cover maps; patch size; land-cover diversity; edge density; connectivity; fragmentation; adjacency among landscape elements	Supports assessment of habitat continuity, hydrological connectivity, functional diversity, and areas where land-use change may weaken landscape resilience.
Ecological processes and ecosystem services	Which ecological processes sustain the landscape, and what ecosystem services do they provide? Who depends on these functions, and at what scale?	Habitat quality; species occurrence; water retention; flood regulation; soil protection; nutrient cycling; food, water, biomass, and cultural services	Reveals the ecological functions that should be maintained or rebuilt and clarifies how ecosystem services support livelihoods, communities, and wider institutions.

Table 2 Suggested analytical questions for applying the landscape-ecological SES framework (Cont.)

Framework component	Key analytical questions	Examples of evidence or indicators	Relevance for planning and adaptive stewardship
Individual knowledge, values, and practices	How do local people understand ecological conditions? Which land-use practices, livelihood activities, and everyday decisions directly affect the landscape?	Local ecological knowledge; seasonal calendars; resource-use practices; farming systems; forest use; water management; livelihood dependence	Identifies locally grounded knowledge and practices that can support adaptive management, as well as practices that may create ecological mismatches.
Community institutions and collective action	What shared rules, collective arrangements, local organisations, and management responsibilities exist? Do they enable coordination across land parcels and common resources?	Community rules; land and water agreements; collective labour; local organisations; conflict-resolution mechanisms; participation patterns	Clarifies whether local institutions can sustain coordinated management of shared ecological processes, including water systems, forests, and habitat corridors.
Broader institutional networks and cross-scale governance	How do laws, tenure systems, zoning, sectoral policies, and external organisations enable or constrain local management? What forms of support or conflict occur across scales?	Land tenure; zoning regulations; protected-area rules; agricultural policy; water regulations; government programmes; NGO or research partnerships	Identifies institutional barriers and enabling conditions for adaptive stewardship, including policy changes, legal reform, technical support, and resource mobilisation.
Social contexts and stewardship capacity	What demographic, livelihood, landholding, and cultural conditions shape the capacity to maintain landscape stewardship?	Population structure; ageing; migration; labour availability; livelihood conditions; landholding arrangements; local economies; cultural values	Identifies internal social conditions that enable or constrain continued management and distinguishes them from external drivers.
External drivers	Which economic, technological, political, and environmental changes are reshaping the system? How do they affect ecological processes, livelihoods, and management capacity?	Market conditions; infrastructure expansion; technological change; climate risks; policy shifts	Helps distinguish local management issues from broader structural pressures and supports the design of responses appropriate to changing conditions.
Resilience pathways	Are essential ecological functions and stewardship capacities being maintained, adapted, or reorganised? Which relationships are weakening, and which new arrangements may be required?	Continuity of management; recovery of ecological functions; changes in land-use practices; institutional adaptation; new livelihood strategies; emerging partnerships	Supports identification of whether planning should prioritise maintenance, adaptation, or more fundamental reorganisation of land use, institutions, and ecological management.

4.3 Contribution of the proposed framework to existing SES approaches

The proposed framework builds on established SES approaches rather than replacing them. Existing SES approaches, particularly those articulated by Berkes et al. (2003), Ostrom (2009), and McGinnis and Ostrom (2014), provide strong foundations for analysing relationships among ecosystems, actors, institutions, management practices, and social-ecological outcomes. They are especially useful for examining governance arrangements, collective action, and feedbacks within SES.

The main contribution of the proposed framework is to make the ecological dimension of SES more spatially explicit. In many existing SES frameworks, ecological systems are represented as resource systems, ecosystems, or environmental conditions. Although these categories may include spatial characteristics, they do not explicitly distinguish how ecological functions are organised through the composition, configuration, connectivity, and change of heterogeneous landscape elements.

The proposed framework therefore conceptualises the ecological dimension as a landscape-ecological system comprising biophysical conditions, ecosystem units, and the landscape mosaic. This enables analysis not only of the ecological elements present within a landscape, but also of how their spatial relationships influence ecological functioning and resilience.

The framework also clarifies how social and institutional mechanisms are expressed through landscape change. Ecological knowledge, management practices, collective action, and institutions influence whether particular landscape elements are maintained, restored, converted, connected, or neglected. These changes reshape landscape structure and ecological processes, with consequences for ecosystem functions and resilience.

By defining the landscape mosaic as the spatial organisation of the ecological dimension, the framework adds an explicit basis for analysing how social mechanisms alter landscape configuration, ecological processes, ecosystem services, and resilience. Its contribution is therefore complementary: it retains the institutional and actor-centred strengths of existing SES approaches while extending their treatment of spatial ecological relationships.

Table 3 Comparison of existing SES approaches with the proposed landscape-ecological SES framework.

Analytical emphasis	Ostrom's SES framework and related SES approaches	Proposed landscape-ecological SES framework
Ecological dimension	Resource systems, resource units, and related ecosystems. Ecological conditions are generally represented as system attributes, resource characteristics, or contextual conditions.	Biophysical conditions, ecosystem units, landscape mosaic, and ecological processes. Ecological conditions are examined as spatially organised and dynamically connected across the landscape.
Social dimension	Actors, governance systems, institutions, rules, and action situations shape resource use, decision-making, and collective outcomes.	Individuals, communities, and broader institutions interact through ecological knowledge, management practices, collective action, and governance arrangements that shape landscape conditions over time.
Social–ecological interaction	Focuses on interactions among resource systems, resource units, actors, and governance systems through focal action situations and feedbacks.	Links institutions, knowledge, and management practices to changes in landscape mosaic and ecological processes, which shape ecosystem functions and the provisioning, regulating, and cultural services derived from interconnected landscape elements.
Main contribution	Provides a diagnostic framework for analysing institutional arrangements, actor interactions, and social–ecological outcomes.	Extends the ecological dimension of SES by conceptualising landscape mosaic as its spatial organisation, linking social mechanisms more explicitly to landscape change, ecological functioning, and resilience.

4.4 Limitations and Directions for Future Research

This review has several limitations. First, the literature-identification process relied primarily on citation tracing from a foundational seed publication and its related citation network. Although this approach was appropriate for identifying conceptually connected scholarship, relevant studies located outside this network may not have been captured. The English-language and full-text accessibility criteria may also have excluded relevant publications, particularly studies published in Japanese or other languages.

Second, the literature covers diverse concepts, scales, methods, and indicators, limiting direct comparison across cases and preventing the identification of uniform causal relationships. The proposed framework should therefore be understood as an analytical structure rather than a predictive model.

Third, the framework is grounded primarily in Satoyama scholarship. Although it may be relevant to other socio-ecological production landscapes, its applicability should be tested across different ecological, institutional, and cultural contexts.

Fourth, future research should examine landscape-ecological and social-institutional processes longitudinally to clarify feedbacks, thresholds, and temporal dynamics in landscape change. Combining historical analysis, remote sensing, ecological monitoring, field observation, and institutional analysis would enable a more systematic examination of how ecological conditions, landscape configuration, social mechanisms, and governance arrangements interact over time. Future studies should operationalise each

component using GIS-derived landscape metrics, ecological indicators, institutional assessments, and resilience outcomes to empirically evaluate the framework.

Finally, further work is needed to develop measurable indicators for landscape structure, ecological processes, management practices, institutional capacity, and adaptive stewardship. Such indicators could support comparative research and improve the practical application of the framework in planning and management.

5. Conclusion

This study conceptualises Satoyama as a spatially structured social-ecological system in which ecological and social processes are continuously co-produced. Its main contribution is to make the ecological dimension of SES more spatially explicit by defining it as a landscape-ecological system composed of biophysical conditions, ecosystem units, and the landscape mosaic.

The framework shows that resilience does not result from ecological quality, landscape diversity, local knowledge, or institutional capacity in isolation. It emerges from the capacity of relationships among these components to sustain essential ecological functions, ecosystem services, and stewardship arrangements under changing conditions.

Rather than viewing landscape as the backdrop of social–ecological systems, this study positions landscape as the spatial ecological architecture within which socio-ecological resilience is produced and expressed. The framework emphasises maintenance, adaptation, and reorganisation. It provides a basis for future research and planning that jointly considers ecological connectivity, landscape structure, ecosystem functioning, social capacity, and external drivers in the pursuit of long-term sustainability.

6. References

Berkes, F. (2018). *Sacred ecology* (4th ed.). Routledge.

Berkes, F., Colding, J., & Folke, C. (Eds.). (2003). *Navigating social-ecological systems: Building resilience for complexity and change*. Cambridge University Press. https://doi.org/10.1017/CBO9780511541957

Convention on Biological Diversity. (2010). *Decision X/32: Sustainable use of biodiversity*. https://www.cbd.int/doc/decisions/cop-10/cop-10-dec-32-en.pdf

Duraiappah, A. K., Nakamura, K., Takeuchi, K., Watanabe, M., & Nishi, M. (Eds.). (2012). *Satoyama–satoumi ecosystems and human well-being: Socio-ecological production landscapes of Japan.* United Nations University Press.

Folke, C. (2006). Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change*, 16(3), 253–267. https://doi.org/10.1016/j.gloenvcha.2006.04.002

Forman, R. T. T. (1995). *Land mosaics: The ecology of landscapes and regions*. Cambridge University Press.

Forman, R. T. T., & Godron, M. (1986). *Landscape ecology*. John Wiley & Sons.

Fukamachi, K. (2020). Building resilient socio-ecological systems in Japan: Satoyama examples from Shiga Prefecture. *Ecosystem Services*, 46, 101187. https://doi.org/10.1016/j.ecoser.2020.101187

Fukamachi, K. (2022). Satoyama landscapes: Creating resilient socio-ecological production landscapes in Japan. In A. Rastandeh & M. Jarchow (Eds.), *Creating resilient landscapes in an era of climate change: Global case studies and real-world solutions* (pp. 166–178). Taylor & Francis. https://doi.org/10.4324/9781003266440-11

Fukamachi, K., & Morimoto, Y. (2011). Satoyama management in the twenty-first century: The challenge of sustainable use and continued biocultural diversity in rural cultural landscapes. *Landscape and Ecological Engineering*, 7(2), 161–162. https://doi.org/10.1007/s11355-011-0163-2

Fukamachi, K., Oku, H., & Miyoshi, I. (2009). Changes of land use and vegetation in Satoyama landscape of Tango Peninsula, Kyoto, Japan: Where are they bound for? In E. Saratsi (Ed.), *Woodland cultures in time and space: Tales from the past, messages for the future* (pp. 276–283). Embryo Publication.

Fukamachi, K., Oku, H., & Nakashizuka, T. (2001). The change of a satoyama landscape and its causality in Kamiseya, Kyoto Prefecture, Japan between 1970 and 1995. *Landscape Ecology*, 16(8), 703–717. https://doi.org/10.1023/A:1014464909698

Hasegawa, H., Asanami, F., Sudo, T., Ito, K., & Kamada, M. (2024). Emergence process of governance for restoring an unmanaged ecosystem: comparison of two activities at the Satoyama forest and coastal pine forests in Fukutsu City, Japan. *Landscape and Ecological Engineering*, 20(3), 299–310. https://doi.org/10.1007/s11355-023-00593-3

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, *4*, 1–23. https://doi.org/10.1146/annurev.es.04.110173.000245

Horiuchi, M., Fukamachi, K., & Oku, H. (2011). Reed community restoration projects with citizen participation: An example of the practical use of Satoyama landscape resources in Shiga Prefecture, Japan. *Landscape and Ecological Engineering*, 7(2), 217–222. https://doi.org/10.1007/s11355-010-0129-9

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. (2019). *Global assessment report on biodiversity and ecosystem services*. https://doi.org/10.5281/zenodo.3831673

IPSI Secretariat. (2014). *The International Partnership for the Satoyama Initiative (IPSI): Working towards societies in harmony with nature*. https://satoyamainitiative.org/wp-content/uploads/2014/10/IPSI-booklet-formation-to-current.pdf

Iwachido, Y., Uchida, K., Ushimaru, A., Yokota, S., & Sasaki, T. (2020). Nature-oriented park use of satoyama ecosystems can enhance biodiversity conservation in urbanized landscapes. *Landscape and Ecological Engineering*, 16(2), 163–172. https://doi.org/10.1007/s11355-020-00413-y

Jiao, Y., Ding, Y., Zha, Z., & Okuro, T. (2019). Crises of biodiversity and ecosystem services in Satoyama landscape of Japan: A review on the role of management. *Sustainability*, 11(2), 454. https://doi.org/10.3390/su11020454

Kamada, M. (2017). Satoyama landscape of Japan—past, present, and future. In S. K. Hong & N. Nakagoshi (Eds.), *Landscape ecology for sustainable society* (pp. 87–109). Springer. https://doi.org/10.1007/978-3-319-74328-8_6

Kamada, M., & Nakagoshi, N. (1997). Influence of cultural factors on landscapes of mountainous farm villages in western Japan. *Landscape and Urban Planning*, 37, 85–90. https://doi.org/10.1016/S0169-2046(96)00372-6

McGinnis, M. D., & Ostrom, E. (2014). Social-ecological system framework: Initial changes and continuing challenges. *Ecology and Society*, 19(2), 30. https://doi.org/10.5751/ES-06387-190230

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: Synthesis*. Island Press.

Miyanaga, K., & Shimada, D. (2018). 'The tragedy of the commons' by underuse: Toward a conceptual framework based on ecosystem services and satoyama perspective. *International Journal of the Commons*, 12(1), 332–351. https://doi.org/10.18352/ijc.817

Morimoto, Y. (2011). What is Satoyama? Points for discussion on its future direction. *Landscape and Ecological Engineering*, 7(2), 163–171. https://doi.org/10.1007/s11355-010-0120-5

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science*, 325(5939), 419–422. https://doi.org/10.1126/science.1172133

Saito, O., & Shibata, H. (2012). Satoyama and Satoumi, and ecosystem services: A conceptual framework. In A. K. Duraiappah, K. Nakamura, K. Takeuchi, M. Watanabe, & M. Nishi (Eds.), *Satoyama–satoumi ecosystems and human well-being: Socio-ecological production landscapes of Japan* (pp. 17–59). United Nations University Press. https://doi.org/10.18356/5d7e4936-en

Takeuchi, K. (2003). Satoyama landscapes as managed nature. In K. Takeuchi, R. D. Brown, I. Washitani, A. Tsunekawa, & M. Yokohari (Eds.), *SATOYAMA: The traditional rural landscape of Japan*. Springer.

Takeuchi, K. (2010). Rebuilding the relationship between people and nature: The Satoyama Initiative. *Ecological Research*, 25(5), 891–897. https://doi.org/10.1007/s11284-010-0745-8

Takeuchi, K., Brown, R. D., Washitani, I., Tsunekawa, A., & Yokohari, M. (Eds.). (2003). *SATOYAMA: The traditional rural landscape of Japan*. Springer.

Takeuchi, K., Ichikawa, K., & Elmqvist, T. (2016). Satoyama landscape as social-ecological system: Historical changes and future perspective. *Current Opinion in Environmental Sustainability*, 19, 30–39. https://doi.org/10.1016/j.cosust.2015.11.001

Turner, M. G. (2005). Landscape ecology: What is the state of the science? *Annual Review of Ecology, Evolution, and Systematics*, 36, 319–344. https://doi.org/10.1146/annurev.ecolsys.36.102003.152614

Washitani, I. (2001). Traditional sustainable ecosystem SATOYAMA and biodiversity crisis in Japan: Conservation ecological perspective. *Global Environmental Research*, 5(2), 119–133. https://doi.org/10.57466/ger.5.2_119

Wu, J. (2013). Landscape sustainability science: Ecosystem services and human well-being in changing landscapes. *Landscape Ecology*, 28, 999–1023. https://doi.org/10.1007/s10980-013-9894-9

Yokohari, M., & Bolthouse, J. (2011). Keep it alive, don't freeze it: A conceptual perspective on the conservation of continuously evolving satoyama landscapes. *Landscape and Ecological Engineering*, 7(2), 207–216. https://doi.org/10.1007/s11355-010-0116-1