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Review

A Review of Changes in Mountain Land Use and Ecosystem Services: From Theory to Practice

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Abstract: Global changes impact the human-environment relationship, and, in particular, they affect the provision of ecosystem services. Mountain ecosystems provide a wide range of such services, but they are highly sensitive and vulnerable to change due to various human pressures and natural processes. We conducted a literature survey that focused on two main issues. The first was the identification of quantitative methods aimed at assessing the impact of land use changes in mountain regions and the related ecosystem services. The second was the analysis of the extent to which the outcomes of these assessments are useful and transferable to stakeholders. We selected papers through a keyword-driven search of the ISI Web of Knowledge and other international databases. The keywords used for the search were mountain land use change and ecosystem service. Quantitative approaches to ecosystem service assessment rely on suitable indicators, therefore land use/land cover can be used as an appropriate proxy. Landscape metrics are a powerful analytical tool; their use can increase the accuracy of assessments and facilitate the mitigation of specific phenomena, such as fragmentation or the reduction of core habitat areas. Mapping is essential: it is the basis for spatial analyzes and eases the interactions between stakeholders. Land use/land cover change is a temporal process, so both past and future approaches are meaningful. It is necessary to enhance information transfer from theory to practice. Increasing stakeholder awareness can lead to suitable management solutions, and, reciprocally, stakeholder feedback can help improve current assessment methodologies and contribute to developing new tools that are suitable for specific problems.

Keywords: mountain ecosystem services; land use change; scenarios; stakeholders

1. Introduction

Mountain ecosystems offer a variety of important goods and services for humans. At the same time, there is a wide consensus that they are highly susceptible to severe impacts on biodiversity and human well-being under the influence of climate and land use changes [1–4]. The general scientific opinion is that accelerated global climate change is occurring, and it will have clear effects on the future evolution of mountain agro-ecosystems [5–9]. Mountain ecosystem services and the well-being of people living in these areas are particularly vulnerable to climate change in view of water availability and natural hazards associated with extreme weather events, slope instability and changes in the vegetation structure [10,11]. In addition, Bebi et al. [12] explore the critical linkages between future climate and land use changes and the functioning of mountain ecosystems through the consideration of snow avalanche disturbances.

Furthermore, Mori et al. [13] argue that the response of ecosystem services to climate change is complex; in this view, any change in one or more ecosystem components can affect and alter other ecosystem properties and processes in a significant way. The authors further posit that many changes can occur in an ecosystem, and they provide examples of such changes from the scientific literature: the development of new plant communities as well as changes in phenology, plant–animal interactions, food-webs, vegetation carbon balance and natural disturbance regimes. Many of these consequences have been the unintended result of insufficiently planned management actions [14].

For Schroth et al. [15], the incorporation of expert knowledge can be useful in climate impact assessments by providing perspectives regarding human behavior in the context of environmental change, such as the importance of non-climatic factors in decision making or the synergistic interactions between social change and climate impacts. Such social changes include the marginalization of economic activities, the migration of economically active segments of society and local population ageing. Philpott et al. [16] also call for a greater understanding of the repercussions that climate change has on food and timber provisioning services for the livelihoods of mountain communities. Huber et al. [17] predict that the expected anthropogenic climate change will exacerbate these issues by changing disturbance regimes, intensifying drought conditions and negatively affecting the development of at least some ecosystems in mountain regions.

In terms of key ecosystem services provided by mountain ecosystems, it is widely recognized that mountain ecosystems provide an array of services, such as wood [18] and food production [6,10,19,20], that support the livelihoods of upland farming communities, in addition to the well-being of communities in the surrounding lowlands [15,21]. Services benefiting lowlands include long-term carbon sequestration in woody biomass and forest soils [20,22–24], which Harrison et al. [10] rank as being of key importance for mountain ecosystems. Furthermore, mountain forests play a major role in lowland communities through water-regulating services [25]. Because mountain ecosystems provide goods and services to people who live in mountain regions [1] and the surrounding lowlands [26], it is important to better understand how the concept of ecosystem services can influence spatial decision-making processes [27]. For example, agriculture provides various ecosystem services in mountainous areas including nutrient cycling, habitat provisioning, aesthetics and cultural services [28,29], but mountain farming can also be a threat to the provision of other ecosystem services, through the use of chemical fertilizers to increase production.

In recent decades, mountain ecosystems have become more and more vulnerable to anthropogenic pressure, especially that resulting from change (land use/land cover change, climate change and changes in traditional land use practices). Increasingly, such changes in land use are affecting key ecosystem services. For example, the abandonment of traditional pasture management in the Carpathian Mountains impacts carbon sequestration [30]. Abandonment of traditionally managed pastureland is directly linked to declining ecosystem services in mountain areas [31]. In the mountainous areas of Spain, nature-based tourism services are affected by the development of large tourism infrastructure and inappropriate tourist behavior [32]. Environmental issues, such as forest fires that are caused by depopulation of mountain areas, call for mapping land use and land cover changes, and building evidence for improved land management solutions [9].

According to Huber et al. [17], climate change, ecosystems and their dynamics, socio-economics and politics are all part of an interconnected system with multiple feedbacks. When investigating the impacts of climate and land-use change on the provision of ecosystem goods and services in mountain regions, a complex system approach is needed to accurately analyze both human and environmental dynamics over a range of spatial and temporal scales. Therefore, only by integrating multi-disciplinary research with dedicated disciplinary research into individual processes and mechanisms can these comprehensive systems be understood to ultimately address interlinked environmental and social problems [17].

Land use/land cover change and ecosystem services are two concepts that appeared and evolved in different ways. The first was considered to be a common driver of landscape dynamics [33,34], whereas the second originated to capture the relationship between ecosystem functions and their economic value [35–40]. However, these two concepts have only recently been considered as a joint approach for assessing the impacts and consequences of land use/land cover changes on ecosystem services [41], pointing to the need to discuss more cross-cutting perspectives [27,35,42–47].

Ecosystem services represent the basic precondition for human existence and well-being [1,36,37]. Literature provides various definitions and classifications of ecosystem services [36,37,48–54], but the definitions are not fully compatible [55,56], which might be misleading to the people applying them in landscape planning and management [57,58]. The most widely used classification of ecosystem services was the Millennium Ecosystem Assessment [38], which identified four major types of ecosystem services: (i) supporting / habitat services, (ii) provisioning services, (iii) regulating services, and (iv) cultural services. The revision done by The Economics of Ecosystems and Biodiversity [39] aimed to synthesize the work in this field and prevent double counting in ecosystem services audits. It revised the Millennium Assessment definition by removing the 'supporting services' and dividing them into 'habitat services' on the one hand and 'ecosystem functions' on the other; the latter are defined as a subset of the interactions between ecosystem structure and processes that underpin the capacity of an ecosystem to provide goods and services' [39]. A further step towards a common classification of ecosystem services [59] has been undertaken by the European Environment Agency (EEA) through the development of the Common International Classification of Ecosystem Services (CICES), which proposes a section–division–group–class–class type hierarchical structure [60].

In addition to the concept of ecosystem functions, the related and comp(l)eting concepts of landscape services and landscape functions move the discussion forward to a more holistic view, in which human society is connected with the natural structures and processes of the landscape [61]. When landscape functions are valued by people, they provide landscape services, and this concept was proposed to better integrate a broad range of services that relate to the landscape's living and inanimate natural entities and result from the interaction of humans with natural landscapes [62–65]. However, this concept was not designed to replace or overlap with the concept of ecosystem services; it adds to the field as it predominantly relies on the anthropocentric character of the landscape and highlights those services that are derived from the spatial relationships among the landscape elements or the interaction between cultural and natural resources. The concept of landscape services is considered to be more comprehensive, as it integrates different disciplines from both the natural and social sciences and encourages participatory approaches and sustainable landscape planning [63].

The introduction sections of some papers present literature surveys from a standpoint similar to the present study, offering various perspectives of and relationships among ecosystem services. Kienast et al. [66] investigate the relationships between ecosystem services and their capacities (stocks - landscape function) to provide goods and services (flows). Burkhard et al. [67] define the concepts of the supply of ecosystem services, the demand for ecosystem services and the ecosystem service footprint, while Bastian [55] investigates the links between biodiversity and ecosystem services. Albert et al. [57] discuss the enhanced relevance of ecosystem services, and Bürgi et al. [35] link ecosystem services with landscape history, while Tratalos et al. [68] point out the need to measure cultural ecosystem services. Finally, Martín–López et al. [69] argue the need for interdisciplinary perspectives on the interconnections between socio-economic and ecological systems, including for studying ecosystem services.

In this context, a natural question can be raised: who are the beneficiaries? *Qui prodest?* Who needs to understand these changes in mountain land use and ecosystem services? The answer lies in the concept itself: 'ecosystem services form a useful link between the functioning of ecosystems and their role for society' [70]. But how do people understand and manage these services and benefits?

Despite the incorporation of ecosystem services into landscape planning and decision making, the relevant results are still in their very beginnings [57,71]. Understanding ecosystem services and the implications of changes for planning and decision making could contribute to the development of more appropriate management strategies. Furthermore, the concept could become an accepted tool for natural resource management [66].

There are numerous reviews about ecosystem services that concern definitions, classifications, mapping, indicators, assessment, economic value, etc. Nichols et al. [72] provide a quantitative review of the importance of certain species in the maintenance of ecosystem services with a focus on the issue of habitat fragmentation and the response of insect communities. Harrison et al. [10] survey the structure and trends of ecosystem services across Europe through a literature review and scientific expert knowledge, and Hermann et al. [56] discuss the state of the art of ecosystem service assessment in landscape research. Seppelt et al. [73] perform a quantitative review of ecosystem service studies while Seppelt et al. [74] take a deeper look at ecosystem services assessments. Mountain ecosystem services are the topic of the paper by Grêt-Regamey et al. [1], while Mori et al. [13] review and discuss the literature about ecosystem processes, mitigation and adaptation strategies to identify the limitations of ecosystem management approaches, the relevant issues and the state of knowledge related to forests. Iverson et al. [75] discuss the relevance of landscape ecology and ecosystem services, and Wolff et al. [76] define and identify four 'demand types' and discuss mapping the demand for ecosystem services. Recent studies [69,77] focus on the uptake of the concept of ecosystem services into policymaking and on the interdisciplinary nature of the reviewed studies.

Against this introductory background, our review is focused on two major research questions:

(i) What quantitative methods have been developed for linking land use change in mountain regions with ecosystem services?

To answer this question, Section 3 of the paper outlines the approaches to studying land use changes in mountain ecosystems. As shown in Table 1, land use and land cover data are used as input for the assessment of ecosystem services, mapping potential conflicts among ecosystem services and to discuss scenarios for the provision of ecosystem services under different land use planning strategies. Complex patterns of land use changes [78] stand out as one of the main pressures on ecosystem services, such as the effects of deforestation on greenhouse gas emissions, and could have permanent effects on ecosystems and the supply of ecosystem services, like in the case of insufficiently planned development [79].

Table 1. Linking land use change in mountain regions with ecosystem services.

Method	Linkages to Ecosystem Services
Land use/ land cover change	Changes in LULC influence the provision of ES; spatial variation effect on the supply-side of the ecosystem services flow
Landscape metrics	Changes in landscape pattern influence landscape functions and the provision of ES
Mapping	Classification of land uses; scenario development for land use planning
Landscape history	Understanding the evolution of landscape over time; it enables estimations of future ES
Scenario development	Scenario modeling for the supply of ES under different land use planning strategies

(ii) To what extent is linking land use change in mountain regions with ecosystem services useful to stakeholders?

In Section 4 of the paper, we present an overview of embedding the link between human land use activity and its impact on ecosystem services from the perspective of planning and policymaking. As illustrated in Table 2, the challenge is to align different methods for bridging land use and ecosystem services with the needs and levels of various stakeholders and governance levels. Also, the methods usually applied in policy design require a multi-level stakeholder engagement approach, to ensure an open, collaborative and coherent decision-making process and to balance interests in certain types of land use/ land cover and ecosystem services.

Table 2. Linkages between land use change, mountain ecosystem services and stakeholders.

Type of Stakeholder	Approach to LU Change and ES	Benefits for Stakeholders
Residents	Mental maps Local knowledge transfer during the policy formulation process	Ultimate beneficiaries of successful governance (identification of most pressing needs and significant opportunities)
Subnational decision-maker	Participatory assessment of ES Local planning process Impact assessment studies	Inform decision-making process for management and planning
National policy decision-maker	Ex-ante policy assessment models of ES Participatory planning Payments for ecosystem services	Confirm and validate planning and policy measures, reducing uncertainties related to effects on future land uses

In this view, it is of utmost importance to provide high quality and in-depth information on competing land uses and demand for ecosystem services, in terms of sectoral policies addressing environmental issues, conservation, forestry, agriculture and rural development, as well as in cross-sectoral processes like regional development and spatial planning.

The review process focused on research articles regarding land use and ecosystem services in mountain areas across the globe, trying to understand the scientific debate about the outcomes of assessment methods and their uptake in planning and policymaking practices. Therefore, the results of our systematic review reflect the level of linking human land uses and ecosystems services in the scientific literature, as well as the extent of orienting research activities towards practical policymaking requirements. The conclusions are influenced by the selection of research articles, which is limited to the international databases, thus some important national and regional perspectives related to mountain land uses and ecosystem services are lacking in this paper. In this view, there is a need for more nuanced information on the integration of ecosystem services assessments into decision-making across different levels of governance in future qualitative thematic analyses.

2. Methods

We used *mountain land use change and ecosystem service* as a literature search term. A search of the ISI Web of Knowledge and other databases, such as Science Direct and Springer. A total of 151 papers were selected as the basis for further analyses. We analyzed the papers from two perspectives: (i) year of appearance to identify trends over time, and (ii) the category of the journal in which the paper was published, according to the Web of Science classification.

The papers were classified using two criteria. The first relates to the category/categories of ecosystem services addressed, and the second refers to the type of analysis performed in the paper. Following a quick survey of the selected papers, we classified them into five categories: (i) theoretical/conceptual, (ii) spatial analysis, (iii) social analysis, (iv) mixed methods, and (v) review. Chronologically, the analyzed papers present general research on ecosystem services (Figure 1), and most were published in 2017 (15%) and 2019 (12%). The research papers that were focused on specific types of ecosystem services were mostly published in the period 2011–2015 (71%). Research on the four major categories of ecosystem services was mainly published in 2014 and 2015 (47%).

Firstly, the analyzed papers present predominantly spatial analysis and a mixed-method approach to ecosystem services followed by theoretical/conceptual analysis, social analysis and a literature review. Mixed method approaches and spatial analysis papers mostly appeared in 2012–2015 (54% and 58%, respectively) (Figure 2). Most of the papers presenting a theoretical/conceptual approach were published in 2013–2014 (38%), and the papers employing social analyses were largely published in 2014–2015 (40%). Those studies that focus on literature review were mostly published in 2011–2013 (53%).

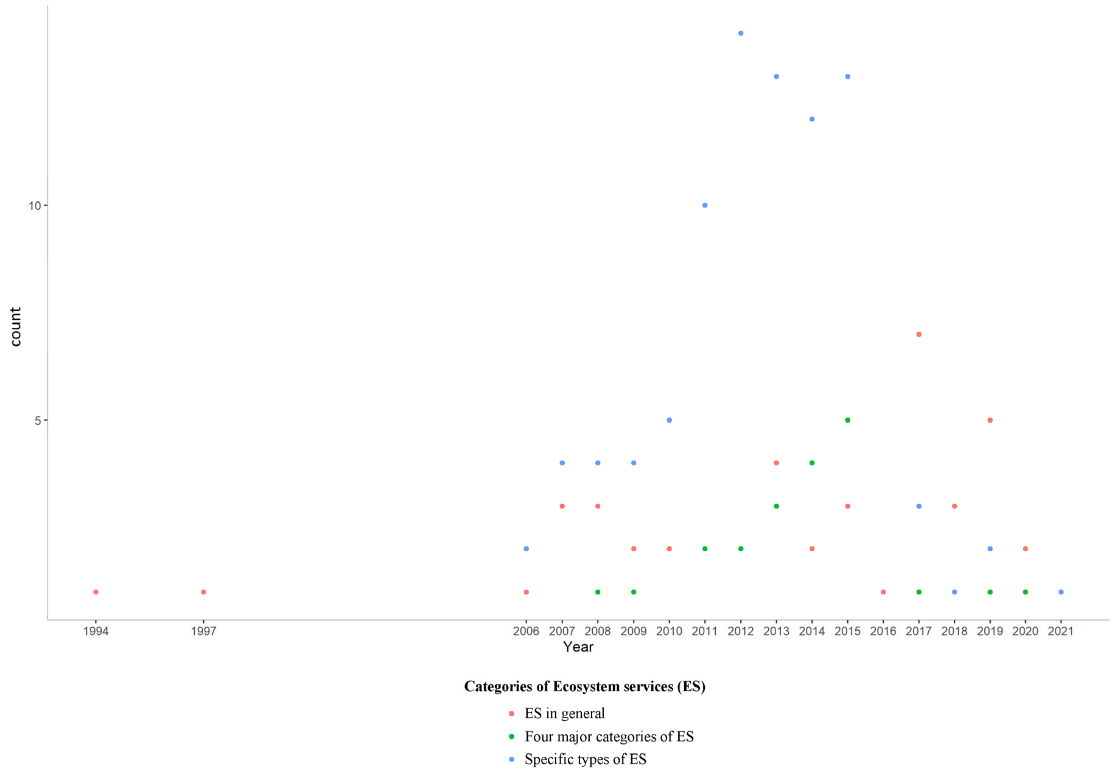

Figure 1. Categories of ecosystem services addressed in the analyzed papers.

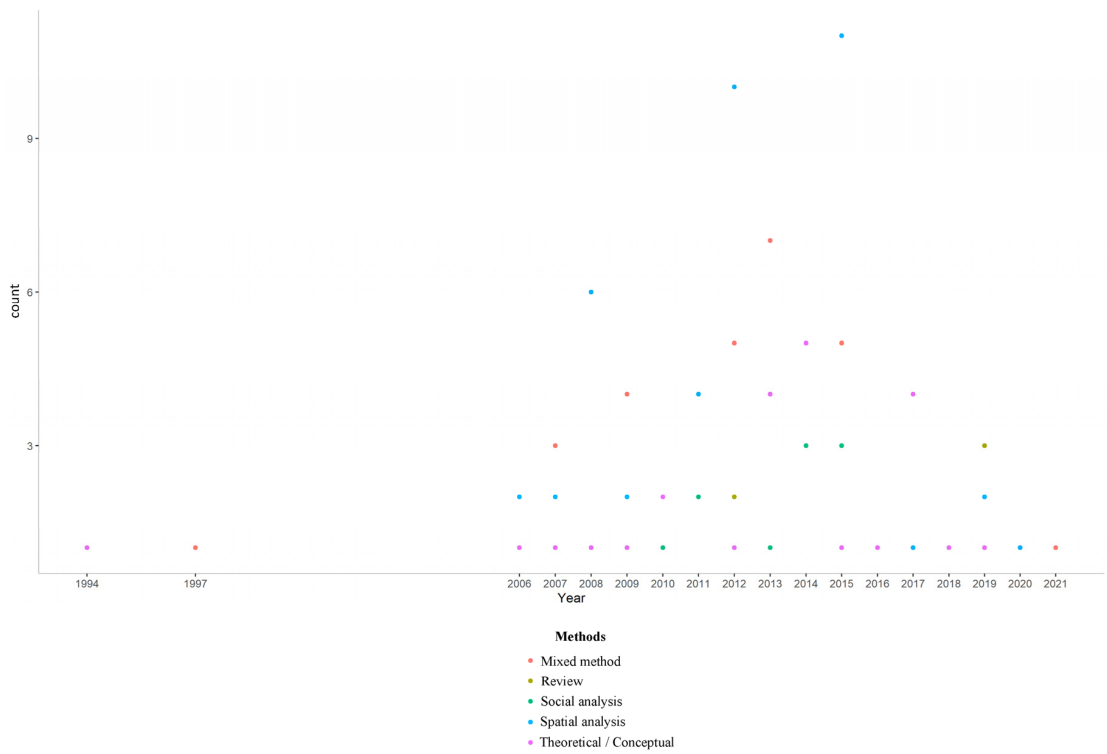

Figure 2. Methods used to assess mountain ecosystem services in the analyzed papers.

The journals focused on subjects classified as belonging to ecology and the environmental sciences contain the greatest number of papers that present research on specific types of ecosystem services, the four major categories of ecosystem services and ecosystem services in general (69%).

Together, the journals classified as focused on subjects related to ecology, the environmental sciences and environmental studies contain the most types of ecosystem service analyses.

3. Approaches to Studying Land Use Changes in Mountain Ecosystems

Land use/land cover indicators are usually used as a proxy for ecosystem service assessment. In this view, the assessment of ecosystem services includes an important quantitative component that depends on suitable indicators. To accurately and comprehensively assess the various facets of ecosystem supply, a whole set of indicators has been assigned to the major classes of ecosystem services over time [38,39,60]. Land use/land cover represents an appropriate proxy that can be used to estimate some of these indicators [80]. Maes et al. [44] analyze spatial patterns of biodiversity and indicators of biodiversity at the scale of Europe and demonstrate that land use/land cover explains a significant portion of the spatial variation in ecosystem service supply. Kandziora et al. [81] and Zulian et al. [82] present a comprehensive list of proposed indicators for regulating, provision and cultural services as well as other components of human well-being, and they explore the interrelationships between these indicators. Helfenstein and Kienast [83] use the framework outlined in the Common International Classification of Ecosystem Services [60] to systematically evaluate the state of and predict the trends in selected ecosystem services based on their associations with land use categories.

To outline ecosystem service dynamics over time, it is appealing for researchers to incorporate the temporal scale into the already-established connection between land use/land cover and indicators of ecosystem services. To detect trends in the supply of ecosystem services over time, Lautenbach et al. [84] examine four indicators related to water quality regulation, food production, outdoor recreation and pollination. Balthazar et al. [80] estimate the impacts of forest cover change on ecosystem services using landscape capacities as a proxy, while landscape history is linked to environmental changes and analyzed from the perspective of its effects on ecosystem services by Grunewald and Bastian [85] and Bastian et al. [86], who further emphasize the need for sustainable landscape development. Finally, a significant correlation between the drivers of landscape change (e.g., agricultural policy) and ecosystem service indicators is demonstrated by Guerra et al. [87].

Another quantitative method that helps link land use change in mountain regions with landscape patterns and the supply of ecosystem services consists in the use of landscape metrics. Landscape metrics have become a standard tool for transforming the assessment of spatial characteristics into ecologically meaningful information. From this perspective, they may represent an appropriate tool for connecting land use changes to ecosystem services. The changes in land cover or land use are related to specific patterns, such as fragmentation or the reduction of core habitat areas, but changes in landscape patterns also directly or indirectly impact landscape functions, such as habitat, regulation or information functions [88]. Frank et al. [89] propose a conceptual framework that explicitly links several landscape metrics to the assessment of ecosystem services and test this approach on afforestation scenarios. Syrbe and Walz [90] consider a set of landscape metrics and detail how they can be useful for evaluating ecosystem services. Grêt–Regamey et al. [91] proposed an integrative approach and discussed the impact of marginal land use changes on ecosystem services by accounting for changes in landscape patterns [78].

Spatial analysis is a powerful tool for the transfer of information into decision-making and planning processes. The emergence of the spatial analysis of ecosystem services strongly contributed to the linking of land use with ecosystem services because it produces maps that display data related to land use/land cover change [56]. Mapping is used for extracting information related to land use to understand ecosystem services. To integrate ecosystem services into planning and decision making as well as different existing programs, researchers have evaluated various model areas that produce ecosystem services using spatial analyses.

Great attention has been drawn to developing methods and indicators as well as to mapping approaches that can help quantify ecosystem services, their trade-offs or bundles [35,43,84,89,90,92–97]. For example, Haines–Young et al. (2012) study the relationships between land use/land cover and ecosystem services and the impacts of different drivers of change through the development of different scenarios. The use of remote sensing and GIS to map land use/land cover change is a common approach in many other studies [19,98–101]; but the process of mapping and quantifying land use and ecosystem functions could also be based on stakeholder [6], community [102] or tourists surveys [103].

Fürst et al. [104] emphasize the role of the spatial dimension of management and governance, pointing out that stakeholders are seeking spatial solutions because they are more interested in knowing "where" to implement planning than "why". Generating maps of ecosystem services is useful for obtaining information about land use conversion and for understanding the value and flow of benefits [105]. The mapping of ecosystem service supply, demand and budgets [67,106] as well as mapping demands [76] can be integrated into the planning and management workflow at different stages: vulnerability assessments [70], identifying conservation priorities [105], management decision making [27], and developing benefit scenarios that provide returns to landowners [46].

Landscape history and scenario development highlight how land use decision altered the provision of ecosystem services and future possible situations that are determined by different planning strategies. Land use change can be viewed from a temporal perspective, so two approaches are possible: looking backward or forward, that is, in the past or in the future. Scientists have argued that both directions on the temporal scale are useful in the context of ecosystem service assessment; historical analyses can improve our understanding of ecosystem service dynamics [35] while modeling scenarios support the consideration of global changes through the joint perspectives of socioeconomics and climate [42].

The link between the two concepts is *change*, which acts as a key driver. Thus, understanding the influence of land use change on ecosystem services leads to understanding the dynamics of and the changes in ecosystem services. Currently, these dynamics have mainly been observed by analyzing scenarios [42,45,91] or linking ecosystem services with landscape history [35,84,107]. Another approach is to study the sustainability of ecosystem services in changing landscapes [107,108]. Analyzes of land use changes and their influence on ecosystem services have highlighted both positive and negative impacts on the supply of ecosystem services. For example, MEA [38], Nelson et al. [45] and Haines-Young et al. [43] all emphasize the possible loss of the benefits that ecosystems provide, but other studies emphasize the benefits of land use change, e.g., forestation [109].

Understanding how landscapes and ecosystem services change over time can contribute to better predictions of the future [35,107]. Lautenbach et al. [84] detect trends over 50 years by using indicators based on proxies, and a basic hypothesis tested in the paper is that land use configuration plays an important role. Balthazar et al. [80] assess the impact of forest cover change on ecosystems and test the feasibility of extending analyzes over longer periods. Bürgi et al. [35] develop a framework for linking ecosystem services with landscape history, starting from the premise that ecosystem services are directly impacted by temporal landscape dynamics and emphasizing the need to assess the historical provisioning of ecosystem services. As far as projecting the responses of mountain ecosystems to climate change, the results of numerous studies are strongly scenario-dependent [19,110]; e.g., Miller et al. [111] use long historical and contemporary time-series of climatological variables with fire occurrence and land use change data.

Scenarios support the understanding of potential conflicts between competing land uses, as well as associated trade-offs [112]. Many studies examine the potential for scenario analysis [7,19,20,110,113]. For example, Lundström et al. [19] present a methodological approach to the ALPSCAPE model based on an explicit scenario, and Nelson et al. [45] present map changes in ecosystem services by applying the InVEST spatial modeling tool to stakeholder-defined scenarios. A few years later, Petz et al. [114] reference different land management scenarios and use the InVEST tool to quantify and map water yield using vegetation, hydrological and sediment retention data. Briner et al. [115] develop an economic land allocation model, ALUAM, aimed at simulating competition and trade-off scenarios, and based on this model, Briner et al. [42] present a modeling framework that allows for the investigation of the trade-offs between ecosystem services by considering a spatial scale that is relevant for decision making. Hirschi et al. [28] extend the ALUAM model by considering the land-use dynamics triggered by market and policy changes, and Grêt–Regamey et al. [27] use a GIS-based Bayesian network that integrates local expert knowledge to map forest ecosystem services values to develop a trend scenario for 2050. Grêt–Regamey et al. [91] emphasize the role of marginal land use changes and their impact on ecosystem services by accounting for changes in landscape patterns, such as fragmentation. Many other studies also examine the potential for scenario analysis [7,19,20,110,113].

4. From Theory to Practice

The purpose of this section is to highlight the applicability of assessing land uses and their interaction with ecosystem services in various governance practices. A key point in this regard is the existence of a multi-level stakeholder engagement approach to understanding cases of competing land uses and demands for ecosystem services.

The assessment of ecosystem services, as performed by researchers, becomes more conclusive when placed in a broader context, i.e., in direct relationship to management and planning. Top-down and bottom-up approaches complement each other, and because ecosystem services are closely connected to social systems, the commitment of decision-makers to the use of the ecosystem service concept must be based on research [116]. This approach is supported by policymakers, such as MEA and TEEB, which have incorporated the ecosystem concept into political considerations [117]. Several international agreements, such as the Aichi Targets of the Convention on Biological Diversity (CBD) and the EU's Biodiversity Strategy, address ecosystem services [57]. Recently, Diehl et al. [117] discuss the opportunity for integrating ecosystem services into impact assessment studies, but there is also an increasing need to incorporate stakeholder perspectives when addressing issues related to ecosystem service assessments. Albert et al. [118] describe various approaches to integrate planners, their interests and perspectives and the impact of the ecosystem service concept into planning. There are various stages at which the interaction between scientists, local communities, planning experts and decision-makers at national and subnational levels can occur on the linkages between human land use activities, and they have different implications for ecosystem services (Figure 3).

Using maps, Kienast et al. [66] investigate the characteristics of the land and its capacity to provide ecosystem services and discuss the supply and demand of ecosystem services. Five experts were directly involved in establishing the binary links between land characteristics and landscape functions. Moreno et al. [32] model mental maps, which help to improve knowledge, understand the various points of view of the diverse stakeholders and consider their proposals to solve specific problems in protected areas [119].

Wolff et al. [76] and Aguilar–Gomez et al. [9] present the advantages of participatory approaches. They note that stakeholder involvement can be useful, for instance, in identifying what ecosystem services exist and can be valued on a map. A focus when using participatory approaches to assess mountain ecosystem services is on cultural ecosystem services [29] due to their less quantifiable nature. Furthermore, Grêt–Regamey et al. [27] prove that including local knowledge in ecosystem service assessments and modeling could contribute to mutual learning between stakeholders but also be very useful for reducing uncertainties related to avalanche occurrence, timber production, and carbon sequestration. Frank et al. [120] analyze how the decline of a regulating service impacts other ecosystem services. Several scenarios were developed and discussed in workshops by scientists and regional planners.

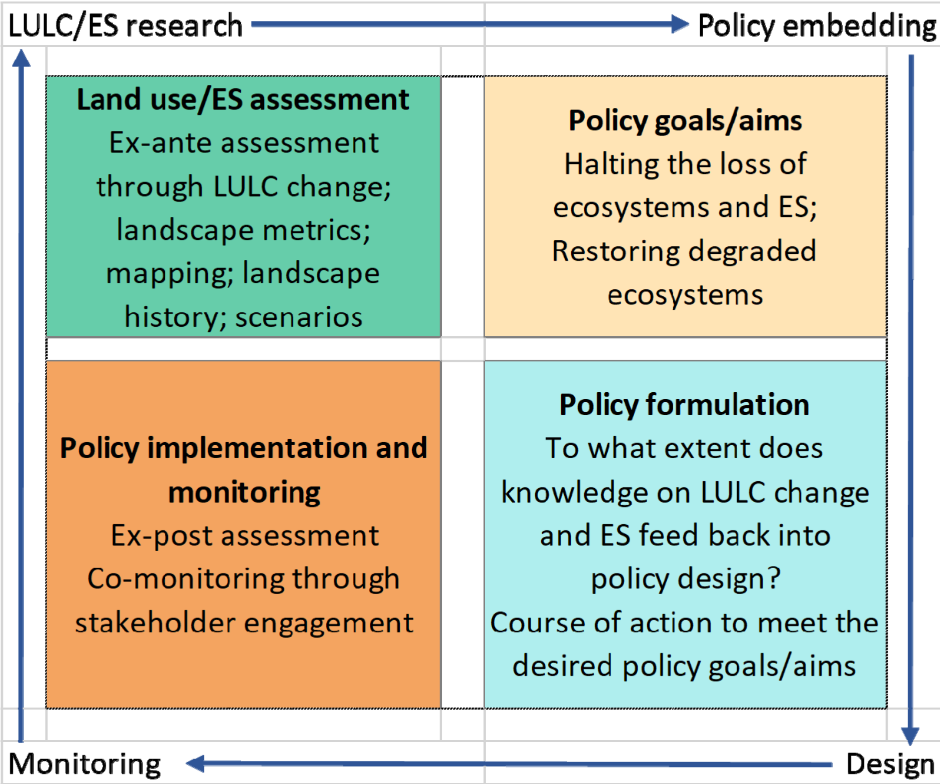

Figure 3. Embedding linkages between land use and ecosystem services into the policy cycle.

Turning to the question whether ecosystem service assessments can contribute to the planning and decision-making process by meeting the requirements and interests of targeted stakeholders, it is known that assessing ecosystem services can underpin planning and decision making at different stages, and recent studies cover an entire gradient of perspectives from informing, assisting and providing support to confirming and validating planning and policy measures. Thus, such assessments can inform land use planning [100,121,122] or provide input into management decisions in high-risk mountain areas [16,123]. The influences of historical/temporal [123,124] and spatial dynamics [14,125] on the current provision of multiple ecosystem services can contribute to the understanding of how service delivery will be altered under land use/land cover change [126]. Hirschi et al. [28] use ex-ante policy assessment models of ecosystem goods and services to indicate which policy measures will have strong support in the political process and show that assessments of ecosystem services could assist planners and decision-makers.

Understanding the links between conservation demands and management practices and understanding the fact that multifunctional landscapes increase the benefits for stakeholders considering their multiple demanded ecosystem services [127] can increase awareness of the value of the benefits that ecosystems provide [128]. Ecosystem service assessments provide knowledge to aid the pursuit of suitable policies for the management of ecosystem services [10,114,129]; a key challenge it is the management of multiple ecosystem services across landscapes [130]. Linking the social values of ecosystem services to ecological data can guide decision making for the management of protected areas [119,131]. The mapping of ecosystem services can support management decisions [27,132], and an overall insight into the value of ecosystem services can support sound conservation policy [72,116] and proper forest management decisions [17,111]. Appropriate models can predict the effects of policy decisions on future land uses [133], and assessing the services provided by ecosystems can also confirm planning decisions, e.g., choosing between abandoning or intensifying a specific land use [110] by considering the relevant opportunities [6]. Furthermore, the assessment of ecosystem services could validate the consistency of policy goals, which is why they must be integrated into planning processes.

Last but not least, the ecosystem service approach may be used to add value to traditional conservation approaches [134].

To meet the expectations of planners and decision-makers, the interdisciplinary scientific achievements regarding ecosystem services must be transferred into the decision-making process [135]. The knowledge-transfer process itself requires a transdisciplinary perspective, thus various approaches to achieving this aim have been proposed and explored in the literature. Effective models have been developed to enhance the link between the perspectives of researchers and planners; for example, the PRESET model indicates how to incorporate the ecosystem services concept into planning [136]. The authors highlight the importance of integrating both the available ecosystem services and the ecosystem services that are utilized in the model, as both are very important for planning and enhancing the provision of ecosystem services.

The participatory identification of ecosystem services has become a well-established tool through several studies that investigate the importance of local system knowledge [19] in the pursuit of landscape management strategies [100] or for understanding how land use might evolve based on current needs and decisions [110]. Swetnam et al. [20] create a participatory scenario-building exercise to develop quantitative maps that could assist decision-makers better than simple statistical reports. Moreno et al. [32] use a participatory technique to reveal the complexity of ecosystem services and integrate the ecosystem services framework into ecosystem-based management.

The literature on integrating the ecosystem service concept or instruments into planning indicates a bias between theory and its actual uptake into governance decisions or policymaking. However, there are a few exceptions that prove that the ecosystem service concept is moving towards integration into public policies and strategies and that policy impact assessment procedures are suitable for transferring the scientific concept of ecosystem services into policymaking. Helming et al. [137] link 3 separate frameworks, i.e., (i) the concept of ecosystem services, (ii) the Driver-Pressure-State-Impact-Response (DPSIR) system, and (iii) the steps of the IA (impact assessment) process, to build a single comprehensive framework for the application of the ecosystem services concept to the policy impact assessment process.

Organizations that hold an intermediate position at the interface between science and the practice of ecosystem services assessment are crucial for ‘communicating information across scales and policy areas for the design and implementation of responses to the degradation of ecosystem services’ [138]. McNeely [139] notes that all levels of governance (from the supranational to the local) play a role in enhancing the ecosystem services provided by protected areas and conclude that bioregionalism constitutes the best approach for the designation and management of protected areas. Monzón et al. [140] support the idea that ecosystem services should be at the core of protected area management structures, but governance schemes should support making good use of ecosystem services [141]. These schemes should follow a multi-level governance arrangement based on the vertical coordination between different European, national and subnational institutions to actively involve all these levels in policymaking [142].

Walz et al. [7] state that the results of research into the participatory ecosystem services mapping ended in the integration of the project team into a committee for the design of a regional development concept. Padilla et al. [24] acknowledge the importance of knowing the quantity and location of services to inform management decisions and policymaking at regional levels. Pfund et al. [100] argue that the mechanisms for developing reward schemes could be integrated into development strategies, and Lopa et al. [23] review the Tanzanian CARE/WWF pilot project of an operational PES scheme in the Uluguru Mountains. PES approaches that have been less developed in ecosystem service research targeting mountain areas, leaving a knowledge gap that is partially filled by country-wide studies focusing on the payment schemes for forest and water ecosystem services [143].

Public instruments (e.g., payments and subsidies) represent a much more common conservation approach than private, market-oriented instruments (e.g., sponsoring and donations) [144]. Lambin et al. [145] argue that, under favourable institutional and governance contexts, well-designed public-private instruments can be effective in leveraging the benefits of ecosystem services.

The practical application of the ecosystem service concept is seen in compensation payments for farmers [5,15,23,146–148], which could result in the generation of more ecosystem services. This tool is targeted at the farm level and directly included in the decision-making process [5,149].

Sikor et al. [150] note that payments for ecosystem services (PES) typically require the involvement of national governments due to their territorial authority, whether the interventions take the form of large-scale programs or small-scale projects. However, these mechanisms can be inefficient, e.g., in the case of urban sprawl [151] or if lacking a targeted and practical approach [152]. Caro–Borrero et al. [153] offer important insights into improvements in PES to fulfil their scope, such as dedicating more funds for additional social training on the roles of PES, in the context of the urban-rural fringe in Mexico. In terms of the private sector, instruments like the Balanced Scorecard (BSC) successfully integrate the concept of ecosystem services into business decision-making and strategic planning [135].

Other implementation measures, such as reducing emission from deforestation and forest degradation and enhancing carbon sinks (REDD), could act as mechanisms for developing reward schemes [100,154]. From this perspective, Swetnam et al. [20] argue that such mechanisms would depend on the uptake of a participatory land use planning process, the existence of payments for environmental services, and the equitable governance of rural landscapes. Thus, Hein and van der Meer [155], as cited by Mori et al. [13], emphasize the fact that REDD has the advantage of demonstrating the benefits to local stakeholders of preserving long-term ecosystem functioning, while Tegegne et al. [156] assert that institutional and policy factors are the most important factors for successfully implementing the REDD approach.

5. Conclusions

Modeling and assessing the impact [157] of land use change on ecosystem services triggered the development of cutting edge methodological approaches and yielded outcomes that are useful for management and decision making [27,45,77]. New problems and challenges are raised by the studies that cover a wide range of topics from pure theory to its applications. The classifications and the definitions of ecosystem services have varied over time [35]. However, to optimize information transfer for decision making, ecosystem services must be clearly defined [116], thus flexible and uncomplicated language must be applied constructively. This can help strengthen research-policymaking-stakeholder connections over the meaning and applicability of ecosystem services [158], making use of consistent concepts and instruments to inform coherent policies and enable the engagement and support of key stakeholders.

Developing new methodological approaches and tools for assessing ecosystem services [57], followed by their implementation and evaluation in practice [135,159] remain hot topics, considering the importance of transferring knowledge of ecosystem services into policy design and implementation, based on spatially explicit quantitative information. These methods and tools may offer important information to direct the management and preservation of mountain ecosystem services on the list of planning priorities.

Even though there are several tools that have been developed within the ecosystem service method, they are not integrated enough in the socio-political landscape [160]. Taking into account the articles analyzed in this paper, there is a mismatch between the place where ecosystem services are generated, in this case in mountain areas, and the location of the ultimate beneficiaries of these services. For instance, the sequestration of carbon by montane forests has a trans-boundary, even global scale impact, yet the land use change and ecosystem services assessment tools developed so far have not succeeded in translating international goals into local governance decisions.

However, recent initiatives like the European Green Deal and the EU Biodiversity Strategy to 2030 call for sound monitoring and assessment in the field of ecosystem services, keeping the issue high on the political agenda. More straightforward lines of actions are needed for integrating ecosystem services in national and subnational governance processes. Also, the UN Agenda 2030 for Sustainable Development targets to integrate ecosystem and biodiversity values into national and local planning, and development processes. As such, there is a need to better integrate the use of tools that help analyze land use change impact on the supply-side of ecosystem services and the effects on human well-being into the policy design process.

The vulnerability of mountain ecosystem services remains crucial to future investigations. In addition to analyzing which services are most vulnerable to change [35], a better understanding of the deep links between the vulnerability of ecosystem services, landscape change and their drivers is needed [107]. Particular attention should be paid to the role of disturbances in different scenarios [107]. Landscape metrics remain a suitable approach for the analysis of the services provided by landscapes and ecosystems [161]. In this sense, landscape metrics could be adequate indicators to evaluate qualitative changes in landscape services for spatial planning and could provide more accuracy to scenario-based ecosystem services assessments [89]. We consider that in the view of drivers of change that affect ecosystems and ecosystem services, it is essential to apply indicator-based quantitative assessments, landscape metrics and mapping of land use/land cover change to build evidence for spatial planning and policymaking. Future ecosystem services assessments could be easier integrated into planning and policymaking through more coherent classifications, and models that predict the supply of ecosystem services under land use and climate change scenarios.

The ongoing socio-economic transformations of mountain ecosystems negatively impact important ecosystem services [1]. Under such conditions, these services interact and trigger conflicts that have to be carefully explored to contribute to policy recommendations to mitigate the associated negative effects. Therefore, there is a need to increase awareness of existing and potential conflicts among ecosystem services because they are an important part of a continuously changing landscape. Scholars have already highlighted conflicts related to the uncontrolled expansion of tourism, water regulation services and water provisioning services [32]. Solving or mitigating conflicts can be achieved at regional or local levels by suitably adapting the decision-making process [12]. Accurate assessments of ecosystem services can be performed when working at the local scale, but many drivers of change, such as climate change, occur at a global scale [27,66]. Thus, developing additional approaches to link scales can enhance our knowledge of the impact of change on mountain ecosystems.

Conceptual and applied linkages between human land uses, ecosystem services and society could be better embedded in research-policymaking interactions, especially considering the demand for ecosystem services and the fact that the beneficiaries of these services may be located in distant regions from the place where they are generated. Reciprocal interactions with stakeholders need to be intensified. For instance, practical guidelines and illustrative case studies that explain the application of the ecosystem service concept to planning would be welcome [8,118]. Moreover, it is a crucial and delicate matter to 'negotiate' the differences between the perspectives of the scholars and stakeholders. Altogether, placing ecosystem services in a broader context and regarding them as components of a complex decision-making system [162] could bring new insights and lead to future developments.

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