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Spatial relationships and impacts of global change on ecosystem services in the European Alps

Uta Schirpke

University of Innsbruck, Department of Ecology, Sternwartestr. 15, 6020 Innsbruck, Austria; Eurac Research, Institute for Alpine Environment, Drususallee 1, 39100 Bozen/Bolzano, Italy.
Email: uta.schirpke@uibk.ac.at

https://orcid.org/0000-0002-2075-6118

Abstract

The increasing interest in the concept of ecosystem services (ES) for decision-making requires a profound understanding of ecological processes, social values and spatial patterns to mitigate the effects of global change on human well-being. Although great progress has been made in the assessment and valuation of ES, scientists are still facing challenges due to a frequent emphasis on ES potential and individual ecosystems as well as disciplinary thinking. This post-doctoral thesis addresses these challenges by (1) contributing to novel mapping approaches with a focus on cultural ES, (2) examining impacts of global change on ES at the ecosystem and landscape level and (3) analysing spatial patterns and interactions between ES supply and demand for ES across multiple spatial scales. This work focuses on the European Alps, as mountain regions are highly important for providing ES while being particularly vulnerable to global change. The findings clearly confirm the relevance of mountain landscapes not only to local populations, but indicates spatial interactions that go far beyond the regional level with great implications for decision- and policy-making. The findings also indicate how the concept of ES may promote biodiversity conservation and the maintenance of multiple ES supported by a sustainable use of natural resources. This work also suggests how interdisciplinary approaches can help to integrate ES supply and demand across different temporal and spatial scales for decision-making in planning and management, taking into account ecological processes in response to climate change. Finally, this work reveals research gaps that need to be addressed in future research to deepen the understanding of socio-ecological systems and underlying mechanisms, as well as to enhance interdisciplinary research.

Keywords:
cultural ecosystem services, global change, mountain landscape, spatial analysis

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1 Introduction

In recent decades, the concept of ecosystem services (ES) has become extremely popular not only within the research community, but also for decision-making and landscape management (Guerry et al., 2015). ES are broadly defined as the benefits that humans obtain from ecosystems (Costanza et al., 1997; MEA, 2005) and are mostly co-produced through human interventions (Palomo et al., 2016). Although topography, climate, geology and land cover largely determine ES potentials, the type and intensity of the management of ecosystems influences the type and level of ES provision (Nagler et al., 2015; Tasser et al., 2020). ES are usually divided into the three categories provisioning, regulating and cultural services, which are supported by basic ecological services or functions (Haines-Young and Potschin, 2018). While first studies concentrated on the capacity of ecosystems to supply ES or used simple assessment methods (Burkhard et al., 2009), the development of indicators and modelling approaches advanced considerably during the last decade (Burkhard and Maes, 2017; Hernández-Morcillo et al., 2013; Wolff et al., 2015). Nevertheless, there are still numerous challenges in the research and implementation of the ES concept, for example, related to lacking social-ecological validity of ecosystem data and models, insufficient understanding and consideration of trade-offs between ES, exclusion of stakeholders and low relevance of case study results for an operational use (Lautenbach et al., 2019).

For informed decision making at different levels, accurate data on ES supply and demand are highly important (van Oudenhoven et al., 2018). In particular, mapping ES at the landscape scale is crucial, as such information can easily be aggregated to larger spatial scales despite some restrictions (Zen et al., 2019). Curent knowledge on spatial distribution of ES is, however, not sufficient, as ecosystems are continuously affected by changing environmental conditions and human activities. In particular, agricultural intensification and urbanisation, together with changing climatic conditions, put growing pressure on natural ecosystems, and thus, on the provision of ES worldwide (Cumming et al., 2014). Here, mountain regions are increasingly important, and the relevance of ES provided by them is more and more acknowledged (Grêt-Regamey and Weibel, 2020; Locatelli et al., 2017). For example, mountain regions are key supply areas for water provision and regulation, timber production, grazing and recreation, providing the benefits to their inhabitants and tourists as well as to people living in the adjacent and mostly highly populated lowlands (Grêt-Regamey et al., 2012). However, mountain regions are especially vulnerable to global change and characterised by long-term effects on the landscape and related ES (Bürgi et al., 2017; Locatelli et al., 2017; Schirpke et al., 2021).

To support the management of mountain regions and to develop effective strategies and policies, knowledge on spatial patterns, interactions and relationships of multiple ES is required (Lautenbach et al., 2019; van Oudenhoven et al., 2018). Focusing on mountain landscapes, which are rather underrepresented in ES research, this post-doctoral thesis aims at advancing current knowledge by addressing three major challenges: (1) the assessment of cultural ES, (2) the analysis of impacts of global change on ES and (3) the analysis of spatial interactions.

2 Research approach and methodological advancements

This thesis is based on 15 key publications, which are grouped according to three objectives (Figure 1). To reach the objectives, different approaches and methods are applied, which are also shortly presented in the following subsections. All publications focus on the European Alps and range from local case studies to the entire mountain range, also including the surrounding lowlands or even the global level.

This work includes the development of novel tools and approaches to map ES at the landscape scale, with a focus on cultural ES, and the application of statistical methods as well as spatial analysis tools to generate new information. The analysis of the resulting ES maps aims not only to the understanding of spatial patterns, but it also seeks to provide a better knowledge of underlying mechanisms in mountain

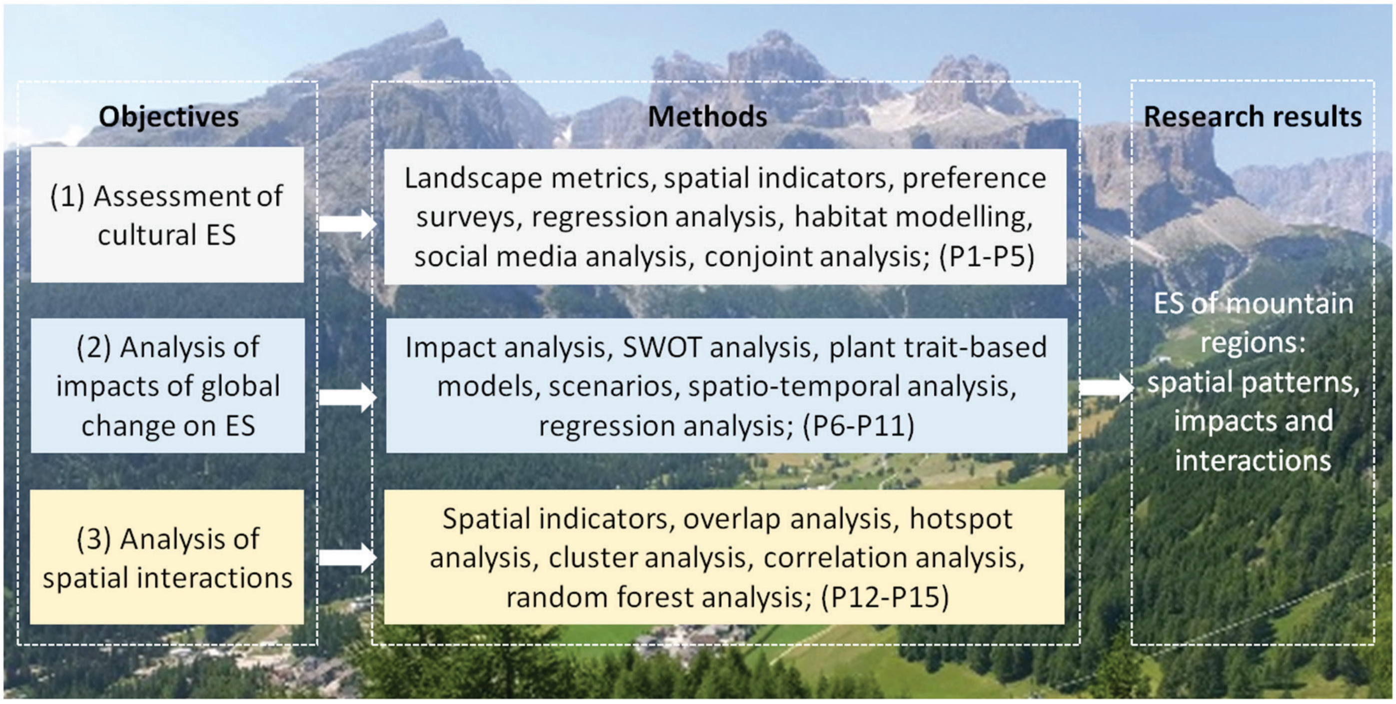

Figure 1. Three sub-objectives and applied methods to analyse spatial patterns, impacts and interactions of ES in the European Alps. Related publications (P) are indicated by P1-15.

social-ecological systems as well as past and future impacts on ES and human well-being. This work pursues a strong interdisciplinary approach, as ES are at the interface of ecology and social science research. This is also reflected in the methods used, as ecological models and statistical methods are combined with surveys or stakeholder workshops to gather human preferences and values. Consequently, the results of the analysis accounting for both socio-economic as well as environmental influencing factors make an important contribution to interdisciplinary research.

2.1 Assessing cultural ES

Cultural ES are of particular importance, as people often more directly perceive the cultural and social values of ecosystems than their biophysical contribution (Chan et al., 2012; Hirons et al., 2016). However, cultural ES seem particularly vulnerable to global changes such as urban sprawl, intensification of land use and climate change (Guo et al., 2010). Here, mountain regions are of high importance, as they include many natural and semi-natural ecosystems, which provide, for example, recreational opportunities, aesthetic landscape enjoyment and inspiration to both residents and tourists (Pastur et al., 2016; Tenerelli et al., 2016). However, their spatially explicit assessment is challenging, because cultural ES are rather independent from biophysical ecosystem processes (Hernández-Morcillo et al., 2013). This work applies different novel approaches to map cultural ES in mountain regions, namely aesthetic values, recreational ES and symbolic species. **Publication 1** enhances a spatially explicit modelling approach to estimate the aesthetic value for any location in the Central Alps (Schirpke et al., 2016). The modelling approach relates human preferences from a photo-based survey to landscape characteristics via a regression model. The model has been improved by accounting for the visibility of selected landscape features and a more comprehensive survey on landscape preferences. Using the results of the survey, further insights into landscape preferences at the individual level are obtained through conjoint analysis and presented in **Publication 2** (Schirpke et al., 2019c). This kind of analysis helps to identify the relative importance of selected landscape indicators and reveals non-linear relationships between landscape indicators and landscape preferences. **Publication 3** focuses on the mapping of the supply, actual use and demand of outdoor recreation in the European Alps and their surroundings (Schirpke et al., 2018b). Different approaches and data sources are combined, including spatially explicit landscape indicators, accessibility derived from the road network, census data at the municipality level and crowd-sourced information from social media. **Publication 4** proposes a methodology to identify and map symbolic species as cultural ES in the European Alps (Schirpke et al., 2018c). While the use of symbolic plants and animals is assessed in a qualitative way, the supply of this ES is mapped at the landscape level, based on occurrence data or potential habitat modelling. **Publication 5** advances the former qualitative examples of the use of symbolic species by a spatially explicit assessment of two aspects, the cultural identity of the local population represented in emblems/coats of arms and the importance of symbols for the tourism sector represented in hotel names (Rüdisser et al., 2019). Moreover, the publication examines which Alpine species are perceived as symbolic through a multilingual questionnaire.

2.2 Examining impacts of global change on ES

Mountain ecosystems are highly susceptible to land-use changes and climate change. In the last century, the abandonment and the intensification of agricultural land have been responsible for land-use and land-cover changes, with consequences for the provision of ES (Bürgi et al., 2015; Locatelli et al., 2017). To provide deeper insights into past developments, **Publication 6** analyses the long-term landscape dynamics over the past 150 years for eight case studies across the European Alps as well as related effects on five ES, including cultivated crops, plant material, climate regulation, soil erosion control and aesthetic value (Egarter Vigl et al., 2016). Focusing on the municipality of Sölden in Austria, **Publication 7** analyses the changes in the actual supply of aesthetic values along roads and paths over the past 150 years (Schirpke et al., 2019a). **Publication 8** examines the future impacts of changes in land-use and climate on six ES of mountain grassland, using plant trait-based models (Schirpke et al., 2017a). As protected areas play a crucial role in assuring future provision of multiple ES, **Publication 9** uses an ES-based SWOT analysis to support the definition of conservation measures (Scolozzi et al., 2014). Changes in 10 ES are estimated for all Natura 2000 sites in Italy between 1990 and 2006. Similarly, **Publication 10** proposes a framework based on the concept of ES to increase the management effectiveness of protected areas (Schirpke et al., 2017b). In 21 study sites in Italy, 55 ES are quantified in biophysical and monetary terms, and 41 payments for ES (PES) are implemented in a participatory process. Comparing the management effectiveness before and after the implementation of PES indicates that integrating ES into the management of protected areas can also improve their management effectiveness. On a larger scale, **Publication 11** (Schirpke et al., 2018a) examines the effects of PES on biodiversity, ES and socio-economic development.

2.3 Analysing spatial interactions

Understanding the relationships and interactions of ES is crucial for managing multiple ES and their integration into land management, decision making and the definition of policies (Cord et al., 2017). However, synergies and trade-offs between land uses and between ES as well as ES flows are not yet sufficiently understood, as they are highly complex and context-specific (Spake et al., 2017). By including beneficiaries or the demand for ES, this work advances earlier studies that focused mainly on ES supply. In this way, obtaining deeper insights into spatial interactions and underlying mechanisms can be derived. **Publication 12** proposes indicators and applies spatially explicit modelling approaches for identifying and quantifying potential beneficiaries of Natura 2000 sites on the local and regional level for 16 ES (Schirpke et al., 2014). **Publication 13** examines the relationships among supply, demand and actual use of eight key ES at a greater spatial scale, the Alpine Space area (Schirpke et al., 2019b). **Publication 14** enhances the previous findings by assessing major directions and types of spatial flows of six key ES from and to mountain regions considering regional and global interactions (Schirpke et al., 2019d). For developing sustainable management strategies, the understanding of spatial congruencies and mismatches between ES and sustainability is important, which is addressed in **Publication 15** through hotspot and overlap analyses (Schirpke et al., 2019e).

3 Key findings

3.1 Preferences and spatial patterns of cultural ES

The results of the preference surveys contribute to a deeper understanding of landscape preferences, indicating that natural and semi-natural ecosystems are preferred over artifical features and highly modified landscapes (Schirpke et al., 2016). Moreover, landscape diversity and complexity are highly important for predicting landscape preferences (Schirpke et al., 2016), but mean levels of landscape complexity are generally preferred over low or high complexity (Schirpke et al., 2019c). However, ongoing landscape changes in the European Alps, such as the abandonment of mountain grassland or the intensification of the valleys, have mostly negative impacts on aesthetic values. Focusing on the municipality of Sölden in Austria, aesthetic values started to decrease after 1950 because of landscape changes caused by the change from predominantly agricultural to touristic use, although areas of high aesthetic value were made increasingly accessible (Schirpke et al., 2019a). In addition to aesthetic values, outcomes underpin the importance of Alpine landscapes in providing various opportunities for outdoor recreation and symbolic values. While accessibility and the location of potential visitors influence the actual use of outdoor recreation (Figure 2), symbolic species concentrate on high elevations but their value for the cultural identity extents over the regional level (Figure 3).

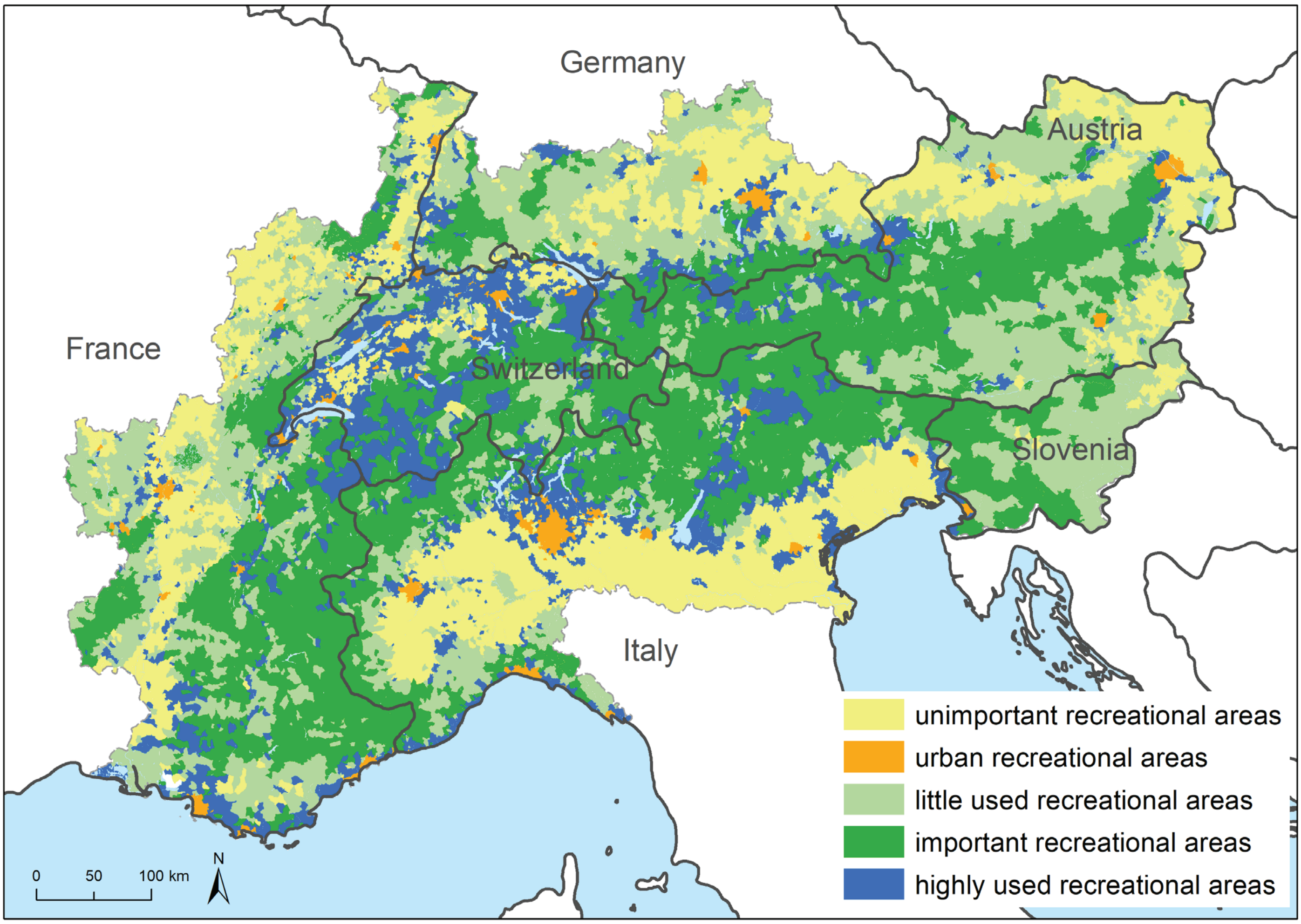

Figure 2. Spatial patterns of supply, demand and actual use of outdoor recreation at the municipality level in the Alpine Space area. From Schirpke et al. (2018b).

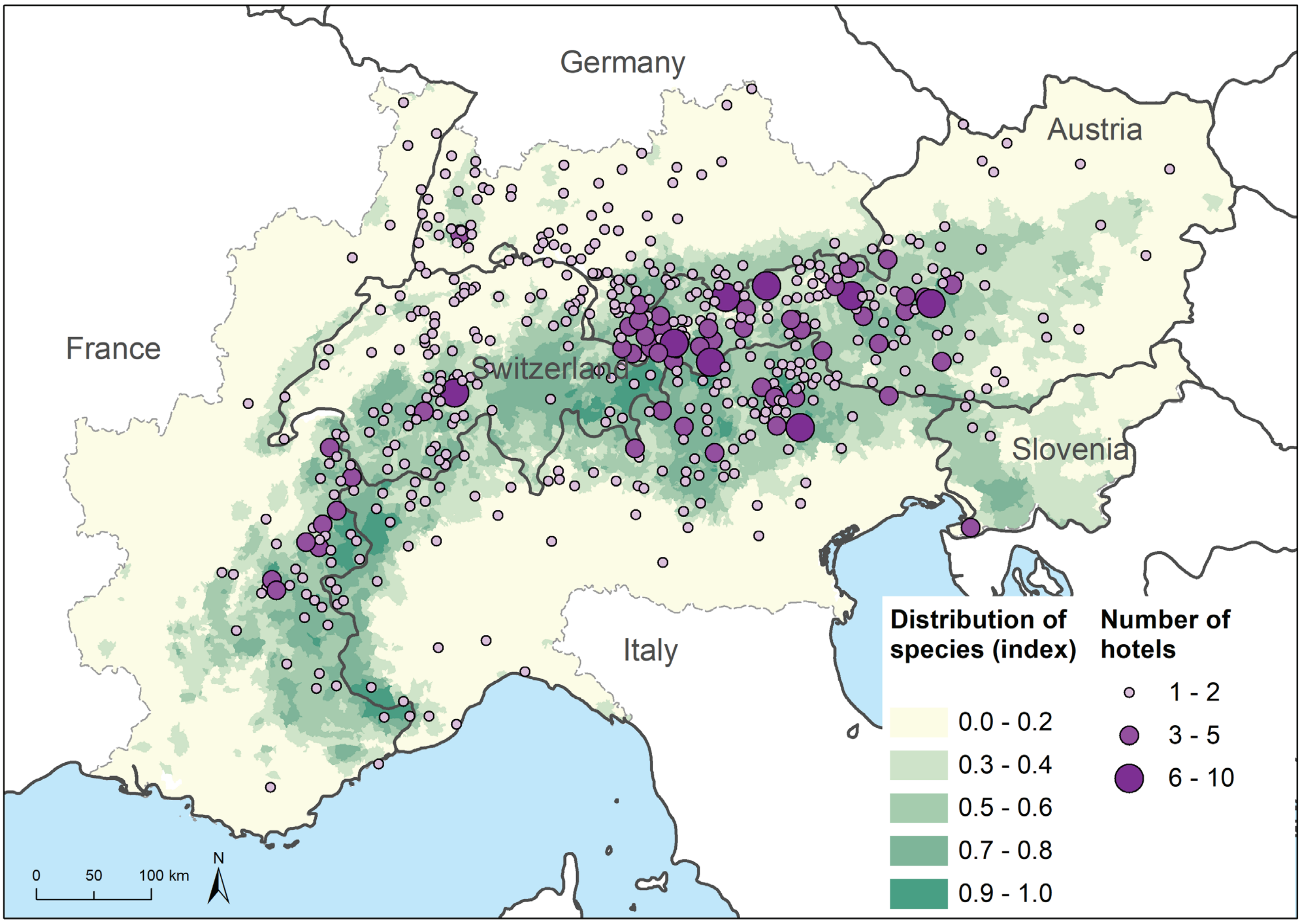

Figure 3. Spatial distribution of habitats of symbolic species and hotels that refer to symbolic species in their names in the Alpine Space area. Data sources: Rüdisser et al. (2019) and Schirpke et al. (2018c).

3.2 Impacts of global change on ES and the role of protected areas

Analysing landscape dynamics and their impacts across the European Alps, the results indicate a shift in ES supply from provisioning services towards predominantly regulating services in the past, whereby three major trajectories occur: regions developing from single to multifunctional sites, sites reducing their service capacities and sites with rather stationary patterns over long periods (Egarter Vigl et al., 2016). Under future conditions (Figure 4), socio-economic driven land-use changes will have a greater influence on ES than climate change in the short term. However, this will be reversed in the long term, especially at high elevations (Schirpke et al., 2017a). Moreover, the results suggest that legacy effects resulting from the abandonment of mountain grassland, together with accelerating climate change, will increase the vulnerability of managed ecosystems and constrain management options.

With regard to protected areas, changes in 10 ES of Natura 2000 sites were analysed in Italy between 1990 and 2006 (Scolozzi et al., 2014). Compared to other regions, Alpine protected areas are larger and better connected and provide more ES per hectare, because land cover of the sites as well as of the adjacent area is more stable and more natural. This will increase the possibility to meet conservation goals if adequately managed. Based on the results of 21 study sites in Italy, comparing the management effectiveness before and after the implementation of PES indicates that integrating ES into the management of protected areas can also improve their management effectiveness (Schirpke et al., 2017b). On a larger scale, PES may have positive effects on biodiversity and socio-economic development, in

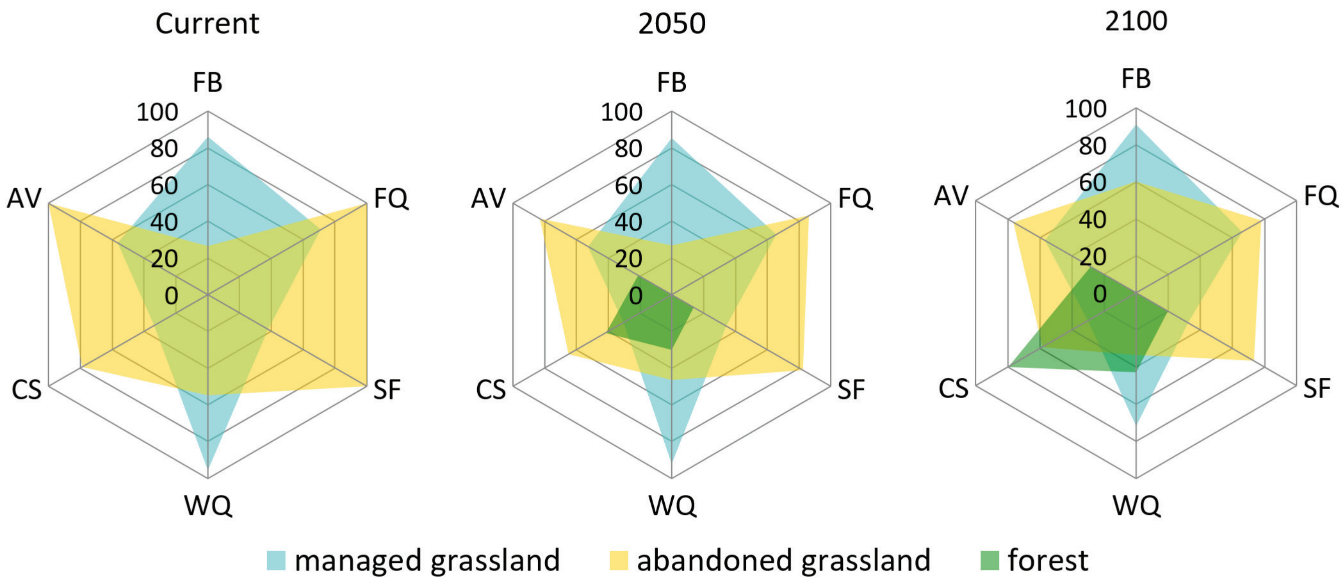

Figure 4. Predicted shifts in ES of mountain grassland in the Stubai Valley (Austria) until 2050 and 2100 under a trend scenario (projecting current trends into the future). ES include FP – forage production, FQ – forage quality, SF – soil fertility, WQ – water quality, CS – carbon storage, AV – aesthetic value. Increasing forest cover results from natural reforestation of abandoned grassland. Modified from Schirpke et al. (2017a).

addition to positive effects on ES provision (Schirpke et al., 2018a). In particular, PES related to regulating (e.g. water recharge, flood mitigation) and cultural services (e.g. recreational value) support a positive development of ecological and socio-economic conditions.

3.3 Spatial interactions and dependencies

The mapping of potential beneficiaries of Natura 2000 sites at the local and regional level for 16 ES highlights that beneficiaries of regulating services are mostly located in proximity to or within protected sites and involve the local population and public authorities, which is highly dependent on the maintenance of these services (Schirpke et al., 2014). Some provisioning and many cultural services involve beneficiaries outside the sites and regard beneficiaries that have substitution opportunities. Examining the relationships among supply, demand and actual use of eight key ES at a greater spatial scale, the Alpine Space area, the results indicate variations in trade-offs and synergies, highlighting important supply-use-demand mismatches across landscapes (Figure 5). More natural mountain regions are hotspots of supply, whereas a high demand for ES is mostly associated with highly urbanised areas or intensively used agricultural areas in the lowlands. Moreover, spatial patterns of ES bundles are explained by 12 socio-ecological variables; the highest influence can be related to agricultural use, topography and population density (Schirpke et al., 2019b).

By assessing the spatial flows of key ES from and to mountain regions at the regional and global level, the results reveal that the spatial interactions range from the local to the global level and extend far beyond the regional level (Schirpke et al., 2019d). For most ES, the spatial flow is directed from mountain regions towards lowland areas (Figure 6). Transportation processes comprise passive biophysical processes for carbon sequestration, the active transportation of goods such as water or agricultural products, the distribution of information in case of symbolic species as well as the movement of people for recreational purposes. With regard to developing sustainable management strategies, hotspots of ES supply, mainly mountain areas, are generally characterised by high sustainability levels, in particular, in the environmental dimension. However, discrepancies in the social or economic dimensions may reduce sustainability levels (Schirpke et al., 2019e). Rural and highly urbanised municipalities show the greatest misbalances. In conclusion, high levels of ES are not equivalent to high sustainability, as ES indicators do not adequately depict social and economic dimensions.

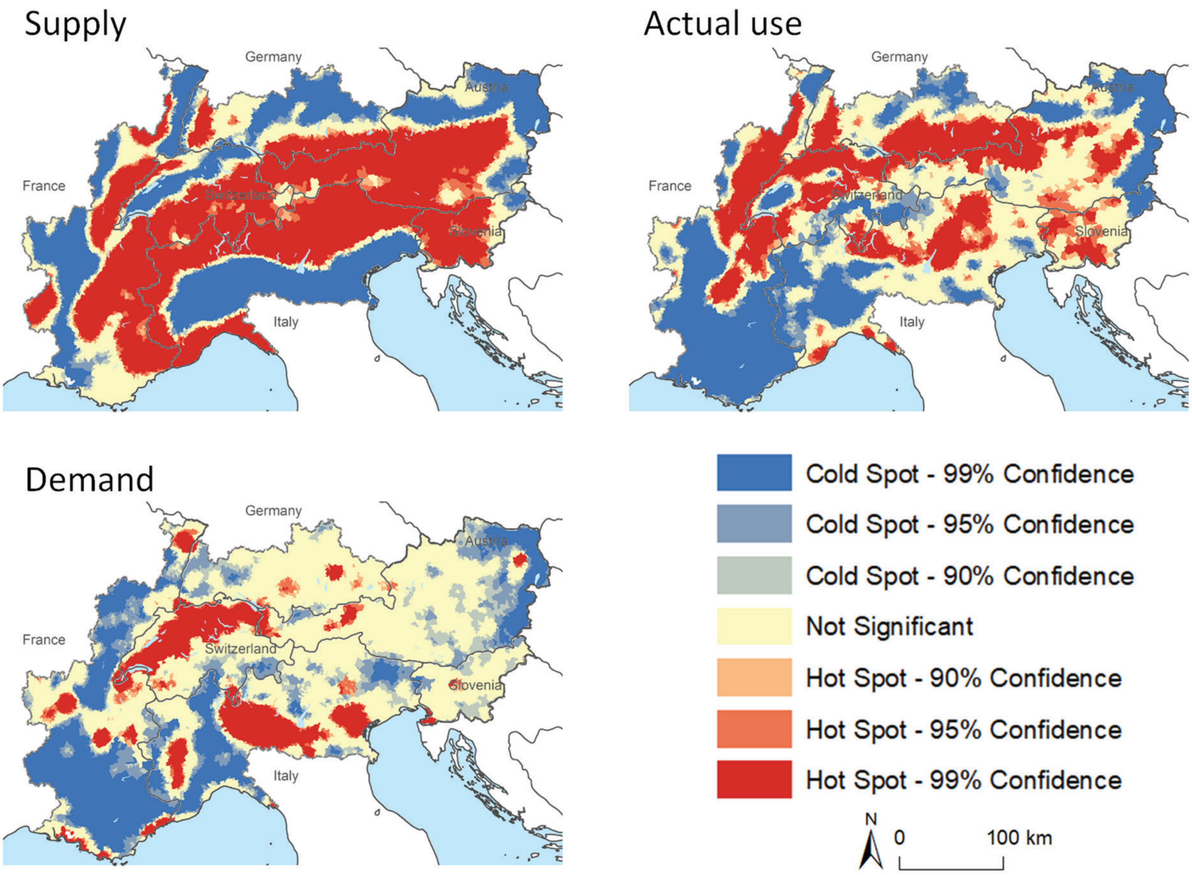

Figure 5. Hotspots of supply, actual use and demand for multiple ES in the Alpine Space area. ES include freshwater, grassland biomass, fuel wood, filtration of surface water, protection against mountain hazards, carbon sequestration, outdoor recreations, symbolic plants and animals. Data sources: Schirpke et al. (2019b).

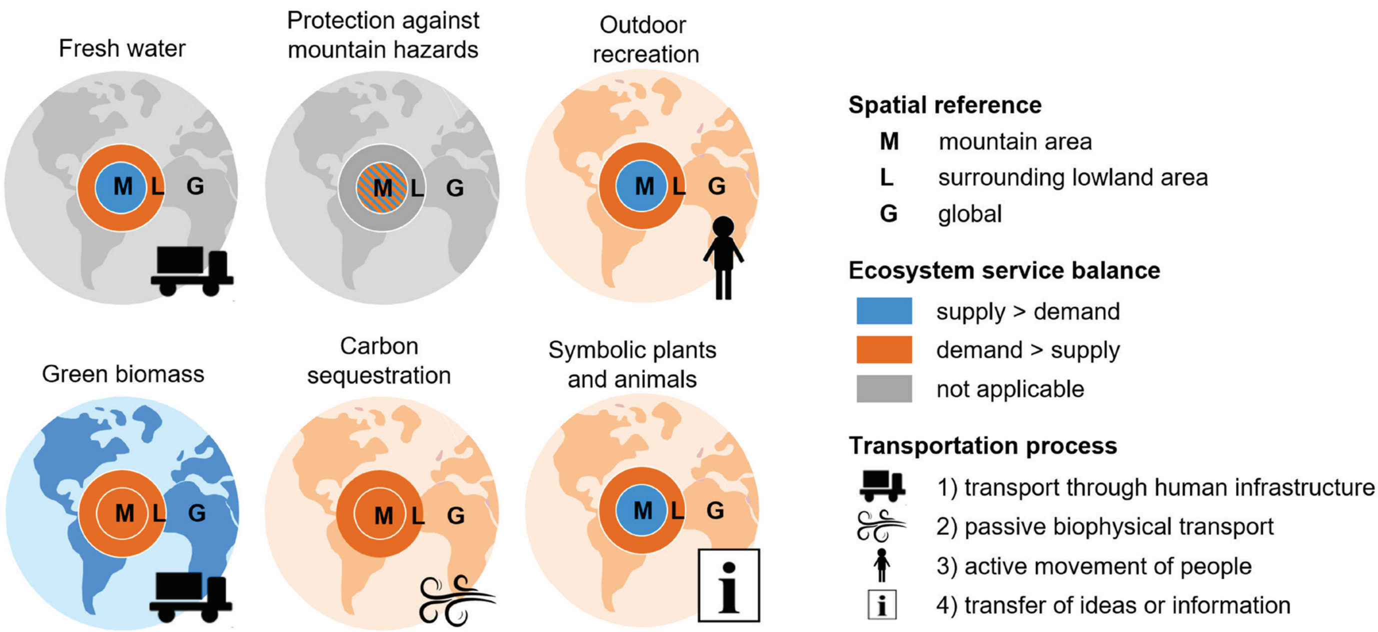

Figure 6. Generalized schemes of ES transfer. The colours indicate for each zone whether it is a service-providing (supply > demand) or a service-demanding area (demand > supply). The symbols represent different types of transportation processes (1–4). From Schirpke et al. (2019d).

4 Outlook

In recent decades, research in ES has achieved important results, but numerous challenges remain, mostly related to the operationalising of the concept, impeding a successful implementation into management and decision-making (Lautenbach et al., 2019; Schröter et al., 2017). Hence, several limitations of current research need to be addressed to develop integrated valuation methods as well as sustainable management strategies of ecosystems in response to global change (Barton et al., 2018; Guerry et al., 2015; Hossain et al., 2018; van Oudenhoven et al., 2018; Wood et al., 2018). Science therefore needs to examine and inform about the impacts of global change on the demand for and supply of ES (Bryan et al., 2018). This includes the identification of underlying ecological mechanisms to adapt to climate change (Lavorel et al., 2015; Seidl et al., 2019) as well as the improvement of knowledge on societal demands and preferences (Schröter et al., 2017). In addition, or related to these issues, several emerging research questions need to be addressed in research on ES to increase its suitability for an effective application.

First, it is necessary to reconcile terminology, classification systems as well as research reporting (McDonough et al., 2017; Wong et al., 2015). While studies point out the importance of using clear definitions and streamlining terminology in the application of the ES concept with stakeholders (Ruckelshaus et al., 2015), a great challenge for researchers is the development of suitable indicators and the reporting of their results (van Oudenhoven et al., 2018). Assessment and clear communication of the uncertainty and the robustness of research results are critical for decision makers (Hou et al., 2013; Landuyt et al., 2015), but this issue has gained interest only recently. In the past, reporting of uncertainty were lacking in most assessments of ES (Schägner et al., 2013), and different methods often lead to inconsistent results (Eigenbrod et al., 2010); therefore, decision makers need to be informed about the accurateness of research results (Landuyt et al., 2015). Conceptual studies point out that the uncertainties in ES studies may regard input data, assessment approaches, modelling techniques and human perceptions or values and that there are huge research gaps (Baustert et al., 2018). However, the accuracy of ES assessments can only be improved when the understanding of ecosystem processes is also improved (Stritih et al., 2019). In the context of climate change, the knowledge about ecosystem thresholds, i.e. vulnerability and resilience of ecosystems in response to management actions, needs to be deepened to adapt management measures and to develop new technologies for land management (Khanna et al., 2018).

Other important research questions are related to the consideration of human-nature interactions in assessments of ES (Barton et al., 2018; Hossain et al., 2018). To date, most studies provide quantitative data on the supply or demand side of ES, but research on how to measure the benefits of ES is still underdeveloped (Olander et al., 2018; Nowak-Olejnik et al., 2022). This means that the linkages between ecological and social processes need to be addressed in depth, for example by visualising the flows of ES to people (Keeler et al., 2019). Focusing on the social dimension, recent studies have emphasised that the relationships among stakeholders and/or beneficiaries of ES are highly complex and characterised by conflicting interests and unequally distributed influence, which may lead to socially unfair outcomes (Schirpke et al., 2020; Turkelboom et al., 2018). A broader understanding of power relationships, asymmetries as well as social dynamics is therefore essential for developing collective solutions based on the concept of ES (Barnaud et al., 2018).

Moreover, as it often remains unclear how the goods and services are being produced and distributed, the concept of ES needs to be reconciled with other existing norms and principles (Bennett et al., 2015; Birch et al., 2014; Schröter et al., 2017). In particular, studies have raised limitations of the concept of ES with respect to sustainable development (Schröter et al., 2017; Wood et al., 2018). Although the provision of ES often matches hotspots of environmental quality, ES indicators usually do not reveal whether the ecosystems are used in a sustainable manner and whether they are associated with positive effects on socio-economic well-being (Schirpke et al., 2019e).

In general, the indicated challenges and emerging issues emphasise the need for extending the knowledge about ecological processes in response to climate change, deepening the understanding of socio-ecological systems and underlying mechanisms as well as enhancing interdisciplinary research.

About this work

This work is a synthesis of a cumulative post-doctoral thesis (habilitation) for the Venia Docendi in Ecology, entitled "Ecosystem services of mountain regions: spatial patterns, impacts and interactions", concluded at the Leopold-Franzens-Universität Innsbruck in 2020. It comprises results of 15 published articles as specified in section 2.

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Declaration of Competing Interest

The author reports no potential conflict of interest.

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