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Mountain Ecosystem Services: Who Cares?

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Mountain regions provide diverse goods and services to human society. At the same time, mountain ecosystems are sensitive to rapid global development. Over the past 2 decades the number of papers mentioning "ecosystem services" (ESS) has risen exponentially. While the concept holds great potential to improve the societal relevance of conservation efforts, it is at risk of dying of misuse and reduction to a buzzword. The definitions of the term often compete and the utility of the concept is under debate. The present article reviews the literature on mountain ESS to investigate whether the term was understood correctly by the community, and addresses the question whether ESS is a suitable concept to protect mountain regions. We link land use and other physical properties of terrestrial ecosystems with their capacity to provide ESS with a view to mapping the global supply of ESS and we contrast it with population density data as a proxy for the demand for ESS. The spatially explicit assessment shows that we can distinguish between mountain areas where demand and supply are well balanced from mountain areas where demand and supply are unbalanced. For these different types of mountain regions we suggest different approaches to package the concept of ESS into spatial decision-making.

Keywords: *Mountains; ecosystem services; ecosystem functions; review; global mapping.*

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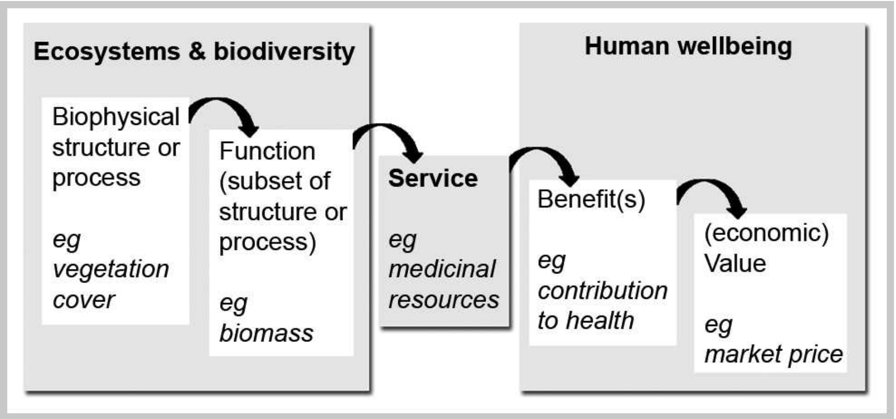
Introduction

Mountain ecosystems provide a vast array of goods and services to humanity, both to people living in the mountains and to people living outside mountains (eg MA 2005; TEEB 2010a): For example, more than half of humankind depends on freshwater that is captured, stored, and purified in mountain regions; from an ecological point of view, mountain regions are hotspots of biodiversity; and from a societal point of view, mountains are of global significance as key destinations for tourist and recreation activities. At the same time, mountain ecosystems are sensitive to rapid global development (eg Körner 2000; Schröter et al 2005). The main pressures result from changes in land use practices, infrastructure development, unsustainable tourism, fragmentation of habitats, and climate change (EEA 2002). While the importance of protecting mountain ecosystems has been widely accepted (eg UN 1992; UNEP 2002), traditional conservation approaches have become a matter of debate, and the concept of ecosystem services (ESS) has risen to prominence (eg Singh 2002; Naidoo et al 2008). Over the past 2 decades research and publications on ESS have grown exponentially (Fisher et al 2009).

The idea of ESS dates back to Westman (1977), who suggested that the social value of the benefits that ecosystems provide could potentially be enumerated so that society can make more informed policy and management decisions. The concept was first termed "ecosystem services" by Ehrlich and Ehrlich in 1981 and gained momentum in scientific literature due to several seminal publications in the 1990s (eg de Groot 1992; Constanza et al 1997; Daily 1997). Currently, the concept is embraced as a bridge between the natural environment and human wellbeing. In popular terms, ESS are the benefits people obtain directly or indirectly from ecosystems (MA 2005). Contrary to traditional conservation approaches focusing on the intrinsic value of nature, the utilitarian concept of ESS explicitly involves beneficiaries, that is, society's demand for services. In mountain areas, where livelihoods are considerably more susceptible to environmental and economic change than those in the lowlands, the concept of ESS that frames the idea of conservation in light of economic benefits can open new revenue streams and make conservation broad-based and commonplace (Chan et al 2006).

Although the concept holds great potential to improve the societal relevance of conservation efforts, it is at risk of dying of misuse and reduction to a buzzword, meeting the fate of the word "sustainability." The term "ecosystem services" has been defined numerous times, but the definitions often compete and do not standardize the meaning, constraints, and measurement of ESS (Boyd and Banzhaf 2007). Many scholars are beginning to question the clarity of the concept, and others have begun to doubt its utility in practice (eg Ghazoul 2007; Sagoff 2010). If the purpose of the concept is to help appreciate natural systems as vital assets, recognize the central roles these assets play in supporting human wellbeing, and incorporate their material and intangible values into decision-making, the supply of and demand for ESS have to be determined. Indeed, if the demand exceeds the supply, a system cannot be self-sustaining, often resulting in ecological degradation. If there is no demand, ESS are

FIGURE 1 The pathway from ecosystem structure and processes to human wellbeing (TEEB 2010a).



unthreatened, and the concept may not serve as a useful management strategy.

In order to contribute toward a clear delineation of the ESS concept, we review the literature on mountain ESS and investigate whether the concept was understood correctly by the scientific community. In a second step, we address the question whether ESS is a suitable concept for protecting mountain regions and suggest how to apply the concept in order to support spatial decision-making in different mountain areas.

Mountain ecosystem services: a review

Our review made use of 3 databases on the world wide web (Web of Science, ScienceDirect, Web of Knowledge) to search for English-language, peer-reviewed journal articles (excluding reviews) using the term "ecosystem services" and either "mountain," " mountainous," "Alps," "Alpine," "Andes," "Carpathians," "Himalaya," or "Kilimanjaro" in their title, abstract, or keywords. We identified a total of 115 studies and analyzed them for their assessment of supply of and demand for ESS. We excluded a total of 22 studies that were not conducted in mountain regions (as defined by UNEP 2002) and an additional 45 studies that mention, but do not concretely deal with, ESS. Appendix 1 provides the list of the remaining studies organized according to the definition of the pathway from ecosystem structure and processes to human wellbeing given in TEEB (2010a) and reproduced in Figure 1. ESS are defined as the direct and indirect contributions of ecosystems to human wellbeing.

The review shows that only a few studies address supply of and demand for ESS. Of the 93 studies conducted in mountain areas, 48 contributions (52%)

FIGURE 2 Number of papers addressing mountain ecosystem services identified in a comprehensive literature review. Shown are the proportion of contributions that (1) identify ecosystem functions (ESF), (2) include a valuation of ecosystem services (ESS), and (3) consider local demand for ESS.

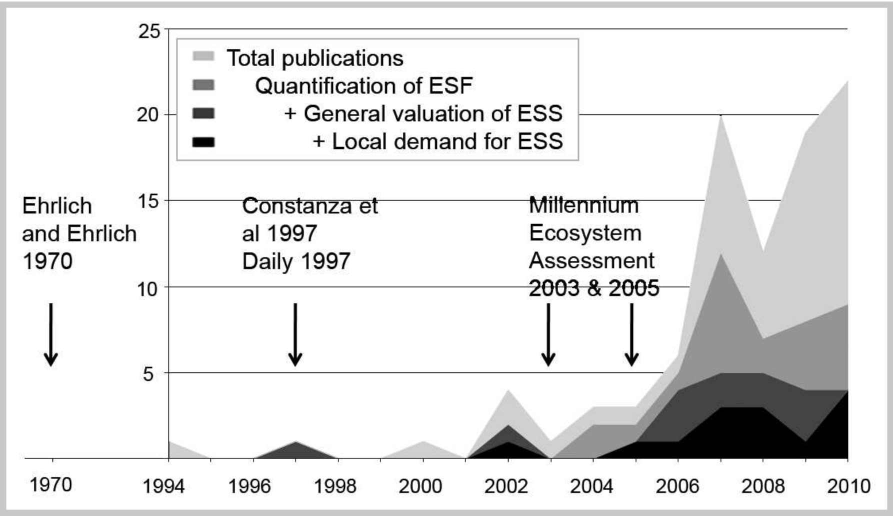


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TABLE 1 Binary links between land characteristics and ecosystem services: 0 = indifferent role, 1 = supportive role (based on Kienast et al 2009). (Table extended on next 2 pages.)

Land characteristics	Production services				
	Wildlife products	Cultivated products	Commercial forest products	Transport and housing	Energy (biofuel and renewable energy)
Land use					
Artificial surface (MODIS class 13)	0	0	0	1	0
Forested area (MODIS classes 1, 2, 3, 4, 5)	1	1	1	0	1
Heterogeneous agricultural areas (MODIS class 14)	1	1	0	0	1
Open space with little or no vegetation (MODIS classes 9, 15, 16)	1	0	0	0	0
Pastures (MODIS class 10)	1	1	0	0	0
Permanent crops (MODIS class 12)	0	1	0	0	0
Shrub and herbaceous (MODIS classes 6, 7, 8)	1	1	0	0	1
Water bodies (MODIS class 0)	1	0	0	1	0
Wetlands (MODIS class 11)	1	0	0	0	0
Elevation					
Up to 1500 masl	1	1	1	1	1
Higher than 1500 masl	1	0	0	0	1
Slope					
Steep slopes (>30%)	1	0	0	0	1
Urban area					
Urban areas (>50,000 inhabitants)	0	0	0	1	0

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TABLE 1 Extended. (First part of Table 1 on previous page, last part extended on next page.)

Land characteristics	Regulation services					
	Climate regulation	Natural hazard reduction	Water regulation	Water treatment and nutrient cycling	Erosion prevention	Biological control
Land use						
Artificial surface (MODIS class 13)	0	0	0	0	0	0
Forested area (MODIS classes 1, 2, 3, 4, 5)	1	1	1	0	1	1
Heterogeneous agricultural areas (MODIS class 14)	0	0	1	0	1	1
Open space with little or no vegetation (MODIS classes 9, 15, 16)	0	0	0	0	0	0
Pastures (MODIS class 10)	0	0	0	0	0	0
Permanent crops (MODIS class 12)	0	0	0	0	0	1
Shrub and herbaceous (MODIS classes 6, 7, 8)	1	0	0	0	0	1
Water bodies (MODIS class 0)	0	1	1	1	1	0
Wetlands (MODIS class 11)	1	1	1	1	1	1
Elevation						
Up to 1500 masl	1	1	1	1	0	1
Higher than 1500 masl	1	1	1	0	0	1
Slope						
Steep slopes (>30%)	1	0	0	0	0	0
Urban area						
Urban areas (>50,000 inhabitants)	0	0	0	0	0	0

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TABLE 1 Extended. (First and second parts of Table 1 on previous 2 pages.)

Land characteristics	Supporting services	Cultural services		
	Habitat function	Aesthetic information	Recreation and tourism	Cultural and artistic information
Land use				
Artificial surface (MODIS class 13)	1	1	1	1
Forested area (MODIS classes 1, 2, 3, 4, 5)	1	1	1	1
Heterogeneous agricultural areas (MODIS class 14)	1	1	1	1
Open space with little or no vegetation (MODIS classes 9, 15, 16)	1	1	1	0
Pastures (MODIS class 10)	1	1	1	1
Permanent crops (MODIS class 12)	0	1	1	0
Shrub and herbaceous (MODIS classes 6, 7, 8)	1	1	1	1
Water bodies (MODIS class 0)	1	1	1	1
Wetlands (MODIS class 11)	1	1	1	1
Elevation				
Up to 1500 masl	1	1	1	1
Higher than 1500 masl	1	1	1	1
Slope				
Steep slopes (>30%)	0	0	1	1
Urban area				
Urban areas (>50,000 inhabitants)	1	1	1	1

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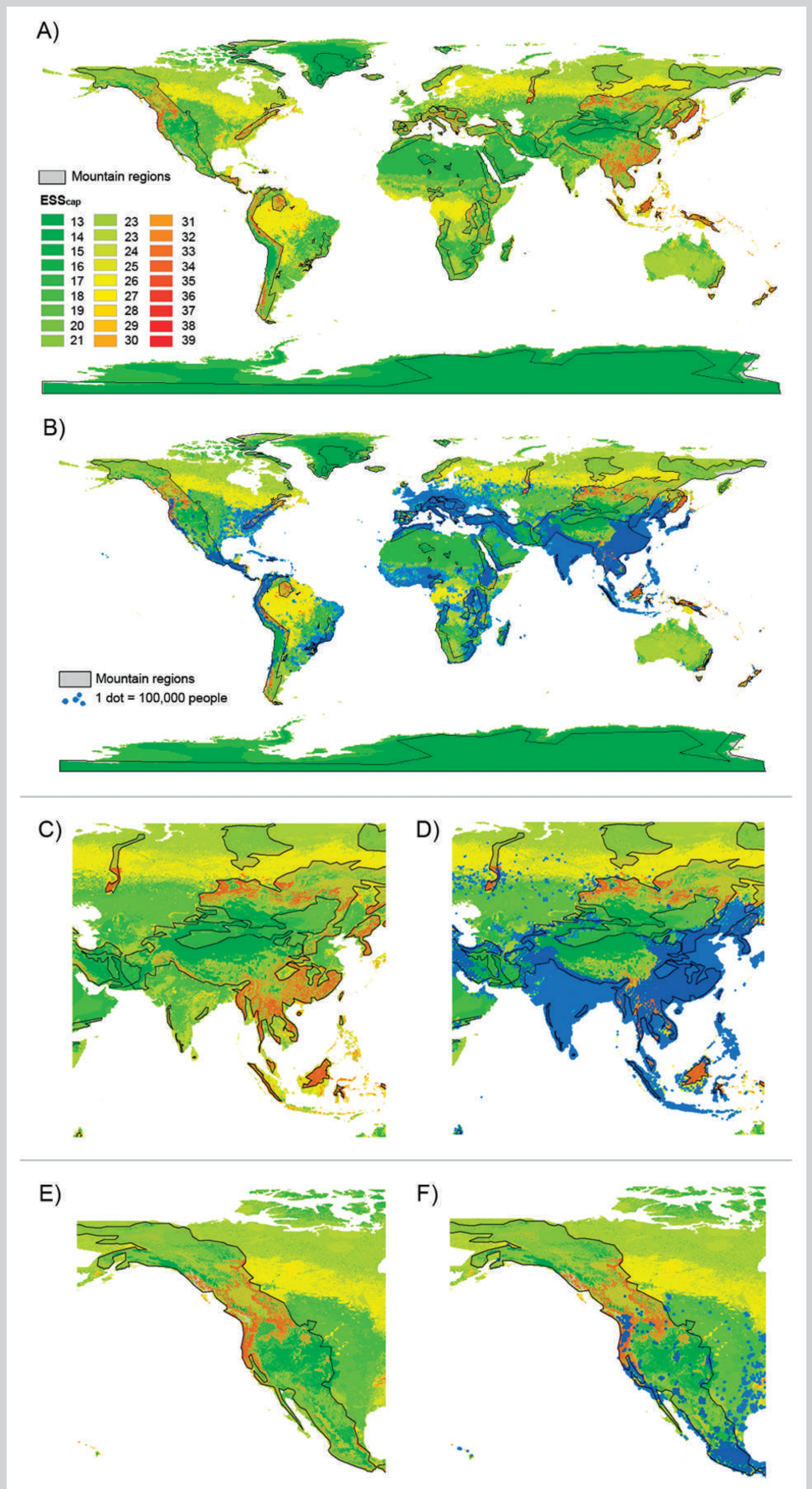
FIGURE 3 (A) Capacity of different mountain regions to provide ecosystem services (ESS). The maps display the proxy ESS_{cap}, measuring to what degree the 15 selected ESS are supported by the underlying land characteristics (see text for calculation details). (B) Population density data highlighting regions of high demand for ESS. (C) and (D) High supply of and high demand for ESS in the Himalaya. (E) and (F) High supply of and low demand for ESS in the mountains of North America.



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quantify ecosystem functions, but only 26 (31%) include a quantitative or qualitative valuation of these functions. Almost half of the latter use global valuation coefficients or similar value transfer methods to value local ESS. Only 14 (15%) of the analyzed studies integrate valuation methods considering the demand for ESS at the study site.

Figure 2 shows the number of publications addressing mountain ESS. Mainstreamed by the Millennium Ecosystem Assessment reports in 2003 and 2005, efforts to put the concept into practice in mountain regions have increased strongly. Nevertheless, more than 80% of the contributions use the concept of ESS as a buzzword, not connecting ecosystem functions with human wellbeing. Only a very small proportion of the studies assess the supply of and demand for ESS. This might result from the still ongoing debate about how to define ESS or from the many uncertain issues that still remain to be resolved to fully integrate the concept of ESS into management (for an overview, see de Groot et al 2010). However, the results raise the question whether ESS is a suitable concept to support the design of management strategies for sustainable development of mountain regions and whether it can innovate traditional conservation planning.

We address this question by globally mapping the distribution of terrestrial ESS and demand for the services. In light of the urgent need for protecting fragile mountain ecosystems, we highlight areas where ecosystems and their services are under pressure. Here, the concept of ESS can provide important support for helping meet conservation objectives, while also ensuring development of a region.

Global supply of and demand for mountain ecosystem services

The increased availability of geo-referenced data boosts the potential to spatially assess ESS by connecting services to mapped physical properties of landscapes (Kienast et al 2009). However, as the lack of appropriate data and the heterogeneity and uncertainty in the interrelationships between properties and services increase with increasing scale (eg Costanza et al 2008), only a few studies provide global spatial assessments of ESS (Constanza et al 1997; Sutton and Constanza 2002; Schröter et al 2005; Metzger et al 2006; Turner et al 2007).

Global-scale assessments in the field of conservation planning are even scarcer. Naidoo et al (2008) present a method for the quantification of 4 ESS (carbon sequestration, carbon storage, grassland production of livestock, water provision) in biophysical units based on complex response functions that capture the link between ESS and land characteristics in sophisticated process models. The study provides valuable information on the global distribution of the selected ESS but is not directly applicable to other services with little process knowledge (Kienast et al 2009).

Burkhard et al (2009) and Kienast et al (2009) present straightforward modeling frameworks at the continental scale that operationalize the links between the characteristics of a given parcel of land and its capacity to provide ESS. The generated maps focus mainly on the capacity to supply services. In a recently published article, Burkhard et al (2011) extend their approach and derive a supply and demand matrix for specific land uses. They show that the more human-dominated the land use, the higher the demands for ESS. Our proxy for demand, that is, population density, thus shares the paradigm proposed by Burkhard et al (2011).

Modeling framework and results

We base our analysis of the *global supply* of ESS on the methodological framework developed by Kienast et al (2009). In their approach the capacity of any given parcel of land to provide specific terrestrial ESS is derived from binary look-up tables. These tables summarize the potentially supportive (value = 1) or neutral roles (value = 0) of selected land characteristics for given ESS. Both the choice of the land characteristics and the look-up tables are driven by literature on ESS at the European scale and by knowledge of an expert panel (5 experts).

In the present modeling framework, we used the look-up tables developed by Kienast et al (2009) and applied them to a global land characteristics raster dataset in 1-km resolution. We restricted our final data set to 4 parameters: land use, elevation, slope, and urban area, and 15 ESS: "wildlife products," "cultivated products," "commercial forest products," "transportation and housing," "energy," "climate regulation," "natural hazard reduction," "water regulation," "waste treatment and nutrient cycling," "erosion prevention," "biological control," "habitat function," "aesthetic information," "recreation and tourism," and "cultural and artistic information" (Table 1).

Land use data of the year 2008 were obtained from the MODIS land cover type product from the US Geological Survey (USGS 2009). Slope and elevation were mapped using the GTOPO30 global digital elevation model (USGS 1996), and urban area was derived from the population data set of the Socioeconomic Data and Application Centre (SEDAC 2010).

In order to determine the capacity of each grid cell (1 km^2) to provide the selected ESS, we first checked which of the 4 pixel characteristics (land use, elevation, slope, urban area) potentially supports a service ("1" in Table 1). If only one land characteristic supports the service, the resulting capacity is "1"; if all 4 characteristics support the service the resulting capacity is "4." The term capacity (ranging from 1 to 4 for each service) does not express any amounts (tons, financial value) of an ESS, but rather a score that this service is likely to be supported by the land characteristics of the grid cell. Subsequently we added the "capacity" values for all 15 ESS per grid cell and

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obtained a final proxy (ESS_{cap}) expressing to what degree the land characteristics of the cell support the 15 selected services. If ESS_{cap} is high (maximum obtained 39), many services are strongly supported. If ESS_{cap} is low (minimum obtained 13), support for the selected 15 services is very limited. Consequently ESS_{cap} strongly correlates with the richness of ESS at a given cell of the earth's surface.

As a proxy for the *global demand* for ESS, we used population density data of the year 2010 from SEDAC (2010) at a resolution of 5 km.

We acknowledge that there are many conceptual problems inherent to this pragmatic approach. Our results, however, help to (1) illustrate that the spatial distribution of supply of and demand for ESS matters, (2) set up a preliminary framework for further refined analysis, and (3) distinguish different applications of how the ESS concept can influence spatial decision-making in mountain regions.

The map showing the capacity (ESS_{cap}) of land to provide terrestrial ESS at a global scale reveals that the highest values of ESS_{cap} coincides with mountain regions (Figure 3A). This is plausible, since mountain areas have the highest heterogeneity of land use characteristics, and ESS_{cap} primarily measures ESS richness. Especially mid-elevated sites at the border of mountain areas potentially support many different services, while the world's highest summits and plateaus carry less capacity to deliver ESS. Figure 3B shows the same map of ESS capacity (ESS_{cap}), but overlaid with the world's population of the year 2010. With regard to mountain areas, the population density is highest in the northern part of the Andes and in larger parts of the Himalaya (Figure 3C, D), at the borders of the mountain areas where the potential to supply many different ESS is high. By contrast, larger regions of the mountains in North America (Figure 3E, F) as well as in Europe are less densely populated. Thus, local demand for ESS—contrary to the supply—substantially varies throughout the world's ecosystems. One can distinguish mountain regions with a high capacity to supply ESS and a high local demand from mountain regions with high local supply and low local demand. This pattern may become even more pronounced in the future due to population dynamics: In mountain regions of developing countries, the population has increased a great deal in the last decades, such as by 25% in the Himalaya between 1991 and 2001 (Zutshi 2003). In contrast, many mountain regions in industrialized countries show marginalization tendencies over the past few decades; for example, more than a quarter of all municipalities in the Alps experienced a population decrease over the last 20 years (CIPRA 2007).

While the approach shows that a spatially explicit application of the ESS concept can demonstrate the importance of mountain areas in supporting human wellbeing, the approach used here clearly needs further refinement. The binary links between ecosystem properties and the capacity to deliver services should be further elaborated with stakeholders to get a more accurate quantification of the spatially explicit assessments of the capacity to deliver services. We acknowledge that the population density is only a rough proxy for the demand for ESS.

Discussion

Due to their integrative character ESS have a high potential for application in resource and environmental management (eg de Groot et al 2010). Supply of and demand for ESS are equally important issues of the concept (eg Burkhard et al 2011). However, the review of literature on ESS studies in mountain areas revealed that many contributions concentrate only on the supply and the quantification of ecosystem functions. Another considerable fraction of the publications uses global valuation coefficients to value EES based on local ecosystem characteristics. For some ESS, for example, for carbon sequestration, this might be an adequate approach, as supply and demand can be balanced at the global scale. However, for many services, local or regional demand is crucial for developing appropriate management strategies.

We are aware that using population density data as a proxy for ESS demand is a very rough estimate, since not only population dynamics but also people's perceptions and behavior and economic factors determine the local demand (Burkhard et al 2010). Moreover, demand in certain mountain areas can vary according to seasons, depending heavily on the inrush of tourists, which can lead to up to double the number of residents (eg Grêt-Regamey and Kytzia 2007); these seasonal variations are not recorded in CIESIN datasets. Nevertheless, our approach of contrasting the spatially explicit distribution of the capacity of land to deliver ESS with population data allowed for some interesting insights: We were able to distinguish areas where demand and supply are well balanced and areas where the 2 proxies differ widely. The latter are found primarily in areas with high population density (eg the Andes, the Himalaya, and Africa), where the local demand for ESS is high. Here the concept of ESS should especially focus on making apparent local trade-offs between the various ESS and aim at maximizing the "output value" of an ecosystem, that is, the value attached to direct ecosystem services and benefits, while preserving its "insurance value," that is, the capacity to maintain the benefits in future (TEEB 2010b). Thus, the concept should help support the provision of services that are socially valuable and open new income opportunities for the local population. This strategy helps to meet conservation objectives while ensuring the development of a region. Case studies from such regions (eg Saxena et al 2001; Chettri et al 2007; Turpie et al 2008) demonstrate that local participation and the incorporation of concerns, knowledge, and perceptions of indigenous people is crucial for the success of ESS-based management.

In areas characterized by agricultural abandonment, where traditional farming systems are in decline (eg the Alps or the Pyrenees), the local demand for ESS and their trade-offs are decreasing. The landscape is likely to be conserved without action, but we need to make sure that these ecosystems are resilient to changes. Management strategies should target the maintaining of the "insurance value" of the ecosystems (TEEB 2010b). However, some of the areas are characterized by hotspots of high touristic activities. Here, local demand for ESS is high, and the application of the ESS concept should focus on complementing conservation efforts, especially to support mechanisms where farmers take a role as stewards of the landscape measures that reinforce current support for forest and agricultural systems in recognition of cultural ESS. Such strategies have been suggested by various authors (eg Grêt-Regamey et al 2008b; Quetier et al 2010), who recognized that cultural ESS are the most prominent drivers of the ESS concept at study sites in the Alps and Pyrenees.

Conclusions

While the ESS concept has taken flight and the number of studies on the topic published is increasing exponentially, we need to make sure that this powerful concept—allowing us to link nature and human wellbeing—does not become worthless. Demand for ESS should not exceed the supply of the services. Especially in mountain regions, which are highly vulnerable to socioeconomic and climatic changes, human wellbeing will, on the one hand, depend on the sustainable supply of ESS, and thus on optimal land management ensuring the availability of the resources. On the other hand, human wellbeing will depend on the capacity of the systems and human societies to cope with the impacts of local and global change. Projections of expected impact on the demand for and supply of ESS under shifting socioeconomic, political, and climatic trends will provide a basis to support spatial decision-making at regional scale that optimizes quality of life while securing ESS for a more sustainable form of development.

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APPENDIX 1 Papers addressing mountain ecosystem services (ESS). All studies consider ecosystem structures and functions (ESF).

Location	Ecosystems services (ESS) considered	Study
Local demand for ESS and ESS valuation		
Africa	Carbon sequestration, water supply, timber production (quantitative valuation)	Chisholm (2010)
	Various (qualitative valuation)	Kijazi et al (2010)
Alps	Avalanche protection, carbon sequestration, biomass production (quantitative valuation)	Grêt-Regamey and Kytzia (2007)
	Avalanche protection, scenic beauty, wood production, habitat (quantitative valuation)	Lundström et al (2007)
	Avalanche protection, wood production, scenic beauty, habitat (quantitative valuation)	Grêt-Regamey et al (2008a)
	Avalanche protection, scenic beauty, carbon sequestration, habitat (quantitative valuation)	Grêt-Regamey et al (2008b)
	Avalanche protection (quantitative valuation)	Teich and Bebi (2009)
	Biodiversity, fodder/grass production, cultural heritage, habitat, aesthetics (qualitative valuation)	Quetier et al (2010)
Andes	Food production, habitat, erosion control (quantitative valuation)	Rodriguez et al (2006)
	Water supply (qualitative valuation)	Mulligan et al (2010)
Himalaya	Food production, soil/biodiversity conservation, hydrological balance, carbon sequestration (quantitative valuation)	Saxena et al (2002)
	Various (integrative qualitative valuation)	Chettri et al (2007)
	Water/fodder/fuelwood/food supply (qualitative valuation)	Tiwari (2008)
Portugal	Various (qualitative valuation)	Pereira et al (2005)
ESS valuation, but no local demand for ESS		
Africa	Water production, wildflower harvest, ecotourism, habitat (quantitative valuation)	Higgins et al (1997)
	Water supply, tourism (quantitative valuation)	Currie et al (2009)
Alps	Nature conservation, biodiversity (qualitative valuation)	Geneletti (2007)
China	Ecotourism, water/soil conservation, air purification, nutrient cycling (quantitative valuation)	Wu et al (2002)
	Gas regulation, water regulation/supply, soil conservation, biomass (quantitative valuation)	Li et al (2006)
	Natural resources, gas regulation, water/soil conservation, OM production, nutrient storage, biodiversity, recreation, social effect (quantitative valuation)	Chen et al (2006)
	Natural resources, gas regulation, water/soil conservation, OM production, nutrient storage, biodiversity, recreation, social effect (quantitative valuation)	Zhou et al (2006)
	Various (integrated quantitative valuation)	Li et al (2007)
	Various (integrated quantitative valuation)	Li et al (2008a)
	Various (integrated quantitative valuation)	Li et al (2008b)
	Water supply, soil protection, biodiversity, products (qualitative valuation)	Wang et al (2009)
	Erosion control (qualitative valuation)	Zhao et al (2009)
Only quantification of ecosystem functions (ESF)		
Africa	Water quality, flood attenuation, carbon sequestration, biodiversity	Walters et al (2006)
	Water supply, biodiversity, fire protection	Turpie et al (2008)
Alps	Fodder production, snow gliding protection, cultural heritage, soil fertility, sustainable production	Diaz et al (2007)
	Grass production, forage quality, aesthetics, biodiversity, cultural heritage, snow gliding protection	Quetier et al (2007)
	Avalanche protection	Ramming et al (2007)
	Climate/gas regulation, water supply	Tenhunen et al (2009)
	Biodiversity, pollination	Obrist and Duelli (2010)
Andes	Climate regulation, water supply	Farley et al (2004)
	Nutrient cycling, soil formation, raw materials	Farley (2007)
	Biodiversity, wood production	Jameson and Ramsay (2007)
	Water supply, biodiversity	Gerold et al (2008)
	Climate regulation, nutrient cycling	Carvajal et al (2009)
	Water supply, flood protection	Ponette-Gonzales et al (2010)
Carpathians	Carbon storage, habitat	Keeton et al (2010)
Himalaya	Biodiversity, food production, resource recycling	Semwal et al (2004)
	Biodiversity	Singh et al (2005)
	Soil/water/nutrient conservation	Sharma et al (2007a)
	Nutrient cycling, erosion protection, biodiversity, resource protection, carbon sequestration, food production, aesthetics	Sharma et al (2007b)
	Soil/water conservation, carbon sequestration, aesthetics, recreation, education, ecotourism	Sharma et al (2009)
Sierra Nevada (USA)	Nutrient cycling, aesthetics, erosion prevention, buffering capacity	Burt and Rice (2009)
	Water supply, hydropower generation	Null et al (2010)
Sierra Nevada (Spain)	Carbon sequestration	Padilla et al (2010)

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