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MAPPING ECOSYSTEM SERVICES SUPPLY IN MOUNTAIN REGIONS: A CASE STUDY FROM SOUTH TYROL (ITALY)

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Abstract – Mountain regions provide many ecosystem services and spatially explicit assessments have to account for their specific topographic and climatic conditions. Moreover, it is fundamental to understand synergies and trade-offs of multiple ecosystem services. In this study, ecosystem services supply, including forage production, timber production, water supply, carbon sequestration, soil stability, soil quality, and the aesthetic value, was quantified in bio-physical terms on the landscape scale for South Tyrol. Mean ecosystem services values of the 116 municipalities were grouped in 5 clusters. The results indicate that carbon stock is the prevailing ecosystem service of valley municipalities. On contrast, they suffer from water deficit and depend on water supply from high mountain municipalities. Trade-offs can be also found between the aesthetic value on one hand and timber production, carbon sequestration and soil stability on the other hand. The latter are characteristic for municipalities dominated by forest. The resulting maps can support landscape planning, ecosystem management and conservation of biodiversity.

Keywords: Ecosystem services; cluster analysis; topography; spatial analysis; Alps, mapping; trade-offs

Introduction

The action 5 of the EU Biodiversity Strategy to 2020 requires the assessment and mapping of ecosystem services to support the protection and restoration of ecosystems and their services (Maes et al., 2013). A spatially explicit assessment in bio-physical terms is essential to quantify and value ecosystem services (Hein et al., 2006). Moreover, it is a principal requirement for ecosystem services maps which can support ecosystem or landscape planning, ecosystem management and conservation of biodiversity (Tallis & Polasky, 2009; Caspersen & Olafsson, 2010; Koschke et al., 2012; Burkhard et al., 2013).
Mountain regions provide many ecosystem services, which are essential on the local and regional level, such as provision of food, fibre and drinking water, as well as flood regulation and recreation (MEA, 2005; Gios et al., 2006). At the same time, many of them are of great importance for the related lowland regions, because ecosystem services supply and their beneficiaries may be in different locations (Fisher et al., 2009; Bagstad et al., 2013). The delivery of ecosystem services in general is mainly influenced by the landscape composition and configuration (Schröter et al., 2005; Metzger et al., 2006; Verburg et al., 2009). In mountain regions, many ecosystem services also depend on topographical conditions (De Groot, 2002) which influence ecological functions and processes, for example microclimate (Beniston, 2006), plant distribution and growth (Gottfried et al., 1999; Dirnböck et al., 2003), soil development, soil moisture and nutrient availability (Becker et al., 2007). Although there is a growing number of studies dealing with mapping ecosystem services on the landscape scale (see Martínez-Harms & Balvanera, 2012 for review), only few spatially explicit studies of ecosystem services were carried out in mountain regions, especially in the Alps (Grêt-Regamey et al., 2008; Lavorel et al., 2011; Schirpke et

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al., 2013). Moreover, it is important to evaluate the interrelations of multiple ecosystem services regarding their synergies and trade-offs (Bennett et al., 2009; Raudsepp-Hearne et al., 2010).
This study aims to assess multiple ecosystem services of mountain regions on the landscape scale, including forage production, timber production, water supply, carbon sequestration, soil stability, soil quality, and the aesthetic value. All ecosystem services were quantified in bio-physical terms for South Tyrol accounting for the specific topographical conditions of mountain regions. Finally, the different ecosystem services were summarized on municipality level and bundled into similar groups to assess synergies and trade-offs.

MATERIALS AND METHODS

Study area and input data

The Autonomous Province of Bolzano-South Tyrol (Italy), organized in116 municipalities, is located in the Central Alps and covers an area of 7.400 km² (Figure 1). Elevation ranges from 194 m to 3.893 m and about 40 % of the area is situated above 2.000 m. Almost 50% of the total area is covered by forest and about 30% is used for agriculture. While the lower valleys are characterized by strong anthropogenic use with settlements and intensive agriculture (mainly orchards and vineyards), dairy farming and forestry prevail in regions above 900 m a.s.l. . With increasing elevation, agriculture is getting less intensive.

The following spatial datasets were used for mapping ecosystem services:

- Land use/cover map with a scale of 1:10,000 (Autonomous Province of Bolzano-South Tyrol, 2001), integrated with forest typologies (Autonomous Province of Bolzano-South Tyrol, 2009);
- Digital Elevation Model (DEM) with a spatial resolution of 20x20 m (Autonomous Province of Bolzano-South Tyrol, 2000), from which slope and aspect were derived;
- Municipality borders map (Autonomous Province of Bolzano-South Tyrol, 2010);
- Precipitation data (Autonomous Province of Bolzano-South Tyrol, 2011).

Mapping ecosystem services

Multiple ecosystem services (forage production, timber production, water supply, carbon sequestration, soil stability, soil quality, aesthetic value) were quantified in bio-physical terms for the whole area of South Tyrol. All ecosystem services were assessed on landscape scale and mean values were calculated for the 116 municipalities of South Tyrol. These mean values were used for ecosystem services maps with natural breaks classification for symbology (Figure 2). To identify synergies and trade-offs, the correlations between ecosystem services were tested by Spearman's correlation for rank-ordered data. For each ecosystem service, the applied method is shortly described in the following.

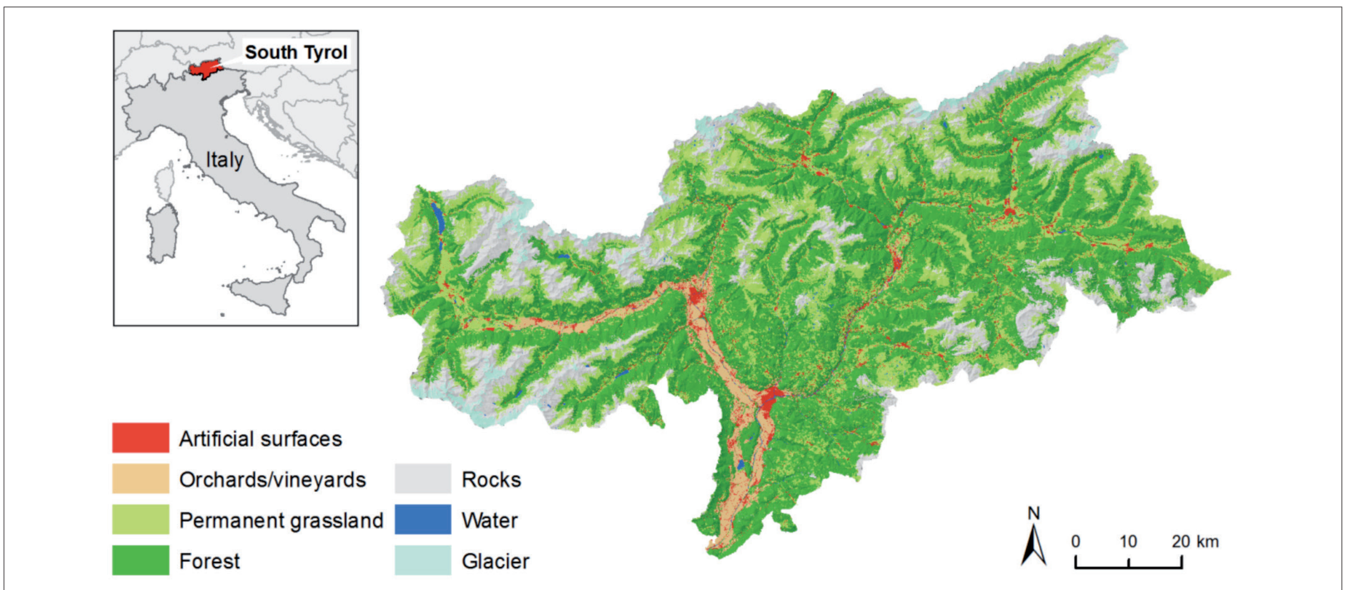

Figure 1. Location of the study area and main land use/cover classes of South Tyrol.

Forage production

Forage quantity of permanent grassland was estimated based on the productivity of different grassland types (Egger et al., 2005; Tasser et al., 2012) and taking into account the growing season, which depends on elevation and the climate zone (Harflinger & Knees, 1999). The resulting forage quantity was corrected by slope and aspect and by the total amount of summer precipitation (April to September) which is limiting the forage production. For more details see Egger et al. (2005) and Schirpke et al. (2013).

Timber production

Potential timber production was mapped for forest areas by relating the forest types of the land use map to average yearly growth rates of the different forest types as estimated by the second Italian National Forest Inventory on regional level (INFC, 2005).

Water supply

Water supply is defined as the amount of available water for domestic and industrial use, tourism and energy supply during the main growing season (Mai – August) where the water demand for agricultural production is highest and water shortages are most critical (Grashey-Jansen, 2010). To quantify the water supply, the water balance was calculated based on precipitation and evapotranspiration. Monthly mean precipitation was interpolated from point measurements and corrected with elevation (Sevruk, 1997). Evapotranspiration was based on the days with vegetation growth (Harflinger & Knees, 1999) and mean evapotranspiration rates of the different land-use types. Subsequently, evapotranspiration was corrected by slope and aspect. For more details see Schirpke et al. (2012).

Carbon sequestration

Mapping and quantification of carbon stocks was based on above- and belowground phytomass of vegetation types and carbon densities related to the land use/cover classes. Carbon stock values were derived from literature data complemented with own measurements. For more details see Schirpke et al. (2013) and Tappeiner et al. (2008). Carbon sequestration of forests was quantified based on the average yearly growth rate of forest types (INFC, 2005). The associated amount of fixed carbon was estimated by applying a biomass expansion factor, the wet-to-dry ratio and the carbon fraction (Federici et al., 2008).

Soil stability

Mapping of soil stability was based on the Universal Soil Loss Equation (Wischmeier and Smith 1978) and included slope, root density, and vegetation cover. Slope characteristics were derived from the DEM; root density and the percentage of vegetation cover were based on a root model and own measurements (Tasser et al., 2005). All variables were weighted equally and a soil stability index with values from 0 to 100 was calculated on pixel basis.

Soil quality

To assess the soil quality, the Biological Soil Quality (BSQ) index (Parisi et al., 2005) was used as an indicator. Soil quality is related to the number of soil macrofauna groups well adapted to soil habitats which can be measured by the Ecomorphological index (EMI). The BSQ of each land use class was based on the sum of the EMI of all present taxa (Rüdisser et al., in pers. comm.).

Aesthetic value

The aesthetic value was derived from a photo-survey comprising 24 pictures of different typical mountain landscapes. A total of 966 persons, locals and tourists, were interviewed in different locations in the Central Alps and asked to value the pictures according to their beauty (1 = “I do not like it at all” … 10 =” I like it very much”). Mean preference values were calculated for each picture. As the pictures presented specific land use/cover types, it was possible to associate them to the land use/cover classes of the map (Timmermann, 2012).

Cluster analysis

To group municipalities with similar ecosystem services, a Hierarchical (agglomerative) Cluster Analysis (HCA) was applied after rescaling mean values for each municipality of South Tyrol from 0 to 1. Thereby, the Euclidean distance measure and Ward’s linkage method were used and the group membership at each step of cluster formation was written to a file. We used the Euclidean distance measure, because it weights large differences more heavily than several small differences, which results in greater sensitivity to outliers (McCune & Grace, 2002).

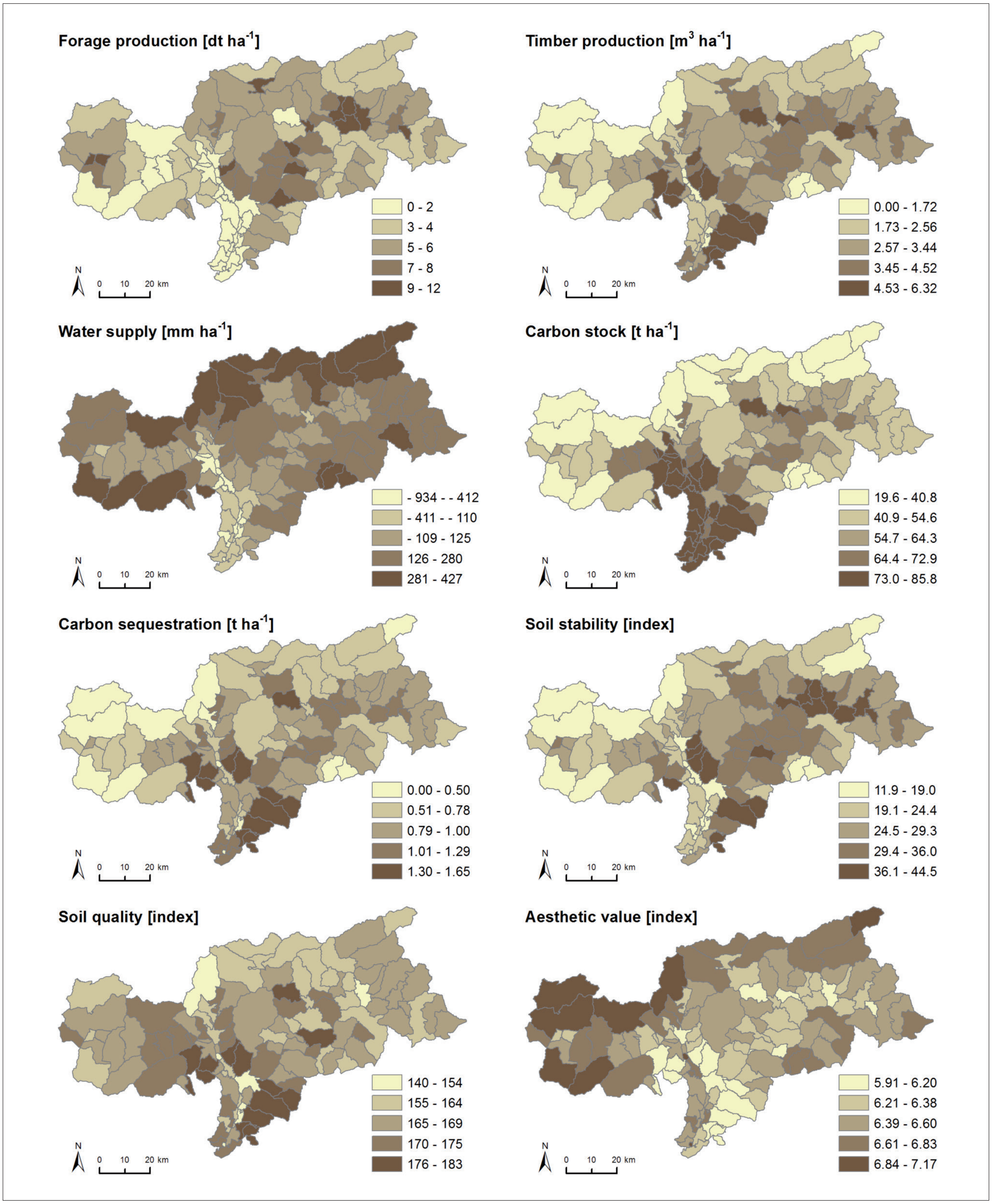

Figure 2. Mean ecosystem service values for all municipalities of South Tyrol. All ecosystem services are presented in bio-physical terms with natural breaks classification.

Results

Mean values of the different ecosystem services were mapped for each municipality of South Tyrol. Thereby, differences of ecosystem services supply were revealed for the 116 municipalities (Figure 2). Forage production is highest in the central and eastern part of South Tyrol for municipalities with a high percentage on permanent grassland. While high mountain regions, in particular along the main mountain ridge of the Alps, are characterized by a water surplus, the municipalities in the valleys show a great water deficit, especially those with intensive permanent cultivations in the Adige Valley. Carbon stock decreases with increasing elevation. Timber production, carbon sequestration, soil stability and soil quality are highest for municipalities with a high percentage of forest, which are located mainly in the central and eastern part. On contrast, the aesthetic value is lowest for these municipalities and highest for high mountain regions, especially in the western part of South Tyrol.

To identify municipalities with similar ecosystem services, a cluster analysis was carried out leading to 5 clusters (Figure 3). Mean ecosystem services values for the different clusters are summarized in Table 1. Cluster 1 consists of mountain municipalities dominated by forest and characterized by the highest values for timber production, carbon sequestration, soil stability and soil quality, whereas the aesthetic values is lowest in comparison with the other clusters. Cluster 2 contains small valley municipalities with intensive agricultural use, i.e. orchards and vineyards. It has the lowest values for forage production, timber production, water supply, soil stability, and soil quality. Cluster 3 includes valley municipalities with large differences in elevation, high percentage of artificial areas, forest and intensive agriculture. These municipalities have the highest values for carbon stock, a good carbon sequestration and soil quality, while forage production and water supply are low. Cluster 4 comprises of mountain municipalities which have the highest values for forage production, good values for timber production, water supply and soil stability. Cluster 5 represents large high mountain municipalities which have the highest water supply and the highest aesthetic value, whereas carbon stock and carbon sequestration are lowest.

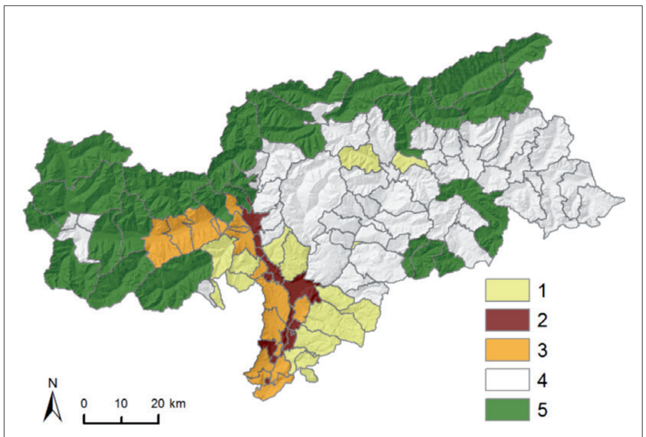

Figure 3. All municipalities of South Tyrol were grouped into 5 clusters by Hierarchical (agglomerative) Cluster Analysis (HCA) based on rescaled mean ecosystem services values of the 116 municipalities.

Table 1. Mean ecosystem services values for the 5 clusters. Topographical variables, land use/cover distribution and mean area are reported for each cluster.

Ecosystem services	Cluster 1 (N = 16)	Cluster 2 (N = 12)	Cluster 3 (N = 16)	Cluster 4 (N = 47)	Cluster 5 (N = 25)
Forage production (dt ha^{-1})	4.69	0.50	1.38	6.89	4.04
Timber production (m^3 ha^{-1})	5.18	1.55	3.24	3.48	1.90
Water supply (mm ha^{-1})	107.6	-572.5	-245.1	157.5	297.2
Carbon stock (t ha^{-1})	77.4	73.1	79.0	58.4	36.6
Carbon sequestration (t ha^{-1})	1.5	0.6	1.0	0.9	0.5
Soil stability (index)	35.9	17.0	24.4	31.8	19.7
Soil quality (index)	179.2	155.8	170.5	166.4	163.8
Aesthetic value (index)	6.15	6.57	6.41	6.37	6.82
Topography					
Elevation (m a.s.l.)	1281.6	404.1	871.0	1575.1	2066.1
Slope (°)	23.0	14.0	21.0	24.0	28.4
Land use/cover (%)					
Artificial surfaces	1.8	17.7	5.0	2.4	1.1
Orchards/vineyards	1.2	39.6	25.0	0.6	0.7
Permanent grassland	16.7	1.5	7.5	29.3	30.8
Forest	76.8	38.4	57.3	57.6	33.5
Rocks	3.0	0.9	4.3	9.7	29.6
Water	0.4	1.8	0.8	0.4	0.7
Glacier	0.0	0.0	0.1	0.0	3.7
Mean area (km²)	41.2	14.1	32.9	61.6	125.5

Discussion

In line with other studies (Gimona & van der Horst, 2007; Naidoo et al., 2008; Egoh et al., 2009), the assessed ecosystem services for South Tyrol are mainly related to land use/cover, which in mountain regions is conditioned by topography influencing plant distribution and growth, soil development, soil moisture and nutrient availability (Dirnböck et al., 2003; Becker et al., 2007). Many ecosystem services (timber production, carbon sequestration, soil stability and soil quality) are positively related to forest, and, therefore, municipalities with a high forest percentage have higher values. Especially in the valley bottom, soil sealing and intensive agriculture lead to a decline of these services. Furthermore, our results reveal strong synergies between these ecosystem services, but also trade-offs with the aesthetic value (Table 2).

Table 2. Correlation matrix according to Spearman's rank correlation test for the ecosystem services values for all municipalities of South Tyrol (n = 116).

	Forage production	**Timber production**	**Water supply**	**Carbon stock**	**Carbon sequestration**	**Soil stability**	**Soil quality**	**Aesthetic value**
Forage production		.379**	.327**	-.348**	.213*	.694**	-.053	-.323**
Timber production	.379**		-.029	.515**	.950**	.860**	.667**	-.849**
Water supply	.327**	-.029		-.721**	-.248**	.051	.023	.270**
Carbon stock	-.348**	.515**	-.721**		.703**	.269**	.483**	-.591**
Carbon sequestration	.213*	.950**	-.248**	.703**		.757**	.712**	-.885**
Soil stability	.694**	.860**	.051	.269**	.757**		.421**	-.769**
Soil quality	-.053	.667**	.023	.483**	.712**	.421**		-.488**
Aesthetic value	-.323**	-.849**	.270**	-.591**	-.885**	-.769**	-.488**	

** $P < 0.01$; * < 0.05.

In mountain regions, topographic characteristics affect ecosystem services (De Groot, 2002; Schirpke et al., 2013). Our maps indicate that forage production generally decreases with increasing elevation, because the growing season is shorter and land-use intensity is lower on alpine pastures and meadows than on meadows on the valley bottom with several cuts per year. The total quantity, however, mainly depends on the land use. Furthermore, forage production is limited by water availability which causes lower production rates in the western part of South Tyrol with very low precipitation. Water supply follows the trend of precipitation and increases with increasing elevation (Sevruk, 1997). While high mountain municipalities have a water surplus, the municipalities in the valley show negative values during the main growing season because permanent cultivations, such as orchards and vineyards, have a very high water consumption. Hence, the beneficiaries of this ecosystem service are the valley municipalities, for which the water coming from the high mountains is fundamental, affecting agricultural production and water availability for domestic and industrial use. Even on the regional scale, i.e. within South Tyrol, ecosystem services flows from a source area to a benefitting area are of great importance (Fisher et al., 2009). On the global scale, mountains are considered the water towers of the world and more than half of the population relies on water coming from the mountains (Beniston, 2006).

Regarding cultural ecosystem services, the aesthetic value is linked to both land use/cover and topography. High mountain regions have the highest aesthetic value which can be explained by more natural land cover, high visibility and high landscape diversity (Ribe, 2009; Schirpke et al., 2013). As especially forest, permanent cultivations and bare agriculturally used landscapes were less preferred by the respondents in the photo-survey, these regions have the lowest aesthetic value.

The cluster analysis confirms these findings by grouping the municipalities according to their ecosystem services into clusters which can be associated to topography, especially elevation, and land use/cover. Moreover, the cluster analysis reveals synergies and trade-offs between multiple ecosystem services as described above and confirmed by the correlation matrix (Table 2).

Due to the differences in land use/cover on the local and regional scale, a spatially explicit assessment of ecosystem services is necessary to support decision makers regarding an appropriate management of natural resources and ecosystem services.

Conclusions

Many ecosystem services are sensitive to topography and, therefore, ecosystem services assessments, in particular their quantification in bio-physical terms, have to consider the particular topographic and climate conditions of mountain regions. As even on the regional scale great differences between ecosystem services supply can be found, a spatially explicit assessment and mapping of ecosystem services is essential to support landscape planning, ecosystem management and conservation of biodiversity.

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