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Spatial assessment of multiple ecosystem services in an Alpine region

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Summary

Ecosystem Services (ESs) are the goods and services supplied by ecosystems. In order to fully understand their contribution to human wellbeing, there is a need to identify them, assess their supply, recognise areas where they appear together repeatedly and analyse the interactions that may exist among them. Most of these tasks are also specifically required by the European Biodiversity Strategy for 2020, which asks Member States, by 2014, to identify key ESs and to spatially assess their supply and demand (European Commission, 2011). Nevertheless, these are difficult tasks and to date they have been only partly performed: existing studies in fact have typically focused on a small sub-set of ESs and made use of information that poorly reflects the actual variability of the ESs distribution across a region. The present research aims to fill these gaps, by developing methods involving a wide set of ESs and providing a detailed ESs assessment, based on spatial and statistical analyses. The methods have been tested on an Alpine region of Italy, Trentino. The Alps present a heterogeneous landscape, resulting from the combination of natural and urbanized environments, that allows the supply of a wide range of ESs.

The research has four specific objectives. The first objective focuses on the selection and the representation over specific spatial units of the real supply of multiple ESs. Operatively, 51 experts from the local administrative offices and research institutes have been involved in the selection of the most important ESs and spatial indicators for the case study. The experts identified 25 ESs and 57 representative spatial indicators (1 to 5 indicators for each service), and provided data for indicators mapping. To consider the heterogeneity of the ESs supply across the region, indicators were mapped over 20 different spatial units, including: land cover classes, cadastral parcels, fishing zones and catchments.

The second objective is to develop and test a statistical method for identifying key indicators that are spatially-explicit and able to measure the biophysical, socio-cultural and economic values of ESs (both in terms of stock and flow). Spearman pairwise correlation analysis was performed among the indicators of the same service in order to identify the highly correlated ones, hence deemed to provide redundant information. Key indicators were selected among

the lowly correlated ones. 35 indicators were selected for the case study (out of the 57 initial indicators). The analysis showed that there is a minimum number of key indicators for each ES. Accordingly, three general rules were identified for the selection: (i) if the supply of an ES is regulated, both its biophysical-stock and biophysical-flow indicators must be selected, (ii) if multiple stock (flow) biophysical indicators for a single ES are mapped over different spatial units, all stock (flow) indicators must be maintained, (iii) socio-cultural or economic indicators are always selected as key indicators.

The third objective is to develop and test a statistical method for defining bundles of ESs, as sets of spatially correlated services. Principal Component Analysis was used to summarize the information of the 35 indicators, while hierarchical clustering was applied to identify 11 ESs clusters. Clusters were turned into bundles by analyzing the spatial variability of the services due to biophysical (e.g. morphological conditions) and human (e.g. land use) factors. The results of the analysis show that in Trentino multiple ESs can be grouped in a few number of bundles with a complex shape. In particular, areas with poor ESs supply are grouped in one single bundle and the largest bundle follows the spatial distribution of a single land cover class: i.e. forest.

The fourth objective is to develop a method to study interactions among ESs, by combining statistical and spatial analyses. In fact, the supply of a given ES is correlated with the supply of other ESs and it is affected by multiple external factors. Correlations may be positive when an increase in the supply of one service corresponds to higher supplies of other services (i.e. synergies), or negative when an increase in the supply of one service corresponds to lower supplies of other services (i.e. tradeoffs). The degree of interactions among 35 key indicators is determined by performing a Spearman pairwise correlation analysis. The latter enabled to identify six patterns of ESs interactions, one pattern of tradeoffs and five of synergies. The analysis showed that the local land use management has not compromised the capacity of ecosystems to provide regulating services while supplying the provisioning ones. The external factors causing the variability of the services across the region were identified and explained by means of spatial and Spearman correlation analyses among the ESs principal components. Principal components were turned into drivers of change by analyzing the spatial variability of the ESs due to biophysical (e.g. forest density) and human (e.g. land use) factors. Land use management was found as the external factor that causes the greatest variability of the ESs distribution across the region. Within forest areas, forest management activities that involve loss of vegetation were found as the main drivers of ESs change.

This research aimed to consider a wide set of ESs and information able to reflect the actual variability of the services distribution across a region. It proposed a scientifically sound methodology to deal with the main issues of the ESs spatial assessment, that may reveal efficiently applicable in other geographical areas where ESs are heterogeneously supplied.

1 Scope and outline of the thesis

1.1 Introduction

Ecosystem services (ESs) are the goods and the services supplied by ecosystems (MA, 2003), and used by human populations to maintain and develop their own wellbeing (MA, 2005). A forest ecosystem, for instance, can supply the ESs of food, timber, fresh water and fuel wood that people may use to satisfy their basic material needs. It can also supply the ESs of regulation of flood, disease, carbon and climate that guarantee secure and healthily environmental conditions for people, and also recreation and aesthetic values (MA, 2003). ESs are recognized in relation to the presence of human wellbeing needs (i.e. basic material, security, health and social relationships; MA, 2005), and their number vary according to the heterogeneity of morphology, land cover and land use of the territory (MA, 2003; Costanza, 2008).

Schwartz et al. (2000) pointed out that ESs are directly and positively dependent on the presence and on the dynamics of a wide range of species and habitat types, and that the safeguarding of ESs may strongly contribute to the conservation of biodiversity (Schwartz et al., 2000 and later Kremen, 2005). Furthermore, Haines-Young and Potschin (2010b) observed that the provision of ESs is highly sensitive to the variation of biodiversity, especially in case of low biodiversity values.

Therefore, the ESs concept considers nature for the benefits it can directly and explicitly provide to human society, and promotes the conservation of biodiversity not for its intrinsic value but for its value to people (Balmford et al., 2008). The challenge is to acknowledge the value of ESs and to link it to biodiversity and human wellbeing, in the perspective to assess the dynamics that can cause ESs loss (Carpenter, et al., 2006; Daily and Matson, 2008 and Anton et al., 2010).

1.2 Evolution of the ecosystem service concept

The awareness that ecosystems, and more in general nature, can provide tangible and intangible benefits for human wellbeing goes back to the myth of Eden. Anyway, the idea that those benefits can be enumerated is relatively new, dating back to (Westman, 1977), and such benefits were named "ecosystem services" for the first time by Ehrlich and Ehrlich only in 1981. The concept emerged as a topic of discussion in the latest 1990s, when Costanza et al. (in 1997) estimated the worldwide economic value of 17 ESs for 16 biomes. The first comprehensive global assessment of the consequences of ecosystems changes for human wellbeing dated back to 2001. It was a project promoted by the United Nation that involved more than 1300 scientists all around the world: the Millennium Ecosystem Assessment (MA). The project delivered new knowledge about the conditions, the trends, the options to restore the major ESs worldwide and the measures for a sustainable ESs use. The key finding of MA was that 60% of ESs were being degraded and used unsustainably by 2005 and that this has been having really negative consequences for human wellbeing, compromising both the achievement of the Millennium Development Goals of 2000 and the objective of poverty alleviation of the Brundtland Commission of 1987.

The ESs concept was also covered by the Biodiversity Targets set in the Convention on Biological Diversity (CBD) in 1992 in Rio de Janeiro that sought to put human needs at the centre of biodiversity management in order to achieve sustainable management of ecosystems by 2010. The impact of biodiversity loss on wellbeing was evaluated within an initiative of G8+5 Environment Ministers that took place from 2007 to 2010, i.e. The Economic of Ecosystems and Biodiversity (TEEB). Among all, TEEB pointed out that Biodiversity Targets for 2010 were not met. In the European Union, the new Biodiversity Strategy set new targets for 2020, where the conservation of ES is explicitly address. In particular, by 2014 Member States are asked for the identification of the important ESs and for the spatial assessment of the service supply and demand in their countries (European Commission, 2011).

The ESs concept is a thriving field of research (Fisher et al., 2009; Seppelt et al., 2011), that combines conceptual efforts and applications to case studies. According to Vihervaara et al. (2010), until 2008 a large proportion of such research was focused on improving of the conceptual knowledge of ESs, and remaining proportion was oriented to application purposes. Surprisingly, the latter considered case study areas with low presence of ESs: according to a review performed by Seppelt et al. (2011), until 2010 50% of the ESs studies represented a group of countries with about the 23% of the world ESs values (as calculated by Sutton and Costanza, 2002). Approaches based on the concept of ESs have being increasingly used also in nature conservation projects. In fact, it is demonstrated that projects which involves the ES concept have a strong capability to address concerns that relate to the conservation of biodiversity and the improvement of human wellbeing, and also to get considerable funding (Goldman et al., 2008; Tallis et al., 2008; de Groot et al., 2010). Projects are usually carried out in areas with high presence of ESs, like rural areas of Asia, Africa and Latin America (WWF and IUCN), with the aim to restore those ecosystems where basic materials and social relations were strongly exploited and at the cost of ESs that guarantee human health and security. For instance, several projects have being carried on in Indonesia after the Indian Ocean tsunami of 2004, focusing on the restoration of the storm protection capacity of mangrove forests. Seppelt et al. (2011) suggested that ESs research is still driven mainly by curiosity rather than by the need to respond to local issues. In contrast, projects are carried out mainly to respond to environmental and sustainable development issues (Liu et al., 2010).

Millennium Ecosystem Assessment in 2003 and later in 2005 highlighted the importance of the identification, the assessment and the monitoring of the ESs, the importance of the analysis of the ESs provision at different temporal and spatial scales, and the importance of the definition of the links that exist between ESs, human wellbeing and drivers of change. MA provided a classification of ESs that is still widely employed and it has been the reference for various classifications, such as TEEB and The Common International Classification of Ecosystem Goods and Service (CICES) (Haines-Young et al. 2010a and 2010b), and frameworks to make the concept operative. Kremen (2005) stressed the importance to understand the ecology of the ESs and the benefits for humans both in space and time. Carpenter et al. (2006) suggested that research community needs to develop analytical tools to monitor biological, physical and social changes that may regard ESs; in fact, people deeply depend on ESs for their wellbeing and they are vulnerable to the drivers causing the degradation of ecosystems where ESs are generated. Daily and Matson (2008) suggested that approaches based on the concept of ESs must endorse the study of ecosystem production functions and service mapping, the design of appropriate finance, policy, and governance systems, and the implementation in the biophysical and social context. They also stressed the importance of giving stakeholders the opportunity to express opinions, because they provide ground truth about the extent to which ESs are significant to their wellbeing. Cowling et al. (2008) recommended the development of models to make the ESs concept operative. Fisher et al. (2009) stressed the importance of recognizing spatial relationships between service production areas and service benefits areas. De Groot et al.

(2010) highlighted the need to analyze trade-offs between the ESs provision and the changes in the ecosystems. Anton et al. (2010) summarized a number of these information in a number of priority research needs: the analysis of the ecological underpinning of ESs and of the drivers that affect ecosystems, the valuation in different spatial and temporal scales, the development of indicators, and the study of habitat management and conservation policy.

1.3 Objectives of the study

The general aim of this research is to improve the knowledge about the spatial assessment of ESs at regional scale. In particular, the research focuses on the mapping of the actual supply of multiple ESs for an Alpine region and on the study of the relationships that exist among them. Mapping calls for the definition of key spatially-explicit indicators that allow biophysical, socio-cultural and economic values of important ESs (both in terms of stock and flow) to be measured, and the spatial heterogeneity of the ESs to be represented. The study of the relationships requires the development of methods, based on spatial and statistical analyses, that allow the distribution of multiple ESs across the region, the variance of the ESs distribution, the common drivers to this variance and the synergies and tradeoffs between ESs to be explained. The specific research objectives and related research questions are described hereafter.

1. **Mapping multiple ESs in an Alpine region**. The first objective of the research is the selection of the important ESs for an Alpine region of Italy (Trentino) and the mapping of important indicators. Selected ESs are those able to satisfy actual human wellbeing needs (Chapter 2), and selected indicators are those able to measure the biophysical, economic and socio-cultural value, in terms of stock and flow, of the ESs supply (Chapter 3). Mapping must take into account the differences in the spatial units over which ESs are supplied (e.g. cadastral parcels, water network and river sub-catchments) and the availability of existing data (Chapter 3).

   Research questions
   - Are there ESs that are exclusively associated with the Alpine region?
   - How can available data be used to measure/map the biophysical, economic and socio-cultural value, in terms of stock and flow, of the ESs supply?
   - On which spatial units must single ESs be mapped?

2. **Identifying key ESs indicators**. When ESs are many, their characterization can be problematic due to the considerable human resources needed for data recovery, and to computational requirements for the analysis of all relevant information. Therefore, the identification of a non-redundant set of indicators (i.e. key indicators) is a priority. Chapter 4 presents a method, based on statistical correlations, for the selection of key indicators out of a large set and lists three criteria to guide the definition of indicators in data-poor environments.

   Research questions

   - Can the number of ESs assessment indicators be consistently reduced?
   - How to assess the sensitivity of the selection?
   - Can rules be defined to allow the identification of a minimum set of ES indicators?

3. **Defining bundles of ESs**. ESs have been historically mapped over land uses or administrative units, but this is not consistent with the areas (i.e. spatial units) over which they are actually supplied. As these areas are ESs-specific (e.g. agricultural cadastral parcels for the ES "Agriculture production", fishing zones for the ES "fishing" and river sub-catchments for the ES "water flow regulation"), the consideration of multiple ESs calls for the definition of spatial units where sets of ESs are supplied simultaneously, i.e. bundles. These are obtained by multivariate statistical analyses on key indicators. In order to give these bundles a meaning, the distribution of bundles across the region and distribution of ESs across bundles are studied through spatial and statistical analyses (Chapter 5).

   Research questions

   - How to consider multiple ESs on the basis of their spatial distribution and value?
   - How to account for the spatial heterogeneity of the ESs supply?
   - How to define a suitable number of bundles?

4. **Analysing ESs tradeoffs and drivers of change**. The supply of a given ES is correlated with the supply of other ESs and affected by multiple external factors. Correlations may be positive (i.e. an increased supply in one service corresponds to higher supplies of other services) or negative (i.e. an increased supply in one service corresponds to lower supplies of other services). These cases are often referred to as synergies and tradeoffs, respectively. Chapter 4 presents a method, based on statistical correlations between key ESs indicators, to identify synergies and tradeoffs among related ESs. While multiple factors may have an influence on the ESs provision, land use management is assumed to be the single most important one. This study verifies this hypothesis through a scientifically sound methodology and explores which management actions have the greatest influence on the ESs supply (in Chapter 5).

Research questions

- Which synergies and tradeoffs exist between ESs?
- Which ESs are correlated in terms of supply across different spatial units?
- Is land use management the strongest factor affecting the ESs provision?

1.4 Case study

Figure 1.1. Localization of Trentino (the orange area) within the Alps (the green area)

The Alpine region is an important source of ESs for the entire Europe (MA, 2003; Grêt-Regamey et al., 2012), that contribute to the maintenance and the development of the wellbeing of dwellers and people living in outside areas. In fact, the Alps constitute the reservoir of the 40% of freshwater and their forests, that cover more than 40% of the territory, are the third reservoir of carbon in Europe. One fifth of the forests extension contributes to the protection of urban settlements and, annually, people from all over the world make use of such forests and of the mountains' upper part for recreation activities, like trekking and skiing (Morandini et al., 2009). Alpine ecosystems provide also storage in biomass and soil, natural resources and biodiversity (Grêt-Regamey et al., 2008). Details are likely to change depending on the morphological (e.g. altitude and forest composition) and on the socio-economic characteristics (e.g. agricultural produce, tourism activities) of specific Alpine regions.

The present research has focused on Trentino, Italy (Figure 1.1). This is an autonomous province located in the eastern Alps with an area of 6212 km^2 and a population of 524,826 inhabitants, as of 2010 (average population density: 82.5 inhabitants km^{-2}). The elevation varies greatly, ranging from 62 to 3343 m above the sea level (the highest peak is Marmolada), with about 30% of the territory under 1000 m (Figure 1.2) , about 50% between 1000 and 2000 m and about 20% over 2000 m. Areas over 2000 m are covered essentially by glaciers, bare rocks, natural grasslands and pastures (Figure 1.3). Glaciers and bare rocks constitute about 16% of the region, while grasslands and pastures about 17.9%. Mountains are spread all over the region, creating a mosaic of valleys enclosed mountain chains. In its central part the region is crossed by a river of national importance, i.e. the Adige river, that follows the north-south direction. The area occupies 14 catchments, and the lateral major rivers follow east-west or west-east directions to the Adige river. The remain water network is widespread and significantly extended, covering about 1% of the region. More than 300 lakes are found including the northern part of Lake Garda, which is the largest lake of Italy. Forests cover about 55.8% of Trentino and are found up to about 1800 m a.s.l. . Forests provide very different services (e.g. timber, fuel wood, mushroom, honey and hunting); their use is planned by the local administration, in order to guarantee the availability through the years. Several activities are located on the territory. Agricultural areas (i.e. arable lands, permanent crops and heterogeneous agricultural areas) cover 5.8% of the whole region and the produce is renowned (e.g. apples, which correspond to 25% of national production, and grape of optimum quality). Tourism is the mainstay of the economy, as the region offers several opportunities for leisure activities (like skiing, trekking, climbing, surfing, etc.). In fact, it is renowned for its mountains, such as the Dolomites, which are an UNESCO site. Urban settlements cover 3.1% of the region and they are located mostly along the Adige river axis. For each valley there a major urban settlement but several small villages or scattered houses are found across the entire region. For this reason the region is crossed also by roads and railways. The north-south network links Italy to Germany.

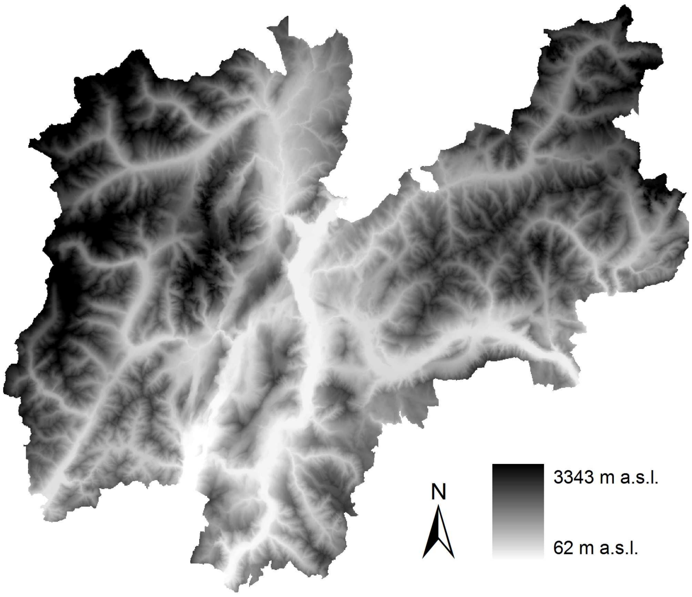


Figure 1.2. Digital Terrain Model of Trentino

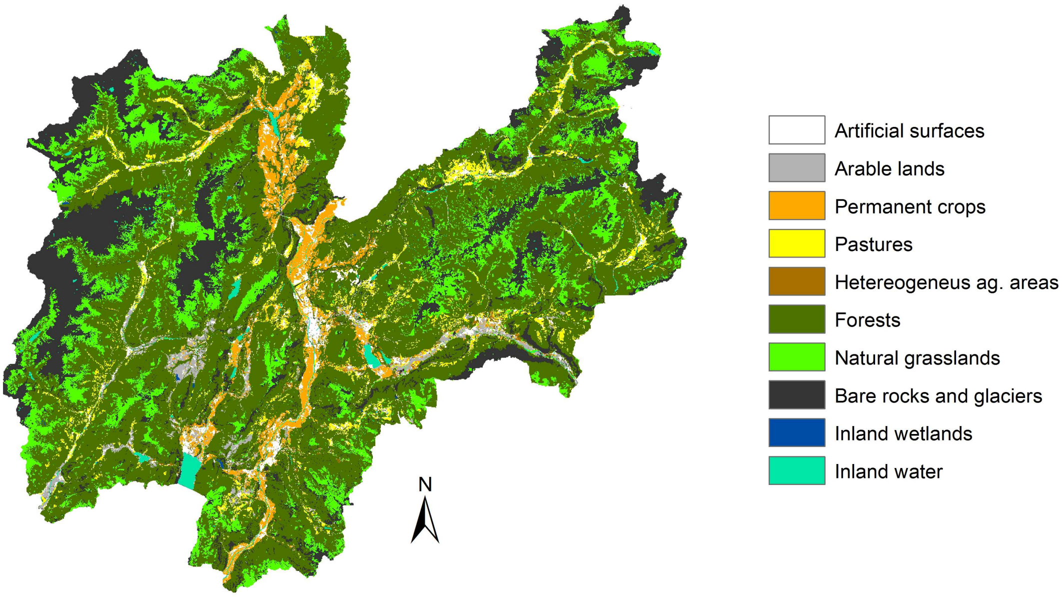


Figure 1.3. Land Cover classes (adapted from the Corine Land Cover map)

1.5 Outline of the thesis

Chapter 2 describes the important ESs of Trentino, while indicators are selected and mapped in **Chapter 3**. The description of selected ESs strongly emphasizes their specific characteristics (e.g. of being storable and renewable services). Selected indicators can represent the biophysical, socio-cultural and economic values of the ESs supply in terms of stock and flow, and the mapping process deals with the issue of representing the spatial heterogeneity of single ESs. In **Chapter 4** key indicators are selected by means of statistical correlations, general criteria of selection are defined, and synergies and tradeoffs are explored. Key indicators feed the spatial and statistical analyses introduced in **Chapter 5**, that define bundles of ESs and combine indicators from which to explain the spatial distribution of ESs and the main drivers of change. Finally, **Chapter 6** summarizes the main findings of the research, discusses their strengths and weaknesses and contains directions for the future research.

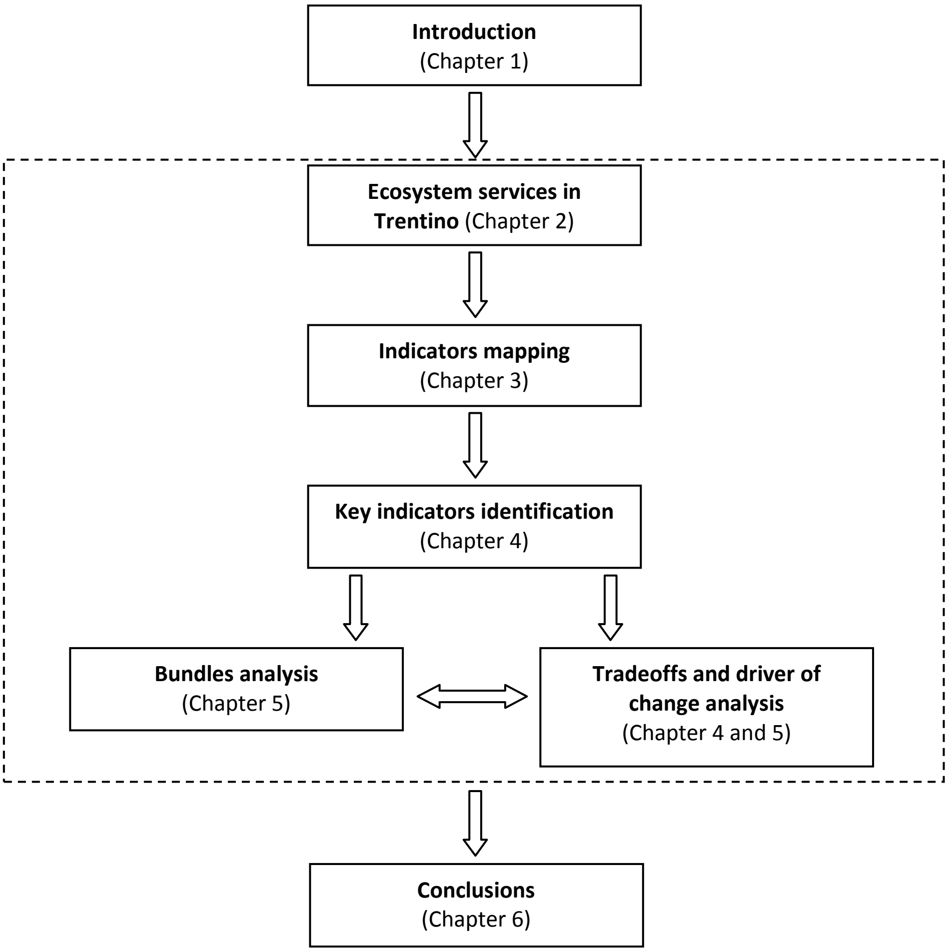


Figure 1.4. Outline of the thesis

2 Ecosystem services in the Trentino region

In this Chapter important ESs for Trentino are identified. They are selected from the list provided in Maes et al. (2011b) by a number of experts belonging to local administrative offices and local research institutes; selected ESs are classified under the CICES systems (Haines-Young and Potschin, 2010a). Then, they are described reporting specific information for the study region. In particular, Section 2.1 introduces the concepts of definition, classification and characterization of ecosystem services. Section 2.2 reports the list of local offices, associations and institutes with the number of experts involved in the ESs selection, the selection criteria used by experts and the list of selected ESs. Sections 2.3, 2.4 and 2.5 describe respectively provisioning, regulating and cultural ESs, while Section 2.6 provides some final considerations.

2.1 Definition, classification and characterization of ecosystem services

Several definitions of ES have been developed through the years by different professional figures (scientists, economists, practitioners and policy makers) in order to fit different purposes (such as education, environmental accounting, landscape management and valuation; de Groot et al., 2010). Daily (1999) defined ESs as "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life", while Boyd and Banzhaf (2007) as "the ecological components directly consumed or enjoyed to produce human wellbeing". Analogously, the physical constituents and the processes/functions of ecosystems, and the linkages to human wellbeing, have been described and defined in many ways. Fisher et al. (2009) called the physical constituents “intermediate services”, the processes and functions “final services”, and the linkages to human wellbeing “benefits”. Haines-Young and Potschin (2010b) considered the physical constituents and the processes and functions of ecosystems as “intermediate products”, and services and benefits as “final products” of the interactions between biodiversity, ecosystem functions and human wellbeing. Despite the differences in terminologies, both of them argued that an ES exists only in relation to the presence of a human wellbeing need; in other words, ESs can be recognized only when their use is explicit. The existence of an ES depends on the presence of a real use or demand of the service supply, that clearly differentiates from the potential supply (Bastian et al., 2012).

The choice of the classification system follows the definition of ESs (Carpenter et al., 2006; Fisher et al., 2009; Haines-Young and Potschin, 2010a). The MA classified ESs according to four main categories of the benefits people obtain from ecosystems: supporting, regulating, provisioning and cultural services. The Economics of Ecosystems and Biodiversity project (TEEB) added another service category, "habitat services" to account the capacity of ESs to sustain biodiversity (Balmford et al., 2008). The Common International Classification of Ecosystem Services (CICES) was proposed to standardize the way of naming and describing ESs in the perspective of environmental accounting and landscape management (see Haines-Young et al., 2010a). Here ESs are defined as the contributions of ecosystems to human wellbeing. CICES covers the categories of the MA classification except the 'supporting services' category, since it focuses on final outputs of ecosystem processes. Such categories constitute the first level of CICES. They are nested in nine classes, 23 groups and 59 types of services. The importance of ESs is case-specific; accordingly, they must be selected in relation to specific human wellbeing needs and to the heterogeneity of morphology, land cover and land use of the studied territory.

Scientific literature has argued that ESs may be described according to a number of aspects (Fisher et al., 2009), among which:

- *Public-Private accessibility to the service*. Costanza (2008) suggested to apply the economic classification of goods (i.e. public, private, common and club goods) to characterize single ESs, that means that ESs may be grouped according to the degree to which people can be excluded or can have complete access to them. Therefore, public services are those with complete and free access (not rival and not excludable services), private services are those limited to payers (rival and excludable services), common services are those limited but free (rival and not excludable services) and club services are those that can be freely accessed but only by payers (not rival and excludable services).
- *Spatial dynamism*. Costanza (2008) also suggested that ESs can be classified according to the spatial dynamism existing between the areas where services are supplied and the areas where they are used. The relationship between SPU and SBU may be "identical" (services are supplied and used in the same area), "omni-directional" (services are supplied and used without any directional bias), "slope dependent" (services are supplied

by a gravitational process to the to the beneficiaries) and “directional” (services are supplied by directional effects to the to the beneficiaries).

2.2 Selection and classification

ESs have been selected with the aid of experts belonging to local administrative offices of the Autonomous Province of Trento, local research institutes or associations. 51 Experts (see Table 2.1) with knowledge about the ecosystem goods and services in Trentino have been involved in the selection.

Table 2.1. List of the administrative offices, local research institutes and associations where the experts involved work. The official names of offices, institutes and associations are in the first column; the definition in the second and the number of experts involved in the third column.

Names of the administrative offices, local research institutes or associations	Definition	Experts number
Associazione Cacciatori Trentini	Local hunters association	1
Associazioni produttori ortofrutticoli Trentini (APOT)	Association of local farmers	1
Associazione Troticoltori Trentini	Local trout breeder association	1
Fondazione Edmund Mach (FEM)	Edmund Mach Foundation - Research institute	6
FEM - Centro di Ecologia Alpina	FEM - Centre for Alpine Ecology	1
Museo Civico di Rovereto	Civic Museum of Rovereto	1
MUseo delle Scienze (MUSE)	Science museum of Trento	1
Provincia autonoma di Trento (PAT) - Agenzia Provinciale per la Protezione dell'Ambiente (APPA)	PAT- Local Environmental Protection Agency	3
PAT - Agenzia Provinciale per i Pagamenti in agricoltura (APPAG)	PAT - Agency for payments of public subsidies in agriculture	1
PAT - Dipartimento Agricoltura	Food and Agriculture Department	4
PAT - Dipartimento Territorio, Ambiente e Foreste	PAT - Territory, Environment and Forests Department	3
PAT - Servizio Bacini Montani	PAT - Rivers and streams office	1
PAT - Servizio Conservazione della Natura e Valorizzazione Ambientale	PAT - Nature conservation office	2
PAT - Servizio Foreste e Fauna	PAT - Forests and wildlife office	8
PAT - Servizio Geologico	PAT - Geologic office	3
PAT - Servizio Gestione Risorse Idriche ed Energetiche	PAT - Water and energy resources office	2
PAT - Servizio Minerario	PAT - Mining office	2
PAT - Servizio Statistica	PAT - Statistics office	1
PAT - Servizio Urbanistica e Tutela del Paesaggio	PAT - Urban and landscape planning office	2
Unità Operativa Igiene e Sanità Pubblica Veterinaria	PAT - Operative unit for hygiene and public veterinary medicine	3
Università di Trento - Dipartimento di Ingegneria civile, ambientale e meccanica (DICAM) - Gruppo di idrologia	University of Trento - DICAM - Group of Hydrology	2
Università di Trento - DICAM - Gruppo di meteorologia	University of Trento - DICAM - Group of Meteorology	2

The list of ESs proposed by Maes et al. (2011) has been used as starting point for the selection of the important ESs. Experts have selected 25 ESs "types", then grouped in nine "classes" and three "themes" (provisioning, regulating and cultural services). ESs themes, groups and types are listed in Table 2.3. From this point onwards, the acronym "ESs" will stay for "ESs types".

ESs are also described according to the following characteristics: their the degree of access, renewability and storability. Costanza (2008) proposed an ESs classification based on the degree to which users can access freely to them, i.e. based on the consumption rivalry and the ability to exclude non-payers. This classification reflects the economic classification of goods: public, private, common and club (Table 2.2). Renewability is the ability of ecosystems to guarantee a continuous provision of the service through the years, while Storability indicates the property of ESs to be used in a long period after the provision.

Table 2.2. Economic classification of goods (adopted from Costanza, 2008)

	No rival	**Rival**
No excludable	Public	Common
Excludable	Club	Private

Table 2.3. List of 25 ESs types, grouped in nine classes and three themes. The classification framework follows Haines-Young et Potschin (2010), while the names are adapted from Mayes et al. (2011).

Themes	Classes	Types
1 Provisioning services	1 Food supply	1 Agriculture production
		2 Hunting production
		3 Fishing production
		4 Mushroom production
		5 Honey production
	2 Raw material supply	6 Inorganic matter extraction
		7 Timber production
	3 Energy supply	8 Fuel wood production
	4 Water supply	9 Water supply from surface water network
		10 Water supply from groundwater
2 Regulating services	5 Water cycle regulation	11 Water flow regulation
		12 Water quality regulation
	6 Atmosphere components regulation	13 Air quality regulation
		14 Micro-Climate regulation
		15 Macro-Climate regulation
	7 Natural hazards regulation	16 Flood prevention capacity
		17 Hazards protection capacity
3 Cultural services	8 Tourism opportunities	18 Cultural heritage
		19 Scenic beauty
	9 Leisure opportunities	20 Hunting
		21 Fishing
		22 Mushroom collection
		23 Honey collection
		24 Outdoor recreation
		25 Leisure

2.3 Provisioning services

Agriculture production

It is the ability of any cultivated land to provide vegetable food for people and animals (MA, 2003; Burkhard et al., 2009 and Maes et al., 2011b). It is a private, renewable and storable good. In Trentino, agriculture is practiced for commercial purposes and agricultural products are trade all around Italy (e.g. apples are the 25% of national production). 5.8% of the region is occupied by agricultural areas where 27 types of agricultural products are cultivated: kiwi, grapes, apples, pears, olives, plums, cherries, apricots, hazelnuts, walnuts, chestnuts (tree farming), polyphitic/monophitic grass and grasslands, corn (crop cultivation) and potatoes, lettuces, carrots, cabbage, pumpkins and small fruits - gooseberries, strawberries, redcurrants, blackberries, raspberries and blueberries (market gardening).

Hunting production

It is the availability of animals for hunting and it is a common, renewable and storable good. In Alpine regions it is not a primary source of food but it involves natural ecosystems with a large potential in providing food for local people. In Trentino the activity mostly aims to regulate the presence of animals; the region is divided in 226 game reserves and the service supply is planned at administrative level for every game reserve: there are rules and restrictions about the game season, the species and the number of animals that can be hunted. Moreover, in the Stelvio National Park (in the north-west of Trentino) hunting is forbidden. Species available for hunting are ungulates (Roe deer, Red deer, Chamois, Muflon and Wild boar), big birds (Rock partridge and Black grouse), some species of songbirds and little mammals (Fox, Hare, Alpine hare). The activity represents also a cultural service.

Fishing production

It is the availability of fish in the water network, both in rivers and lakes. It is a common, renewable and storable good. In Trentino each river or lake is divided into fishing zones (7776 for rivers and 379 for lakes), in order to measure the fish biomass and the caught. Fishing can be practiced only for self consumption; any angler can catch maximum five units per day. Since fishing is not a sustainable activity, several rivers and lakes are periodically restocked. Species available for fishing are: *Salmo trutta marmoratus* (Marble trout), *Salmo trutta fario* (Brown trout), *Thymallus thymallus* (Grayling), *Coregonus lavaretus* (Lavaret), *Esox lucius* (Pike), *Perca fluviatilis* (Perch), *Salmo gairdneri* (Rainbow trout), *Cyprinus carpio* (Common carp), *Salvelinus alpinus* (Arctic char), *Salvelinus fontinalis* (Brook trout) and *Tinca tinca* (Tench). The service does not consider the fish production by aquaculture. The activity represents also a cultural service.

Mushroom production

Forest ecosystems provide suitable conditions for the production of mushroom. Conditions depend on the pedological-lithological characteristics of the forest subsoil and on the forest typologies. Mushrooms are a common, renewable and storable good. The activity represents also a cultural service.

Honey production

Forest and grass ecosystems provide suitable conditions for the production of nectar and honeydew. Conditions depend on the slope, altitude, forest typologies and on the presence of obstacles for bees (like lakes or walls); in fact, bees cannot fly more than 500 m far away from their hive and over a water surface. Honey is a common, renewable and storable good. The activity represents also a cultural service.

Inorganic matter extraction

It is a no-biomass product for human constructions or other uses and it represents a private, non-renewable and storable good. In Italy the extractions are regulated by a royal law of 1936, that defines mines as inorganic matters of national interest (e.g. mineral water, dolomite rock) and quarries as inorganic matters of local interest (e.g. clay, basalt, limestone). The law regulates the extraction rights: the exploitation of mines is planned at national level, while the exploitation of quarries is planned at local administrative level. The provincial plan establishes the amount of matter annually extractable for each quarry every 10 years. The exploitation rights are related to the market trends, the economic convenience and the avoidance of environmental hazards: e.g. erosions or landslides. The inorganic matter of Trentino quarries are: clay, granite, basalt, limestone, marble, gypsum and porphyry.

Timber production

It is a biomass product of forests for building or other uses and it represents a private, renewable and storable good. Trentino forests cover more than 56% of the total area and 75% of them are public. In order to guarantee the provision of material through the years and to maximize the income of felling, the service supply is planned at administrative level in each public property and also in some large private properties, every 10 years. The growing stock and the increment of wood are monitored, in order to estimate the amount that can be cut per year while ensuring the sustainability. In Trentino the most renowned timber is that of Valle di Fiemme (in the North-East of the region), whose wood is used to make violins.

Fuel wood production

It is the ability of ecosystems to provide wood for energy production. This ES is a private, renewable and storable good. In Trentino fuel wood is mostly supplied for domestic use and its provision follows the same rules of the service Timber production. Fuel wood is the only ES for the energy production considered in this study. The other energy resources (e.g. biomass, sun, wind and water) have been disregarded because of lack of data.

Water supply from surface water network

Water for drinking, irrigation and industrial uses is withdrawn by the surface water network. In Trentino water is withdrawn from 2803 points over rivers, lakes and reservoirs. The quality of water ecosystems is guaranteed by the fact that a minimum discharge is assured in each water course. The service is a private, renewable and storable good.

Water supply from groundwater

Aquifers also provide water for drinking, irrigation and industrial uses. Water is withdrawn in 10617 points (springs or wells) and its quality is assured by a area of respect of 200 m around each point, where any activity is forbidden. The service is a private, renewable and storable good.

2.4 Regulating services

Water flow regulation

It is the capacity to accumulate water and to regulate the hydrological flows in normal weather conditions. Water is accumulated mostly in lakes/reservoirs (in Trentino they are 372 elements for 4657 ha), in glaciers (3775 ha) and in aquifers (no precise data on their capacity are available). Rainfall, snow melting processes, evapotranspiration and water losses due to percolation towards deep aquifers, contribute to the long term average discharge production per sub-catchment. The ES represents a public, renewable and non-storable good.

Water quality regulation

It is the capacity of permeable riverbeds and riparian areas to regulate the chemical elements in water, by filtering and absorbing incoming pollutants from agricultural activities. In Trentino 87% of the riverbeds are permeable (total river length: 5920 km), while the 13% is disturbed by the presence of impermeability elements like, training walls or paved channel (total length in rivers: 753 km), and groynes or dikes (15603 groynes or dikes dislocated in the water network). The hygrophilous vegetation in riparian areas has the best capacity in absorbing pollutants but it is only the 3% of the whole area close to rivers; active riparian areas are those 30 m around the water course. The ES represents a public, renewable and non-storable good.

Air quality regulation

It is the capacity to regulate the concentration in the air of the pollutants affecting human health and the quality of urban life. In Trentino, the presence of mountains and valleys influences local circulations, sensibly reducing the pollutants' transport range. Moreover, the presence of forests may help the deposition of such pollutants. At local scale, the presence of buildings, trees or other obstacles close to the roads may prevent the dispersion of pollutants emitted by the cars. In general, the air quality regulation capacity of rough surfaces depends on their proximity to the emission sources; the regulating effect of forests depends also on their density and on the type of trees (Jim and Chen, 2008). The ES represents a public, renewable and non-storable good.

Micro-Climate regulation

Forests actively contribute to mitigating microclimate conditions, in terms of temperature and humidity, with positive effects for human habitations and health (Teuling et al., 2010). In fact, they provide shadow with transpirations attitudes, that depend on the forests shape and the density of trees. The ES represents a public, renewable and non-storable good.

Macro-Climate regulation

The extraction and the stock of the carbon dioxide from the atmosphere are essentially performed by forest and agriculture ecosystems. In Trentino the growing stock and the stocking capacity of forest ecosystems is significant (forest covers more than 56% of Trentino) and it has been accurately measured. Indeed, Rodeghiero et al. (2010) built an inventory of the organic carbon stored in the forest ecosystems in both above- and below-ground pools, according to the Kyoto protocol and IPCC requirements. The ES represents a public, renewable and storable good.

Flood prevention capacity

It is the capacity of the territory of preventing negative consequences for human life and buildings coming from natural events like floods, debris flows, landslides and avalanches. The ES represents a public, renewable and non-storable good.

Hazards protection capacity

Forest vegetation covers an important role in the stabilization of the terrain during floods, debris flows, landslides and avalanches. Forests are also important for the protection of building and infrastructures from falling rocks, by mechanical action. Despite the presence of large and extended forested areas in Trentino 1609 floods and debris flows, 6527 landslides and 644 avalanches occurred from 1965 to 2005 (ARCA, 2006). The ES represents a public, renewable and non-storable good.

2.5 Cultural services

Cultural heritage

Ecosystems may create the conditions for the visit of cultural heritage sites. The ES represents a public, renewable and non-storable good. The regional landscape plan (PUP, 2008) has identified 173 landscape goods and 595 archeological sites. Landscape goods are: historical and rural buildings within an appreciable natural landscape, like castles and isolated churches, monumental trees, and waterfalls.

Scenic beauty

Ecosystems may create landscapes of particular beauty, inspiring spiritual, aesthetic values and historic memory. The ES represents a public, renewable and non-storable good. The regional landscape plan (PUP, 2008) has identified 199 points of natural and cultivated ecosystems of particular beauty, 396 landscape fronts (i.e. terraces), 173 landscape goods and 595 archeological sites.

Hunting

It represents a leisure activity performed by more than 7000 hunters at year. It depends on the availability of animals in game reserves. The ES represents a common, renewable and non-storable good. In Trentino hunting is planned at administrative level, in order to guarantee the activity through the years. There are specific rules and restrictions about game season, the species and number of animals that can be hunted. For further details see the service Hunting production above.

Fishing

This leisure activity depends on the availability of fish in fishing zones. For further details see the service Fishing production above. The ES represents a common, renewable and non-storable good.

Mushroom collection

It is a leisure activity and depends on the availability of mushroom of good quality in forests. The ES represents a common, renewable and non-storable good. According to local regulations, maximum 2 kg of mushrooms per person per day can be harvested; local people can gather without any permit, while visitors must get a permit and pay a fee (that is 12€ per person). The activity is usually performed three km close to forest roads. For further details see the service Mushroom production above.

Honey collection

This leisure activity depends on the availability of nectar and honeydew in forests, pasture and scrublands. The ES represents a common, renewable and non-storable good. Trentino honey is of good quality and its production is principally for self-consumption The activity is mostly performed 150 m close to forest roads, that is the maximum distance walked by beekeepers bearing hives. For further details see the service Honey production above.

Outdoor recreation

Trentino environment offers several opportunities to practice outdoor activities, like walking, cycling, climbing, skiing, rafting, windsurfing and sailing. At 2008 cycling paths were 573 km long and forest roads 7532 km; there were also 236 ski lifts. Mountaineering is practiced both in summer and winter over 984 paths long more than 5000 km. About 45 Alpine refuges can host climbers and trekkers. The ES represents a club, renewable and non-storable good.

Leisure

In Trentino, lakes and forests provide opportunities to spend free time and relax. 372 lakes are spread all over the region. Large lakes are present in the valleys bottom, while small lakes up to the highest mountain peaks. The ES represents a public, renewable and non-storable good.

2.6 Conclusion

Undoubtedly, a certain degree of subjectivity affects the selection of ESs, as involved experts have personal opinions. However, the high number of experts and of institutions they belong to, ensures acceptable robustness to the selection.

Selected ESs are typical of semi-urbanized areas with large forests: in fact, 18 services are provided by forest ecosystems. A number of them is typical of Alpine regions, like Hazard protection capacity and Water flow regulation by glaciers. The number of ESs belonging to provisioning, regulating and cultural themes is comparable (10, 7 and 8), ensuring a good assortment over the territory. All of them, a part the Inorganic matter extraction service, are renewable resources used by local communities to satisfy a wide range of wellbeing needs. 11 ESs (all the provisioning and one regulating service) are storable. All regulating services are public goods, while provisioning are common or private goods and cultural are public, common or club goods.

3 Mapping ecosystem service indicators

The assessment of ESs typically consists in the computation of indicators that can measure specific characteristics of ESs (Carpenter et al., 2006; Vihervaara et al., 2010; Haines-Young, et al., 2012). Such indicators may be used to include ESs in decisions that regard the management of ecosystems (Egoh et al., 2007; Goldman and Tallis, 2009; de Groot et al., 2010; Muller et Burkhard, 2012). In this Chapter indicators for 25 ESs of Trentino are identified. Indicators are selected among a great number listed in 19 peer reviewed papers and scientific reports, by 51 experts of local administrative offices and research institutes, and according to two criteria: (1) indicators must measure the biophysical, economic and socio-cultural value, in terms of stock and flow, and must take into account of the spatial heterogeneity of the ESs supplied, and (2) indicators must be computed with existing and available data.

Each indicator is described by reporting: a definition, the ES value that it is measured, whether indicators is a proxy of the measure, data and methods for the computation and mapping. In particular, in Section 3.1 a rational for mapping ESs is proposed, in Section 3.2 the list of peer reviewed papers from which indicators are selected, the explanation of selection criteria followed by experts and the table of selected indicators for each ES are reported. In Section 3.3, Section 3.4 and Section 3.5 each indicator is described; the unit of measurement, data and mapping methods are summarized in a table. Conclusions are in Section 3.5.

3.1 Key issues on ecosystem service mapping

The need to assign values to ESs was already emphasized by Westman (1977). Since then, the science of the ESs assessment has been improved: several indicators for the measure of the ESs values have been defined (e.g. Daily, 1999; de Groot et al. 2002 and 2006; Grêt-Regamey et al., 2007; Liu et al., 2010), and the modelling of such indicators has been developed (e.g. Nelson et al., 2009; Maes et al., 2011b; Van Oudenhoven et al., 2012), as well their mapping (Willemen et al., 2008; Raudsepp-Hearne et al., 2009; Plieninger et al., 2013). In this Section main issues on the definition of ESs indicators, on the selection of the proper ones (based on suitable selection criteria) and on their mapping (that accounts for the spatial heterogeneity of the ESs supply across the region) are explored, in order to provide background knowledge for the assessment of the ESs in the Trentino region.

Multiple indicators need to be defined for a single ES in order to account for the variety of meanings of the ES concept (see Section 2.1) (Niemeijer and de Groot, 2008; Cowling et al., 2008). Several lists of ESs indicators have been developed through the years (e.g. Daily and Ehrlich, 1999; Eales et al., 2007; Burkhard et al., 2009; Liu et al., 2010), each of them reporting a single indicator for each service (Niemeijer and de Groot, 2008). For instance, Turner et al. (2010) proposed a contingent valuation to assess the economic value of the carbon storage, in the perspective to link the ecology and economy for the ecosystem management, while Naidoo et al. (2008) proposed a land cover based proxy indicator to produce a spatial representation of the state of the carbon storage.

Prerequisites for the selection of proper indicators for a single service are their applicability and utility in the study context (de Groot et al., 2010). Specific criteria are identified in order to ensure scientific credibility of selected indicators: measurability, low resource demand, international compatibility, analytical soundness, policy relevance and sensitivity to changes (Dale and Beyeler, 2001; Niemeijer and de Groot, 2008). Anyway, the ESs assessment may involve further aspects:

- *Supply and demand assessment*. ESs are supplied by the ecosystems in relation to a human well-being demand (Carpenter et al., 2006). Supply and demand involve two complementary perspectives: an ecological and an anthropogenic one. At present, research efforts have been focused mostly on the supply assessment (the ecological perspective), while little has been done on the demand side (Nelson et al., 2008; Grêt-Regamey et al., 2012b; Maes et al., 2012;). In contrast, field applications of the ES concept start from the assessment of the ES demand to promote sustainable management of ecosystems and sustainable use of the ESs supplied (Goldman et al., 2008).
- *Real and potential supply assessment.* The definition of indicators for the assessment of the current use of ESs assumes the existence, or the possibility to collect, field information about the ESs supply. Interviews to beneficiaries (García-Nieto et al., 2013) or mapping of available field data (e.g. Willemen et al., 2008) may be used as suitable methods. Modelling is instead a good option to assess the potential supply of ESs (MA, 2003).

- *Flow and stock assessment*. Carpenter et el. (2006) highlighted the need to measure the amount of the ESs supplied (the flow) and the capacity of the ecosystems to deliver such services (the stock). The first provides a measure of the sustainable use of the ES, while the second provides a measure of the renewability of the service. Such measures have been rarely considered together in the assessment of ESs: the definition is usually oriented on stock indicators for provisioning services and on flow indicators for the regulating ones (cf. Layke, 2009 and Maes et al., 2011a).
- *Environmental, social and economic value assessment.* Biophysical value provides information about the types and location of biophysical features that affect the capacity to generate/use ESs, while economic and social information helps to understand the importance of ESs for the people who use them (Haines-Young et al., 2012). Indicators must be able to assess all such values, given that ESs may take on all three of them (Anton et al., 2010).

The first attempts to mapping ESs information date back to the late 1990s, when the worldwide economic value of ESs was spatially represented (Costanza et al., 1997). ESs were considered homogeneously distributed across biomes and the latter were assumed as spatial units of representation. It was soon realized that different ecosystems provide diverse ESs (MA, 2003) and that different spatial units of ESs provision must be taken into account in the valuation processes (Blaschke, 2005). Several authors stressed that services are usually provided within "process-related landscape units" such as water network, water catchments, habitat and forest boundaries (Dale and Polasky, 2007; Willeman et al., 2008; Kienast et al., 2009; Maes et al., 2012b). De Groot (2010) also stressed this aspect, pointing out that "the recreational function of a landscape or ecosystem is not only defined by the land cover of a specific location (e.g. natural areas) but depends also on the accessibility (e.g. distance to roads) and characteristics of the surrounding landscape". It was also realized that there is an intrinsic heterogeneity in the quantity and quality of the service provision across different landscape units (Troy and Wilson, 2006). Such heterogeneity is the result of differences in biophysical and socio-economic conditions at different scale levels. This means that across the spatial units where ESs are provided, their amount may change. This aspect is particularly important in landscape planning or governance context. To account for the intrinsic (sometimes called *specific*) spatial heterogeneity additional work is required, as intrinsic heterogeneity may be detected only in the field (de Groot et al., 2010; Syrbe and Walz, 2012).

3.2 Selection of indicators of multiple ecosystem services

Experts selected indicators from the lists of: Costanza et al. (1997), Daily (1999), de Groot et al. (2002), Chee (2004), MA (2005), de Groot (2006), Eales et al. (2007), Egoh et al. (2007), Balmford, et al. (2008), Beier et al. (2008), OECD DAC (2008), Willemen et al. (2008), Burkhard et al. (2009), Feld et al. (2009), Kienast et al. (2009), Nelson et al. (2009), Eigenbrod et al. (2010), Liu et al. (2010), Turner et al. (2010).

Experts selected indicators following two criteria:

1. indicators must measure the biophysical, economic and socio-cultural value, in terms of stock and flow, and must take into account of the spatial and temporal heterogeneity of the ESs supplied.

   Biophysical value provides information about the types and location of biophysical features that affect the capacity to generate/use services, while economic and social information helps to understand the importance for people who use them (Haines-Young, et al., 2012). Stock indicators represent the amount of an ES that is present in a region, i.e. the capacity of an ecosystem to deliver a service, while flow indicators are the services provided in a specific time reference (Maes et al., 2012a and Layke, 2009). The representation over specific spatial units allows us to take into account of the spatial heterogeneity of multiple ESs. First of all, ESs are not present over the whole region. Most of the ESs is distributed overlapping land use units but also cadastral parcels, forest lots, catchments, etc. (Willemen et al., 2008; Kienast et al., 2009; Fisher et al, 2009; Maes et al. 2012b). Temporal heterogeneity takes into account that ESs are not evenly distributed over time; before selecting indicators it is important to recognize the services that are important for the period of the analysis (Willeman et al., 2008; Maes et al., 2011; Grêt-Regamey et al., 2012b).
2. Indicators must be computed with existing and available data.

Experts have disregarded a number of indicators from those listed in peer revied papers and scientific reports, and they have added a number of new. Experts have also changed the names of indicators when necessary. In total, they have selected 57 indicators for 25 ESs (see Table 3.1, fourth column). For each ES they have selected from one to five indicators: more indicators are necessary when the biophysical, economic and socio-cultural value in terms of stock and flow can be measured.

Table 3.1. List of 57 indicators (fourth column) assessing 25 ESs types (third column), that are grouped in nine classes (second column) and three themes (first column).

Themes	Classes	Type	Indicators
Provisioning services	Food supply	1 Agriculture production	[1] Density of stumps and seeds [2] Quality of agricultural products [3] Amount of agricultural products [4] Nutritive value of agricultural products [5] Selling price of agricultural products
		2 Hunting production	[6] Density of ungulates [7] Amount of hunting products [8] Nutritive value of hunting products [9] Proportion of ungulates out of the entire hunted population
		3 Fishing production	[10] Fish biomass [11] Amount of fishing products [12] Nutritive value of fishing products [13] Proportion of key Alpine species out of the entire caught population
		4 Mushroom production	[14] Intensity of mushroom production [15] Mushroom quality
		5 Honey production	[16] Intensity of honey production [17] Nectar value
	Raw material supply	6 Inorganic matter extraction	[18] Amount of inorganic matter in quarries [19] Amount of inorganic matter extracted [20] Selling price of inorganic matter
		7 Timber production	[21] Wood density in forests [22] Amount of timber harvested [23] Selling price of timber harvested
	Energy supply	8 Fuel wood production	[24] Amount of fuel wood harvested [25] Energy embedded in fuel wood [26] Selling price of fuel wood
	Water supply	9 Water supply from surface water network	[27] Water flow from surface water network [28] Water consumption from surface water network [29] Selling price of surface water supply
		10 Water supply from groundwater	[30] Water flow from groundwater [31] Water consumption from groundwater [32] Selling price of groundwater supply
Regulating services	Water cycle reg.	11 Water flow regulation	[33] Surface area of lakes, reservoirs and glaciers [34] Specific discharge coefficient
		12 Water quality regulation	[35] Capacity of water ecosystems to reduce pollutants
	Atmosphere components.	13 Air quality regulation	[36] Roughness of land surfaces adjacent to roads [37] Density of forests adjacent to roads
		14 Micro-Climate regulation	[38] Ability of forests in mitigating temperature based on shape [39] Ability of forests in mitigating temperature based on density
		15 Macro-Climate regulation	[40] Carbon stock [41] Carbon increment
	Natural hazards reg.	16 Flood prevention capacity	[42] Curve number

Themes	Classes	Type	Indicators
		17 Hazards Protection capacity	[43] Forest extension [44] Forest watershed protection factor
Cultural services	Tourism opportunities	18 Cultural heritage	[45] Proximity of cultural heritage sites to road network
		19 Scenic beauty	[46] Landscape visibility
	Leisure opportunities	20 Hunting	[47] Density of hunters [48] Game density
		21 Fishing	[49] Fishing intensity [50] Amount of caught fish
		22 Mushroom collection	[51] Revenues from permits [52] Availability of mushrooms of good quality
		23 Honey collection	[53] Availability of honey of good quality
		24 Outdoor recreation	[54] Intensity of sporting activities [55] Revenues from ski passes [56] Season length
		25 Leisure	[57] Density of recreational activities

The indicators are grouped per ES and ESs are grouped under three themes (see Table 3.1 first, third and fourth column). Each indicator is defined below with information regarding its value (biophysical, economic or socio-cultural) and type (stock or flow), and specification of whether it is a proxy because real biophysical, economic or socio-cultural data are missing. Further information is provided in tables, as follows:

- the unit of measurement;
- the list of data used to compute each indicator;
- details on the mapping method (when necessary);
- the spatial unit of representation. Possible spatial units are: Cadastral parcels, Water network - fishing zones, Buffer of 30 m around water network, Sub-catchments, Buffer of 200 m around springs, Glaciers/reservoirs and lakes surface, Forest types areas, Forest lots, Forest patches, Buffer of 3 km around forest roads, Habitat units, Game reserves, Land Cover classes, Quarries, Ski areas, Buffer of 30 m around main roads, Buffer of 150 m around main roads, Grid cell.

Indicators have been mapped by combining database with GIS analyses. Software used to manipulate data of databases are: Kettle from the Pentaho suite for the Extraction, the Transformation and the Load of heterogeneous data and Oracle Express. Maps are obtained by means of three GIS software: ArcGis, ILWIS Academic and GRASS. Indicators have been mapped based on the spatial units of each ES. They are modelled as raster maps with a spatial resolution of 100 m x 100 m. This resolution will allow further analyses with acceptable computational resources to be carried out. The maps use the Universal Transverse Mercator projection, zone 32N and the geodetic datum WGS84 is adopted. The coordinates of the maps' extent are: 5157060 m N, 5059560 m N, 726184 m E, 612484 m E.

Details on data are reported in ANNEX I, while indicators maps in ANNEX II. In ANNEX III main statistics are reported for each ESs indicator.

3.3 Indicators for provisioning services

3.3.1 Agriculture production

Density of stumps and seeds. Agricultural products in non-arable agricultural lands grow because of the presence of stumps and seeds. The proposed indicator measures the estimated number of stumps and seeds of permanent cultures per agricultural type per hectare. It measures the service's biophysical value in terms of stock.

Quality of agricultural products. Soil characteristics, altitude, and climate of agricultural lands influence the quality of products, i.e. the flavour and the organoleptic properties. The European Community promotes and protects highest quality products assigning to them the labels of Protected Designation of Origin (PDO) and Protected Geographical Indications (PGI) (EEC, 2081/92). Agricultural areas can also create appreciable landscapes; such areas are designed as "valuable areas" in the regional landscape plan (PUP, 2008). In order to take into account the quality of agricultural products, scores of quality have been assigned to areas of PDO/PGI products (optimum quality, score 3), to valuables areas (very good quality, score 1) and other agricultural areas (good quality, score 1). This indicator is a proxy for the socio-cultural value in terms of stock.

Amount of agricultural products. The indicator measures the amount of the annual agricultural production (in quintals) for each agriculture type per hectare. It is a measure of the biophysical value in terms of flow.

Nutritive value of agricultural products. It represents the nutritive value (in kilocalories) of the annual agricultural production for each agriculture type per hectare. It is a measure of the biophysical value in terms of flow.

Selling price of agricultural products. It represents the income of agricultural products for each agriculture type per hectare per year. The income of sub-products (like the wine from grapes) is not included. The indicator is a measure of the economic value in terms of flow.

Table 3.2. Unit of measurement, data for mapping and spatial unit of representation for the indicators of the Agriculture production service

	Density of stumps and seeds	Quality of agricultural products	Amount of agricultural products	Nutritive value of agricultural products	Selling price of agricultural products
Unit of measurement	(no. of stumps/seeds) ha^{-1}	Dimensionless	q ha^{-1} year^{-1}	kcal ha^{-1} year^{-1}	€ ha^{-1} year^{-1}
Data for mapping	• Number of stumps and seeds • Agricultural cadastral parcels	• DOP and DGI areas for apples and grapes • Valuable agriculture areas	• Agricultural production • Nutritive values per agriculture product • Selling price values per agriculture product • Agricultural cadastral parcels		
Spatial unit of representation	Cadastral parcel	Patches of agricultural areas	Cadastral parcel		

3.3.2 Hunting production

Density of ungulates. This indicator measures the counted number of ungulates available for hunting (Red Deer, Roe Deer, Chamois, Muflon and Wild Boar) in their habitat; it represents the service biophysical value in terms of stock.

Amount of hunting products. The indicator measures the amount of animals hunted in 2008 (in kilograms) per game reserve. It is a measure of the biophysical value in terms of flow.

Nutritive value of hunting products. It represents the nutritive value (in kilocalories) of the animals hunted per game reserve per year. It is a measure of the biophysical value in terms of flow.

Proportion of ungulates out of the entire hunted population. Ungulates are considered the most appreciated hunting products. In order to measure the socio-cultural value in terms of flow, the ratio of ungulates to all the animals hunted per game reserve per year is calculated.

Table 3.3. Unit of measurement, data for mapping and spatial unit of representation for the indicators of the Hunting production service

	Density of ungulates	Amount of hunting products	Nutritive value of hunting products	Proportion of ungulates out of the entire hunted population
Unit of measurement	(no. of ungulates) ha^{-1}	kg ha^{-1} year^{-1}	kcal ha^{-1} year^{-1}	(no. of hunted ungulates) (no. of hunted animals)$^{-1}$ year^{-1}
Data for mapping	• Number of ungulates in their habitats • Habitat of ungulates	• Game reserves • Number of hunted animals per specie in each hunting area • Weight of hunted animals • Nutritive values per hunted specie		
Spatial unit of representation	Habitat unit	Game reserve		

3.3.3 Fishing production

Fish biomass. The indicator represents the mass (in kilograms) of available fish per fishing zone. It is a measure of the biophysical value in terms of stock.

Amount of fishing products. The indicator measures the amount of caught fish (in kilograms) in 2008 per fishing zone. It is a measure of the biophysical value in terms of flow.

Nutritive value of fishing products. It represents the nutritive value (in kilocalories) of the harvested fish per fishing zone per year. It is a measure of the biophysical value in terms of flow.

Proportion of key Alpine species out of the entire caught population. *Salmo trutta marmoratus, Salmo trutta fario* and *Salmo trutta lacustris* are considered the most appreciated fishing products. The ratio of key Alpine species annually harvested per fishing zone per year is calculated. It is a measure of the socio-cultural value in terms of flow.

Table 3.4. Unit of measurement, data for mapping and spatial unit of representation for the indicators of the Fishing production service

	Fish biomass	**Amount of fishing products**	**Nutritive value of fishing products**	**Proportion of key Alpine species out of the entire caught population**
Unit of measurement	kg ha^{-1}	kg ha^{-1} year^{-1}	kcal ha^{-1} year^{-1}	(no. of harvested key Alpine species) (no. of harvested fishes)$^{-1}$ year^{-1}
Data for mapping	Fishing zones			
	Fish mass	• Number of caught fishes • Weight of caught • Nutritive value of fish		
Spatial unit of representation	Water network - fishing zone			

3.3.4 Mushroom production

Intensity of mushroom production. The indicator represents the quantity of mushrooms available for harvesting for each forest type, according to pedological-lithological characteristics of the forest subsoil. It is a proxy indicator, whose values range from 0 to 1. It is a measure of the biophysical value in terms of stock.

Mushroom quality. The indicator indicates the quality of mushrooms available for harvesting in each forest type, according to pedological-lithological characteristics of the forest subsoil. It is a proxy indicator, whose values range from 0 to 1. It is a measure of the socio-cultural value in terms of stock.

Table 3.5. Unit of measurement, data and methods for mapping and spatial unit of representation for the indicators of the Mushroom production service

	Intensity of mushroom production	Mushroom quality
Unit of measurement	Dimensionless	Dimensionless
Data for mapping	Forest type	
	Mushroom production capacity	Mushroom quality
Spatial unit of representation	Forest type	

3.3.5 Honey production

Intensity of honey production. The indicator represents the quantity of nectar and honeydew available for harvesting in each forest type, according to the terrain slope and altitude, and to the forests typologies (Matteotti and Miori, 2005). It is a proxy indicator, whose values range from 0 to 1. It is a measure of the biophysical value in terms of stock.

Nectar value. The values indicate the quality of nectar and honeydew, according to the vegetation characteristics of forest typologies. It is a proxy indicator, whose values range from 0 to 1. It is a measure of the socio-cultural value in terms of stock.

Table 3.6. Unit of measurement, data and methods for mapping and spatial unit of representation for the indicators of the Honey production service

	Intensity of honey production	Nectar value
Unit of measurement	Dimensionless	Dimensionless
Data for mapping	• Forest roads • Forest types	
	Honey production capacity per forest type	Nectar value
Spatial unit of representation	Area 500 m close to forest ways	

3.3.6 Inorganic matter extraction

Amount of inorganic matter in quarries. It is the available volume (in m^3) of inorganic matter per quarry. It is a measure of the biophysical value in terms of stock.

Amount of inorganic matter extracted. The indicator measures the volume of inorganic matter extracted (in m^3) per quarry per year. It is a measure of the biophysical value in terms of flow.

Selling price of inorganic matter. It represents the annual income of extractions per quarry. The indicator is a measure of the economic value in terms of flow.

Table 3.7. Unit of measurement, data for mapping and spatial unit of representation for the indicators of the Inorganic matter extraction service

	Amount of inorganic matter in quarries	**Amount of inorganic matter extracted**	**Selling price of inorganic matter**
Unit of measurement	$m^3\ ha^{-1}$	$m^3\ ha^{-1}\ year^{-1}$	€ $ha^{-1}\ year^{-1}$
Data for mapping	Quarries Volume of inorganic matter type per quarry	• Extracted volumes per quarry • Selling price for each inorganic matter type	
Spatial unit of representation	Quarry		

3.3.7 Timber production

Wood density in forests. It is the volume of wood (in m^3) per forest lot. It is a measure of the biophysical value in terms of stock. This indicator is also used to quantify the Fuel wood production service.

Amount of timber harvested. The indicator measures the volume of timber (in m^3) harvested per forest lot per year. The annual volume value is an average value over 10 years. It is a measure of the biophysical value in terms of flow.

Selling price of timber harvested. It represents the income of the annual cutting per forest lot. It is a measure of the economic value in terms of flow.

Table 3.8. Unit of measurement, data for mapping and spatial unit of representation for the indicators of the Timber production service

	Wood density in forests	**Amount of timber harvested**	**Selling price of timber harvested**
Unit of measurement	$m^3\ ha^{-1}$	$m^3\ ha^{-1}\ year^{-1}$	€ $ha^{-1}\ year^{-1}$
Data for mapping	Volume of wood per forest lot	• Forest types • Volume of wood for cutting per forest lot • Proportion of wood for timber per forest type • Selling price of cut timber	
Spatial unit of representation	Forest lot		

3.3.8 Fuel wood production

Amount of fuel wood harvested. The indicator measures the volume of fuel wood (in m^3) annually harvested per forest lot. The annual volume value is an average value over 10 years. It is a measure of the biophysical value in terms of flow.

Energy embedded in fuel wood. It represents the energy that can be generated from the fuel wood harvested per forest lot. It is a measure of the socio-cultural value in terms of flow.

Selling price of fuel wood. It represents the income of annual cutting per forest lot. It is a measure of the economic value in terms of flow.

Table 3.9. Unit of measurement, data for mapping and spatial unit of representation for the indicators of the Fuel wood production service

	Amount of fuel wood harvested	Energy embedded in fuel wood	Selling price of fuel wood
Unit of measurement	m^3 ha^{-1} $year^{-1}$	kWh ha^{-1} $year^{-1}$	€ ha^{-1} $year^{-1}$
Data for mapping	• Forest types • Volume of wood for cutting per forest lot • Proportion of wood for fuel wood per forest type • Energy value of fuel wood • Selling price of cut fuel wood		
Spatial unit of representation	Forest lot		

3.3.9 Water supply from surface water network

Water flow from surface water network. It is the water discharge from withdrawals per sub-catchment. It is a measure of the biophysical value in terms of stock.

Water consumption from surface water network. The indicator measures the annual volume of water supplied from withdrawals for livestock, aquaculture, agriculture and local industry per sub-catchment. The volume has been calculated assuming that each withdrawal works 365 days per year. It is a measure of the biophysical value in terms of flow.

Selling price of surface water supply. It represents the annual income of water supplied from withdrawals. The economic value is calculated referring to the price paid for the use of the public aqueduct network. It is a measure of the economic value in terms of flow.

Table 3.10. Unit of measurement, data for mapping and spatial unit of representation for the indicators of the Water supply from surface water network service

	Water flow from surface water network	Water consumption from surface water network	Selling price of surface water supply
Unit of measurement	m^3 s^{-1} ha^{-1}	m^3 ha^{-1} $year^{-1}$	€ ha^{-1} $year^{-1}$
Data for mapping	Sub-catchments Discharge from per withdrawal points	• Water flow for drinking, irrigation and industrial uses from withdrawal points • Selling price of withdrawn water	
Spatial unit of representation	Sub-catchment		

3.3.10 Water supply from groundwater

Water flow from groundwater. It is the water discharge from springs and wells. It is a measure of the biophysical value in terms of stock.

Water consumption from groundwater. The indicator measures the annual volume of water supplied from springs and wells for livestock, aquaculture, agriculture and local industry per a circular buffer area of 200 m of radius around springs and wells. The volume has been calculated assuming that each withdrawal works 365 days per year. It is a measure of the biophysical value in terms of flow.

Selling price of groundwater supply: It represents the annual income of water supplied from springs and wells. The economic value refers to the price paid for the use of the public aqueduct network. It is a measure of the economic value in terms of flow.

Table 3.11. Unit of measurement, data for mapping and spatial unit of representation for the indicators of the Water supply from groundwater service

	Water flow from groundwater	Water consumption from groundwater	Selling price of groundwater supply
Unit of measurement	$m^3\ s^{-1}\ ha^{-1}$	$m^3\ ha^{-1}\ year^{-1}$	€ $ha^{-1}\ year^{-1}$
Data for mapping	Discharge from springs or wells	• Water flow for drinking, irrigation and industrial uses from springs or wells • Selling price of withdrawn water	
Spatial unit of representation	Buffer of 200 m around springs and wells		

3.4 Indicators for regulating services

3.4.1 Water flow regulation

Surface area of lakes, reservoirs and glaciers. The storage capacity of surface water is related to the water volumes stocked in lakes, reservoirs and glaciers. Only the values of lakes, reservoirs and glaciers surface areas were available; they have been used as the proxy measure of the biophysical service value in terms of stock.

Specific discharge coefficient. The water discharge production per square km of each sub-catchment is due to rainfall, snow melting processes, evapotranspiration and water losses due to percolation towards deep aquifers. This value is usually computed on monthly basis. The proposed indicator considers the annual average value for each sub-catchment as a proper measure of the biophysical value in terms of stock.

The contribution of groundwater to water flow regulation has not be taken into account because of lack of information.

Table 3.12. Unit of measurement, data for mapping and spatial unit of representation for the indicators of the Water flow regulation service

	Surface area of lakes, reservoirs and glaciers	Specific discharge coefficient
Unit of measurement	m^2	$m^3\ s^{-1}\ ha^{-1}$
Data for mapping	Corine land cover (lakes, reservoirs and Glaciers classes)	Specific discharge coefficient
Spatial unit of representation	Land cover class of lakes, reservoirs and glaciers	Sub-catchment

3.4.2 Water quality regulation

Capacity of water ecosystems to reduce pollutants. The capacity of water ecosystems (i.e. riverbeds and riparian areas 30 m close to the rivers) to reduce incoming pollutants is assumed as a proxy measure of the service biophysical value in terms of stock. Capacity values range from 0 to 1: 0 is assigned to rivers segments where the waterbed and the riparian area are impermeable, while 1 is assigned where the waterbed is permeable and the riparian area is formed by hygrophilous vegetation. Intermediate values combine the absorbing pollutants capacity (abs. capacity) of the riverbeds and of different land cover classes in riparian areas. Impermeable elements of waterbeds are: training walls (abs. capacity = 0) and groynes or dikes (abs. capacity = 0.5). Land cover types are: artificial grounds (abs. capacity = 0), arable lands (abs. capacity = 0), grass (abs. capacity = 0), non-hygrophilous forests (abs. capacity = 0) and hygrophilous forests (abs. capacity = 1). The table with the combined values is reported hereafter (Table 3.13): values of absorbing capacity of riverbeds have been multiplied to the values of land cover types.

Table 3.13. Values of absorbing capacity of the water ecosystems: riverbeds with elements of impermeability (training walls and groynes or dikes) and different land cover types of riparian areas 30 m close to the rivers

	Training wall	Groynes or dike	Natural bed
Artificial ground	0	0	0
Arable land	0	0.15	0.3
Grass	0	0.2	0.4
Forest	0	0.4	0.8
Hygrophilous forest	0	0.5	1

Table 3.14 Unit of measurement, data and methods of mapping and spatial unit of representation for the indicator of the Water quality regulation service

	Capacity of water ecosystems to reduce pollutants
Unit of measurement	Dimensionless
Data for mapping	• Water network • Elements of impermeability in riverbeds • Corine land cover (classes comparable to artificial ground, arable lands, grass and forests) • EUNIS Habitat (Hygrophilous vegetation) • Absorbing capacity values of water ecosystems (scalar values, see Table 3.13)
Methods of mapping	Assign values of absorbing capacity to the elements of impermeability of the waterbed, and to the riparian areas (30 m close to the hydrographic water network) considering the land cover types (artificial areas, arable lands, grass and forests) and the presence of Hygrophilous forests.
Spatial unit of representation	Buffer of 30 m around water network

3.4.3 Air quality regulation

Roughness of land surfaces adjacent to roads. Rough surfaces (like buildings and trees) obstacle air circulation; their action may retain traffic emissions from adjacent roads. This capacity is represented by the surface roughness values in a buffer area of 30 m around the road network; the lower the roughness values are, the lower the retaining capacity of the corresponding surfaces is. The indicator is a proxy that measures the service biophysical value in terms of stock.

Density of vegetation adjacent to roads. The capacity of vegetation to stop the diffusion of traffic emissions depends on its density. The Normalized Density Vegetation Index (NDVI) has been used to measure this capacity in a buffer area of 30 m around the road network. The index ranges from 0 to 1: values close to 0 generally correspond to barren areas of rock or snow, while highest values correspond to very dense forests. Grasslands values range from 0.2 to 0.4. The indicator is a proxy that measures the biophysical value of the service in terms of stock.

Table 3.15. Unit of measurement, data for mapping and spatial unit of representation for the indicators of the Air quality regulation service

	Roughness of land surface adjacent to roads	**Density of forests adjacent to roads**
Unit of measurement	Dimensionless	Dimensionless
Data for mapping	• Corine land cover • Roughness parameters per land cover type Road network	NDVI
Spatial unit of representation	Buffer of 30 m around roads	

3.4.4 Micro-Climate regulation

Ability of forests in mitigating temperature based on shape. The shape of forest patches influences the mitigation of the forest temperature. In particular, the more compact patches are, the more they are able to mitigate temperature. The shape index of forest patches (i.e. the ratio of patch areas to the relative squared perimeter) may be used to take this into account; in particular shape index values close to 0 represent very long and narrow patches, while the maximum value of 0.075 stands for almost circular shapes (the most compact shape). The shape index is a proxy indicator and it measures the biophysical value in terms of stock.

Ability of forests in mitigating temperature based on density. The ability of the forest in mitigating temperature and humidity depends on the density of trees in forest patches. NDVI of forest patches has been used to measures the service biophysical value in terms of stock.

Table 3.16. Unit of measurement, data of mapping and spatial unit of representation for the indicators of the Micro-Climate regulation service

	Ability of forests in mitigating temperature based on shape	Ability of forests in mitigating temperature based on density
Unit of measurement	Dimensionless	Dimensionless
Data for mapping	Corine land cover (Forests)	• NDVI • Corine land cover (Forests)
Spatial unit of representation	Forest patch	

3.4.5 Macro-Climate regulation

Carbon stock. Forests, grass/grasslands and tree cultivations can store carbon. The values of carbon stock of forests (in tons) derive from an existing regional inventory of the organic carbon stored in forest ecosystems (Rodeghiero et al., 2010). The evaluation refers to eight forest categories: larch forest, mountain spruce forest, secondary spruce forest, fir forest, beech forest, pine forest, other secondary coniferous forests and mesophilic broadleaves forests. The values of carbon stock for grass/grasslands and tree cultivations are esteems. The indicator is a measure of the biophysical value in terms of stock.

Carbon increment. The values of carbon increment of forests are taken from the regional inventory of the organic carbon stored in the forest ecosystems (Rodeghiero et al., 2010). Values are given for eight forest types. The values of carbon stock for grass/grasslands and tree cultivations are esteems. The indicator is a measure of the biophysical value in terms of flow.

Table 3.17. Unit of measurement, data of mapping and spatial unit of representation for the indicators of the Macro-Climate regulation service

	Carbon stock	Carbon increment
Unit of measurement	t ha^{-1}	t ha^{-1} year^{-1}
Data for mapping	• Forest types • Agricultural cadastral parcels (pastures, grassland and orchards) • Carbon storage in forests • Carbon storage in pastures, grassland and orchards	• Carbon increment in forests • Carbon increment in pastures, grassland and orchards
Spatial unit of representation	Forest type and cadastral parcel of grass/grasslands and tree cultivations	

3.4.6 Flood prevention capacity

Curve Number. The prevention capacity from flood has been measured as a function of the runoff coefficient (CN): 100 - CN. CN (Curve Number) is function of permeability and of land cover and its values range from 30 to 100: the lower CN is, the more permeable the soil is. It is an empirical parameter, developed by the Soil Conservation Service (1985) that is typically used in hydrology to estimate the approximate amount of the direct runoff from a rainfall event in a particular area. The indicator is a measure of the biophysical value in terms of flow.

Table 3.18. Unit of measurement, data for mapping and spatial unit of representation for the indicators of the Flood prevention capacity service

	Curve number
Unit of measurement	Dimensionless
Data for mapping	Curve Number
Spatial unit of representation	Grid cell

3.4.7 Hazards protection capacity

Forest extension. The extension of forest patches is an important factor for the protection from natural hazards. It is a measure of the biophysical service value in terms of stock.

Forest watershed protection factor. The indicator combines the capacity of forest vegetation to retain water and stabilise the terrain. It is an output of the FRAGILE model (Della Fontana and Cazorzi, 2005). Values range from 0 to 100, i.e. from low to high capacity. The indicator is a measure of the biophysical value in terms of flow.

Table 3.19. Unit of measurement, data for mapping and spatial unit of representation for the indicators of the Hazards prevention capacity service

	Forest extension	Forest watershed protection factor
Unit of measurement	m^2	Dimensionless
Data for mapping	Corine land cover (forests)	Hazard protection capacity
Spatial unit of representation	Forest patch	Grid cell

3.5 Indicators for cultural services

3.5.1 Cultural heritage

Proximity of cultural heritage sites to road network. The accessibility to cultural heritage sites (i.e. landscape goods and archaeological sites) depends on their proximity to the road network. The Euclidean distance, normalized using minimum and maximum values, has been computed from the road network to each cultural heritage site. The distance has been computed on the basis of the digital terrain model. The indicator is a measure of a biophysical value in terms of stock.

Table 3.20. Unit of measurement, data for mapping and spatial unit of representation for the indicator of the Cultural heritage service

	Proximity of cultural heritage sites to road network
Unit of measurement	Dimensionless
Data for mapping	• Road network • DTM • Points of cultural interest
Spatial unit of representation	Grid cell

3.5.2 Scenic beauty

Landscape visibility. The visibility of particular beauty sites (natural and cultivated ecosystems, landscape fronts and goods, and archaeological sites) depends on the morphology of the territory. The visibility has been evaluated for all points and up to 10 km of distance. The indicator is a measure of a biophysical value in terms of stock.

Table 3.21. Unit of measurement, data for mapping and spatial unit of representation for the indicator of the Scenic beauty service

	Landscapes visibility
Unit of measurement	(no. of visible points) ha^{-1}
Data for mapping	• DTM • Points of particular beauty
Method of mapping	Evaluation of the visibility of any point up to 10 km of distance, considering the effects of the terrain's surface (view-shed analysis). For any geo-referenced point the view-shed analysis returns a Boolean map: value 1 is where the point is visible and 0 where not. Maps are then summed in order to obtain the number of visible points for each hectare of region.
Spatial unit of representation	Grid cell

3.5.3 Hunting

Hunting activity has been differentiated from hunting production to distinguish between the recreational activity and the provisioning service.

Density of hunters. The indicator measures the annual number of present hunters in each game reserve. It is a measure of the socio-cultural value in terms of flow.

Game density. The indicator measures the amount of hunted animals per year for each game reserve. It is a measure of the biophysical value in terms of flow.

Table 3.22. Unit of measurement, data for mapping and spatial unit of representation for the indicators of the Hunting service

	Density of hunters	**Game density**
Unit of measurement	(no. of hunters) ha^{-1} year^{-1}	(no. of animals) ha^{-1} year^{-1}
Data for mapping	Game reserves	
	Number of hunters	Number of hunted animals
Spatial unit of representation	Game reserve	

3.5.4 Fishing

Fishing activity has been differentiated from fishing production to distinguish between the recreational activity and the provisioning service.

Fishing intensity. The indicator measures the number of fishing excursions during a year per fishing zone. It is a measure of the socio-cultural value in terms of flow.

Amount of caught fished. The indicator measures the number of fishes caught per year per fishing zone. It is a measure of the biophysical value in terms of flow.

Table 3.23. Unit of measurement, data for mapping and spatial unit of representation for the indicators of the Fishing service

	Fishing intensity	**Amount of caught fished**
Unit of measurement	(no. of fishing activities) ha^{-1} year^{-1}	(no. of harvested fishes) ha^{-1} year^{-1}
Data for mapping	Fishing zones	
	Number of fishing excursions	Number of caught fishes
Spatial unit of representation	Water network - fishing zone	

3.5.5 Mushroom collection

Mushroom collection has been differentiated from mushroom production to distinguish between the recreational activity (mushroom collection) and the provisioning service (mushroom production).

Revenues from permits. It represents the income of harvesting permits to visitors. It is a measure of the economic value in terms of flow.

Availability of mushrooms of good quality. The indicator assesses the presence of mushrooms of good quality in each forest type, according to pedological-lithological characteristics of the forest subsoil. It is a proxy indicator, whose values range from 0 to 1. It is a measure of the socio-cultural value in terms of stock.

Table 3.24. Unit of measurement, data and methods for mapping and spatial unit of representation for the indicators of the Mushroom collection service

	Revenues from permits	**Availability of mushrooms of good quality**
Unit of measurement	€ ha^{-1} year^{-1}	Dimensionless
Data for mapping	• Corine land cover (forests) • Number of mushroom permits • Permits fee for harvesting	• Forest types • Mushroom production capacity • Mushroom quality
Spatial unit of representation	Land cover class of forest	Forest type

3.5.6 Honey collection

Honey collection has been differentiated from honey production to distinguish between the recreational activity (honey collection) and the provisioning service (honey production).

Availability of honey of good quality. The indicator assesses the presence of nectar and honeydew of good quality, according to the vegetation characteristics of forest typologies. It is a proxy indicator, whose values range from 0 to 1. It is a measure of the socio-cultural value in terms of stock.

Table 3.25. Unit of measurement, data and methods for mapping and spatial unit of representation for the indicators of the Honey collection service

	Availability of honey of good quality
Unit of measurement	Dimensionless
Data for mapping	• Honey production capacity • Forest roads • Forest types • Nectar values
Spatial unit of representation	Buffer of 150 m close to forest ways

3.5.7 Outdoor recreation

Intensity of sporting activities. The indicator counts the simultaneous presence of the following activities: walking/climbing, cycling, skiing and windsurfing/sailing. It is a measure of the socio-cultural value in terms of stock.

Revenues from ski passes. Trentino is divided in seven ski areas with 236 ski lifts in total. The indicator measures the revenue from ski passes in each ski area in 2007. It is a measure of the economic value in terms of flow.

Season length. The indicator counts the estimated number of months in which walking/climbing, cycling, skiing and windsurfing/sailing can be practiced. It is a measure of the socio-cultural value in terms of flow.

Table 3.26. Unit of measurement, data and methods for mapping and spatial unit of representation for the indicators of the Outdoor recreation service

	Intensity of sporting activities	Revenues from ski passes	Season length
Unit of measurement	(no. of sport activities) ha^{-1}	€ ha^{-1} $year^{-1}$	(no. of months) ha^{-1} $year^{-1}$
Data for mapping	• Corine land cover (lakes) • Forest roads • Ski slopes	• Ski slopes • Revenues from ski passes	• Corine land cover (lakes) • Forest roads • Ski slopes • Season length
Spatial unit of representation	Patch of lakes, forest roads and ski slopes	Ski slopes	Patch of lakes, forest roads and ski slopes

3.5.8 Leisure

Density of recreational activities. The indicator is a proxy to measure the relaxing activities offered in forest areas and lakes. Scores of disturbances have been assigned to forests lots in order to estimate the intensity of disturbances, while the areas of lakes have been normalized (according to the area of the largest lake) in order to estimate the density of recreational activities.

Table 3.27. Unit of measurement, data and methods for mapping and spatial unit of representation for the indicators of the Leisure service

	Density of recreational activities
Unit of measurement	Dimensionless
Data for mapping	• Forest types • Corine land cover (lakes)
Spatial unit of representation	Patch of lakes and forest types

3.6 Conclusions

57 indicators have been identified for 25 ESs and, to assess each ES, up to five indicators have been selected. 32 indicators have been identified for provisioning services, 12 for regulating services and 13 for cultural services. Among these indicators, 29 are of stock and 28 of flow. Both stock and flow indicators are used to measure biophysical and socio-cultural values, while the economic value is measured only in terms of flow indicators. In particular, 35 indicators measure the biophysical value, eight the economic value and 14 the socio-cultural value. Regulating services are assessed only by indicators of biophysical value. The distinctions between real and potential supply, between stock and flow indicators, and between biophysical, socio-cultural and economic values are innovative with respect to the current state of the art (Carpenter et al., 2006, and Haines-Young and Potschin, 2010a).

According to available data, indicators allow the measure of the real supply of ESs, but not the real/potential demand. Economic value have been computed only for ESs with direct market, like Agriculture production, Inorganic matter extraction, Fuel wood production, Water supply, Mushroom collection and Outdoor recreation. These ESs are both provisioning and cultural services, but not regulating services.

The indicators have been mapped over 20 different spatial units (e.g. cadastral parcels, sub-catchments and land cover classes). This adequately represents the typical spatial heterogeneity of the ESs. In general, indicators of the same ES have the same spatial unit, but there are some exceptions: hunting production (habitat of animals is bigger than the game reserves), water quantity regulation (the capacity to store water is performed by glaciers, lakes and artificial basins, while the capacity to flow is performed by the terrain), and outdoor recreation (the Intensity of sporting activity is mapped over forest lots, lakes and ski slopes, while the Revenues from ski passes only over ski slopes).

4 Identifying key indicators and ecosystem services synergies and tradeoffs

4.1 Introduction

Ecosystem services (ESs) can be recognized at the regional scale in relation to the presence of human wellbeing needs, and their number may increase in relation to the heterogeneity of morphology, land cover and land use (MA, 2003). Their mainstreaming in decision making requires an explicit assessment that, above all, endorses the computation of indicators and the identification of interactions (Muller and Burkhard, 2012). ESs are usually numerous and the estimation of all indicators endorses great efforts in terms of both human resources for data gathering and computer resources due to the severe computational requirements involved in the analysis of such a great amount of information. Therefore, the identification of a proper number of indicators for the assessment (i.e. key indicators) is a priority.

According to Niemeijer and de Groot (2008) and to Van Oudenhoven et al. (2012), the majority of studies has dealt with this topic by (1) compiling lists of reasonable indicators (Troy and Wilson, 2006; Egoh et al., 2007; Tallis and Polasky, 2009), or (2) setting conceptual schemes of selections (Metzger et al., 2006; Van Oudenhoven et al., 2012). Interactions among ESs cause that changes in one service that change the provision of other services (Rodriguez et al., 2006). Interactions are synergies when services are enhanced simultaneously, and tradeoffs when the provision of one service is enhanced at the cost of reducing the provision of other services (Raudsepp-Hearne et al., 2009). Interactions can be temporal and spatial as relations between services may be delayed in time and/or occur in different areas (Rodriguez et al., 2006). Up to day, no study has dealt with the identification of temporal interactions and very few have dealt with the identification of spatial interactions (Raudsepp-Hearne et al., 2009; Maes et al. 2012b; Plieninger et al., 2013; Qiu and Turner, 2013), in which case only few ESs were considered simultaneously (Qiu and Turner, 2013).

The present study aims at (1) selecting a suitable number of indicators (key indicators) that are necessary to make an explicit assessment of the real ES supply in terms of stock and flow of a multiple set of ESs, and (2) identifying synergies and tradeoffs among multiple ESs on the basis of key indicators. The first objective will be accomplished by mapping over specific spatial units the biophysical, economic and socio-cultural value of a range of ESs for the 2000 decade. This is the first study, to my knowledge, that provides a concrete example of how key indicators can be selected at the regional scale, where 25 ESs have been chosen according to their relevance for the local community of the Trentino region in the Alps and 57 indicators have been mapped. The second objective will be accomplished by identifying the positive (synergies) and negative (tradeoffs) interactions that may exist between ESs. Synergies occur when changes in one service enhance the provision of others, while tradeoffs occur when enhancements in the provision of one service cause a decline in other services (Rodriguez et al., 2006).

Results will allow to recognize general rules for the identification of key indicators for each ES. Such rules may facilitate the selection of indicators for regions with high data availability and orientate the selection of indicators to be computed for regions with low data availability. The identification of interactions will allow to prove the existence of patterns of synergies and tradeoffs for multiple ESs, as firstly hypothesized by Rodriguez et al. (2006).

4.2 Methods

The correlation analysis of ES indicators allows to identify pairs of indicators interacting with each other (Raudsepp-Hearne et al., 2009). We adopted Spearman's (1904) rank correlation analysis to detect key indicators (1a) among those of the same ES and (1b) between those of different ESs and (2) to identify the degree of positive (i.e. synergies) or negative (i.e. tradeoffs) interactions among different ESs. Spearman correlation coefficient is a non-parametric measure of the statistical dependence between two variables that is used when variables (i.e. indicators) do show a normal distribution. To identify key indicators for each ES, we considered a correlation coefficient (ρ) threshold of 0.75; indicators that were highly associated (i.e. $|\rho| \geq 0.75$) were deemed to provide redundant information. Lowly associated indicators were all used as key indicators for the purpose of this study. The integrity of source data guides the choice of the key indicator for each highly associated pair. The significance of the statistical inference was corrected by using Bonferroni's (1936) adjustment for multiple comparisons (α = 0.05/no. of multiple comparisons).

The 0.75 threshold is high and its choice ensures the detection of highly correlated indicators and it is needed to show that the number of selected indicators does not change consistently for different thresholds. To assess this requirement, we calculated the selection rate for $|\rho| =$

0.05 to $|\rho| = 1$ with increasing steps of $\rho = 0.05$. The selection rate represents the ratio of pairs of indicators selected for each threshold of ρ.

To identify synergies and tradeoffs among indicators of different ESs, four levels of interactions were defined: high interactions for 0.7 <= |ρ| <= 1, moderate interactions for 0.5 <= |ρ| < 0.7, weak interactions for 0.3 <= |ρ| < 0.5, and null interactions 0 <= |ρ| < 0.3. In this case, |ρ| is used to measure the extent to which the provision of a particular service may affect the provision of a different service. Thus, a positive ρ measures synergies that arise when ESs are enhanced simultaneously, while a negative ρ measures tradeoffs that arise when an ES is enhanced at the cost of reducing the use of another (Raudsepp-Hearne et al., 2009).

The correlation analysis was computed for the 57 indicators of the 25 ESs of the Trentino region by means of the R program (R Core Team, 2013).

4.3 Results

4.3.1 Selecting key indicators of ecosystem services

The Spearman correlation analysis among indicators of the same ES helped to identify 35 key indicators, out of 57 (c.f. Table 3.1 and Table 4.1). It resulted that a single ES is assessed from one up to three key indicators (instead of from one up to five indicators). The correlation coefficients of ES indicators are reported in ANNEX III. Subsequently, a second turn of the Spearman correlation analysis among key indicators of different ESs allowed a further reduction to 28 key indicators. The results are summarized below.

Key indicators for provisioning services

The analysis showed three indicators are sufficient to assess a single provisioning service, namely: one indicator of stock-biophysical value, one of flow-biophysical value and one of economic/socio-cultural value. In particular, stock and flow indicators are redundant when the use of the ESs is not regulated at administrative level: indeed, in this case the stock is proportional to the flow. Indicators of economic/socio-cultural values are always selected as key indicators, since they contain information related to context specific beneficiaries preferences. Following, the case of the Agricultural and Hunting production are considered as illustrative examples of provisioning services. In the case of the Agricultural production (see Figure 4.1) key indicators include: (1) the Amount of agricultural products and (2) the Selling price of agricultural products. In fact, Density of stumps and seeds and Nutritive value of agricultural products are highly correlated with the Amount of agricultural products, as well as the Quality of agricultural products with the Selling price of agricultural products. Similarly, for Hunting production three indicators are key out of four: (1) Density of ungulates, (2) Amount of hunting products and (3) Proportion of ungulates out of the entire hunted population. In fact, the Nutritive value of hunting products is highly correlated with the Amount of hunting products.

Key indicators for regulating services

Stock and flow indicators were selected as key indicators for single regulating services, only if they are mapped over different spatial units. For instance, in the case of Water flow regulation key indicators are: (1) Water storage (mapped over water tables) and (2) Water flow (mapped over catchments). In contrast, Macro-Climate regulation can be assessed only by Carbon stock, since the original indicators (i.e. Carbon stock and Carbon increment) are mapped over the same spatial unit, i.e. forest lot.

Key indicators for cultural services

Two indicators are enough to assess single cultural services: one of stock-biophysical value or flow-biophysical value, and one of flow-economic/socio-cultural value. For instance, key indicators for Hunting are: (1) Density of hunters and (2) Game density. As for provisioning services, stock and flow are redundant when the use of the ESs is not regulated. Indicators of economic/socio-cultural values are always selected as key indicators, since they contain information that is not depending on the amount of the ESs.

Key indicators for multiple ESs

Spearman analysis highlighted also that a strong dependence may exist between 11 indicators of different ESs (out of 35 key indicators). Three patterns of high correlation have been observed:

1) correlation between provisioning and cultural services related to the fishing activity, i.e. between the Amount of Fishing products and Fishing intensity ($\rho = 0.948$);
2) correlations between provisioning services of forests, i.e. between Amount of timber harvested and Amount of fuel wood harvested ($\rho = 0.928$), and between Intensity of mushroom production and Intensity of honey production ($\rho = 0.761$);
3) correlations between ESs of forests, i.e. between Wood density and Mushroom quality ($\rho = 0.839$), Ability of forests in mitigating temperature based on shape ($\rho = 0.772$), Carbon stock ($\rho = 0.787$) and Availability of mushroom of good quality ($\rho = 0.827$).

One service is key for the first pattern, two services are key for the second and 1 for the third pattern: 7 indicators are dependent and 4 are key indicators (out of 11).

Therefore, 35 key indicators are required when considering single ESs, while, when considering the whole set of ESs, only 28 (35-7) are key indicators. They are the minimum set of indicators that may be taken into account in order to assess the 25 ESs of the Trentino region.

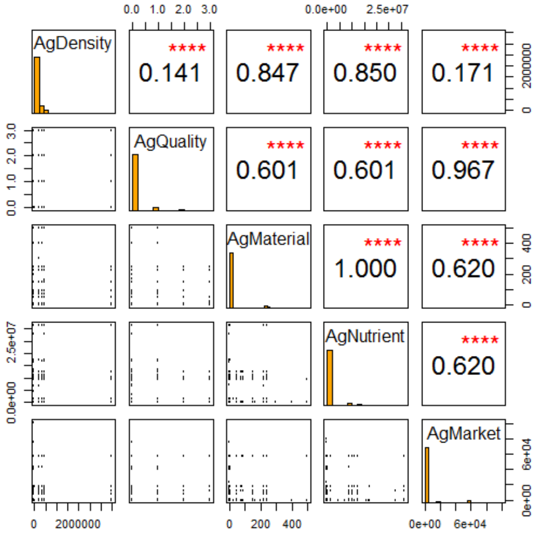


Figure 4.1. Correlation analysis among the five indicators of the ES "Agriculture production". Scatterplots on the down-left allow for a visual interpretation of correlations; Spearman correlation coefficients are on the up-right of the figure and stars represent p-value (p-value for four stars is 2*10^{-16}). Indicators are: AgDensity (Density of stumps and seeds), AgMaterial (Amount of agricultural products), AgNutrient (Nutritive value of agricultural products), and AgQuality (Quality of agricultural products) and AgMarket (Selling price of agricultural products). Histograms of data distribution are graphs in the middle of the figure.

All correlations were statistically significant (p-value < 0.05/57 = 0.00088) and the number of selected indicators did not change consistently for different thresholds of ρ (Figure 4.2). In fact, the selection rate, that is the ratio between the increment in the number of indicators' pairs selected for each ρ threshold and the total number of indicators pairs, is approximately 0 for thresholds 0.25 <= |ρ| <= 0.45. This means that no additional indicators pair is selected for this range of correlation coefficient. On the contrary, the selection rate for extreme values of ρ (|ρ| < 0.15 and |ρ| > 0.9) is above 0.05, and is below or equal to 0.05 around the threshold of 0.75 (for 0.5 <= |ρ| <= 0.9). 33 pairs of indicators were selected for |ρ| = 0.5, while 14 pairs of indicators were selected for |ρ| = 0.9.

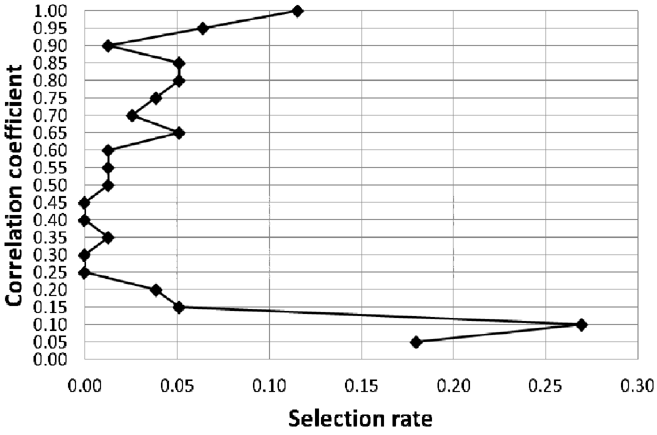


Figure 4.2. Selection rate of pairs of correlated indicators for different thresholds of the correlation coefficient (ρ).

Table 4.1. Key indicators of ESs used in this study. Indicators are both of Stock and Flow (4th column), measuring the Biophysical (B), Economic (E) and Socio-cultural (S-C) values (5th column) and are provided over different spatial units (6th column).

ES theme	ES type	key indicators	Stock Flow	Type of indicator	Service spatial unit
Provisioning	Agriculture production	[1] Agriculture production	S	B	Cadastral parcels
		[2] Selling price of agricultural products	F	E	Cadastral parcels
	Hunting production	[3] Density of ungulates	S	B	Habitat units
		[4] Amount of hunting products	F	B	Game reserves
		[5] Proportion of ungulates out of the entire hunted population	F	S-C	Game reserves
	Fishing production	[6] Amount of fishing products	S	B	Fishing zones
		[7] Proportion of key Alpine species out of the entire caught population	F	S-C	Fishing zones
	Mushroom production	[8] Intensity of mushroom production	S	B	Forest types
	Honey production	[9] Intensity of honey production	S	B	Areas of forest types 500 m close to forest ways
	Inorganic matter extraction	[10] Amount of inorganic matter extracted	F	B	Quarries
	Timber production	[11] Wood density in forests	S	B	Forest lots
		[12] Amount of timber harvested	F	B	Forest lots
	Fuel wood production	[13] Amount of fuel Wood harvested	F	B	Forest lots
	Water supply from surface water network	[14] Water flow from surface water network	S	B	Sub-Catchments
		[15] Water consumption from surface water network	F	B	Sub-Catchments
	Water supply from groundwater	[16] Water consumption from groundwater	F	B	Buffer of 200m around springs and wells
Regulating	Water quality regulation	[17] Capacity of water ecosystems to reduce pollutants	S	B	Buffer of 30 m around water network
	Water flow regulation	[18] Surface area of lakes, reservoirs and glaciers	S	B	Land cover classes of lakes, reservoirs and glaciers
		[19] Specific discharge coefficient	S	B	Sub-Catchments
	Air quality regulation	[20] Roughness of land surfaces adjacent to roads	S	B	Buffer of 30 m around main roads
	Micro-Climate regulation	[21] Ability of forests in mitigating temperature based on shape	S	B	Forest patches
		[22] Ability of forests in mitigating temperature based on density	S	B	Forest patches
	Macro-Climate regulation	[23] Carbon Stock	S	B	Forest types and cadastral parcels of pastures, grasslands and orchards

	Hazards protection capacity	[24] Forest watershed protection factor	F	S	Grid cells
	Flood prevention capacity	[25] Curve number	S	B	Grid cells
Cultural	Cultural heritage	[26] Proximity of cultural heritage sites to road network	S	B	Grid cells
	Scenic beauty	[27] Landscape visibility	S	B	Grid cells
	Hunting	[28] Density of hunters	F	S-C	Game reserves
		[29] Game density	F	B	Game reserves
	Fishing	[30] Fishing intensity	F	S-C	Fishing zones
	Mushroom collection	[31] Availability of mushrooms of good quality	S	S-C	Forest types
	Honey collection	[32] Availability of honey of good quality	S	S-S	Areas of forest types 150 m close to forest ways
	Outdoor recreation	[33] Intensity of sporting activities	S	S-C	Patches of lakes, forest roads and ski slopes
		[34] Revenues from ski passes	F	E	Ski slopes
	Leisure	[35] Density of recreational activities	S	S-C	Patches of lakes and forest types

4.3.2 Identifying positive and negative interactions among different ESs

We identified 42 significant correlations between pairs of indicators, out of the 630 possible correlations between 35 ES indicators (Figure 4.3), and considering the Bonferroni adjustment of alpha value for 35 comparisons ($0.3 <= |\rho| <= 1$, p-value $< 0.05/35 = 0.00143$). Correlations are between 27 key indicators (out of 35 considered). In particular, the Agriculture production indicator and the two key indicators of the Micro-Climate regulation have the highest number of correlations (seven out of 42), and Micro-Climate regulation is the ES with the highest number of interactions (14 out of 42).

Correlations can be grouped into six patterns: one pattern of negative interactions (tradeoffs, Figure 4.4-1) and five of positive interactions (synergies, from Figure 4.4-2 to Figure 4.4-6). *Tradeoffs* have been detected between the Agriculture production and six ESs (seven indicators) that depend on forest characteristics, namely Mushroom production, Honey production, Wood density in forests (provisioning services), Micro-Climate regulation, Macro-Climate regulation (regulating services) and Mushroom collection (a cultural service). Both the two key indicators of Micro-Climate regulation are in tradeoff. Tradeoffs are moderate, except for Macro-Climate regulation where they are low, and they are associated to ESs that do not necessarily cover the same spatial unit. ESs that are in tradeoff with agriculture are in synergies with the ecosystems services of forest. This synergy is represented by the pattern 6 (cf. Figure 4.4-1 and Figure 4.4-6). On the contrary, patterns of *synergies* are not correlated with other patterns. Such patterns have been identified among indicators assessing a single human activity (from which more ESs can arise) or assessing ESs provided by the same unit. Six synergies have been highlighted for the indicators of Hunting (Figure 4.4-2), six for five ESs of water ecosystems (Figure 4.4-3), one for two ESs present in the proximity of the forest road network (Figure 4.4-4), one for the Outdoor recreation services (Figure 4.4-5), and 21 for 12 ESs of forest ecosystems (Figure 4.4-6). The latter present the most complicated system of interactions. Synergies are low or high but never moderate.

Our analysis showed that five ESs out of 25 do not interact with any other, namely: Inorganic matter extraction, Water supply from surface, Water supply from groundwater (provisioning services), Cultural heritage and Scenic beauty (cultural services).

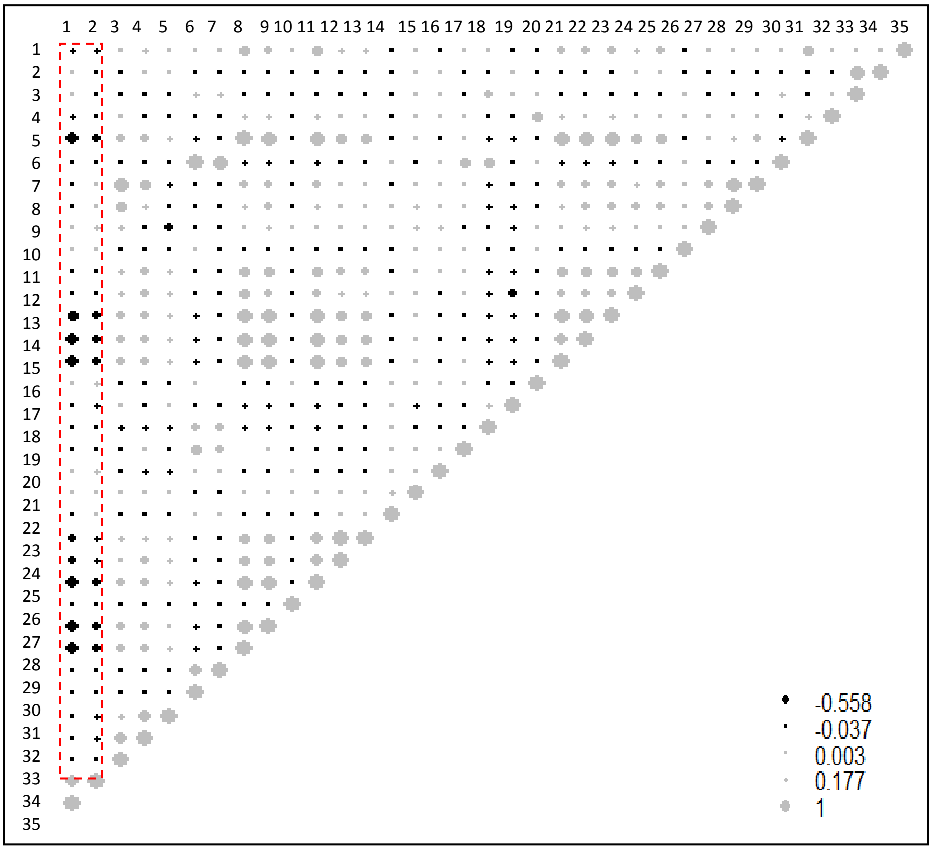


Figure 4.3. Bubble of correlations among 35 key indicators ordered according to the list of Table 4.1. Black points are negative correlations and represent tradeoffs, i.e. negative interactions of ESs indicators, while gray points are positive correlations and represent synergies, i.e. positive interactions of ESs indicators. Point size represents absolute correlation values, i.e. the degree of correlation. The dashed-red rectangle highlights the correlations between the two key indicators of the Agriculture production service and other 33 ESs.

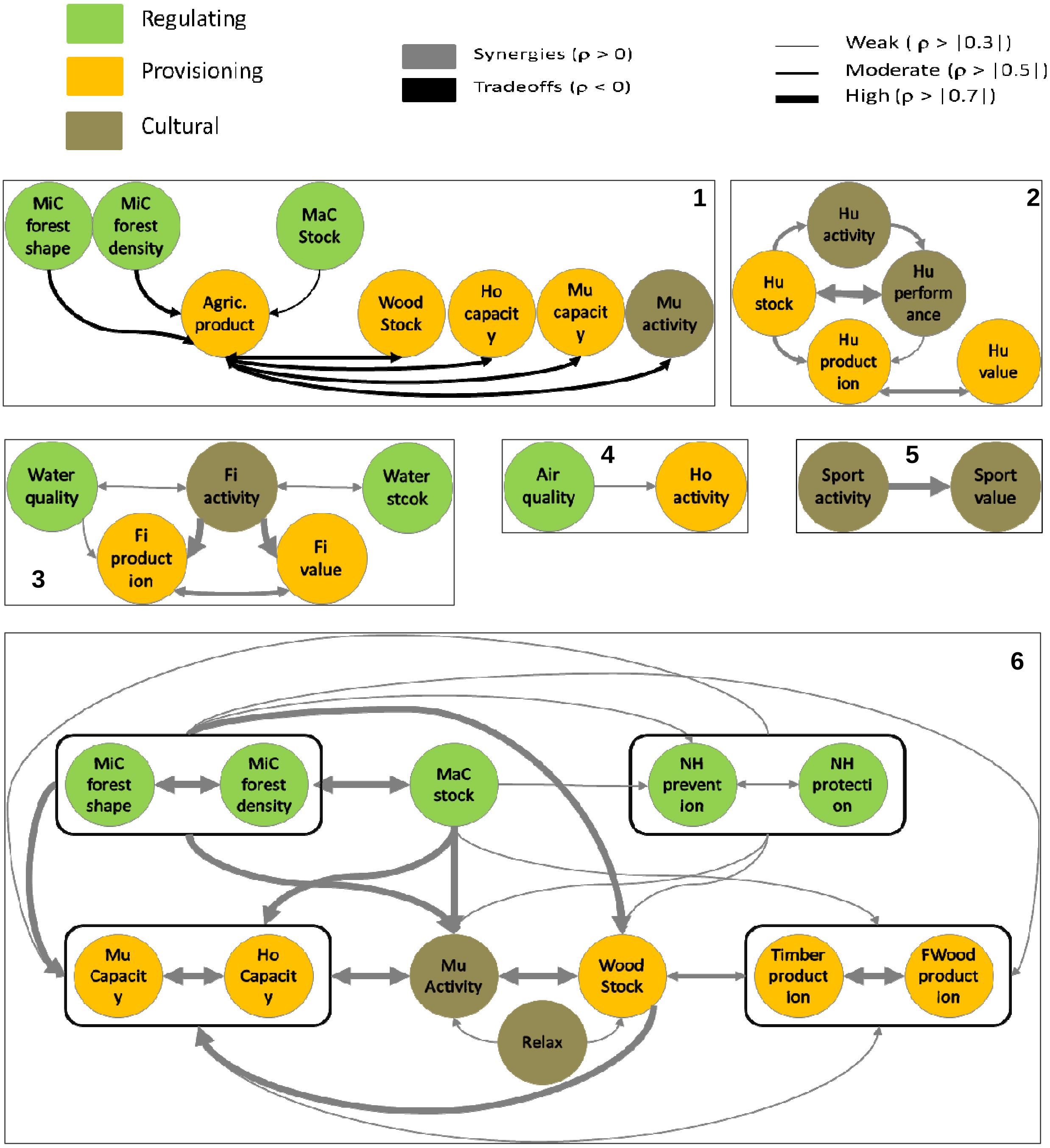


Figure 4.4. Tradeoffs (first sketch) and synergies (all other sketches) among ES types and indicators. 1: tradeoffs with agriculture products. 2: synergies of hunting services. 3: synergies between ESs of water ecosystems. 4: synergies between ESs of forest ecosystems close to roads. 6: synergies between ESs of forest ecosystems. Note that the colour and the width of the arrows are related to the sign and intensity of the relationship.

4.4 Discussion

Selection criteria of key ecosystem service indicators

Existing assessments use generally only one indicator to assess a single ES (e.g. Nelson et al., 2009; Grêt-Regamey et al., 2008; Raudsepp-Hearne et al., 2009). If, on the one hand, this practice may lead to the loss of relevant information of ESs, on the other hand when more than one indicator is available, a problem of redundancy may arise: some indicators may be already explained by others and not contributing with new information to the overall assessment. The Spearman correlation analysis of 57 indicators for 25 ESs (up to five indicators for each ES) has allowed the selection of 35 key indicators (up three key indicators for each ES). This result has showed that not all the important indicators are key indicators, similarly one indicator is not always sufficient to assess single ESs. This is particularly true when other values, different from the biophysical ones, may characterize a service. Furthermore, we found out that indicators of a single ES are never redundant if they are mapped over different spatial units. For instance, the Water supply service is mapped over two different spatial units: sub-catchments for Water supply from surface water network, and areas of 200 m^2 around springs for Water supply from groundwater. Both Water consumption from surface water network and Water consumption from groundwater have been selected.

Secondly, our results showed that stock and flow indicators for a single ES are never redundant when the use of the ES is regulated, i.e. when the actual flow is imposed by law. In the Trentino region Hunting, Timber production, Fuel wood production and Water supply are regulated activities. Indeed their indicators of stock and flow for the biophysical value have been selected as key indicators. On the contrary, stock and flow indicators of biophysical value are redundant if the use of the ES is not planned, i.e. when the flow is proportional to the stock. So, for the ESs of Agriculture, Fishing, Inorganic matter and Macro-Climate regulation only one indicator of the stock-biophysical value or flow-biophysical value has been selected as key indicator. Thirdly, indicators of the economic/socio-cultural value and indicators of biophysical value are never redundant, since they contain information which is context specific and dependent on the preferences of the beneficiaries. Therefore, economic/socio-cultural values are always selected as key indicators. On the basis of these considerations three selection criteria of key indicators for each ES are formulated below:

(1) if the supply of an ES is regulated, both its biophysical -stock and -flow indicators must be selected. Otherwise, either stock or flow indicators can be chosen;

(2) if multiple stock (flow) biophysical indicators for a single ES are mapped over different spatial units, all stock (flow) indicators must be maintained;
(3) socio-cultural or economic indicators are always selected as key indicators.

The correlation analysis between indicators of different ESs has showed that the number of indicators can be further reduced (from 35 to 28 key indicators). Although no general criteria can apply everywhere, this demonstrates that looking at Spearman's correlation coefficients among key indicators of different ESs seems a simple and straightforward way to detect redundancies of indicators. This further reduction has documented that almost half of indicators are redundant for the case study. Redundant indicators of different ESs are those supplied over the same spatial unit (e.g. ESs of forests), or those originated by the same human activity (e.g. provisioning and cultural services linked to fishing).

Given that the number of selected indicators changes for different thresholds of the correlation coefficient, the selection is indeed affected by a certain degree of subjectivity. However, the threshold adopted assures a minimum variation in the marginal increment of the number of selected indicators. Moreover, according the my knowledge, this is the first attempt to rigorously select key indicators by means of analytical tools. In fact, the current research focuses on the definition of conceptual frameworks (e.g. Niemeijer et al. 2008; Rounsvell et al., 2010; Van Oudenhoven et al., 2012). Frameworks are useful because they may account for a wide range of information (like the fact that indicators may measure the state of the ESs or the response to driving forces) but their selection criteria are based more on a scientific and systemic dimension of indicators (like credibility and robustness), rather than to the characteristics of ESs. Such frameworks poorly consider the issue of indicators redundancy (cf. Niemeijer et al. 2008). The ESs assessments that use more than one indicator to assess a single ES (e.g. Maes et al., 2011a; Schröter et al., 2014) focus especially on the mapping of stock and flow indicators, failing to make any effort to verify the indicators redundancy. This may be easily omitted if the final aim is the mere assessment of ESs, but if indicators are used to investigate the ESs relationships (e.g. to define the set of correlated ESs), redundancy may lead to misleading results. Attention should be paid to the possible redundancy of the indicators that are mapped over the same spatial units or that aim to assess ESs arising from the same activity.

We are aware that indicators used for these analyses are not the whole achievable set, since they are just those already available at regional scale; anyway, they represent a large sample (35 indicators for 25 ESs) that can support our findings.

Synergies and tradeoffs between ecosystem services

Our application has proved that looking at statistical correlations among indicators of different ESs is a good option to detect synergies and tradeoffs between multiple ESs. Considering that key indicators measure different values of ESs (and either in terms of stock and flow), the identified correlations are expression of the interactions of such values. Therefore, this analysis allowed the identification of the interactions between specific characteristics of ESs. Moreover, it is one of the first attempts to analyse interactions between a multiple set of ESs. Evidences on it can be found in the sector studies which have dealt with this topic (Qiu and Turner, 2013).

The Spearman correlation analysis of 35 key indicators for 25 ESs allowed the identification of 42 interactions in 20 ESs. It demonstrates that almost all ESs (for at least one value of them) have some interactions, and in particular that regulating services have always interactions with provisioning and cultural services. Both positive and negative patterns of interactions can be identified, as found out also by Raudsepp-Hearne et al. (2009), Maes et al. (2012) and Qiu and Turner (2013). In particular, the provisioning services of Agriculture production was found in tradeoff with other three provisioning, two regulating and one cultural service, respectively. The small number of regulating services in tradeoff with the most intensively managed provisioning service (i.e. Agriculture production) highlights a balanced management of the local authorities. This is in contrast with the global trend, that shows that provisioning services are usually enhanced at the cost of the regulating service supply (cf: Raudsepp-Hearne et al., 2009 and Maes et al., 2012b). Nevertheless, Agriculture production is far away of being in synergy with regulating and cultural services. Good agricultural practices, such as organic farming, are required to increase a joint provision of (for instance) Agriculture and Natural hazard protection service and Scenic beauty.

The specific types of ESs that are in synergy or in tradeoff each other are region-specific. For instance, Water supply was not found in tradeoff with Agriculture production, as hypothesized by Maes et al. (2012b), and Water quality regulation was not found in synergy with Macro-Climate regulation service, as hypothesized by Qiu and Turner (2013).

Pattern of synergies and tradeoffs have several differences: while tradeoffs occur between two specific land cover types (i.e. agricultural and forest areas), patterns of synergies are among indicators assessing a single human activity (from which more ESs can arise) or assessing ESs provided by the same area (cf: Maes et al., 2012b). Moreover, while patterns of synergies are independent from each other and correlated ESs in such patterns have not any other correlation with ESs of other synergy patterns (which means that ESs in synergy in one pattern are not in synergy in any other), ESs in tradeoffs may be in synergy in other patterns. In this case study, it was found that all the services in tradeoffs with the Agriculture production service have been found in synergy in the pattern of forest services. This is the pattern with the highest number of indicators and synergies, that is reasonable because forest ecosystems supply the highest number of ESs in Trentino. Finally, while tradeoffs are identified for low values of the correlation coefficients (recognized also by Maes et al. 2012b), synergies mainly present extreme values (very low or very high correlation values).

5 Analyzing bundles and drivers of change of ecosystem services

5.1 Introduction

Approaches based on the concept of Ecosystem Services (ESs) must produce a variety of information and, above all, information involving the assessment of the supply and the analysis of the relationships among multiple ESs, i.e. bundles, drivers of change and interactions (Daily and Matson, 2008 and Bennet et al., 2009). While the science of ESs assessment is improving (e.g. Naidoo et al., 2008; Willemen et al., 2008, Maes et al. 2011a, and Van Oudenhoven et al., 2012), and interactions among ESs are being increasingly explored (e.g. Raudsepp-Hearne et al., 2009; Maes et al., 2011; Qiu and Turner, 2013), appropriate methods to analyze bundles and drivers of change of ESs are still under development (Anton et al., 2010).

Bundles of ESs are sets of spatially correlated services (Peterson and Bennet, 2009; Raudsepp-Hearne et al., 2009) whose definition, until now, has consisted in the identification of clusters of ESs and on the analysis of the spatial distribution of clusters and of the distribution of ESs across clusters (Raudsepp-Hearne et al., 2009 and Plieninger et al., 2013). Drivers of change are the external factors that directly or indirectly modify the ecosystems and the supply of services, such as climate change, land use change, demography (MA, 2005). Bundles and drivers of change analyses are currently computed by means of spatial and statistical techniques. This represents an appreciable effort responding to the old issue of giving certain and punctual answers to the ESs research needs (see Carpenter et al., 2006). However, there is not general agreement about what specific aspects must be investigated through these techniques. For instance, Raudsepp-Hearne et al. (2009) and Maskel et al. (2013) looked at correlated ESs in their principal components in order to demonstrate that drivers causing the variance are of social and ecological type, while Maes et al. (2012a) looked at the correlations of the first three principal components with land use classes. They seem to be useful analyses that should be considered together when analyzing drivers of change. Moreover, the actual use of such sophisticated techniques is in contrast with the assumptions, the simplifications and the uncertainties affecting the studies. This contrast may lead to misleading results. The most evident simplifications regard the involvement of a limited number of ESs respect to those available in the study region and the use of mapping units not reflecting the actual variability of the ESs distribution across the region (e.g. administrative units). In fact, the definition of bundles and drivers of change strongly depends on the type of the ESs available in the region and on the heterogeneity of their supply over the territory (Fisher et al., 2009). For instance, Raudsepp-Hearne et al. (2009) considered the supply of 12 services whose indicators were mapped over municipalities. Plieninger et al. (2013) considered the demand for 13 cultural services whose indicators were mapped over land use classes.

Maes et al. (2011b) considered the supply of 13 services for all Europe, mapping them over territorial units for the European countries. Any above mentioned study did not clearly explain whether ESs are those ones effectively important for the study region. Moreover, municipalities, land use classes and territorial units are spatial units where the supply or demand of ESs can be only homogeneously represented. On the contrary, each ES has a proper spatial unit where it is provided or used (Fisher et al., 2009). According to Carpenter et al. (2006), disregarding all the important ESs and the intrinsic spatial heterogeneity that characterize a single ES may strongly modify the bundles shape and the spatial distribution, and the correlation of ESs.

The objective of this paper is to present a method to define bundles of ESs and to identify drivers of change by means of spatial and statistical analyses on ESs indicators and a number of explanatory variables.

5.2 Methods

The method involves three steps (Figure 5.1). The first consists in the identification of principal components and clusters of the ESs indicators. The second step is the characterization of clusters in order to achieve a bundle definition, while the third step consists in the characterization of principal components for the identification of drivers that cause the main variability of the ES values distribution.

In the first step statistical analyses are performed on key ESs indicators. The output is a set of new spatial variables (i.e. the principal components of ESs indicators) that can measure the extent to which the ESs values change over their specific spatial units (i.e. the variance of the ESs across the region), and a map where ESs are grouped according to the correlations that exist among their values (i.e. the clusters of ESs).

In the second step, bundles are defined by means of a set of statistical and spatial analyses on the ESs clusters, the key indicators and a number of explanatory variables. The aim here is to understand how clusters are distributed across the region (e.g. if the patches of clusters are fragmented or compact), the extent to which clusters' shape depends on the morphology of the region or on the land use (explanatory variables are used here), and what ESs are represented by each cluster. All this information is used to characterize the clusters, which are the spatial representation of the bundles.

In the third step drivers of change of ESs are defined, by means of a set of statistical and spatial analyses on: the principal components of ESs, the clusters and the explanatory variables. The aim is to understand: if there are ESs that have similar patterns of variability (represented by the values of indicators) across the region, which groups of ESs show high variability (i.e. what the groups of services correlated to the first two principal components are), in which bundles such variability is observed and the extent to which the spatial distribution of the variability depends on the morphology of the region or on the activities of land use management. All this information is used to characterize the principal components, which are the representation of the drivers of change.

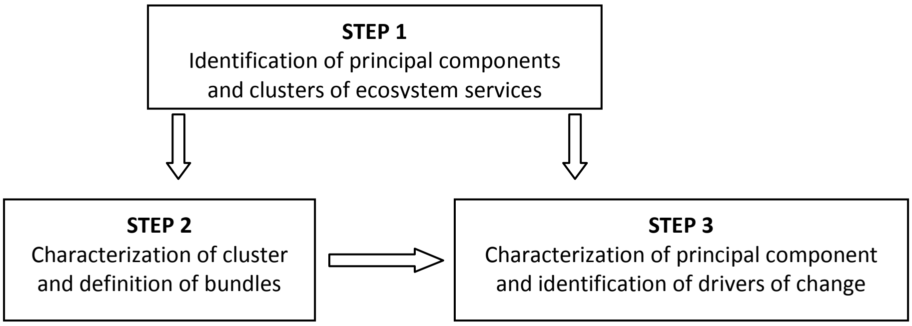


Figure 5.1. Flowchart of the method used to define ESs bundles and drivers of change.

5.2.1 Identification of principal components and clusters of ecosystem services

In the first step, a principal component analysis is used to make a synthesis of indicators. Then, a hierarchical cluster analysis is performed based on the principal components, coupled with an analysis of similarity to identify the proper number of clusters.

Principal Component Analysis (PCA; Pearson, 1901) is used to make a synthesis of indicators. The PCA is a multivariate ordination technique that linearly combines input variables to generate new independent variables, the principal components. The weights by which each original variable must be multiplied to get the principal components are called loadings. Each principal component measures a part of the variance of the original dataset. To be useful, principal components must be able to measure at least the variance of one single input variable. From the mathematical point of view, this means that the variance of the new variables (the so called "eigenvalue" of the principal component) must be greater than 1. PCA guarantees that the number of principal components with variance greater than 1 is always smaller than the number of original variables and just a narrow set of principal components is enough to explain the most of the variance. In clustering principal components may be used instead of original variables in order to avoid computational problems possibly arising from a high number of input variables (in accordance with Plieninger et al., 2013): in the case of Trentino input variables were 35 ES indicators, see Table 4.1.

The hierarchical cluster analysis (Kaufman and Rousseeuw, 1990) is a technique to assign statistical units to one of multiple classes (i.e. clusters), based on the values of those units for different variables. In such a way the units of the same class are more similar to each other than units in any other class. Similarity is measured by Euclidean distance and clusters are compacted by Ward's method (Ward, 1963). The proper number of clusters is identified through an ANAlysis Of SIMilarity (ANOSIM; Clarke, 1993). This technique looks at the similarity of samples among and within classes: the measure of similarity (R) is the difference of mean ranks of statistical units between and within clusters. R ranges from -1 to 1; 0 means no similarity and completely random clustering, while 1 means that all pairs of samples within clusters are more similar than to any pair from different clusters. The choice of the proper number of clusters is made looking at clustering that maximizes R.

The outputs of this step are the map of the ESs clusters and that the maps of the principal components. The first will be one of the input variables of the second step, while principal components will be input variables of the third step (Figure 5.1).

5.2.2 Characterization of clusters and definition of bundles

Clusters are characterized by means of a set of analyses aiming to investigate the clusters spatial distribution and the distribution of ESs across clusters. The spatial distribution of clusters includes information about the shape and the dimension of clusters' patches, and about dependence on the distribution of three explanatory variables: elevation, catchments shape and land use. The distribution of ESs across clusters includes information about where (i.e. in what clusters) the supply of each ES is maximum, minimum or absent, and about the richness, intensity and diversity of multiple ESs in single clusters.

(a) Analysis of spatial distribution of clusters.

- *Shape analysis of clusters*. It consists in the computation of the area, of the total number of clusters patches, of the min, max and mean patch area, and of the fragmentation index for each cluster.
- *Correlation analysis*. Spearman statistical correlations between the clusters and the explanatory variables are computed in order to verify whether the cluster distribution follows the distribution of altitude, catchments shape, or land use classes. Following the method proposed in Maes et al. (2012a), I firstly calculated the Spearman statistical correlation between the clusters and the explanatory variables. Spearman correlation measures the degree of dependence between two variables. The output of the Spearman correlation analysis is a correlation coefficient (ρ) ranging between -1 and 1. High absolute values correspond to high dependence between bundles and mentioned variables, while low absolute values correspond to low dependence. Correlations have been considered significant when $|\rho| >= 0.3$. In order to verify whether clusters and variables are correlated also in space, the maps of clusters and explanatory variables are crossed and the percentage of each variable in clusters is calculated. It has been assumed that a cluster follows the distribution of variables when the percentage is above 90%.

(b) Distribution of ecosystem services across clusters.

- *Distribution of clusters across ecosystem services*. This analysis is carried out in order to understand how single ESs are supplied over clusters, and in particular in which clusters the supply is maximum, minimum or absent. For each ES we calculate the average of the normalized value (to maximum). Only one indicator is used to represent a single service, as proposed by Maes et. (2011a). The distribution of the average value of every service in the clusters is shown in radar charts.
- *Aggregation patterns analysis*. It is carried out in order to understand how multiple ESs are supplied over clusters, and in particular in which clusters the richness, intensity and diversity of multiple ESs is maximum, minimum or absent. I computed and mapped

indices of richness, intensity and diversity (Shannon index), as proposed by Plieninger et al. (2013). Richness services counts the number of ESs that are present in each cluster (values of the service supply greater than zero); intensity sums the normalized values of the ESs supply in every cluster.

Results of analyses of point (a) and (b) are merged to define bundles.

5.2.3 Characterizing principal components and explanation of drivers of change

Principal components are characterized by means of a set of analyses aiming at the investigation of (c) the distribution of ESs across principal components, (d) the distribution of principal components across bundles and (e) the spatial distribution of principal components.

(c) Distribution of ecosystem services across principal components.

Analysis of loadings. The ESs with the greatest variance are those correlated to the first principal component (PC1). PC1 is an artificial variable given by a linear combination of original variables (ESs indicators) that maximizes the variance of the sample. The second principal component (PC2) is another artificial variable, orthogonal to the first principal component, that represents the second highest variance of the sample. Correlations between ESs and principal components is proportional to the loadings of the first two principal components. The graphical representation of ESs in terms of the loadings of PC1 and PC2 is a vector, defined by a modulus and a direction (angle). I assumed that a correlation is significant between an ES and PC1 or PC2 when a vector modulus is greater than 0.1 and the angle between the vectors and PC1 and PC2 axes is lower than 30°.

(d) Distribution of principal components across bundles.

Correlation analysis. Spearman statistical correlations between the principal components and the bundles are computed (in analogy with the correlation analysis of (a)) in order to identify the bundles where the greatest variance is present.

(e) Spatial distribution of principal components.

Correlation analysis. As previously mentioned, principal components explain the variance of the ESs, i.e. their variability across the region. The theoretical rationale of PCA ensures that the first principal components explain most of the variance. The changes in the ESs supply is assumed to be driven by external factors, the so called "drivers of change". According to the existing studies (Raudsepp-Hearne et al., 2009; Maes et al., 2011a and Maskel et al., 2013), land use management is the external factor driving main changes in ESs values. In order to explore the influence of land use management on the ESs variability, we look at the Spearman correlations of the first two principal components with land use classes. The latter is adopted as proxy for land use management, as seen in Maes et al. (2012a). In addition I looked at the spatial correlation of the first principal component with forest density, in order to explore the influence of wood harvesting practices on the forest ESs variability.

Results of analyses of point (c), (d) and (e) are merged to explain ESs changes in the territory and drivers of such changes.

5.3 Results

5.3.1 Identification of principal components and clusters of ecosystem services

The 25 ESs considered in this study have been clustered by a hierarchical cluster analysis on the first 5 principal components of the ESs indicators (explaining 41% of the original variance of the ESs indicators). The hierarchies have been defined for 2 to 19 clusters (i.e. large clusters grouping samples with more dissimilar values vs. small clusters grouping samples with very similar values). According to ANOSIM, the Euclidean distance between the hierarchical classes is maximized with 11 clusters (see Figure 5.2).

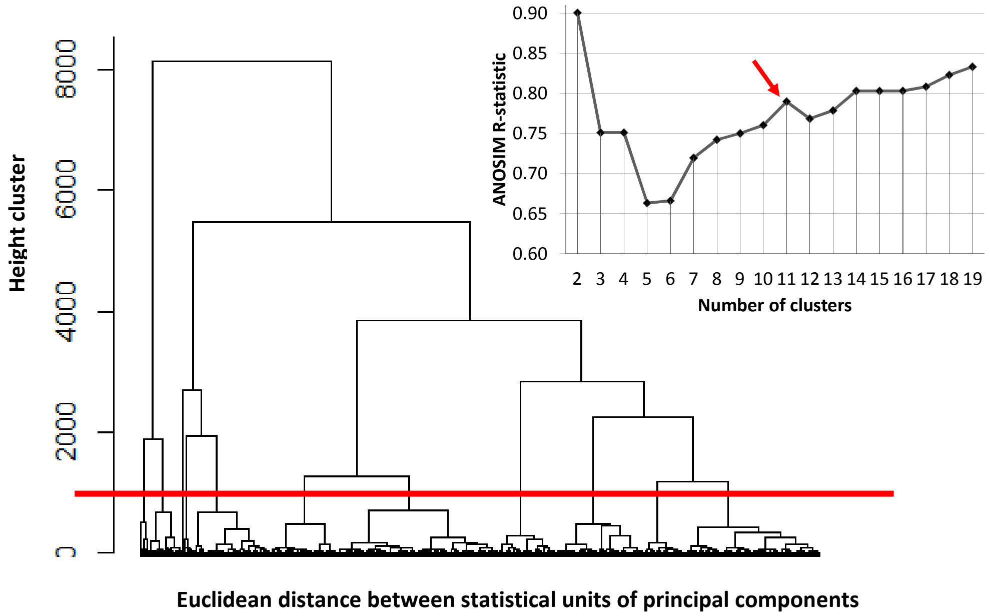


Figure 5.2. The most significant difference between the groups is realized for 11 cluster (local maximum of the ANOSIM, red arrow), which corresponds to about 1000 of height in the dendogram (red line).

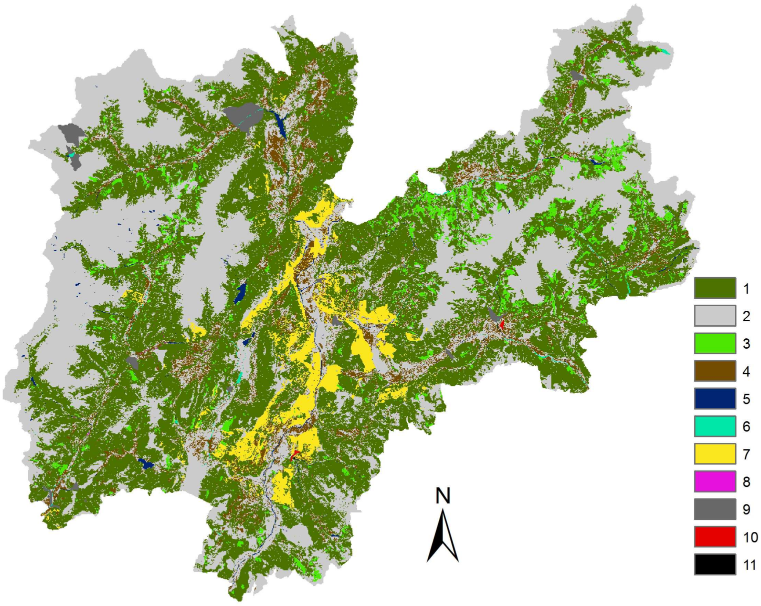


Figure 5.3. Map of 11 clusters

5.3.2 Characterization of clusters

(a) Analysis of spatial distribution of clusters.

- *Shape analysis of clusters*. Clusters are mapped over Trentino in Figure 5.3, which shows that Cluster 1 covers the majority of the forested area, while Cluster 2 corresponds to rocks and urban settlements, Cluster 3 is mainly present in the upper-eastern part, while Cluster 7 occupies preferentially the central part. Fragmentation indices (Table 5.1) highlight that Cluster 1 and Cluster 2 are the largest in area (i.e. more than 40% of the region) and that the smallest are 8, 10 and 11 (less than 0.1%). Cluster 2 has the highest number of patches, followed by cluster 4. The most fragmented one is Cluster 8, while the most compact ones are 1 and 9.
- *Correlations with altitude.* Clusters are homogenously distributed across different altitude values of elevation classes (Table 5.2). Exceptions are Cluster 2, that shows a significant correlation ($|\rho| = 0.4$) with altitude (the 96% of its area lies above 2800 m a.s.l.), and Cluster 11, given it is below 1000 m a.s.l. .

  Correlations with catchments. Also catchments are not significantly correlated to clusters. However, small basins often lie in only one or two clusters. Only the Adige catchment, that occupies the central part of Trentino, includes all clusters, while cluster 11 is only found in Adige catchment and in an eastern tributary.

  Correlations with land use. Clusters 1 and 2 are correlated to land use: Cluster 1 contains more than 90% of the whole forested area and Cluster 2 contains more than 90% of glaciers and bare rocks. Forests contains more than 90% of Clusters 3 and 11. Mines are spread in Clusters 2, 4, 7 and 9.

Table 5.1. Indices computed in the Shape analysis of clusters

Clusters	**Area** [%]	**Number of patches**	**Min patch area** [ha]	**Max patch area** [ha]	**Mean patch area** [ha]	**Fragmentation index** [Dimensionless]
1	45.773	6767	1	96555	41.6	0.0
2	40.133	17362	1	54225	14.2	0.1
3	3.465	2642	1	653	8.1	0.1
4	4.901	7882	1	935	3.8	0.3
5	0.599	1655	1	326	2.2	0.4
6	0.166	530	1	85	1.9	0.5
7	4.106	1831	1	4546	13.8	0.1
8	0.016	69	1	6	1	0.7
9	0.816	20	1	2030	250.6	0.0
10	0.024	8	1	69	18.75	0.1
11	0.002	3	1	10	4	0.3

Table 5.2. Spearman correlation coefficients of Clusters and Principal components with Altitude, Catchments and Land use

	Clusters											Principal components	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**PC1**	**PC2**
Altitude	0.2	0.4	0.0	0.2	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.2
Catchments	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Land use	0.6	0.6	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
PC1	0.6	0.7	0.7	0.3	0.3	0.1	0.1	0.1	0.0	0.0	0.0	1	0.0
PC2	0.1	0.1	0.0	0.3	0.3	0.1	0.1	0.3	0.0	0.0	0.0	0.0	1

(b) Distribution of ecosystem services across clusters.

- *Distribution of clusters across ecosystem services*. 25 (out of 35) indicators have been used to represent ESs. Each indicator has been normalized to the maximum value and its average value has been mapped over the clusters. Aggregation patterns show that Cluster 9 has the highest number of ESs (i.e. 23 out of 25, Figure 5.4), while Cluster 8 has the lowest one (i.e. 11 out of 25). Despite that, intensity of cluster 9 is lower than the intensity of cluster 8 (6.75 against 8.6, Figure 5.5). Highest intensity and diversity are in Cluster 3 (10.07 and 0.49 respectively), while lowest intensity and diversity are Cluster 2 (3.49 and 0.49 respectively). The diversity map is in Figure 5.6.
- *Aggregation patterns analysis*. The contribution of the different ES classes to each cluster is shown in 11 radar charts (Figure 5.7). For example, Agriculture production is supplied by 5 clusters (2, 4, 7, 9 and 10); the maximum supply is in Cluster 4, the minimum in Cluster 2. In all clusters, expect Cluster 2, there is at least one ES with maximum supply, and in all clusters, expect clusters 3 and 8, there is at least one ES with minimum supply. Three couples of clusters have very similar types of ESs: (6,8), (1,3) and (9,10). According to what represented in the radar charts, the number of provisioning services per cluster ranges from 3 to 9 (out of 10); the number of regulating services ranges from 4 to 7seven (out of 7); the number of cultural services ranges from 4 to 7 (out of 8).

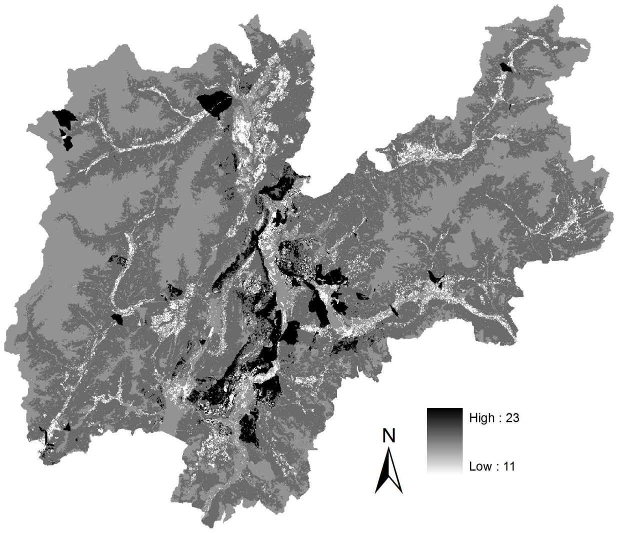


Figure 5.4. Richness index

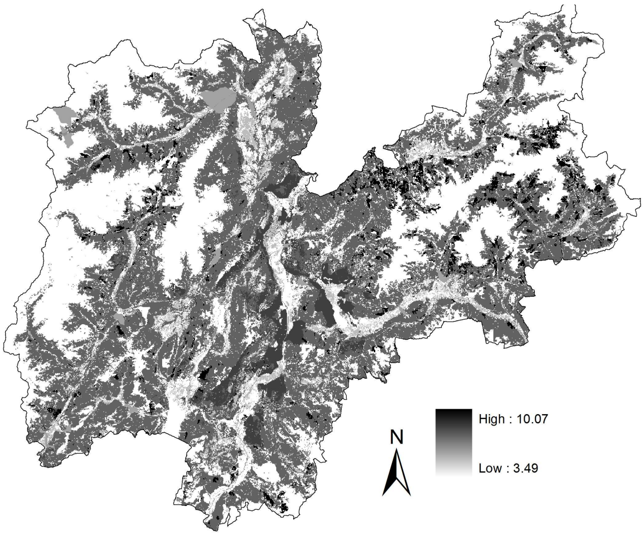


Figure 5.5. Intensity index

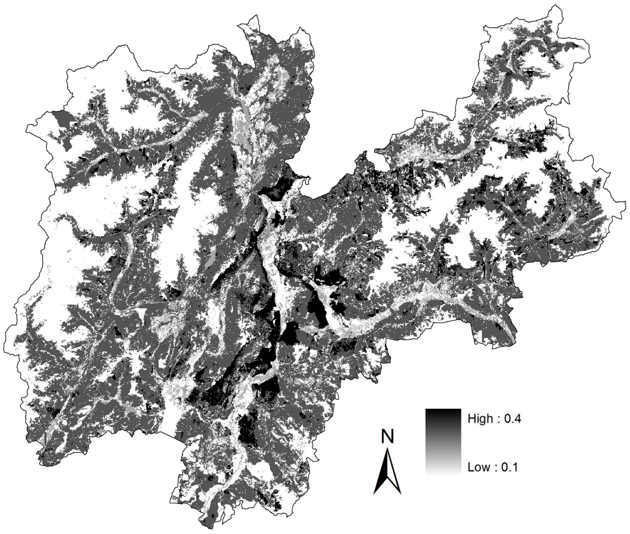
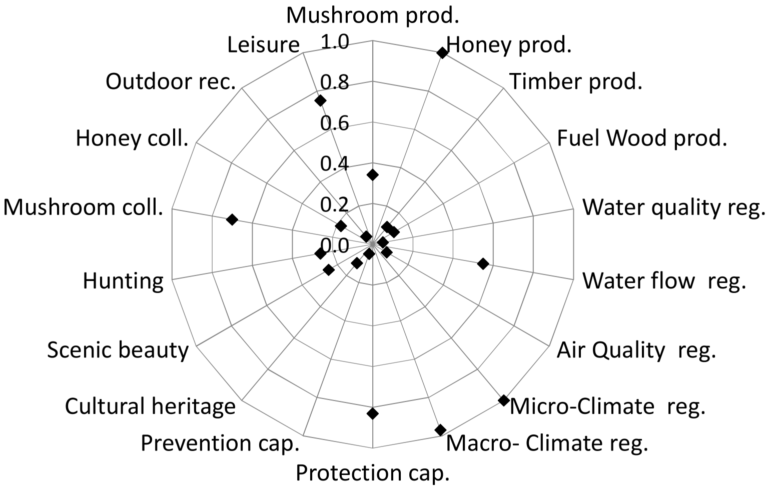
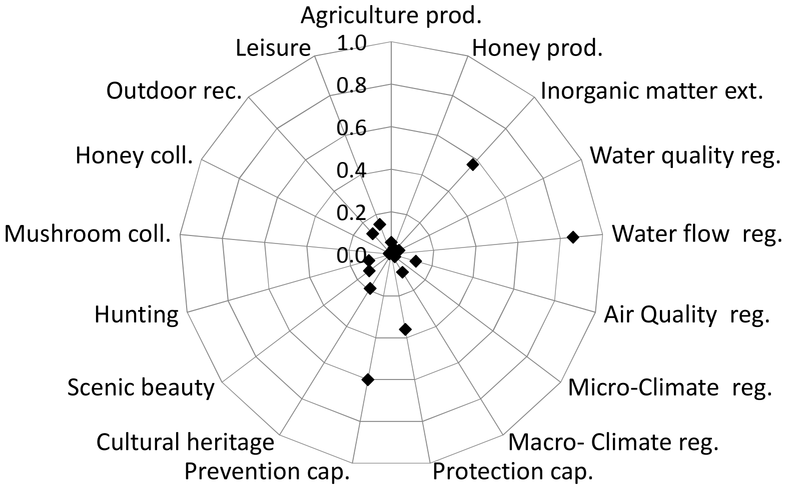


Figure 5.6. Diversity index

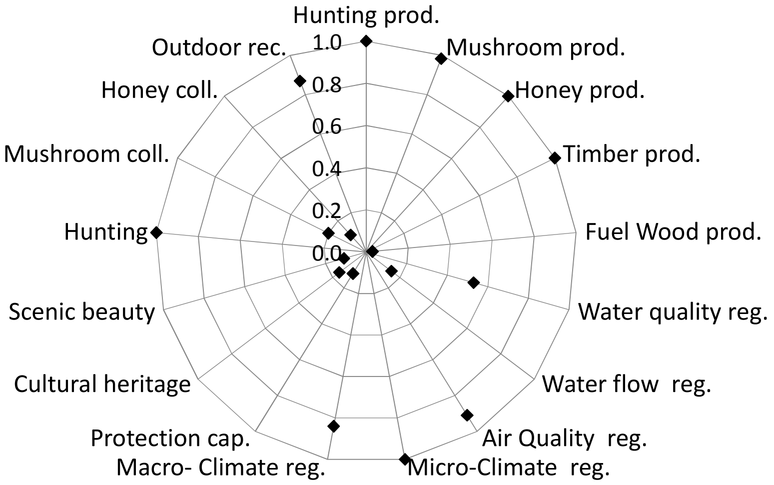
Cluster 1



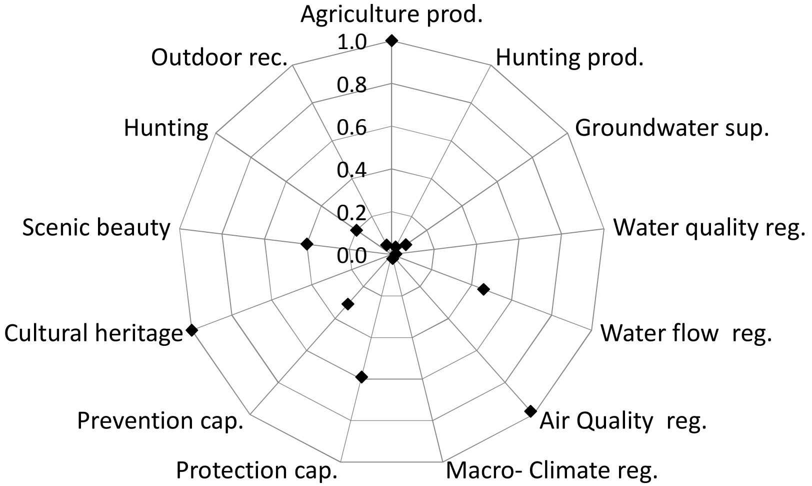
Cluster 2



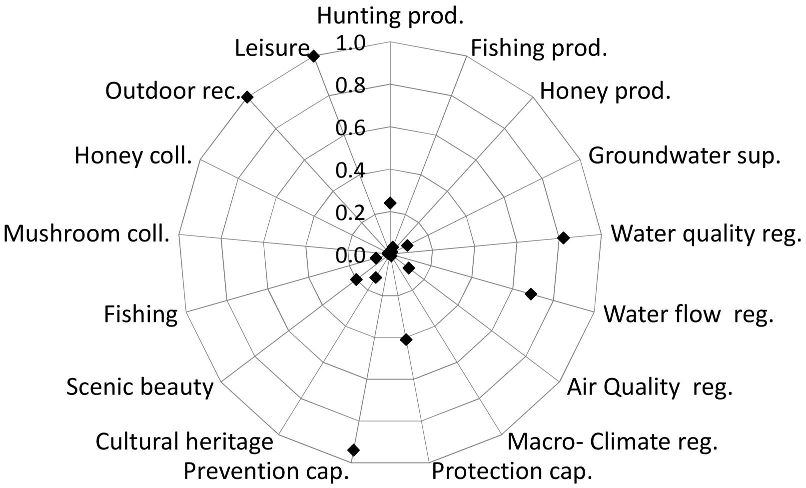
Cluster 3



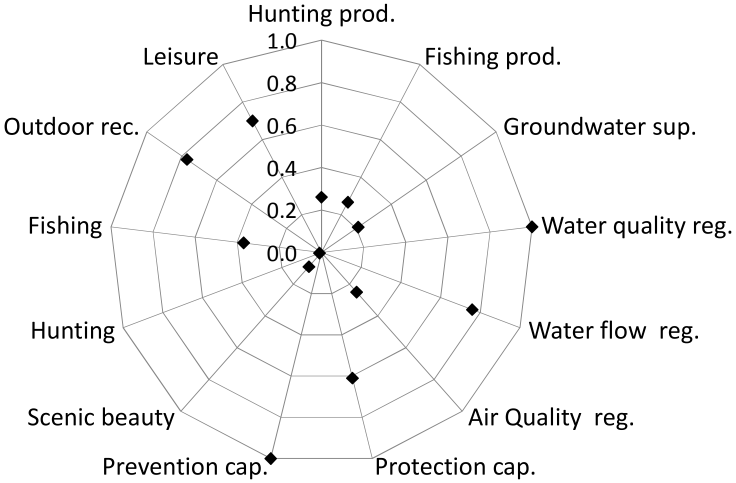
Cluster 4



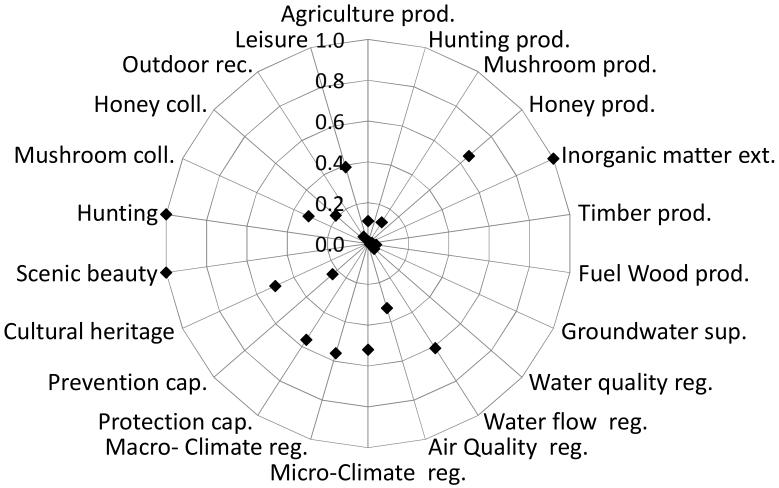
Cluster 5



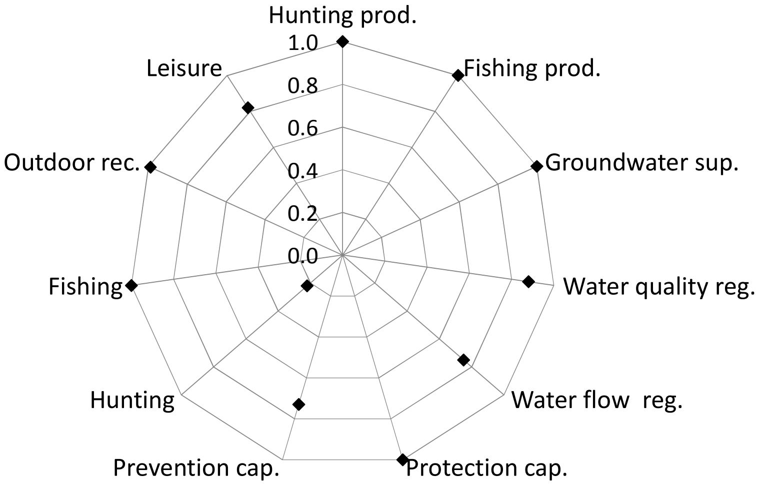
Cluster 6

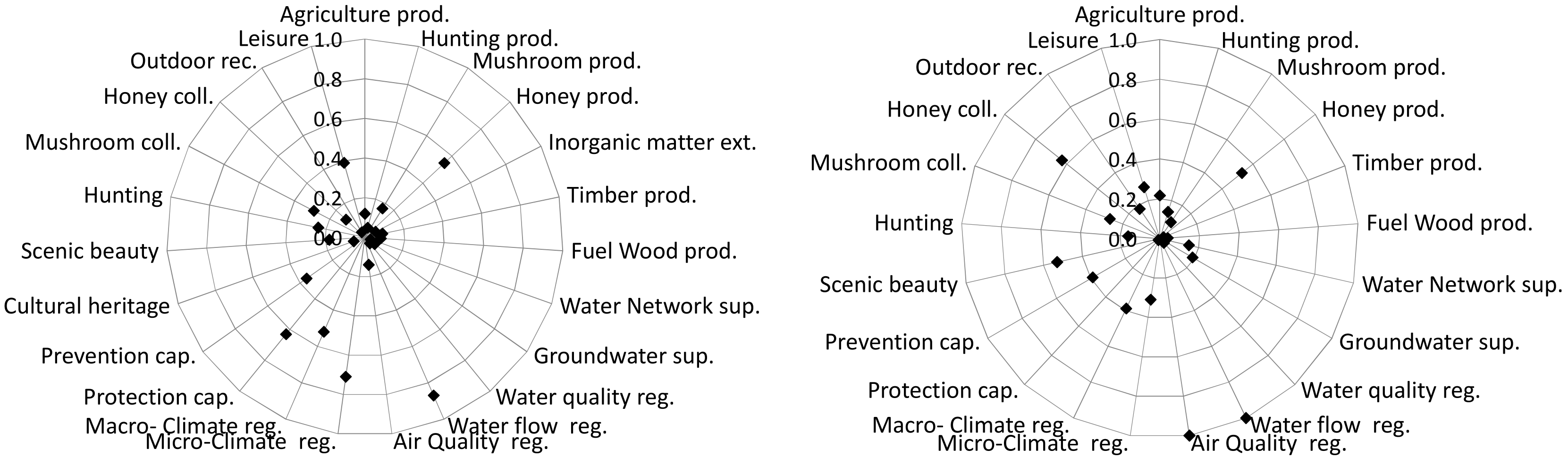


Cluster 7



Cluster 8





Cluster 9

Cluster 10

Cluster 11

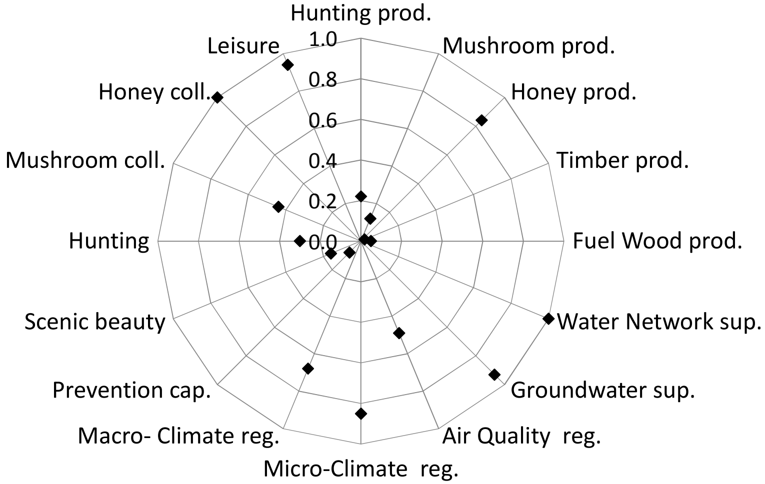


Figure 5.7. Relative contribution of ESs to 11 clusters. Values range from 0 to 1, that is the maximum supply.

5.3.3 Definition of bundles

Few studies identified bundles by means of cluster analyses, not providing any definition in terms of: ESs involved, their values or their geographical distribution. Hereafter, a definition for each bundle is provided, based on the exploratory analyses performed on the identified clusters.

Bundle 1 -> **Cluster of most common ecosystem services in forests**

The bundle corresponds to 90% of forest areas of Trentino. It is composed of large and few fragmented patches, and it is homogeneously distributed over catchments and altitude (up to 2800 m a.s.l.). 18 ESs typically of forest ecosystems are supplied (four provisioning, seven regulating and seven cultural). In particular, the supply is maximum for Honey production and Micro-Climate regulation.

Bundle 2 -> **Cluster of low-intensity and low-diversity ecosystem services**

This bundle covers the areas where the supply of ESs is the lowest in terms of intensity and diversity. It is homogeneously distributed over catchments areas and altitude, and in particular it includes 90% of areas above 2800 m a.s.l., that are essentially glaciers and bare rocks. It is composed of few, large and less fragmented patches. 17 services are supplied (three provisioning, seven regulating and seven cultural). The supply is not maximum for any ES and minimum for five ecosystem services: Agriculture production, Micro-Climate regulation, Mushroom and Honey collection and Leisure.

Bundle 3 -> **Cluster of high-intensity and high-diversity ecosystem services in forests**

This bundle is covered for 90% by forest areas and the supply of forest ESs is the highest in terms of intensity and diversity. The bundle essentially corresponds to the forest areas of Val di Fiemme, where the use of forest services, like timber production, is very high. In total, 18 services are supplied (five provisioning, six regulating and seven cultural). The supply is maximum for six services (Hunting, Mushroom, Honey and Timber production, Micro-Climate regulation and Hunting activity). The bundle is homogeneously distributed over altitude (up to 2800 m a.s.l.).

Bundle 4 -> **Cluster of high-intensity ecosystem services in agriculture areas**

This bundle covers the agricultural areas where the supply of Agriculture production and Cultural heritage is maximum, while the supply of water regulation services (i.e. Water quality and Water flow regulation) is minimum. In total, 13 ESs are supplied: three provisioning, six regulating and four cultural. The bundle is homogeneously distributed over catchment areas and altitude (up to 1000 m a.s.l.).

Bundle 5 -> **Cluster of high-intensity recreation services in forests and over water network**

This bundle covers forest areas and fishing zones where the supply of Leisure and Outdoor activities is maximum. In total, 17 ESs are supplied (four provisioning, six regulating and seven cultural). The bundle is homogeneously distributed over altitude up to 2800 m a.s.l.

Bundle 6 -> **Cluster of high water regulation capacity services**

It is a small bundle composed of fragmented patches, homogeneously distributed over catchments and altitude (up to 2800 m a.s.l.). It is typical of minor tributaries in the lateral valleys. 13 ESs are supplied (three provisioning, five regulating and five cultural); the supply is maximum for two services (Water quality regulation and Flood prevention capacity).

Bundle 7 -> **Cluster of high-intensity human activities in semi-urbanized areas**

The bundle covers the central areas of the region, up to 1000 m a.s.l., where 23 ESs are supplied (nine provisioning, seven regulating and seven cultural); the supply is maximum for Hunting, Inorganic matter extraction and Scenic beauty.

Bundle 8 -> **Cluster with few but high-intensity ecosystem services**

The bundle is small, very fragmented and homogenously distributed over altitude up to 1000 m a.s.l.. It is the less rich of ESs (only 11: three provisioning, four regulating and four cultural), but the supply is maximum for six ESs: Hunting production, Fishing production and activity, Water supply from groundwater, Hazard protection capacity and Outdoor recreation.

Bundle 9 -> **Cluster with several but low-intensity ecosystem services**

The bundle is very few fragmented and it is homogenously distributed over altitude, catchments and it covers all land uses. It is the richest of ESs (23 services: 10 provisioning, seven regulating and seven cultural), but the supply is not maximum for any service. Instead, it is minimum for Inorganic matter extraction, Water supply from surface water network, Cultural heritage and Outdoor recreation.

Bundle 10 -> **Cluster of high-intensity regulating services**

The bundle is homogenously distributed over altitude up to 1000 m a.s.l.. 21 ESs are supplied (eight provisioning, seven regulating and six cultural); the supply is maximum for two regulating services: Water flow regulation and Air quality regulation.

Bundle 11 -> **Cluster of ESs in low-elevation forests**

It is the smallest bundle with only 3 patches. All areas are below 1000 m a.s.l. and they correspond to forests for more than 90%. In total, 16 ESs are supplied (seven provisioning, four regulating and five cultural); the supply is maximum for two ESs: Water supply from surface water network and Honey collection.

5.3.4 Characterization of principal components

(c) Distribution of ecosystem services across principal components.

The loadings of Figure 5.8 show that PC1 is highly correlated to nine ESs (five provisioning, three regulating and one cultural service), while PC2 is highly correlated to four ESs (two regulating and two cultural services). PC1 and PC2 are therefore able to explain 13 ESs (out of 25).

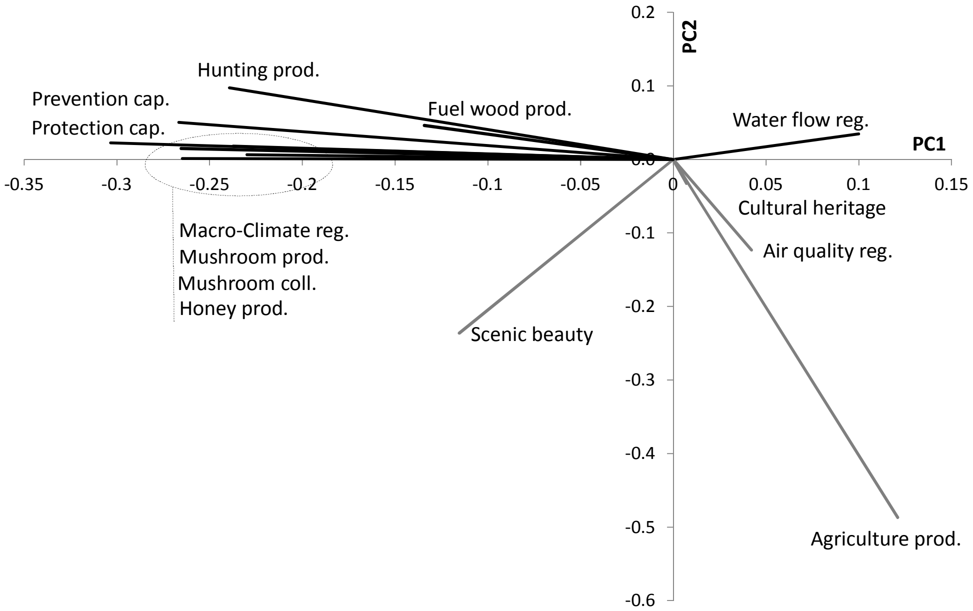


Figure 5.8. Biplot of the first two principal components

(d) Distribution of principal components across bundles

Correlations between PC1 and clusters (Table 5.2) are significant for Clusters 1, 2, 3, 4 and 5, while correlations between PC2 and clusters are significant for Clusters 4, 5 and 8. In total, 6 clusters represent the services with highest variability.

(e) Spatial distribution of principal components.

The map in Figure 5.9 shows that low values of PC1 correspond to forest areas, while high values to bare rocks, glaciers and urban settlements (cf. Figure 1.3). The map in Figure 5.10 shows that low values of PC2 correspond to areas where hunting is forbidden or low practiced (c.f. Figure AII.2), while higher values are in central part of the region, where there is the valley of the Adige river. The correlation of PC1 with land use is high (|ρ| = 0.7), while with altitude or catchments is not significant. PC2 does not have any significant correlation. The cross between PC1 and the land use map (Figure 1.3) highlighted that lowest values of PC1 are found in forested areas (Figure 5.11). The analysis of correlations with forest density (represented in the first picture of Figure AII.7) showed that PC1 decreases for increasing values of forest density.

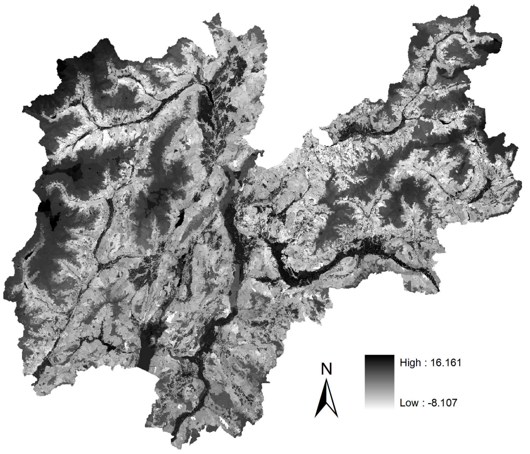


Figure 5.9. Map of the first Principal Component; it explains the 16% of original variance

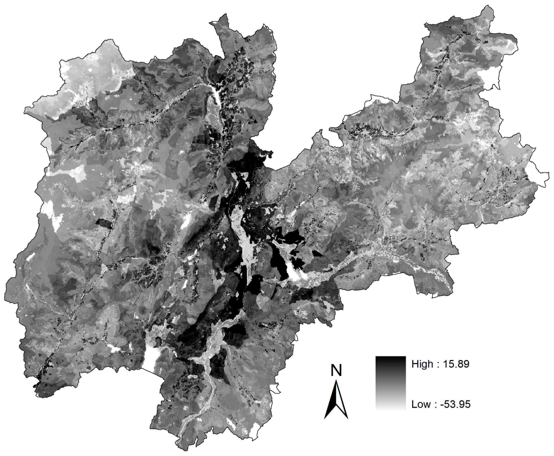


Figure 5.10. Map of the second Principal Component; it explains the 7% of original variance

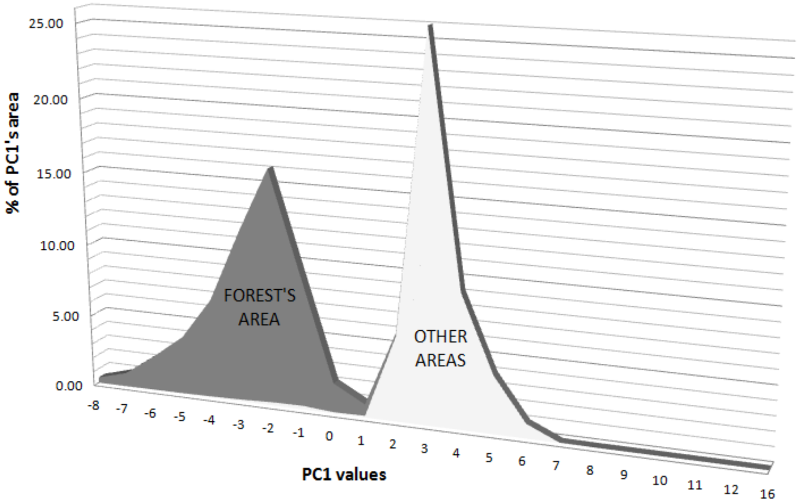


Figure 5.11. Distribution of PC1 scores among forest areas and other areas. 56% of Trentino is forest (the grey area in the picture); lowest values of PC1 are in forest areas.

5.3.5 Explanation of drivers of change

To my knowledge, at present only few studies have dealt with the definition of drivers of change, by means of principal component analysis (Raudsepp-Hearne et al., 2009; Maes et al., 2012a and Plieninger et al., 2013). Hereafter, the spatial distribution of the ESs with the greatest variance caused by land use management is explained.

<u>PC1</u> -> **Variability of forest ecosystem services due to land use management**

> ESs with the highest variability are: Honey production in forest areas of the most common ESs, Mushroom production (and collection), Fuel wood production and Macro-Climate regulation in forest areas of high-intensity and high-diversity ESs. Such variability is due to the effects of land use management and in particular to forest activities that generate forest density loss.

<u>PC2</u> -> **Variability of ecosystem services in agricultural areas**

> ESs with highest variability are: Agriculture production and Cultural heritage in agricultural areas of high-intensity ESs. Such variability is due to the effects of land use management.

5.4 Discussion

To date only few studies have dealt with the definition of ESs bundles by means of analytical tools (e.g. Raudsepp-Hearne et al., 2009 and Plieninger et al., 2013) and even less studies have dealt with an analytical explanation of the ESs variability and of the drivers causing such variability (e.g. Raudsepp-Hearne et al., 2009). The major part of the available literature has only formulated hypotheses on the theoretical framework of the ESs bundles distribution and of drivers of change: indeed, these topics are still an open field of research (Anton et al., 2010). The analyses proposed here allow the identification of the bundles to which each ES belongs to, and of the values of such ESs in the bundles. Moreover, they allow the identification of the factors that cause the main variability of ESs (i.e. land use and forest management) and the specific ESs on which they have great effect.

A number of the proposed analyses have been borrowed from previous studies (Fisher et al., 2009, Raudsepp-Hearne et al., 2009; Maes et al., 2012a and Plieninger et al., 2013), while others are an original contribution. Moreover, the set of statistical analyses used to define ESs bundles appear like a novelty in the present scientific panorama. In fact, principal components have been used here in order to avoid an a-priori selection of indicators, and a statistical criterion (ANOSIM) has been used in order to optimize the clustering. The characterization of the ESs distribution across principal components by means of loadings is a novel application in the definition of drivers of change, as well as the computation of fragmentation indices to investigate the bundles shape for the bundles definition. The main credit of the proposed methodology is that of having organized the analyses in a structured process where they are independent one from another. For instance, a wider set of variables (not only altitude, land use distribution, etc,) may be used to improve the knowledge about the spatial distribution of bundles.

Bundles of ecosystem services

In the present work, clusters of ESs have been identified by means of a small number of principal components and bundles have been defined through a narrow set of explanatory variables. However, the characterization of clusters is able to provide a reasonable explanation for bundles. The Trentino region is characterized by a homogeneous distribution of ESs, both in terms of type and value. In fact, only five bundles (i.e. less than half the number of identified bundles) are enough to represent 98% of the territory. Four of them represent forest areas, corresponding to 56% of the whole region. The fifth bundle represents poor-value ESs areas, covering about 40% of the territory, and consisting in urbanized areas, bare rocks and other natural areas with low values of ESs. On the other hand, small bundles correspond to areas where the supply of a single service, or of a narrow set of services, is very high with respect to other services. For instance, bundle 3 (that covers 7% of total forest areas) discriminates forests with high supply of fine-quality timber from the areas supplying the most common forest services. Such results confirm what found by Raudsepp-Hearne et al. (2009) and by Haines-Young et al. (2012): ESs of a region group on a few number of bundles; this number is smaller than the number of spatial units on which they are mapped (municipalities in the case of Raudsepp-Hearne). In addition, bundles are geographically clustered and little fragmentized across the territory. Finally, poor ESs areas group in one single bundle.

Drivers of change

drivers of change of ESs have been investigated only for the first two principal components, and by means of a narrow set of explanatory variables. It was found that the supply of ESs significantly change across some forest areas due to land use management activities (and especially due to the activities involving forest loss). In particular, the highest supply variability is displayed by nine typical forest ESs, which are distributed over five bundles. This is in accordance with findings of Steffan-Dewenter et al. (2007) and Haines-Young & Potschin (2010b), who demonstrated that the greatest loss of ESs is associated with the initial or the complete conversion of the forest to a different eco-system.

Spatial heterogeneity of ecosystem services distribution

According to Dale and Polasky (2007) ESs are provided within process-related landscape units such as watersheds, specific habitats, or natural units (i.e. intrinsic spatial units), and within such units ESs values may be heterogeneous. Anderson et al. (2009) pointed out that there are few studies on which to base conclusions about the spatial relationships between habitats important for different ESs and benefits for biodiversity, because such studies disregard spatial heterogeneity; Syrbe and Walz (2012) stressed that this is a strong limitation for the analyses that require a spatial representation of ESs. The present study attempts to consider intrinsic spatial heterogeneity for multiple ESs together. The cluster analysis showed that 25 ESs are represented together by 11 spatial units. It demonstrates that the intrinsic spatial heterogeneity of sets of correlated ESs (i.e. of bundles) is lower than the intrinsic spatial heterogeneity of single ESs (they were 20 spatial units of representation for 25 ESs). According to the results, clusters are also different from the spatial units of single ESs: the shape of clusters is not only a combination of spatial units, but they are also dependent on values of single services in such units. Therefore, the number of clusters is lower than the spatial units of single ESs, but their shape is more complex. A moderate degree of correlation was found between forest clusters and land use: the only land use class that can be spatially recognized in bundles is that of forest. It demonstrates that spatial units of land use are not sufficient to represent the spatial heterogeneity of single ESs, but one single spatial unit of land use (i.e. forest) is sufficient to represent the spatial heterogeneity of multiple ESs.

6 Conclusions

This chapter provides a summary of the findings and some concluding remarks related to each of the four research objectives.

6.1 Mapping multiple ecosystem services in an Alpine region

6.1.1 Main findings

Most assessment studies start from an arbitrarily chosen set of ESs and indicators. The present research instead took advantage of expert knowledge to select the ESs that are likely to be the most important in the study region, and to properly map a wide set of indicators measuring the actual biophysical, socio-cultural and economic value, in terms of stock and flow, of the selected ESs.

Experts selected 25 ESs, that are likely to represent typical ESs of Alpine regions and semi-urbanized mountain areas with large forests. In fact, selected ESs are partly recognizable in published lists, while some of them have been defined specifically for the case study of Trentino. ESs were described, highlighting their relevance for dwellers and people living outside. First of all, important ESs are essentially renewable resources, whose use, in some cases, needs to be regulated in order to guarantee the ESs provision through the years. The good assortment of provisioning, regulating and cultural services (respectively: 10; 7; 8 ESs) ensures the satisfaction of a wide range of human well-being needs. Provisioning services are private/common and storable resources, regulating are public and essentially not storable services, and cultural are public/common/club and not storable services. It has been also found out that a number of provisioning and cultural services are supplied together, while satisfying different needs. In this case, the joint production of ESs arises from human activities that aim to satisfy more needs, rather than from the heterogeneity of the territory. This is a strong confirmation that the selection of important ESs is case specific and that it strongly depends on dwellers needs and on the morphology of the region.

Experts selected 57 ESs assessment indicators (up to five indicators for a single ES), which were mapped over 20 different spatial units. The use of available information for a rich-data region, allows the mapping of indicators recognizable in published lists, as well of specific indicators for the study region. Indicators measure the actual supply of single ESs, and their mapping takes into account their intrinsic spatial heterogeneity. As expected, more data are available for mapping biophysical values, than economic or socio-cultural values. While for the economic value, the eventual lack of information is likely due to the fact that very few ESs have a direct market, for the latter the lack of information corresponds to the difficulties in considering such characteristic of ESs. As a consequence, provisioning and regulating services are those that can be most easily assessed. The high number of indicators confirms that in rich-data environments sufficient information is available to characterize ESs, and that the use of modelling may result useless.

6.1.2 Strengths and weaknesses

Strengths

The EU Biodiversity Strategy requires each Member State to assess the actual supply of important ESs by mapping proper biophysical indicators by 2014 (European Commission, 2011). According to the present research, important indicators have also measured the socio-cultural and economic values of ESs, both in terms of stock and flow. A number of experts was asked to select the important ESs and indicators for Trentino. Such indicators were mapped over single ES spatial units in order to take into account that ESs are supplied heterogeneously across the territory, and exploiting existing and available data.

This study was among the first attempt to detect important ESs for an Alpine region and to consider such a high number of ESs, describing them in terms of their renewability, their storability and their access as public/private goods. It has been also the first attempt to map such high number of indicators, only by means of existing and available data and considering the intrinsic spatial heterogeneity of single ESs. Its results may be used in the future to satisfy the requirements of the EU Biodiversity Strategy for 2014, as well as for the creation of an ESs atlas of the Trentino region. Moreover, the distinctions between real and potential supply, between stock and flow indicators, and between biophysical, socio-cultural and economic values are innovative with respect to the current state of the art.

Weaknesses

The major shortcoming is the perceived subjectivity of the selected ESs. Anyway, when no empirical knowledge is available, expert judgment is the only instrument that can be used to provide insight into a topic. The number of involved experts (51) and their varied expertise (that is expressed by the 22 offices and institutes they belong to) was supposed to minimize such risk. Weaknesses also lie in the selection of indicators only on the basis of the available existing data. In fact, it may be argued that the assessment may be limited and incomplete. Such simplifications may actually have affected the final results, and in particular they may have led to loss of relevant information. On the other hand, using existing information without any modelling is more than just an efficiency goal; rather it is an attempt to give value to existing data.

6.1.3 Proposals for future research

The selection of important ESs does not ensure, by itself, that the selected set is exhaustive for Trentino, and in general for Alpine regions. Subjectivity remains an important issue. The present indicators selection should be tested in other Alpine contexts, in order to verify whether other ESs need to be added to the present list, or whether the importance of some of them has been overestimated. Differences between the present list of ESs and lists for other Alpine regions may highlight the different morphological and land use/cover factors, as well as different human assets and well-being needs affecting ESs supply. For example, the shape of valleys or local traditions can determine a specific supply of regulating and cultural services. The need to integrate such a diverse set of information calls for a multidisciplinary approach and for the involvement of experts from various fields.

Moreover, the selection process of important indicators does not ensure that these are exhaustive to assess single ESs. The present selection should be tested in other Alpine contexts too, in order to verify whether other indicators may be added to the present list. Finally, future efforts are expected to lead to the mapping of the actual demand of important ESs and associated indicators. At present such assessment is disregarded in Trentino, even if it is one of the requirements of the EU Biodiversity Strategy by 2020.

6.2 Identifying key ecosystem service indicators

6.2.1 Main findings

Most of the existing assessment studies use only one indicator to assess each single ES. Even if, on the one hand, this practice may lead to the loss of relevant information about ESs, on the other hand a problem of redundancy may arise when more than one indicator is available: some indicators may be already explained by others, not contributing to the overall assessment. In Chapter 4 a pairwise statistical correlation analysis has been carried out for important ESs indicators in order to identify the redundant ones and select the key ones.

Out of 57 indicators, 35 were selected (up to three indicators for a single ES) on the basis of a high threshold value of the Spearman correlation coefficient between indicators pairs from the same ES. Indicators selected for single ESs are those that may be considered independent from one another. This result showed that not all the important indicators are key indicators, but also that one indicator is not always sufficient to assess single ESs. It also showed that there are cases where abundant information is already available and the modelling of ESs values is useless. Given that the number of selected indicators was found to change for different thresholds of the correlation coefficient, the indicators selection is indeed affected by a certain degree of subjectivity. However, the threshold adopted assures the minimum variation in the marginal increment of the selected indicators number. Three selection criteria of key indicators for each ES were formulated:

(1) if the supply of an ES is regulated, both its stock and flow biophysical indicators must be selected. Otherwise, either stock or flow indicators can be chosen;
(2) if different stock (flow) biophysical indicators for a single ES are mapped over different spatial units, they must be maintained;
(3) socio-cultural or economic indicators are always selected as key indicators.

This strongly confirms that key indicators are ESs-specific and that their number depends on the complexity of the service spatial units and on the joint values they have for people.

6.2.2 Strengths and weaknesses

Strengths

The use of statistical analyses is among the first attempt to provide a robust and credible solution to the problem of defining key ESs indicators. A distinction is made between indicators that are key for a single ES and indicators that are key for a multiple set of ESs. In particular, general criteria can be defined in the first case. They may help the selection in rich-data environments and may orient the assessment in poor-data environments. Results demonstrated that looking at correlation coefficients among key indicators of different ESs is a simple and straightforward way to detect dependences.

Weaknesses

The major shortcoming is the perceived subjectivity of the selected indicators. Such set is not the same across any possible value of the correlation coefficient. The basic problem is that it is not possible to avoid to set a threshold value to select key indicators. However, the sensitivity analysis computed justifies the results. Weaknesses also lie in the initial set of indicators. It may be argued that more socio-cultural values may be added to the initial set, and the results of the present research demonstrates that such indicators, when available, need always to be added (that is criteria 3). Therefore, in this case the initial loss of information does not affect the criteria developed.

6.2.3 Proposals for future research

The definition of selection criteria of key indicators has great potential for giving coherency to the assessments of a same ES in different regions. It has also a great potential for turning the ESs assessment in a standardized process. However, further efforts should be done to verify if the defined criteria are exhaustive for other ESs (for instance different from the 25 considered). At present, it can be hypothesized that additional selection criteria could come from the consideration of different characteristics of ESs. For instance, the aspect of being a private or public good may lead ESs to be characterized with different indicators. The present study showed that at maximum three indicators are enough to comprehensively characterize a service. The research of additional criteria should be pursued also to set the exact number of key indicators for each ES. This process could takes advantages from different techniques. A multivariate correlation analysis is undoubtedly better that a pairwise correlation analysis (used here) when more than two indicators must be considered at the same time. Therefore, it should be verified if and to what extent the selection of key indicators by means of a multivariate statistical analysis provide different results. A multivariate analysis may be also implemented by defining selection parameters that do not consider the redundancy of indicators as the main discriminating factor for the selection. For instance, a parameter could be defined that discriminates indicators measuring the socio-cultural value for people living outside the study region from the value for dwellers.

6.3 Defining bundles of ESs

6.3.1 Main findings

In Chapter 5, a method based on spatial and statistical analyses was proposed to delineate new configurations of the territory where multiple ESs are supplied all together. The proposed methodology provides a credible solution to the problem of defining the areas where sets of ESs appear together, i.e. bundles. It is an original piece of work with respect to the current literature, in that it involves the study of the spatial distribution of multiple ESs that are characterized by a specific spatial heterogeneity. Results of the analyses have confirmed what found by other authors: in a region multiple ESs are grouped on a few number of bundles (11 bundles in the case of Trentino); this number is smaller than the number of spatial units on which they are mapped (20 spatial units). In particular, poor ESs areas are grouped in one single bundle. The results showed that, even if the number of bundles is lower than the number of spatial units of single ESs, the bundle shape is more complex. Additionally, they showed that even if the spatial units of land use are not sufficient to represent the spatial heterogeneity of single ESs, one single spatial unit of land use (i.e. forest) is sufficient to represent the spatial heterogeneity of a large set of ESs.

6.3.2 Strengths and weaknesses

Strengths

This research attempted to define spatial bundles of ESs through rigorous criteria and accounting the spatial heterogeneity of multiple ESs. To do so, it proposed an original combination of statistical analyses to define ESs bundles. Principal components have been used in order to avoid an a-priori selection of indicators, and a statistical criterion (ANOSIM) has been used in order to optimize the clustering. The analyses proposed here allow the exact identification of the bundles to which each ES belongs to, and of the values of such ESs in the bundles.

Weaknesses

The use of such sophisticated statistical techniques does not make the methodology user-friendly. It may not be wise to perform such analyses whenever the study of single ESs is based on simplistic assumptions. According to Carpenter et al. (2006), simply disregarding some important ESs or disregarding the intrinsic spatial heteregeneity that caractherizes a single service may strongly modify the bundles shape and the spatial distribution of ESs. However, if data are accurate enough the techniques may handle the issue effectively. On the other hand, the need to re-arrange the huge amount of indicators of this study (it was a required process to tackle computational problems) led to simplifications that may actually have affected the final results and in particular they may have led to loss of information.

6.3.3 Proposals for future research

In the present work, clusters of ESs have been identified by means of a small number of principal components, explaining less than half the variance of the whole set of ESs. This may have resulted in clusters that are not fully representative of the whole set of ESs. In order to obtain a better clustering, a higher number of principal components or single ESs indicators should be considered. Moreover, ESs bundles have been defined by means of a narrow set of explanatory variables. This may have led to some approximation in bundles definition. Future applications could consider additional variables, like additional morphological features and the population distribution across the region.

The map of bundles and associated information may inform conservation efforts in the future. Considering that bundles are sets of ESs, their spatial representation depict areas that provide a considerable amount of ESs to humans. Hence, no matter their biodiversity values, these areas could be given a protection status due to their contribution to the wellbeing of the local population. Future research could be devoted to the identification that offers an optimum provision of ESs and biodiversity value.

6.4 Analysing ecosystem services tradeoffs and drivers of change

6.4.1 Main findings

Understanding the spatial dynamics of ESs arising from landscape planning and management activities is thought to be particularly important in orienting sustainable use of ESs. In Chapter 4 statistical analyses were conducted to explain positive (synergies) and negative (tradeoffs) interactions that may occur between ESs, while Chapter 5 presented a methodology based on spatial and statistical analyses to identify ESs with the most variability across the study region and explain the external factors that may cause such variability.

Tradeoffs analysis.

The correlation analysis between key ESs indicators allowed to identify six patterns of interactions of ESs. Results showed that the local management of the land has not strongly compromised the capacity of ecosystems to provide regulating services, that are those underpinning the production of other services. This is in contrast with the European trend, that sees the regional land management favouring the production of provisioning services and at the cost of the production of regulating and cultural services (cf: Maes et al., 2012). Synergies between ESs were not win-win exceptions (19 out of 25 ESs present positive interactions): services that were not influenced by the dynamics of others were a narrow set as well as services in tradeoffs (as mentioned above).

Drivers of change analysis.

The proposed methodology provides a credible solution to the problem of explaining the factors that cause the main variability of ESs. It is an original piece of work with respect to current literature, in that it involves the study of the spatial variability of multiple ESs and of the external factors causing such variability. For Trentino it was found that the supply of ESs significantly changes across some forest areas due to land use management activities (and especially due to the activities involving forest loss). In particular, the highest supply variability is displayed by nine typical forest ESs, which are distributed over the five forest bundles. A second group of ESs with high supply variability consists of four services distributed over three bundles covering agricultural areas.

6.4.2 Strengths and weaknesses

Strengths

The proposed methodology seeks to demonstrate, in an analytical way, the complex pattern of ESs relationships for the case study area.

Tradeoffs analysis.

Our application has proved that looking at statistical correlations among indicators of different ESs is a good method to detect synergies and tradeoffs. Considering that key indicators measure different values of ESs (and either in terms of stock and flow), the identified correlations are expression of the interactions of such values. Therefore, this analysis allows the identification of the interactions between specific values of ESs.

The present study attempts also to empirically explore the existence of conflicting services and win-win exceptions. The fact that only few regulating services are in tradeoff confirms the validity of the analysis: regulating services are thought to underpin the production of other services and they have to be in synergies (Rodrigues et al., 2006; Raudsepp-Hearne et al., 2009; Maes et al., 2012).

Drivers of change analysis.

The study provides a credible solution to the problem of explaining the factors that cause the main variability of ESs. It supports the hypothesis of previous studies, according to which the factors driving the most variability of ESs regard land use management. The degree of detail of used data, and in particular the intrinsic spatial heterogeneity that characterizes ESs indicators, allows for the identification of the specific management actions that involve ESs changes and of the specific ESs on which actions have great effect. The main credit of the methodology proposed to explore such issues is that of having organized the analyses in a structured process where they are independent one from another. Whether input information are not available they can be neglected and whether further information are available they can be added.

Weaknesses

A major limit of the tradeoff analysis is that the comparison of ESs is a pairwise one. When the interactions regard a large set of ESs, multiple comparisons could lead to identify different patterns of interactions. Anyway, the results of the pairwise correlation performed here have allowed the general pattern of tradeoffs to be confirmed: the production of the most intensively managed provisioning service (Agriculture) is in conflict with the supply of regulating and cultural services. Main shortcomings when explaining variability of ESs across the region and factors causing such variability are that the methodology is limited to a narrow set of explanatory variables (i.e. altitude, basin shapes, land use and forest density) and to a narrow set of principal components (the first two). These aspects may actually have affected the final results and in particular they may have led to little precise characterization of drivers of change.

The use of such sophisticated statistical techniques does not make the analysis of the ESs tradeoffs and drivers of change simple. Moreover, it may not be wise to perform such analyses whenever the study of single ESs is based on simplistic assumptions. Disregarding some important ESs or disregarding the intrinsic spatial heteregeneity that caractherizes a single service may strongly modify the results. However, if data are accurate enough the techniques may handle these issues effectively.

6.4.3 Proposals for future research

Regarding the identification of ESs interactions, a major area for improvement is the study of the locations where the strongest synergies and tradeoffs occur. The mapping of intensity, diversity and richness indices may support such analysis, giving an idea of the actual distribution of multiple ESs across bundles.

Qui and Turner (2013) introduced the theme of the ESs hotspots and coldspots, that seems a promising one. Hotspots and coldspots are defined as the locations containing the highest and the lowest number of ESs, above and under defined thresholds of the ESs value. Naidoo et al. (2008) showed that areas of biodiversity conservation, for instance those of Natura2000, are not hotspots of ESs. Future studies in Trentino could investigate whether protected areas are hotspots or coldspots of ESs. This is particular relevant in a region where more than 20% of the land is given a protection status.

The analysis of the external factors causing changes in the ESs distribution revealed that land use and forest management strongly influence ESs in forest areas. Anyway, the analysis does not ensure by itself that land use and forest management are the only factors affecting ESs. We expect that additional social and ecological conditions may affect the ESs supply. For instance, demographic dynamics may influence the distribution of ESs supply, as well as be oriented by it. Understanding which factors may have an actual influence requires the development of methods able to rank important variables (i.e. ESs) and to explain the relations between these variable and the social and ecological conditions.

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ANNEX I

Data for mapping ecosystem services indicators

The description of every data used to map the ecosystem service indicators, the unit of measurement, the type of data (distinguishing between spatial data - vector or raster - and scalar data), the spatial scale (in the case of spatial data), the reference year (when available), the data provider (the local entity that furnished the data), possible references and the website (if data can be download) are reported in Table AI.1. In case data are estimated, their values are reported in other tables (from Table AI.2 to AI.5). Such data may be valid for mapping indicators in regions whose characteristics are similar to those of Trentino.

Table AI.1. Data for mapping ecosystem service indicators

	Description	Unit of measurement	Type of data Spatial scale Reference year	Data provider	Reference in literature	Website
Agricultural production	Estimated amount of agricultural production for each agricultural type per hectare in Trentino (Table AI.2)	q ha^{-1} year^{-1}	Scalar values	Associazione produttori ortofrutticoli Trentini	-	-
Agricultural cadastral parcels	Map of agricultural cadastral parcels per agricultural product	Dimensionless	Vector map 1:5000; 2008	PAT - Agenzia provinciale per i pagamenti in agricoltura	-	-
Carbon increment in forests	Measured values of carbon increment per forest type (Table AI.6)	t ha^{-1} year^{-1}	Scalar values 2007	FEM - Centro di Ecologia Alpina	Tonolli, et al., 2011	-
Carbon increment in pastures, grassland and orchards	Estimated values of carbon increment in pastures, grassland and orchards in Alpine regions (Table AI.5)	t ha^{-1} year^{-1}	Scalar values	FEM - Centro di Ecologia Alpina	-	-
Carbon stock in forests	Measured values of carbon storage in forests (Table AI.6)	t ha^{-1}	Scalar values 2007	FEM - Centro di Ecologia Alpina	Tonolli, et al., 2011	-
Carbon stock in pastures, grassland and orchards	Estimated values of carbon storage in pastures, grassland and orchards (Table AI.5)	t ha^{-1}	Scalar values	Fondazione Edmund Mach	-	-
Corine land cover	Land cover classes	Dimensionless	Vector map 1:10000 2000	-	EEA, 2007	http://dati.trentino.it/dataset/uso-del-suolo-corine-ispra-ex-apat-edizione-2000
Curve Number	Hydrological parameter assessing the capacity of the land (as a function of the cover types and of the permeability of the subsoil) to retain rain-off	Dimensionless	Raster map; 1:10000 2000	PAT- Servizio Bacini montani	Soil Conservation Service, 1985	-
Discharge from withdrawal points	Discharge values in withdrawal points of surface water	m^{3} s^{-1} ha^{-1}	Vector map 1:10000 2008	PAT- Agenzia Provinciale per la protezione dell'Ambiente	-	-
Discharge from springs or wells	Discharge values in each withdrawal point of groundwater	m^{3} s^{-1} ha^{-1}	Vector map 1:10000 2008	PAT- Agenzia Provinciale per la protezione dell'Ambiente	-	-
DOP and DGI areas of apples and grapes	Map of DOP and DGI areas of apples and grapes	Dimensionless	Vector map 1:10000; 2008	PAT- Servizio Agricoltura	-	-
DTM	Digital Terrain Model map	m a.s.l.	Raster map 30 m * 30 m;	-	-	http://www.ing.unitn.it/~grass/

	Description	Unit of measurement	Type of data Spatial scale Reference year	Data provider	Reference in literature	Website
Elements of impermeability in riverbeds	They are 753 km of training walls and paved channels, and 15603 groynes and dikes over the hydrographic water network	Dimensionless	Vector map 1:10000 2008	PAT- Servizio Bacini montani	-	-
Energy value of fuel wood	Estimated heat energy (Table AI.4.)	kWh m^{-3}	Scalar value	PAT- Dipartimento Foreste, Territorio e Ambiente	-	-
EUNIS Habitat	Map of habitat classification	Dimensionless	Vector map 1:10000	PAT- Servizio Conservazione della Natura e Valorizzazione Ambientale	EEA, 2008	http://dati.trentino.it/dataset?q=habitat&sort=score+desc%2C+metadata_modified+desc
Extracted volumes per quarry	Volume annually excreted in each quarry	m^3 year $^{-1}$	Scalar values	PAT- Servizio Minerario	PAT - Servizio Minerario, 2007	-
Fish biomass	Estimated biomass of fish in each fishing zone	kg fishing zones^{-1}	Scalar values	PAT- Servizio Foreste e Fauna	-	-
Fishing zones	Map of river segments and lakes where fishing	Dimensionless	Vector map 1:10000	PAT- Servizio Foreste e Fauna	-	-
Forest lots	Map of forest lots	Dimensionless	Vector map 1:10000	PAT- Servizio Foreste e Fauna	-	-
Forest roads	Minor roads	Dimensionless	Vector map 1:10000	PAT- Dipartimento Territorio, Ambiente e Foreste	-	-
Forest types	Maps of eight forest types	Dimensionless	Vector map 1:10000; 2001	PAT- Servizio Foreste e Fauna	-	http://dati.trentino.it
Game reserves	Maps of ungulates game reserves	Dimensionless	Vector map 1:10000;	PAT- Servizio Foreste e Fauna	-	-
Habitat of ungulates	Maps of ungulates habitat	Dimensionless	Vector map 1:10000	PAT- Servizio Foreste e Fauna	-	-
Hazard protection capacity	Map of protection capacity of forests	Dimensionless	Raster map 100 m 100 m 2008	PAT- Dipartimento Territorio, Ambiente e foreste	-	-
Honey production capacity	Estimated capacity of honey production per forest type	Dimensionless	Scalar values	PAT- Dipartimento Territorio, ambiente e foreste	Matteotti and Miori, 2005	-
Mushroom production capacity	Estimated capacity of single forest types to provide mushrooms available for harvesting	Dimensionless	Scalar values 2007	PAT- Dipartimento Territorio, ambiente e foreste	-	-

	Description	Unit of measurement	Type of data Spatial scale Reference year	Data provider	Reference in literature	Website
Mushroom quality	Estimated capacity of single forest types to provide mushrooms of good quality	Dimensionless	Scalar values 2007	PAT- Dipartimento Territorio, ambiente e foreste	-	-
NDVI	Fusion of airborne LiDAR and satellite multispectral data, for the prediction of forest stem volume at plot level in a complex mountain area	Dimensionless	Raster map; 60 m * 60 m; 2008	Fondazione Edmund Mach	-	-
Nectar value	Estimated nectar values of forest typologies	Dimensionless	Scalar values	PAT- Servizio foresta e fauna	Matteotti and Miori, 2005	-
Number of caught fishes	Number of caught fishes for each fish species in each fishing zones	(no. of caught fishes) year $^{-1}$	Scalar values	PAT- Servizio foresta e fauna	-	-
Number of fishing excursions	Number of fishing excursions in each fishing zone	(no. of fishing excursions) year $^{-1}$	Scalar values	PAT- Servizio foresta e fauna	-	-
Number of hunted animals	Number of hunted animals for each species in each game reserve	(no. of ungulates) year $^{-1}$	Scalar values	PAT- Servizio foresta e fauna	-	-
Number of hunters	Number of hunters in each game reserve	(no. of hunters) year $^{-1}$	Scalar values	Associazione Cacciatori Trentini	-	-
Number of ungulates in their habitat	Number of ungulates for each species in each habitat	(no. of ungulates)	Scalar values	Servizio foresta e fauna	-	-
Number of stumps and seeds	Estimated number of stumps and seeds for each agricultural type per hectare (Table AI.2)	(no. of stumps or seeds)	Scalar values	Associazione produttori ortofrutticoli trentini	-	-
Number of mushroom permits	Number of permits for mushroom collection	Dimensionless	Scalar values; 2008	Servizio foreste e fauna	-	-
Nutritive value of fish	Estimated nutritive value of fishes (Table AI.4)	kcal (100g)$^{-1}$	Scalar values	Associazione Troticoltori Trentini	-	-
Nutritive values per agricultural product	Estimated nutritive value for each agricultural type (Table AI.2)	kcal (100g)$^{-1}$	Scalar values	Associazione produttori ortofrutticoli trentini	-	-
Nutritive values per hunted specie	Estimated nutritive value for each hunted specie (Table AI.3)	kcal kg^{-1}	Scalar values	Associazione cacciatori Trentini	-	-
Permits fee for harvesting	Price to pay for visitors (Table AI.4)	€ permit $^{-1}$	Scalar values	Servizio Foreste e Fauna	-	-

	Description	Unit of measurement	Type of data Spatial scale Reference year	Data provider	Reference in literature	Website
Points of cultural interest	173 landscape goods; 595 archaeological sites	Dimensionless	Vector map; 1:10000; 2007	Servizio Urbanistica e Tutela del paesaggio	PUP, 2008	http://dati.trentino.it/dataset?q=invarianti&sort=score+desc%2C+metadata_modified+desc
Points of particular beauty	199 points of natural and cultivated ecosystems of particular beauty; 396 landscape fronts; 173 landscape goods; 595 archaeological sites	Dimensionless	Vector map; 1:10000; 2007	Servizio Urbanistica e Tutela del paesaggio	PUP, 2008	http://dati.trentino.it/dataset?q=invarianti&sort=score+desc%2C+metadata_modified+desc
Proportion of wood for timber per forest type	Estimated wood for timber per forest type (Table AI.6)	Percentage	Scalar values	Servizio Foreste e Fauna	-	-
Proportion of wood for fuel wood per forest type	Estimated wood for wood per forest type (Table AI.6)	Percentage	Scalar values	Servizio Foreste e Fauna	-	-
Quarries	Map of quarries per inorganic matter type	Dimensionless	Vector map; 1:1000; 2001	Servizio minerario	-	http://dati.trentino.it/dataset/iv-piano-cave
Revenues from ski passes	Revenues from ski passes per seven ski areas	€ (ski area)$^{-1}$	Scalar values; 2007	Servizio Statistica	PAT-Rapporto Servizio Statistica, 2008	http://www.statweb.provincia.tn.it/annuario/(S(ixehaoaistt2xo45tt2klw45))/Default.aspx
Road network	Map of the main and the secondary roads	Dimensionless	Vector map; 1:10000;	PAT - Dipartimento Territorio, Ambiente e foreste	-	-
Roughness parameters per land cover type	Values of roughness of superficial surfaces	Dimensionless	Scalar values	-	-	www.ral.ucar.edu/research/land/technology/lsm/noahlsm-v3.2/
Season length	Estimated season length of recreational activities	no. of months year^{-1}	Scalar values	-	-	-
Selling price of fuel wood	Average price of selling of fuel wood (Table AI.4)	€ m^{-3}	Scalar values; 2007	PAT - Servizio Statistica	PAT-Rapporto Servizio Statistica, 2008	http://www.statweb.provincia.tn.it/annuario/(S(ixehaoaistt2xo45tt2klw45))/Default.aspx
Selling price of cut timber	Average price of selling of timber (Table AI.4)	€ m^{-3}	Scalar values; 2007	PAT - Servizio Statistica	PAT-Rapporto Servizio Statistica, 2008	http://www.statweb.provincia.tn.it/annuario/(S(ixehaoaistt2xo45tt2klw45))/Default.aspx
Selling price of withdrawn water	Price of water from aqueduct for domestic and other uses (Table AI.4)	€ m^{-3}	Scalar values;	PAT - Servizio Statistica	-	-

	Description	Unit of measurement	Type of data Spatial scale Reference year	Data provider	Reference in literature	Website
Selling price values per agricultural product	Estimated price of selling for each agricultural type per hectare (Table AI.2)	€ ha^{-1}	Scalar values; 2007	PAT - Servizio Statistcia	PAT-Rapporto Servizio Statistica, 2008	http://www.statweb.provincia.tn.it/annuario/(S(ixehaoaistt2xo45tt2klw45))/Default.aspx
Selling price of inorganic matter	Estimated price of each per inorganic matter type	€	Scalar values	Local expert knowledge	-	-
Ski slopes	Map of 236 ski slopes	Dimensionless	Vector map			
Specific discharge coefficient	Monthly values per sub-catchment of the long term average discharge production per square km of contributing basins	$m^3\ s^{-1}\ ha^{-1}$	Vector map; 1:10000; 2009	Università di Trento, Gruppo di idrologia	APRIE, 2013	http://www.energia.provincia.tn.it/ultimora/pagina142.html
Sub-catchments	Shape of sub-catchments	Dimensionless	Vector map; 1:10000	Gruppo di idrologia	-	-
Valuable agricultural areas	valuable and non-valuable agricultural areas classified according to PUP (2008)	Dimensionless	Vector map; 1:10000; 2007	Servizio Urbanistica e Tutela del Paesaggio	PUP, 2008	http://dati.trentino.it/
Volume of inorganic matter per quarry	Available volume of inorganic matter per quarry, per inorganic matter type	m^3 inorganic matter $^{-1}$	Scalar values; 2001	Servizio minerario	-	http://dati.trentino.it/dataset/iv-piano-cave
Volume of wood per forest lot	Available volume of wood per forest lot	m^3	Vector map; 1:10000	Servizio Foreste e Fauna	-	-
Volume of wood for cutting per forest lot	Available volume of wood for cutting per forest lot	m^3	Vector map; 1:10000	Servizio Foreste e Fauna	-	-
Water flow for drinking, irrigation and industrial uses from withdrawal points	Flow of withdrawn surface water used for drinking, irrigation and industrial uses per spring or well	m^3 $year^{-1}$ ha^{-1}	Vector map; 1:10000; 2008	Agenzia Provinciale per la protezione dell'Ambiente	-	
Water flow for drinking, irrigation and industrial uses from springs or wells	Flow of withdrawn water from springs or wells used for drinking, irrigation and industrial uses	m^3 $year^{-1}$ ha^{-1}	Vector map; 1:10000; 2008	PAT - Agenzia Provinciale per la protezione dell'Ambiente	-	-
Water network	Map of the principal and the minor hydrographic network	Dimensionless	Vector map; 1:10000; 2008	PAT - Servizio Bacini montani	-	-
Weight of caught	Estimated weight of fishes (see table A2.1)	g $fish^{-1}$	Scalar value	Associazione Troticoltori Trentini	-	-
Weight of hunted animals	Estimated weight for each hunted specie (Table AI.4.)	kg $specie^{-1}$	Scalar values	Associazione Cacciatori Trentini	-	-

Table AI.2. Estimates of agricultural production data

	Number of stumps and seeds (n. of stumps/seeds) ha^{-1}	**Agricultural production** q ha^{-1} $year^{-1}$	**Nutritive values per agricultural product** kcal $(100\ g)^{-1}$	**Selling price values per agricultural product** € q^{-1}
Kiwi	1500	200	53	72
Grapes	4600	150	70	85
Apples	3000	500	35	85
Pears	3000	300	44	25
Gooseberries	5000	120	44	215
Strawberries	25000	240	44	323
Redcurrants	2700	120	44	299
Blueberries	5000	200	44	374
Raspberries	24000	170	44	801
Blackberries	6000	170	44	594
Plums	1500	200	44	43
Cherries	2500	80	56	290
Apricots	1500	200	44	40
Hazelnuts	2000	25	140	500
Walnuts	2000	25	140	500
Chestnuts	2000	80	140	500
Polyphitic grass	3500000	50	30	14
Monophitic grass	3500000	50	30	14
Polyphitic grasslands	490000	7	30	0
Monophitic grasslands	490000	7	30	0
Potatoes	0	400	55	31
Lettuces	0	200	30	0
Carrots	0	490	30	0
Cabbage	0	200	30	0
Corn (crop cultivation)	0	90	350	87

Table AI.3 Estimates of hunted animals data

	Weight of hunted animals Kg per hunted animal	Nutritive values per hunted specie kcal kg^{-1}
Roe deer	180	1200
Red deer	25	1100
Chamois	40	1200
Muflon	40	1200
Wild boar	0.5	1100
Rock partridge	0.6	1100
Black grouse	1.2	1200
Fox	5	1200
Hare	7	1200
Alpine hare	0.5	1000

Table AI.4 Estimates of additional data

Data	Unit of measurement	Values
Energy value of fuel wood	kWh m^{-3}	4
Nutritive value of fish	Kcal $(100g)^{-1}$	150
Selling price of cut timber	€ m^{-3}	4 (conifers); 6.5 (broad-leaved forests)
Selling price of fuel wood	€ m^{-3}	4
Selling price of withdrawn water	€ m^{-3}	0.7 (drinking water); 0.3 (irrigation)
Permits fee for harvesting	€ $permit^{-1}$	12
Weight of caught	g $fish^{-1}$	250

Table AI.5 Estimates of carbon sequestration data in non-forest areas

	Carbon stock t ha^{-1}	Carbon increment t ha^{-1} $year^{-1}$
Grass	80	0
Pastures	80	0
Orchards	12	1,5

Table AI.6 Estimates of data per forest type

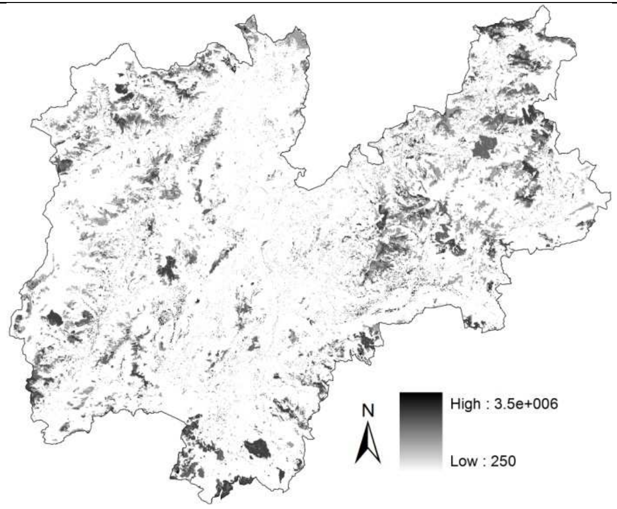
Forest types	**Proportion of wood for timber per forest type**	**Proportion of wood for fuel wood per forest type**	**Carbon stock**	**Carbon increment**
	Percentage	Percentage	t ha^{-1}	t ha^{-1} $year^{-1}$
Quercus ilex wood with *Ostrya carpinifolia*	0.60	0.40	185	2.8653
Xeric *Quercus ilex* wood with *Pistacia terebinthus*	0.67	0.33	185	2.8653
Primitive *Fraxinus ornus - Ostrya carpinifolia* wood	0.50	0.50	185	2.8653
Typical *Fraxinus ornus - Ostrya carpinifolia* wood	0.75	0.25	185	2.8653
Fraxinus ornus-Quercus wood	0.67	0.33	185	2.8653
Quercus - Carpinus wood	0.62	0.38	185	2.8653
Quercus petraea wood	0.56	0.44	185	2.8653
Castanea sativa – Robinia pseudoacacia wood	0.64	0.36	185	2.8653
Castanea sativa wood	0.70	0.30	185	2.8653
Robinia pseudoacacia wood	0.64	0.36	185	2.8653
Acer - Fraxinus wood	0.50	0.50	262	1.0079
Acer - Fraxinus wood with *Alnus*	0.54	0.46	262	1.0079
Acer- Tilia wood	0.53	0.47	262	1.0079
Transient species	0.80	0.20	212	1.5251
Xeric and Alpine *Pinus* wood	0.29	0.71	190	0.3781
Typical *Pinus* wood with *Picea abies*	0.29	0.71	190	0.3781
Hygrophilous pine wood	0.33	0.67	190	0.3781
Pinus wood with *Fraxinus ornus*	0.29	0.71	190	0.3781
Pinus wood with *Fagus sylvatica* or noble species	0.44	0.56	190	0.3781
Pioneer *Pinus* wood	0.40	0.60	190	0.3781
Pinus nigra wood	0.33	0.67	190	0.3781
Fagus sylvatica wood with *Luzula* or *Gramineae*	0.54	0.46	176	2.3368
Mesalpic *Fagus sylvatica* wood with conifers	0.53	0.47	176	2.3368
Typical *Fagus sylvatica* wood with *Dentaria*	0.53	0.47	176	2.3368
Alpine *Fagus sylvatica* wood	0.67	0.33	176	2.3368
Fagus sylvatica wood with *Ostrya carpinifolia*	0.67	0.33	176	2.3368
Fagus sylvatica wood with *Taxus* or *Ilex*	0.53	0.47	176	2.3368
Calcicole *Abies* wood with *Fagus sylvatica*	0.33	0.67	262	1.0079
Abies wood in fertile soil	0.31	0.69	262	1.0079
Silicicole *Abies* wood in acid soil	0.33	0.67	262	1.0079
Pinus mugo wood with *Rhododendron ferrugineum*	0.50	0.50	181	0.8960
Acidophilous *Pinus mugo* wood in pastures	0.50	0.50	181	0.8960
Rhododendron	0.50	0.50	181	0.8960
Erica wood	0.50	0.50	181	0.8960

Forest types	**Proportion of wood for timber per forest type**	**Proportion of wood for fuel wood per forest type**	**Carbon stock**	**Carbon increment**
	Percentage	Percentage	t ha^{-1}	t ha^{-1}
Alnus incana wood	0.78	0.22	185	2.8653
Alnus glutinosa wood	0.60	0.40	185	2.8653
Hygrophilous *Picea abies* wood with *Sphagnum* or *Molinia*	0.40	0.60	184	0.9275
Picea abies wood with *Erica* and *Pinus sylvestris*	0.36	0.64	184	0.9275
Xeric montane *Picea abies* wood	0.36	0.64	254	1.1678
Typical *Picea abies* wood	0.33	0.67	254	1.1678
Subalpine *Picea abies* wood	0.44	0.56	254	1.1678
Picea abies wood with *Alnus viridis*	0.36	0.64	184	0.9275
Secondary or substitutive *Picea abies* wood	0.36	0.64	184	0.9275
Secondary or substitutive *Larix decidua* wood	0.36	0.64	279	1.8617
Typical *Larix decidua* wood with *Rhododenron*	0.36	0.64	279	1.8617
Xeric *Larix decidua* wood with *Juniperus*	0.44	0.56	279	1.8617
Larix decidua wood with *Alnus viridis*	0.44	0.56	279	1.8617
Typical *Larix decidua – Pinus cembra* wood with *Rhododendon*	0.30	0.70	279	1.8617
Xeric *Larix decidua – Pinus cembra* wood with *Juniper*	0.38	0.63	279	1.8617
Larix decidua – Pinus cembra wood with *Alnus viridis*	0.38	0.63	279	1.8617
Typical *Pinus cembra* wood with *Rhododendron*	0.22	0.78	279	1.8617
Xeric *Pinus cembra* wood with *Juniper*	0.29	0.71	279	1.8617
Pinus cembra wood with *Alnus viridis*	0.29	0.71	279	1.8617

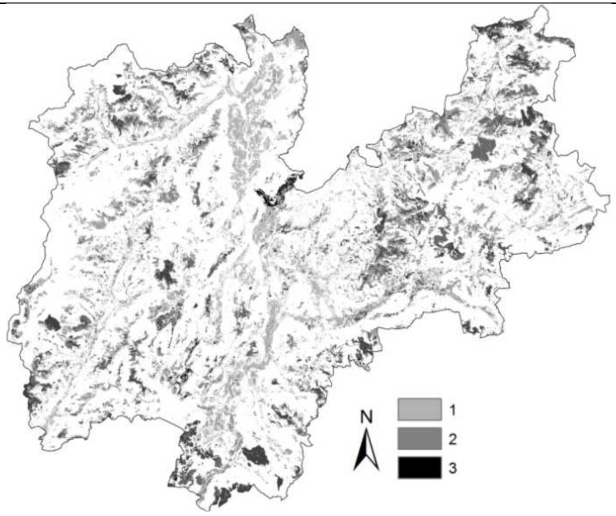
ANNEX II

Maps of ecosystem service indicators

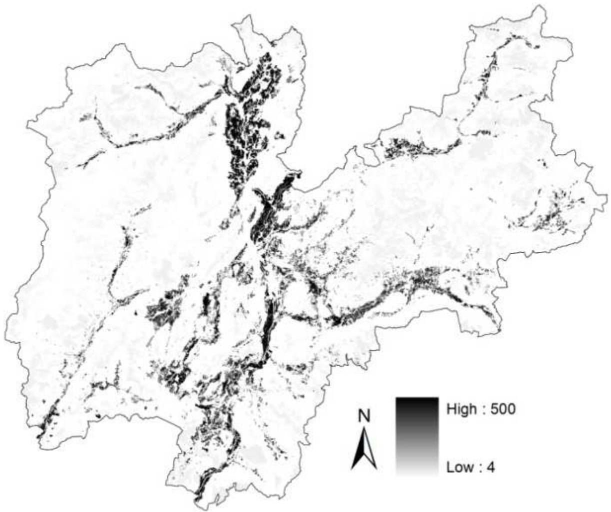
Maps of Ecosystem service (ES) indicators are grouped by ES (From Figure AII.1 to AII.25). For each map the name of indicator, the unit of measurement, the type (i.e. Stock and Flow), the value (i.e. Biophysical, Socio-Cultural and Economic), and the spatial unit of representation are reported.



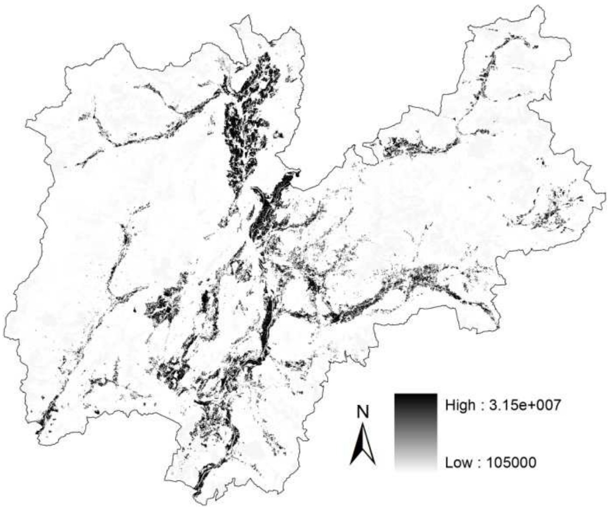
Density of stumps and seeds [no. of stumps/seeds ha^{-1}]
Stock - Biophysical value over Cadastral parcels



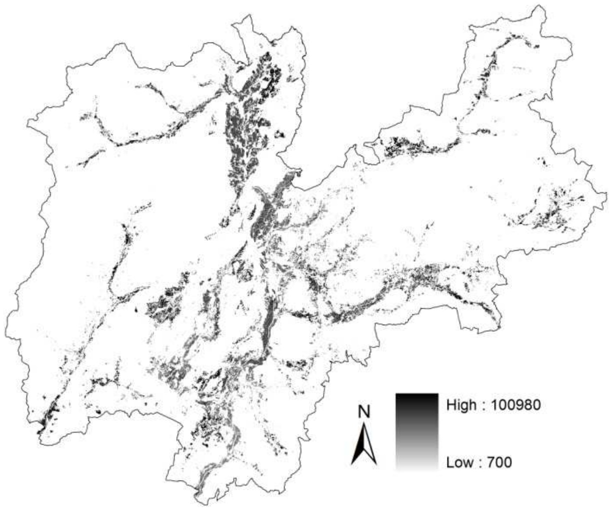
Quality of agricultural production [Dimensionless]
Stock - Socio-Cultural value over Patches of agricultural areas



Amount of agricultural products [q ha^{-1} year^{-1}]
Flow - Biophysical value over Cadastral parcels

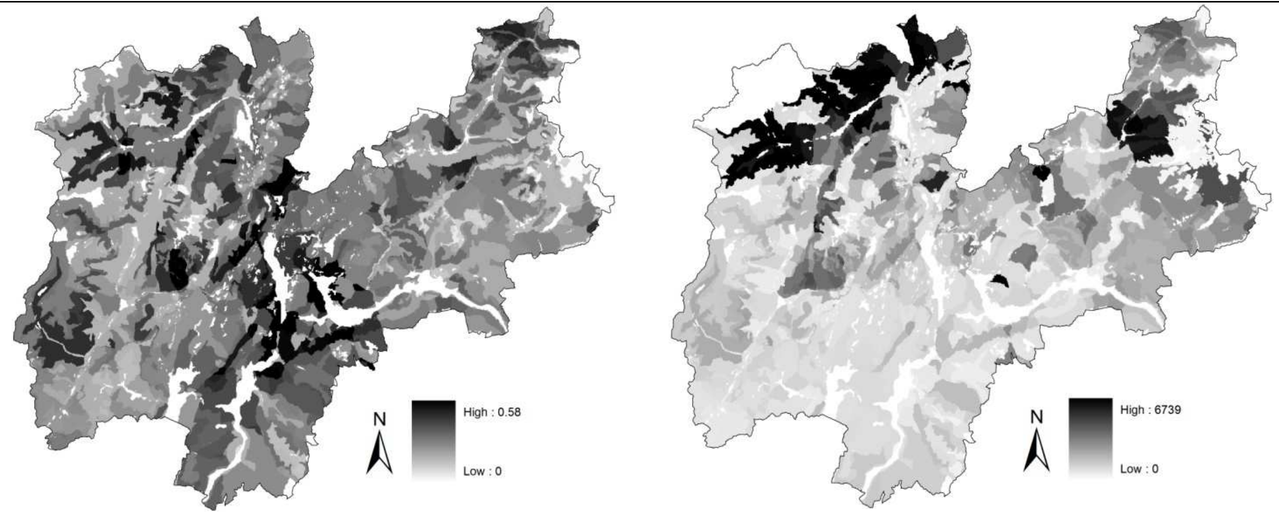


Nutritive value of agricultural products [kcal ha^{-1} year^{-1}]
Flow - Biophysical value over Cadastral parcels



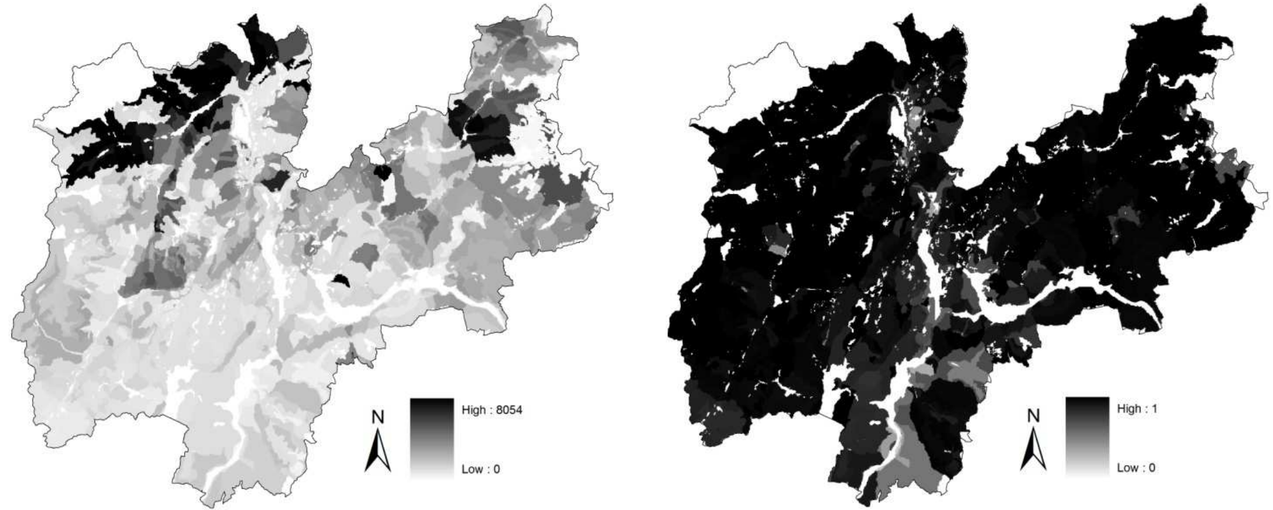
Selling price of agricultural products [€ ha^{-1} year^{-1}]
Flow - Economic value over Cadastral parcels

Figure AII.1. Indicators of the ES "Agriculture production"



Density of ungulates [no. of ungulates ha^{-1}]
Stock - Biophysical value over Habitat units

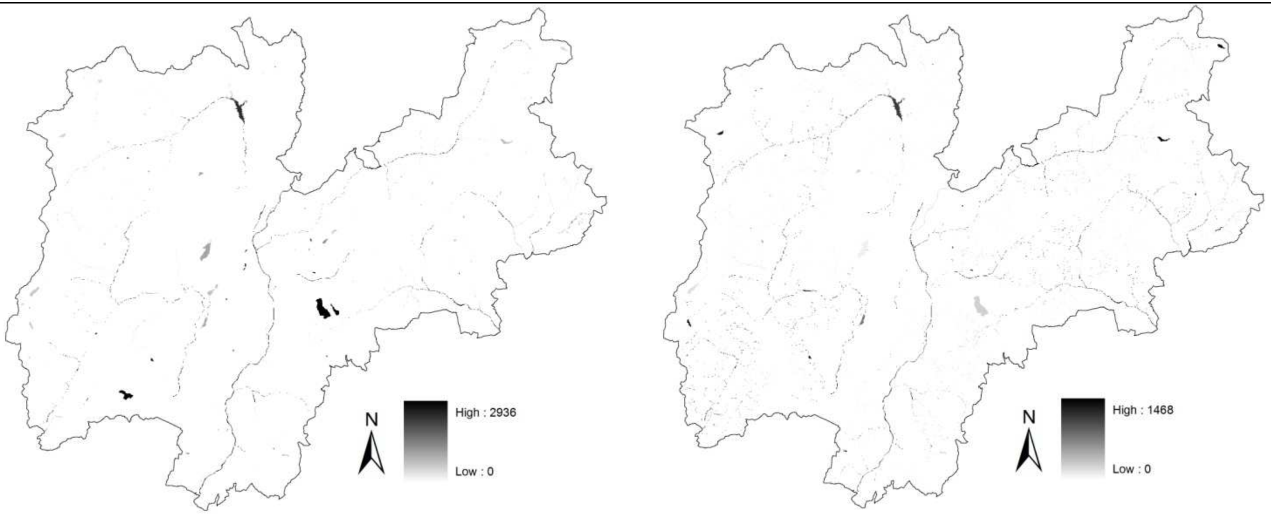
Amount of hunting products [kg ha^{-1} year^{-1}]
Flow - Biophysical value over Game reserves



Nutritive value of hunting products [kcal ha^{-1} year^{-1}]
Flow - Biophysical value over Game reserves

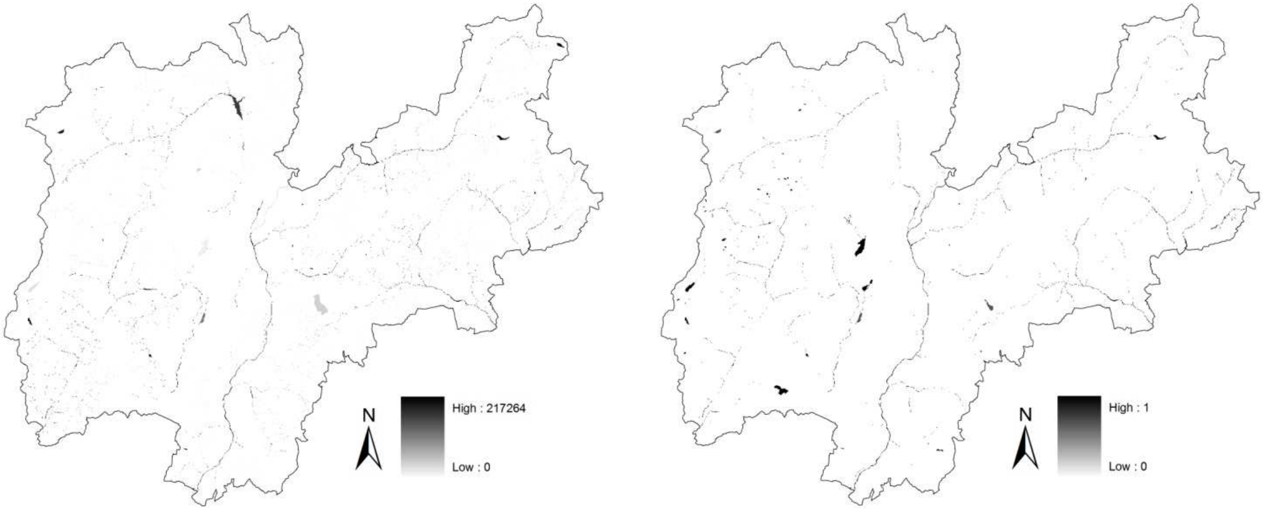
Proportion of ungulates out the entire hunted population
[(no. of hunted ungulates) (no. of hunted animals)$^{-1}$ year^{-1}]
Flow - Socio/Cultural value over Game reserves

Figure AII.2. Indicators of the ES "Hunting production"



Fish biomass [kg ha^{-1}]
Stock - Biophysical value over Fishing zones

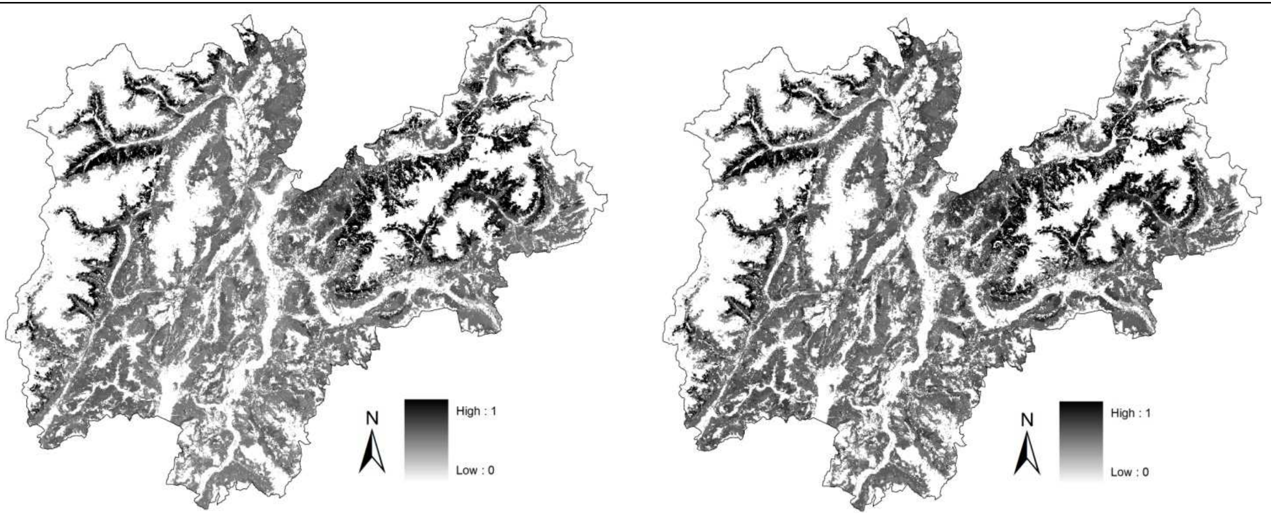
Amount of fishing products [kg ha^{-1} year^{-1}]
Flow - Biophysical value over Fishing zones



Nutritive value of fishing products [kcal ha^{-1} year^{-1}]
Flow - Biophysical value over Fishing zones

Proportion of key Alpine species out of the entire caught population [(no. of harvested key Alpine species) (no. of harvested fishes)$^{-1}$ year^{-1}] **Flow - Socio/Cultural value over Fishing zones**

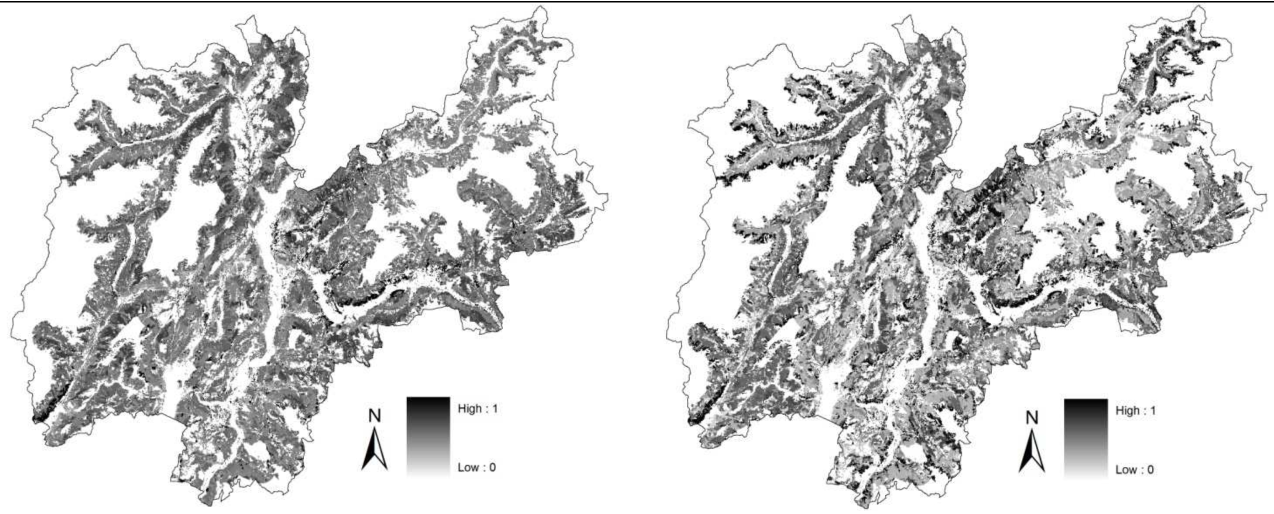
Figure AII.3. Indicators of the ES "Fishing production"



Intensity of mushroom production [Dimensionless]
Stock - Biophysical value over Forest types

Mushroom quality [Dimensionless]
Stock - Socio/Cultural value over Forest types

Figure AII.4. Indicators of the ES "Mushroom production"



Intensity of honey production [Dimensionless]
Stock - Biophysical value over Areas of forest types 500 close to forest ways

Nectar value [Dimensionless]
Stock - Socio/Cultural value over Areas of forest types 500 close to forest ways

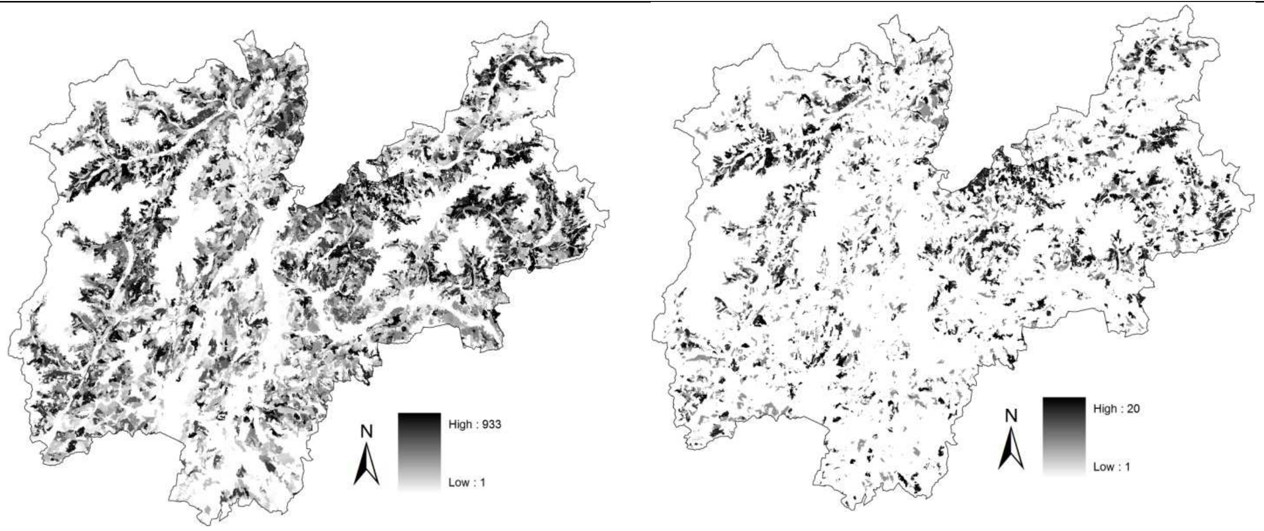
Figure AII.5. Indicators of the ES "Honey production"

Amount of inorganic matter in quarries [m^3 ha^{-1}]
Stock - Biophysical value over Quarries

Amount of inorganic matter extracted [m^3 ha^{-1} year^{-1}]
Flow - Biophysical value over Quarries

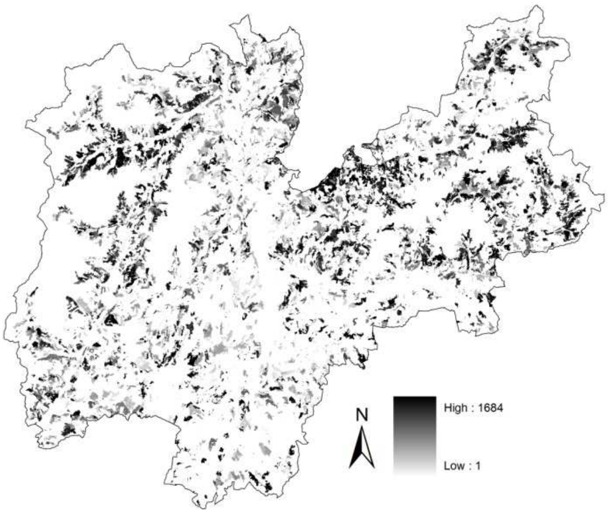
Selling price of inorganic matter [€ ha^{-1} year^{-1}]
Flow - Economic value over Quarries

Figure AII.6. Indicators of the ES "Inorganic matter extraction"



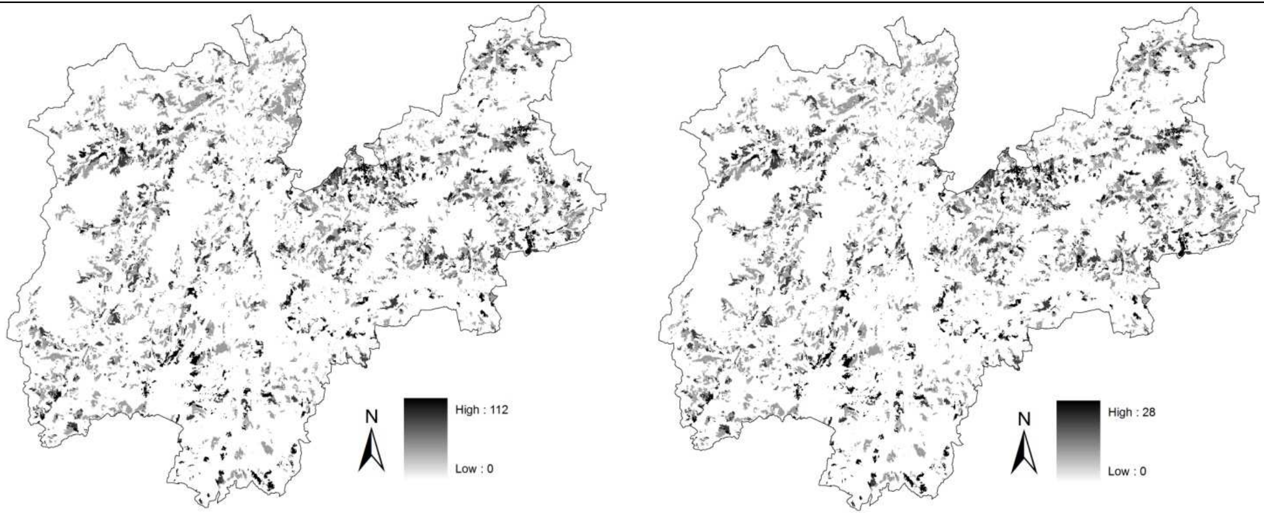
Wood density in forests [m^3 ha^{-1}]
Stock - Biophysical value over Forest lots

Amount of timber harvested [m^3 ha^{-1} year^{-1}]
Flow - Biophysical value over Forest lots



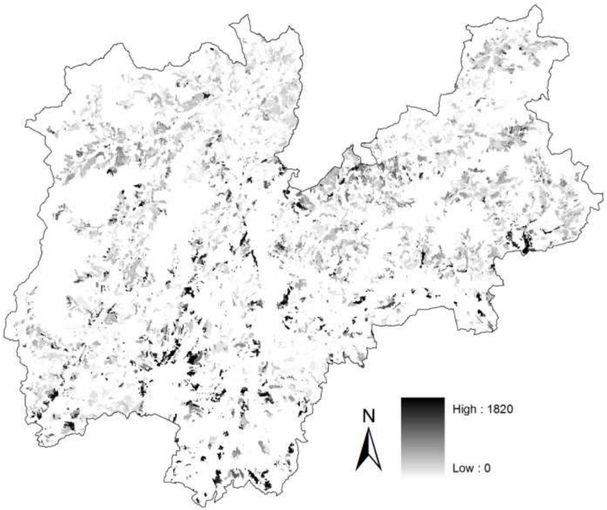
Selling price of timber harvested [€ ha^{-1} year^{-1}]
Flow - Economic value over Forest lots

Figure AII.7. Indicators of the ES "Timber production"



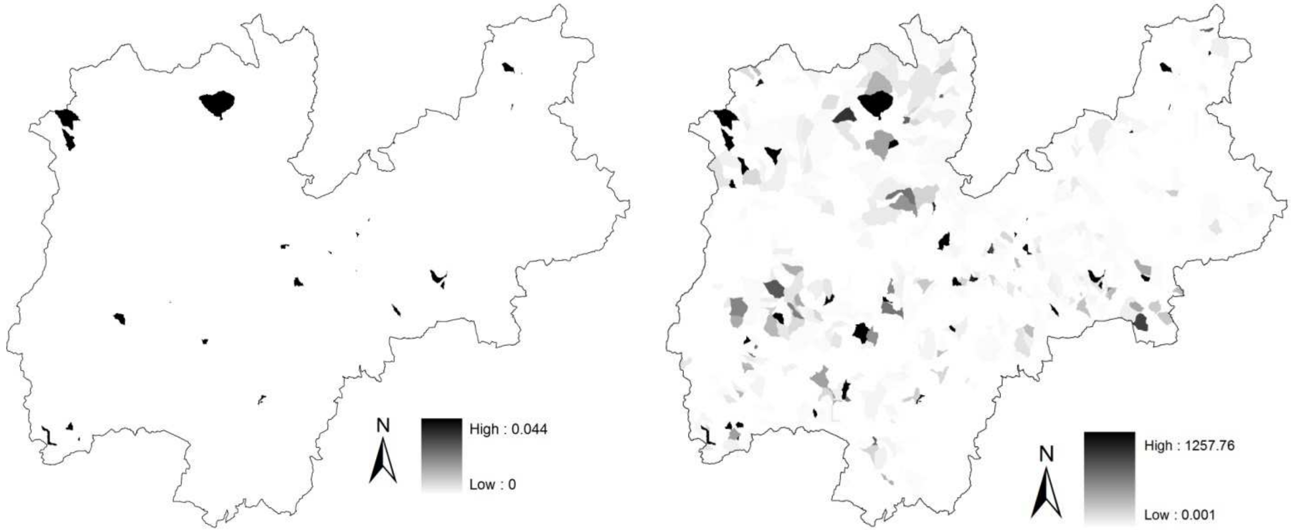
Energy embedded in fuel wood [kWh ha^{-1} $year^{-1}$]
Stock - Biophysical value over Forest lots

Amount of fuel wood harvested [m^3 ha^{-1} $year^{-1}$]
Stock - Biophysical value over Forest lots



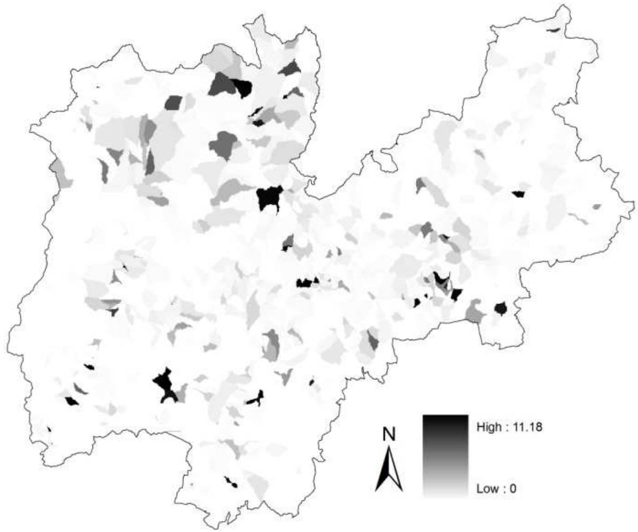
Selling price of fuel wood [€ ha^{-1} $year^{-1}$]
Stock - Biophysical value over Forest lots

Figure AII.8. Indicators of the ES "Fuel wood production"



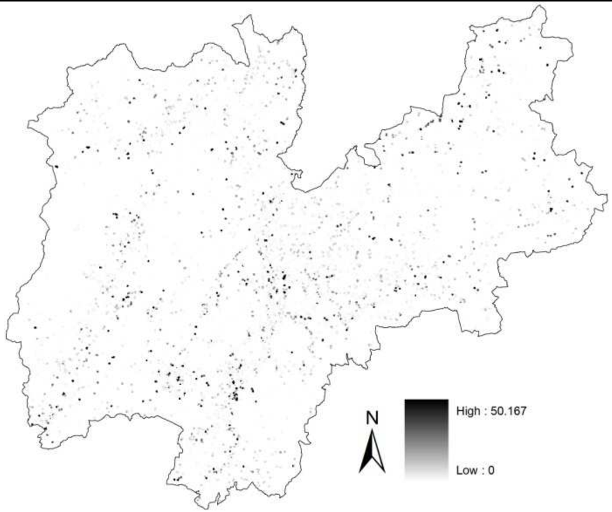
Water flow from surface water network [m^3 s^{-1} ha^{-1}]
Stock - Biophysical value over Sub-catchments

Water consumption from surface water network
[m^3 ha^{-1} year^{-1}] **Flow - Biophysical value over Sub-catchments**

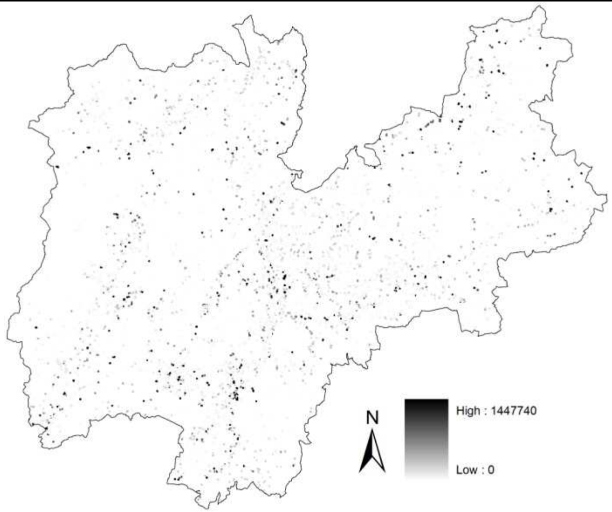


Selling price of surface water network [€ ha^{-1} year^{-1}]
Flow - Economic value over Sub-catchments

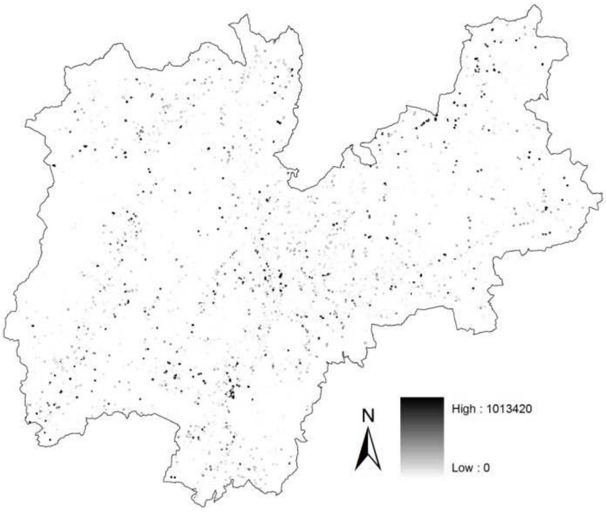
Figure AII.9. Indicators of the ES "Water supply from surface water network"



Water flow from groundwater [$m^3\ s^{-1}\ ha^{-1}$]
Stock - Biophysical value over Buffers of 200 m around springs and wells

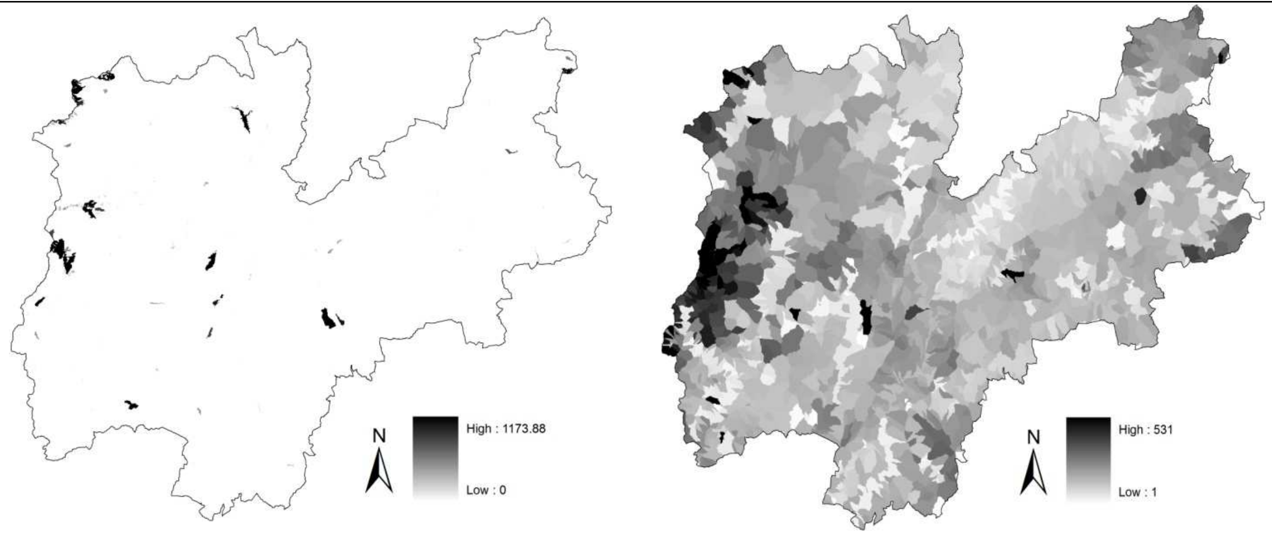


Water consumption from groundwater [$m^3\ ha^{-1}\ year^{-1}$]
Flow - Biophysical value over Buffers of 200 m around springs and wells



Selling price of groundwater supply [€ $ha^{-1}\ year^{-1}$]
Flow - Economic value over Buffers of 200 m around springs and wells

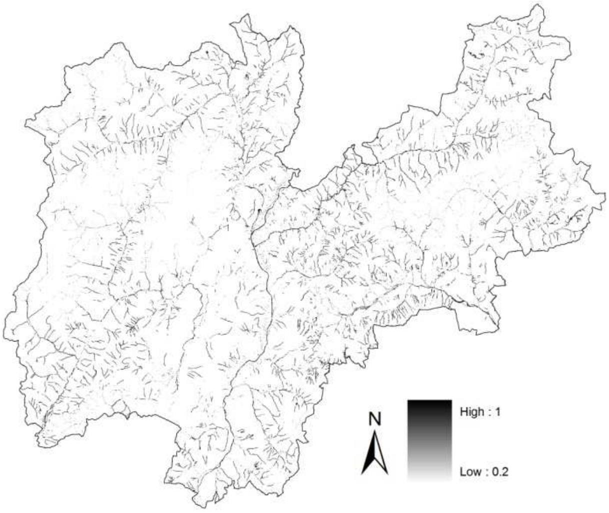
Figure AII.10. Indicators of the ES " Water supply from groundwater"



Surface area of lakes, reservoirs and glaciers [m^2]
Stock - Biophysical value over Land cover classes of Lakes, reservoirs and glaciers

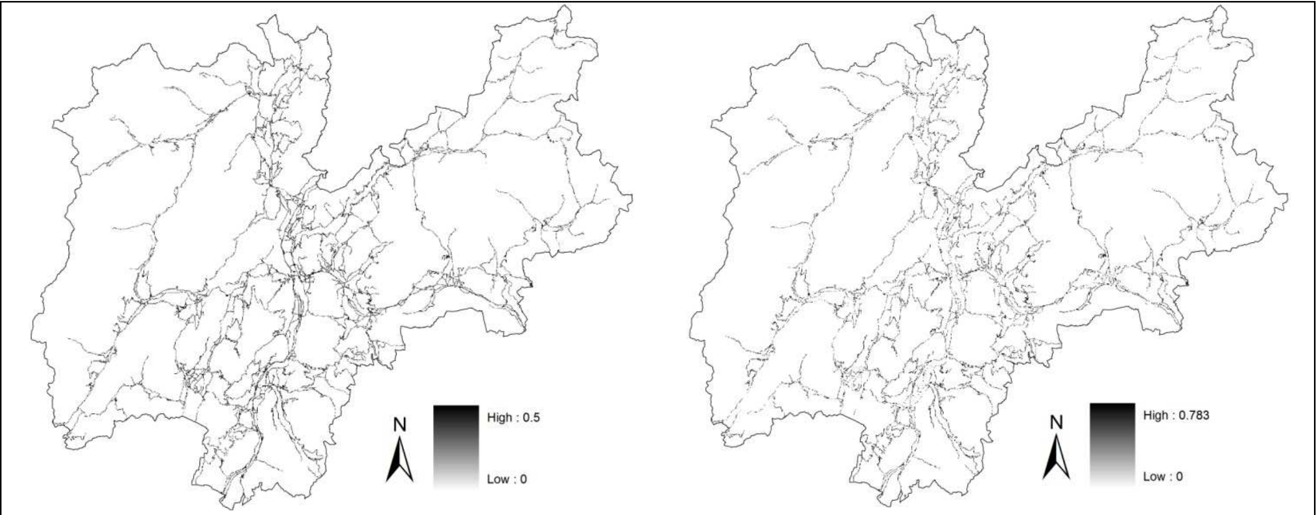
Specific discharge coefficient [m^3 s^{-1} ha^{-1}]
Stock - Biophysical value over Sub-catchments

Figure AII.11. Indicators of the ES "Water flow regulation"



Capacity of water ecosystems to reduce pollutants [Dimensionless]
Stock - Biophysical value over Buffer of 30 m around water network

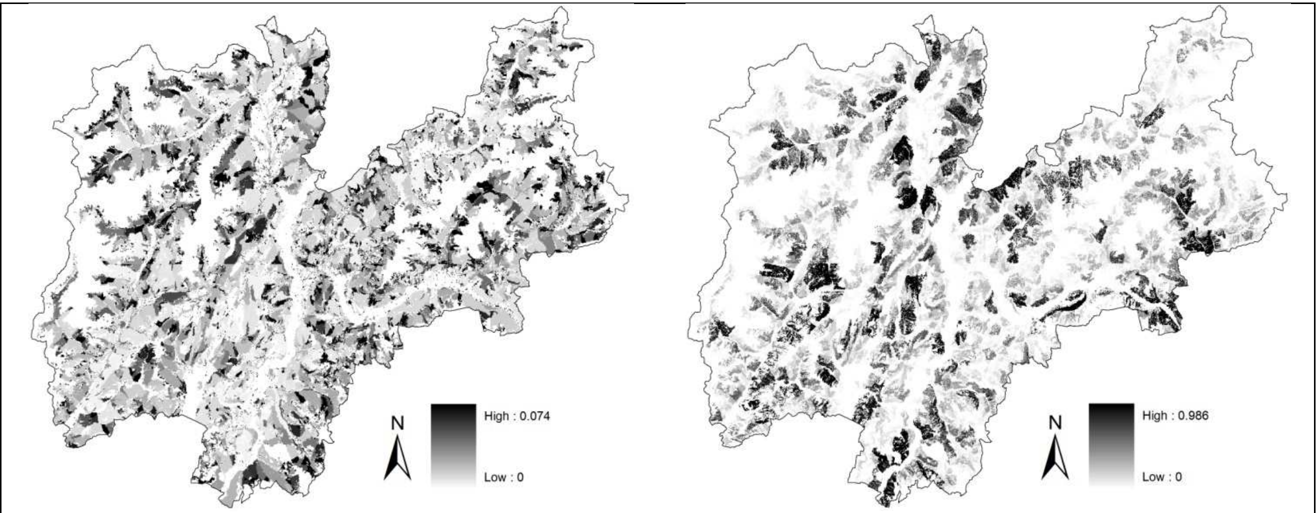
Figure AII.12. Indicators of the ES "Water quality regulation"



Roughness of land surfaces adjacent to roads [Dimensionless] **Stock - Biophysical value over Buffer of 30 m around main roads**

Density of vegetation adjacent to roads [Dimensionless] **Stock - Biophysical value over Buffer of 30 m around main roads**

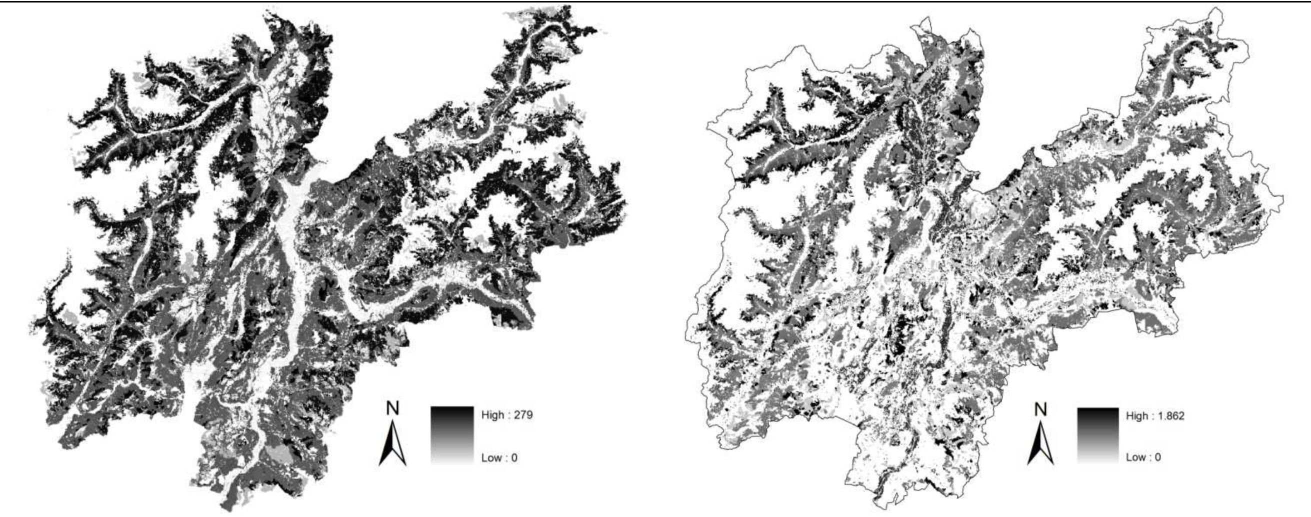
Figure AII.13. Indicators of the ES "Air quality regulation"



Ability of forests in mitigating temperature based on shape [Dimensionless] **Stock - Biophysical value over Forest patches**

Ability of forests in mitigating temperature based on density [Dimensionless] **Stock - Biophysical value over Forest patches**

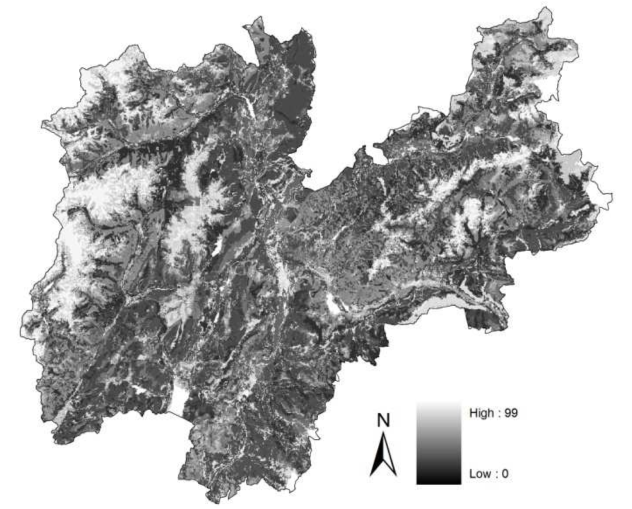
Figure AII.14. Indicators of the ES "Micro-Climate regulation"



Carbon stock [t ha^{-1}]
Stock - Biophysical value over Forest types and cadastral parcels of pastures/grassland and orchards

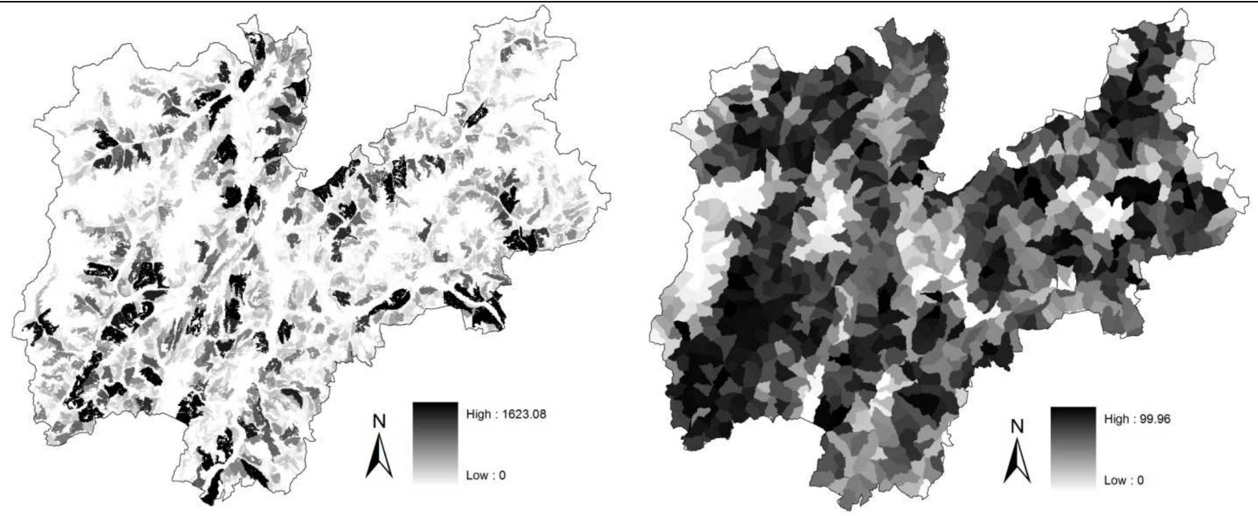
Carbon increment [t ha^{-1} year^{-1}]
Flow - Biophysical value over Forest types and cadastral parcels of pastures/grassland and orchards

Figure AII.15. Indicators of the ES "Macro-Climate regulation"



Curve number [Dimensionless] **Stock - Biophysical value over Grid cells**

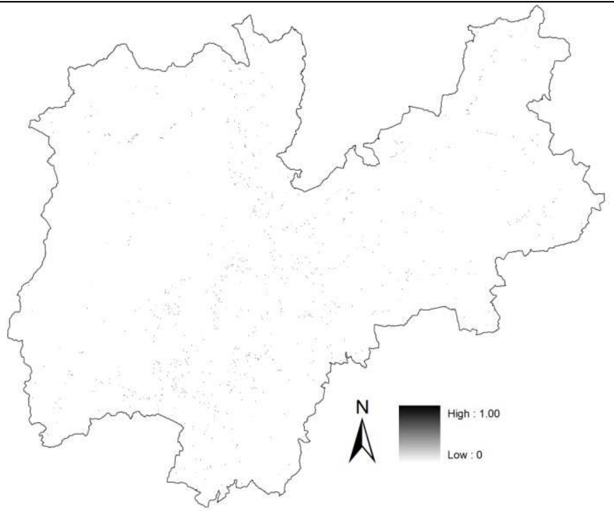
Figure AII.16. Indicators of the ES "Flood prevention capacity"



Forest extension [Dimensionless]
Stock - Biophysical value over Grid cells

Forest watershed protection factor [Dimensionless]
Stock - Biophysical value over Grid cells

Figure AII.17. Indicators of the ES "Hazard protection capacity"



Proximity of cultural heritage sites to road network [Dimensionless]
Stock - Biophysical value over Grid cells

Figure AII.18. Indicators of the ES "Cultural heritage"

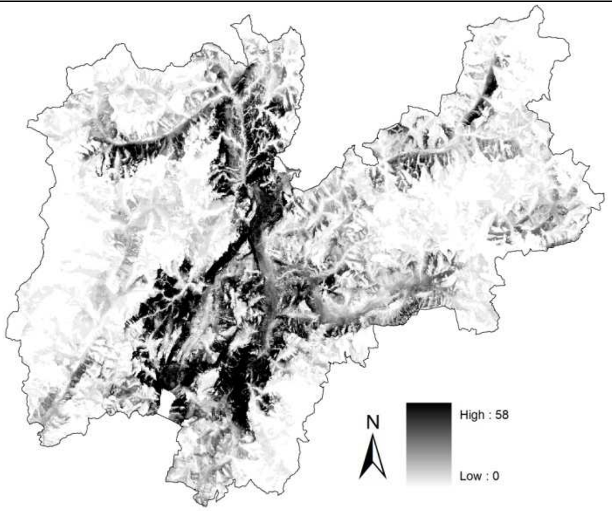
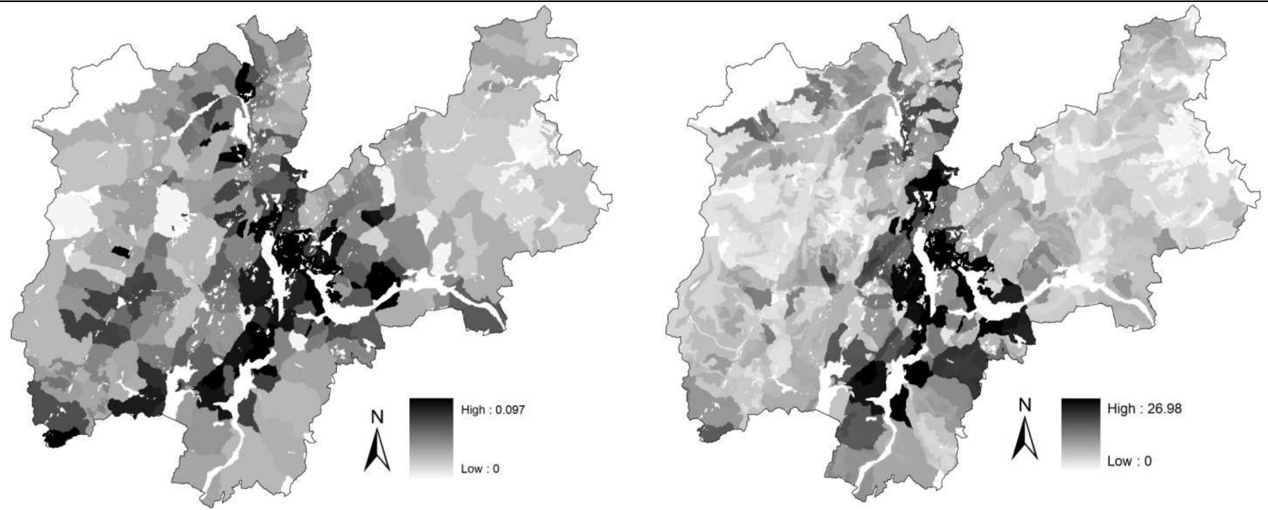


Figure 1 Landscape visibility [no. of visible points ha^{-1}]
Stock - Biophysical value over Grid cells

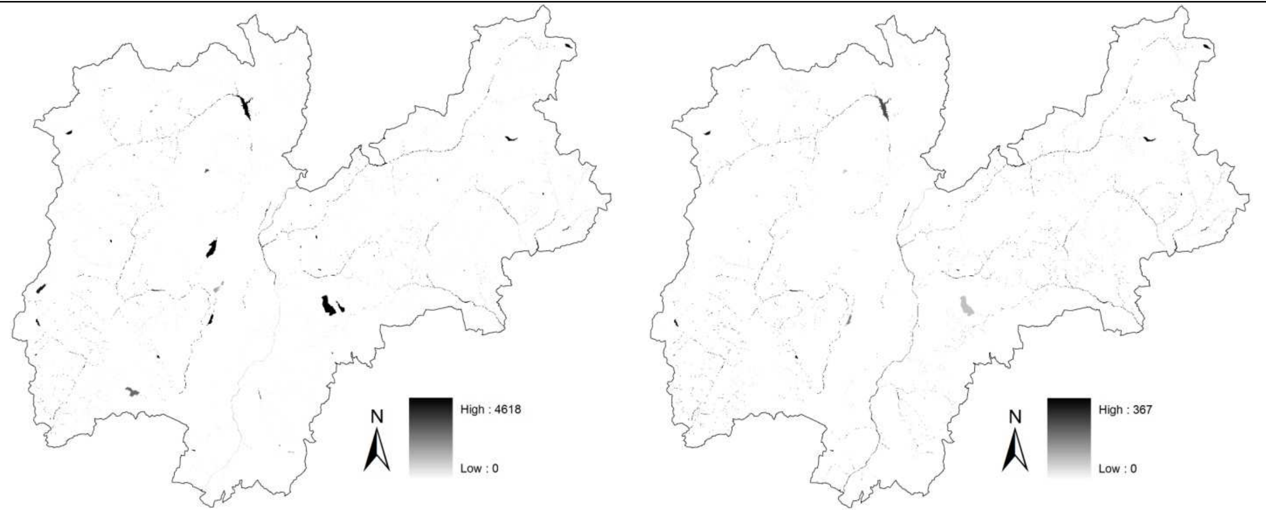
Figure AII.19. Indicators of the ES "Scenic beauty"



Density of hunters [no. of hunters ha^{-1} year^{-1}]
Flow - Socio-Cultural value over Game reserves

Game density [no. of hunted animals ha^{-1} year^{-1}]
Flow-Biophysical value over Game reserves

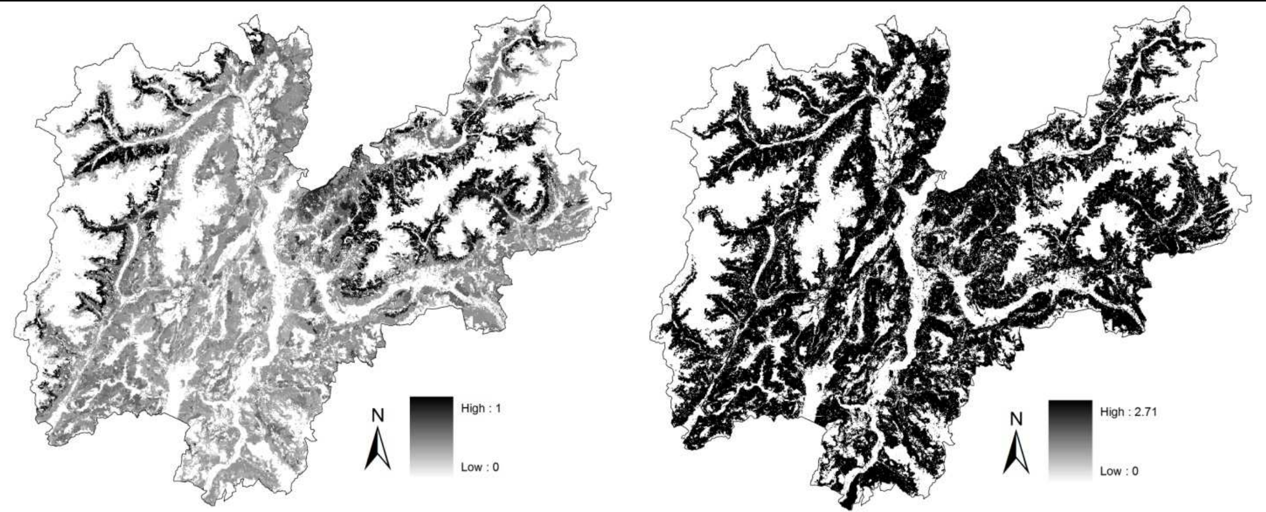
Figure AII.20. Indicators of the ES "Hunting"



Fishing intensity [no. of fishing activities ha^{-1} year^{-1}]
Flow - Socio-Cultural value over Fishing zones

Amount of caught fish [no. of harvested fishes ha^{-1} year^{-1}]
Flow - Biophysical value over Fishing zones

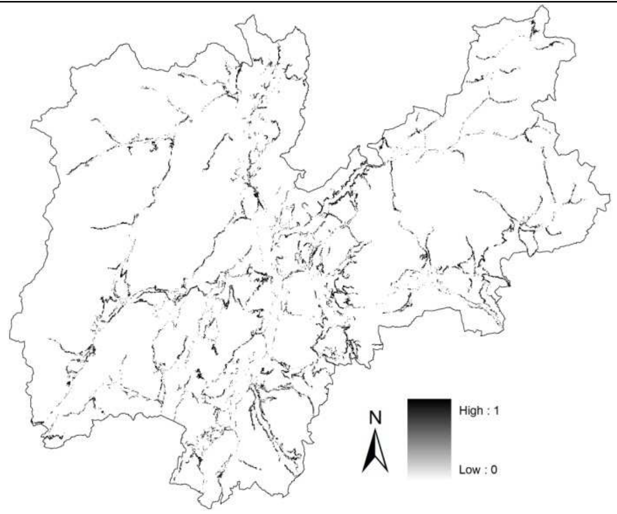
Figure AII.21. Indicators of the ES "Fishing"



Availability of mushrooms of good quality [Dimensionless]
Stock - Socio-Cultural value over Forest types

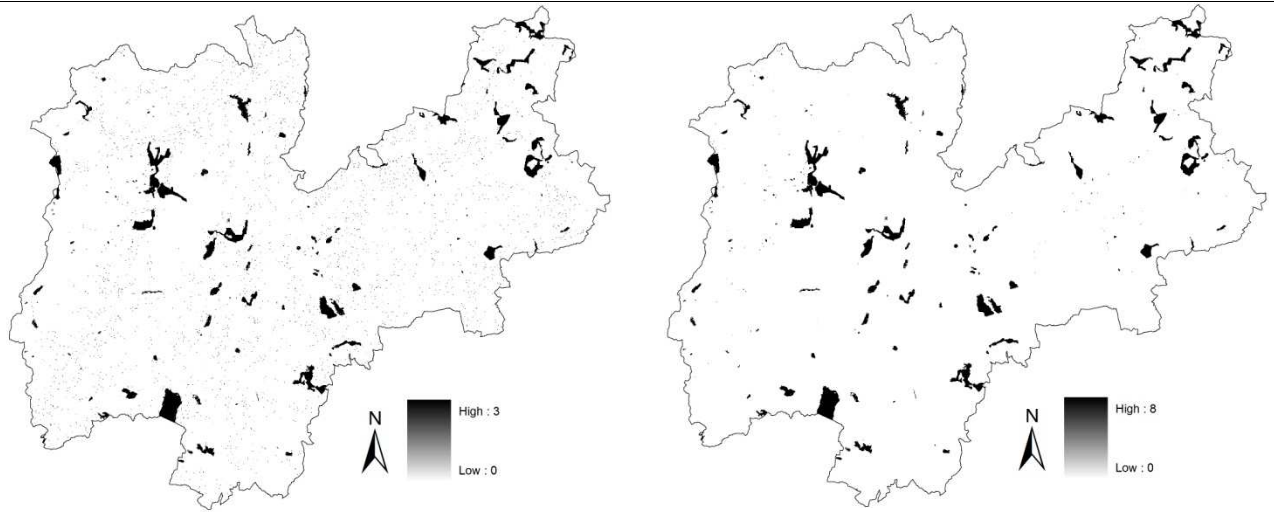
Revenues from permits [€ ha^{-1} year^{-1}]
Flow - Economic over the Land cover classes of forest

Figure AII.22. Indicators of the ES "Mushroom collection"



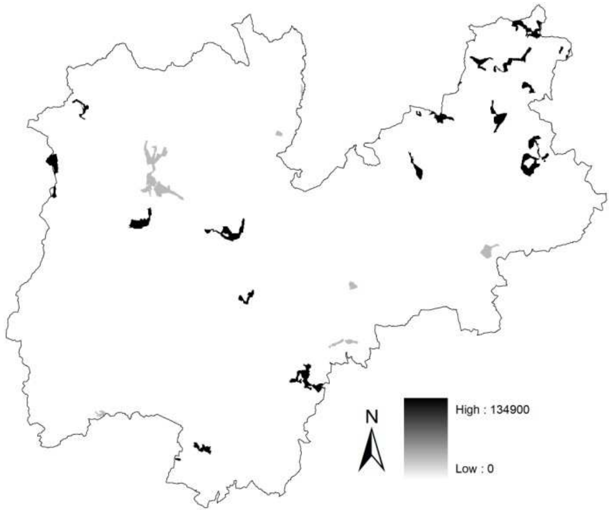
Availability of honey of good quality [Dimensionless]
Stock-Socio-Cultural value over Areas of forest types 150 close to forest ways

Figure AII.23. Indicators of the ES "Honey collection"



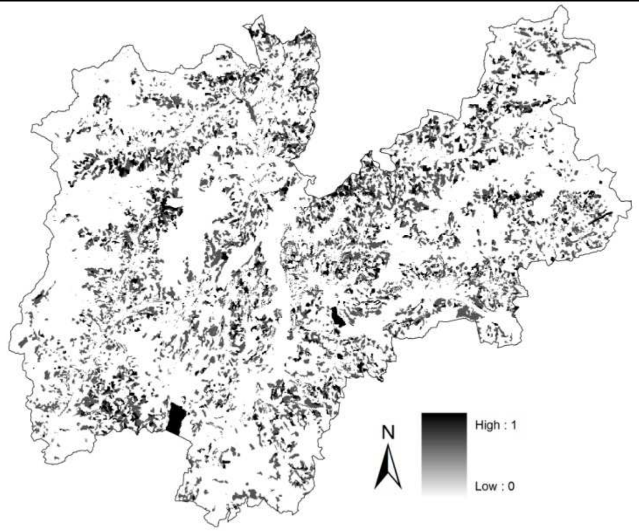
Intensity of sporting activities [no. sport activities ha^{-1}]
Stock-Socio - Cultural value over Patches of lakes, forest roads and ski slopes

Season length [no. of months ha^{-1} year^{-1}]
Flow - Socio-Cultural value over Patches of lakes, forest roads and ski slopes



Revenues from ski passes [€ ha^{-1} year^{-1}]
Stock-Socio - Economic value over Ski slopes

Figure AII.24. Indicators of the ES "Outdoor recreation"



Density of recreational activities [Dimensionless]
Stock - Socio-Cultural value over Patches of lakes and forest types

Figure AII.25. Indicators of the ES "Leisure"

ANNEX III

Exploratory analysis of ecosystem service indicators

Main statistics (i.e. mean, median, standard deviation, skew, min and max value) are reported for each ESs indicator in a table. The high values of skew for some indicators justify the choice of the statistical analyses used in Chapter 4 and 5: Spearman instead of Pearson is used for the pairwise correlation analysis and normalized values of ESs indicators are used in Principal Component analysis.

Graphs report, for each ES, the scatterplots (left corners), the histograms (diagonals) and the Spearman correlation coefficients (right corners) of its indicators. *** indicate p-values lower than $2*10^{-16}$, assuring the consistency of the correlation analysis.

1. Agriculture production

Table AIII.1. Main statistics of the indicators of the Agricultural production service

	Density of stumps and seeds (no. of stumps/seeds) ha^{-1}	**Quality of agricultural products** Dimensionless	**Amount of agricultural products** q ha^{-1} year^{-1}	**Nutritive value of agricultural products** kcal ha^{-1} year^{-1}	**Selling price of agricultural products** € ha^{-1} year^{-1}
Mean	377612.763	1.276	71.562	3438981.83	33850.57
Median	245000	1	7.000	210000	17560
Standard deviation	535060.994	0.552	100.841	5172050.331	21665.69
Min value	250	1	4.000	105000	700
Max value	3500000	3	500.000	31500000	100980
Skew	5.079	1.886	0.974	1.351	0.047

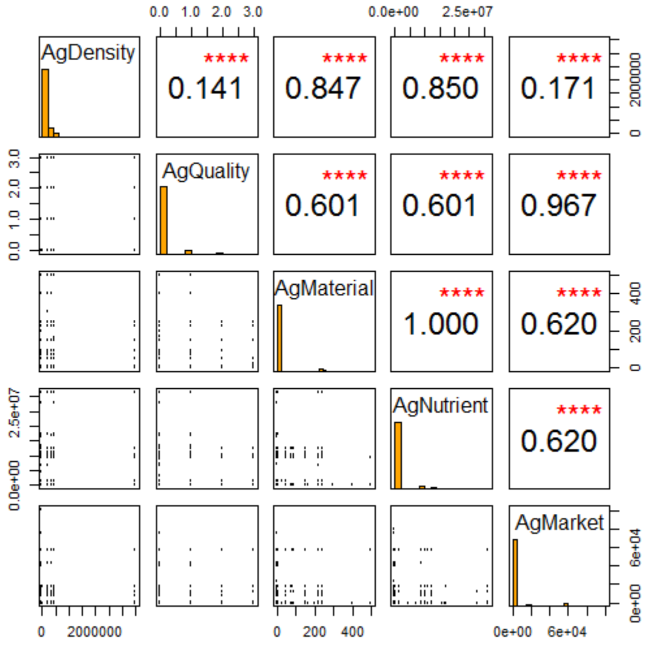


Figure AIII.1. Scatterplots, histograms and Spearman correlation coefficients of five indicators of the Agriculture production service. Acronyms of indicators are: AgDensity for Density of stumps and seeds, AgQuality for Quality of agricultural products, AgMaterial for Amount of agricultural products, AgNutrient for Nutritive value of agricultural products and AgMarket for Selling price of agricultural products.

2. Hunting production

Table AIII.2. Main statistics of the indicators for the Hunting production service

	Density of ungulates (no. of ungulates) ha^{-1}	**Amount of hunting products** kg ha^{-1} year^{-1}	**Nutritive value of hunting products** kcal ha^{-1} year^{-1}	**Proportion of ungulates out of the entire hunted population** (no. of hunted ungulates) (no. of hunted animals)$^{-1}$ year^{-1}
Mean	0.103	951.634	1118.635	0.955
Median	0.099	570	672	0.99
Standard deviation	0.045	1034.759	1240.355	0.082
Min value	0.001	1	1	0.402
Max value	0.58	6739	8054	1
Skew	1.885	2.97	2.969	-2.879

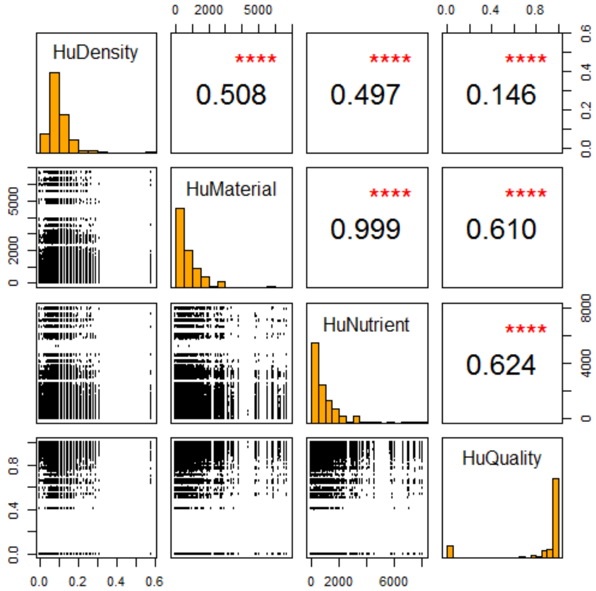


Figure AIII.2. Scatterplots, histograms and Spearman correlation coefficients of four indicators of the Hunting production service. Acronyms of indicators are: HuDensity for Density of ungulates, HuMaterial for Amount of hunting products, HuNutrient for Nutritive value of hunting products, HuQuality for Proportion of ungulates out of the entire hunted population.

3. Fishing production

Table AIII.3. Main statistics of the indicators of the Fishing production service

	Fish biomass kg ha^{-1}	**Amount of fishing products** kg ha^{-1} year^{-1}	**Nutritive value of fishing products** kcal ha^{-1} year^{-1}	**Proportion of key Alpine species out of the entire caught population** (no. of harvested key Alpine species) (no. of harvested fishes)$^{-1}$ year^{-1}
Mean	264.985	30.532	45187.628	0.848
Median	80	8	11840	0.94
Standard deviation	429.279	68.571	101484.711	0.248
Min value	2	1	1480	0.1
Max value	2936	1468	2172640	1
Skew	2.127	6.734	6.734	-2.103

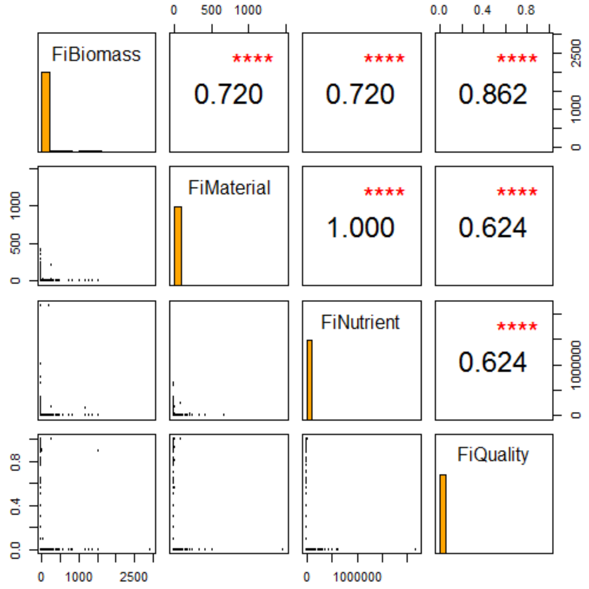


Figure AIII.3. Scatterplots, histograms and Spearman correlation coefficients of four indicators of the Fishing production service. Acronyms of indicators are: FiBiomass for Fish biomass, FiMaterial for Amount of fishing products, FiNutrient for Nutritive value of fishing products and FiQuality for Proportion of key Alpine species out of the entire caught population.

4. Mushroom production

Table AIII.4. Main statistics of the indicators of the Mushroom production service

	Intensity of mushroom production Dimensionless	**Mushroom quality** Dimensionless
Mean	0.614	0.659
Median	0.579	0.63
Standard deviation	0.187	0.181
Min value	0.026	0.024
Max value	1	1
Skew	0.358	-0.154

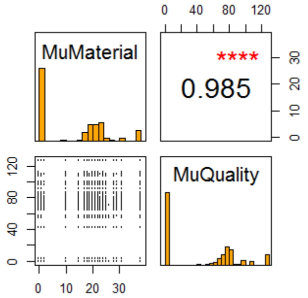


Figure AIII.4. Scatterplots, histograms and Spearman correlation coefficients of two indicators of the Mushroom production service. Acronyms of indicators are: MuMaterial for Intensity of mushroom production and MuQuality for Mushroom quality.

5. Honey production

Table AIII.5. Main statistics of the indicators of the Honey production service

	Intensity of honey production Dimensionless	**Nectar value** Dimensionless
Mean	0.306	0.322
Median	0.302	0.333
Standard deviation	0.129	0.168
Min value	0.012	0.033
Max value	1	1
Skew	3.758	1.545

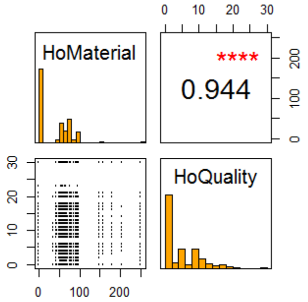


Figure AIII.5. Scatterplots, histograms and Spearman correlation coefficients of two indicators of the Honey production service. Acronyms of indicators are: HoMaterial for Intensity of honey production and HoQuality for Nectar value.

6. Inorganic matter extraction

Table AIII.6. Main statistics of the indicators of the Inorganic matter extraction service

	Amount of inorganic matter in quarries $m^3\ ha^{-1}$	**Amount of inorganic matter extracted** $m^3\ ha^{-1}\ year^{-1}$	**Selling price of inorganic matter** € $ha^{-1}\ year^{-1}$
Mean	372074.271	8038.476	2284469.07
Median	75911	6867	1130388
Standard deviation	543379.935	5312.87	2529676.183
Min value	2	224	64
Max value	3231801	34063	11384180
Skew	3.652	0.962	1.282

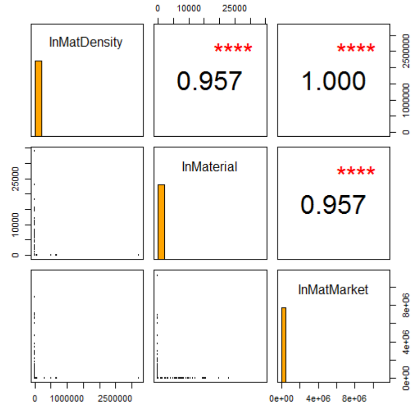


Figure AIII.6. Scatterplots, histograms and Spearman correlation coefficients of three indicators of the Inorganic matter extraction service. Acronyms of indicators are: InMatDensity for Amount of inorganic matter in quarries, InMaterial for Amount of inorganic matter extracted and InMatMarket for Selling price of inorganic matter.

7. Timber production

Table AIII.7. Main statistics of the indicators of the Timber production service

	Wood density in forests m^{3} ha^{-1}	**Amount of timber harvested** m^{3} ha^{-1} year^{-1}	**Selling price of timber harvested** € ha^{-1} year^{-1}
Mean	169.845	2.162	170.314
Median	140	2	141
Standard deviation	129.198	1.569	135.217
Min value	1	1	1
Max value	933	20	1684
Skew	0.742	2.729	2.264

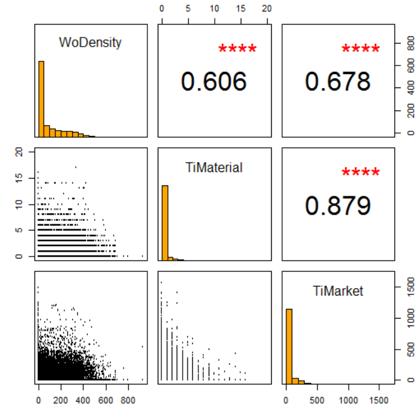


Figure AIII.7. Scatterplots, histograms and Spearman correlation coefficients of three indicators of Timber production service. Acronyms of indicators are: WoDensity for Wood density in forests, TiMaterial for Amount of timber harvested and TiMarket for Selling price of timber harvested.

8. Fuel wood production

Table AIII.8. Main statistics of the indicators of the Fuel wood production service

	Wood density in forests m^{3} ha^{-1}	**Amount of fuel wood harvested** m^{3} ha^{-1} year^{-1}	**Energy embedded in fuel wood** kWh ha^{-1} year^{-1}	**Selling price of fuel wood** € ha^{-1} year^{-1}
Mean	169.845	1.877	7.507	62.006
Median	140	1	4	30
Standard deviation	129.198	2.156	8.623	130.328
Min value	1	1	4	1
Max value	933	28	112	1820
Skew	0.742	5.714	5.714	6.511

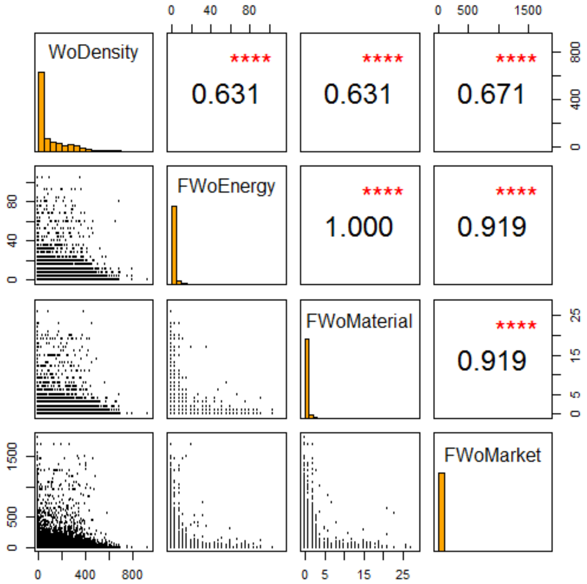


Figure AIII.8. Scatterplots, histograms and Spearman correlation coefficients of four indicators of Fuel wood production service. Acronyms of indicators are: WoDensity for Wood density in forests, FWoEnergy for Energy embedded in fuel wood, FWoMaterial for Amount of fuel wood harvested and FWoMarket for Selling price of fuel wood.

9. Water supply from surface water network

Table AIII.9. Main statistics of the indicators of the Water supply service from surface water network

	Water flow from surface water network $m^3\ s^{-1}\ ha^{-1}$	**Water consumption from surface water network** $m^3\ ha^{-1}\ year^{-1}$	**Selling price of surface water supply** € $ha^{-1}\ year^{-1}$
Mean	0.001	0.927	0.065
Median	0.001	0.05	0.012
Standard deviation	0.001	5.915	0.348
Min value	0.001	0.001	0.001
Max value	0.044	1257.76	11.18
Skew	21.711	87.614	21.1

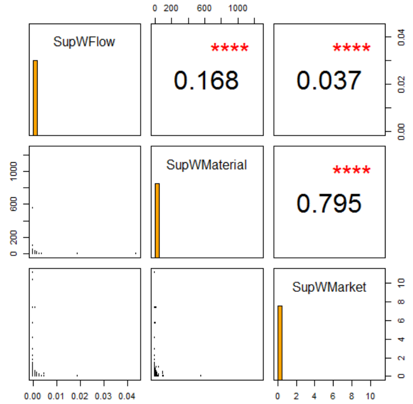


Figure AIII.9. Scatterplots, histograms and Spearman correlation coefficients of three indicators of Water supply service from surface water network. Acronyms of indicators are: SupWFlow for Water flow from surface water network, SupWMaterial for Water consumption from surface water network and SupWMarket for Selling price of surface water supply.

10. Water supply from groundwater

Table AIII.10. Main statistics of the indicators of the Water supply service from groundwater

	Water flow from groundwater $m^3\ s^{-1}\ ha^{-1}$	Water consumption from groundwater $m^3\ ha^{-1}\ year^{-1}$	Selling price of groundwater supply € $ha^{-1}\ year^{-1}$
Mean	0.15	4174.741	2137.732
Median	0.016	459.64	220.83
Standard deviation	1.016	28757.861	15087.291
Min value	0.001	0.02	0.014
Max value	50.167	1447740	1013420
Skew	30.117	30.677	52.455

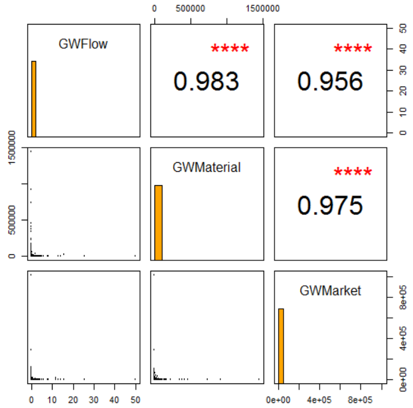


Figure AIII.10. Scatterplots, histograms and Spearman correlation coefficients of three indicators of Water supply service from groundwater. Acronyms of indicators are: GWFlow for Water flow from groundwater, GWMaterial for Water consumption from groundwater and GWMarket for Selling price of surface groundwater supply.

11. Water flow regulation

Table AIII.11. Main statistics of the indicators of the Water flow regulation service

	Surface area of lakes, reservoirs and glaciers m^2	**Specific discharge coefficient** $m^3\ s^{-1}\ ha^{-1}$
Mean	369.238	23.922
Median	281.19	21.176
Standard deviation	401.892	23.391
Min value	0.06	0.136
Max value	1173.88	531.94
Skew	1.123	10.859

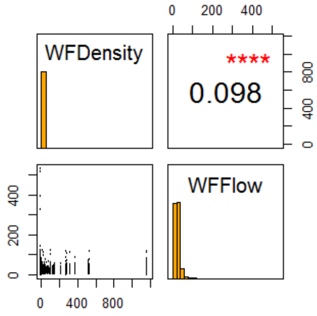


Figure AIII.11. Scatterplots, histograms and Spearman correlation coefficients of two indicators of Water flow regulation. Acronyms of indicators are: WFDensity for Surface area of lakes, reservoirs and glaciers and WFFlow for Specific discharge coefficient.

12. Water quality regulation

Table AIII.12. Main statistics of the indicators of Water quality regulation service

	Capacity of water ecosystems to reduce pollutants Dimensionless
Mean	0.753
Median	0.8
Standard deviation	0.227
Min value	0.2
Max value	1
Skew	-0.735

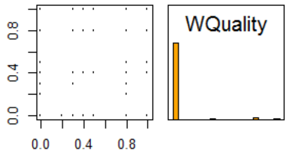


Figure AIII.12. Scatterplot and histogram of the Water quality regulation service indicator. Indicator name: Capacity of water ecosystems to reduce pollutants; acronym: WQuality.

13. Air quality regulation

Table AIII.13. Main statistics of the indicators of Air Quality regulation

	Roughness of land surface adjacent to roads Dimensionless	**Density of forests adjacent to roads** Dimensionless
Mean	0.753	0.367
Median	0.8	0.393
Standard deviation	0.227	0.16
Min value	0.2	0.001
Max value	1	0.715
Skew	-0.735	-0.457

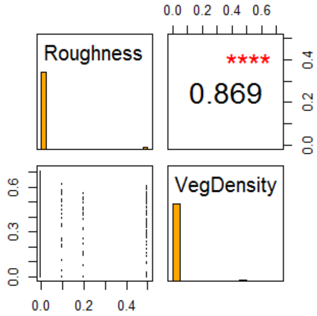


Figure AIII.13. Scatterplots, histograms and Spearman correlation coefficients of two indicators of Air quality regulation service. Acronyms of indicators are: Roughness for Roughness of land surface adjacent to roads and VegDensity for Density of forests adjacent to roads.

14. Micro-Climate regulation

Table AIII.14. Main statistics of the indicators of Micro-Climate regulation service

	Ability of forests in mitigating temperature based on shape Dimensionless	**Ability of forests in mitigating temperature based on density** Dimensionless
Mean	0.09	0.09
Median	0.046	0.046
Standard deviation	0.114	0.114
Min value	0.001	0.001
Max value	0.986	0.986
Skew	2.209	2.209

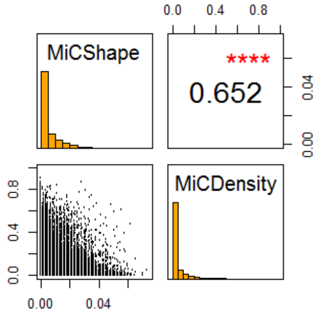


Figure AIII.14. Scatterplots, histograms and Spearman correlation coefficients of two indicators of Micro-Climate regulation service. Acronyms of indicators are: MiCShape for Ability of forests in mitigating temperature based on shape and MiCDensity for Ability of forests in mitigating temperature based on density.

15. Macro-Climate regulation

Table AIII.15. Main statistics of the indicators of Micro-Climate regulation service

	Carbon stock t ha^{-1}	**Carbon increment** t ha^{-1} year^{-1}
Mean	192.993	1.153
Median	185	1.008
Standard deviation	70.226	0.437
Min value	12	0.378
Max value	279	1.862
Skew	-0.973	0.108

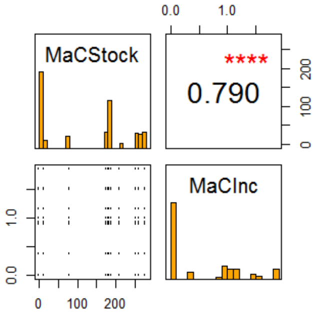


Figure AIII.15. Scatterplots, histograms and Spearman correlation coefficients of two indicators of Macro-Climate regulation service. Acronyms of indicators are: MaCStock for Carbon Stock and MaCInc for Carbon Increment.

16. Flood prevention capacity

Table AIII.16. Main statistics of the indicators of Flood prevention capacity service

	Curve number Dimensionless
Mean	48.44
Median	47
Standard deviation	18.496
Min value	25
Max value	95
Skew	0.677

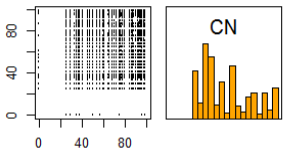


Figure AIII.16. Scatterplot and histogram of the Flood prevention capacity service indicator. Indicator name: Curve number; acronym: CN.

17. Hazards protection capacity

Table AIII.17. Main statistics of the indicators of Hazards protection capacity service

	Forest extension m^2	**Forest watershed protection factor** Dimensionless
Mean	312.711	312.711
Median	185.967	185.967
Standard deviation	338.351	338.351
Min value	0.001	0.001
Max value	1623.08	1623.08
Skew	1.49	1.49

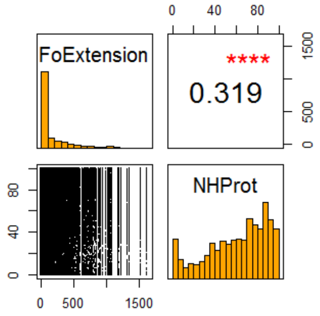


Figure AIII.17. Scatterplots, histograms and Spearman correlation coefficients of two indicators of Hazards protection capacity service. Acronyms of indicators are: FoExtension for Forest extension and NHProt for Forest watershed protection factor.

18. Cultural heritage

Table AIII.18. Main statistics of the indicators of Cultural heritage service

	Proximity of cultural heritage sites to road network Dimensionless
Mean	0.137
Median	0.151
Standard deviation	0.064
Min value	0.075
Max value	1
Skew	1.889

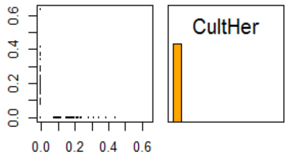


Figure AIII.18. Scatterplot and histogram of the Cultural heritage service indicator. Indicator name: Proximity of cultural heritage sites to road network; acronym: CultHer.

19. Scenic beauty

Table AIII.19. Main statistics of the indicator of Scenic beauty service

	Landscapes visibility (no. of visible points) ha^{-1}
Mean	6.177
Median	4
Standard deviation	6.697
Min value	1
Max value	58
Skew	2.019

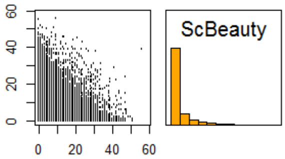


Figure AIII.19. Scatterplot and histogram of the Scenic beauty service indicator. Indicator name: Landscapes visibility; acronym: ScBeauty.

20. Hunting

Table AIII.20. Main statistics of the indicators of Hunting service

	Density of hunters (no. of hunters) ha^{-1} year^{-1}	**Game density** (no. of animals) ha^{-1} year^{-1}
Mean	0.013	0.003
Median	0.01	0.001
Standard deviation	0.009	0.017
Min value	0.001	0.001
Max value	0.097	1.658
Skew	2.111	51.905

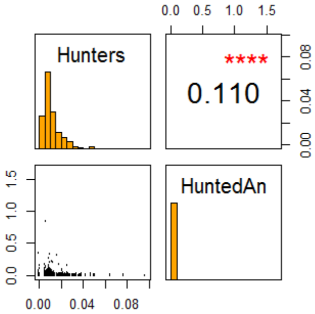


Figure AIII.20. Scatterplots, histograms and Spearman correlation coefficients of two indicators of Hunting service. Acronyms of indicators are: Hunters for Density of hunters, HuntedAn for Game density.

21. Fishing

Table AIII.21. Main statistics of the indicators of Fishing service

	Fishing intensity (no. of fishing activities) ha^{-1} year^{-1}	**Amount of caught fished** (no. of harvested fishes) ha^{-1} year^{-1}
Mean	113.764	9.833
Median	29.19	3
Standard deviation	228.157	18.932
Min value	0.08	1
Max value	4618	367
Skew	6.043	6.123

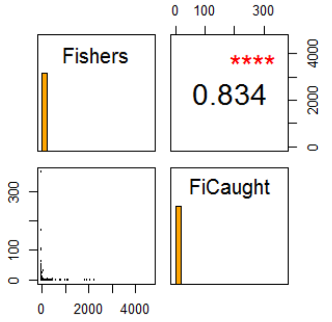


Figure AIII.21. Scatterplots, histograms and Spearman correlation coefficients of two indicators of Fishing service. Acronyms of indicators are: Fishers for Fishing intensity, FiCaught for Amount of caught fished.

22. Mushroom collection

Table AIII.22. Main statistics of the indicators of Mushroom collection service

	Revenues from permits € ha^{-1} year^{-1}	**Availability of mushrooms of good quality** Dimensionless
Mean	2.71	0.44
Median	2.71	0.339
Standard deviation	0	0.245
Min value	2.71	0.001
Max value	2.71	1
Skew	NA	1.315

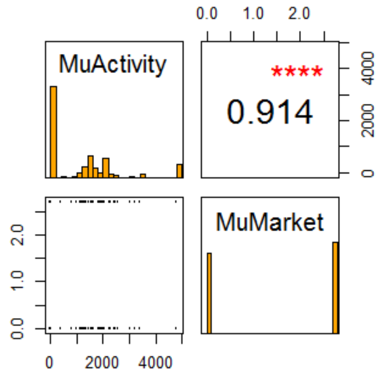


Figure AIII.22. Scatterplots, histograms and Spearman correlation coefficients of two indicators of Mushroom collection service. Acronyms of indicators are: MuMarket for Revenues from permits, MuActivity Availability of mushrooms of good quality.

23. Honey collection

Table AIII.23. Main statistics of the indicators of Honey collection service

	Availability of honey of good quality Dimensionless
Mean	0.257
Median	0.222
Standard deviation	0.201
Min value	0.022
Max value	1
Skew	2.48

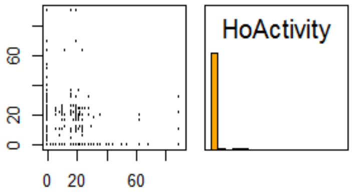


Figure AIII.23. Scatterplot and histogram of Honey collection service indicator. Indicator name: Availability of honey of good quality; acronym: HoActivity.

24. Outdoor recreation

Table AIII.24. Main statistics of the indicators of the Outdoor recreation service

	Intensity of sporting activities (no. of sport activities) ha^{-1}	**Revenues from ski passes** € ha^{-1} year^{-1}	**Season length** (no. of months) ha^{-1} year^{-1}
Mean	1.009	46410.811	6.883
Median	1	55528	8
Standard deviation	0.095	39512.989	1.45
Min value	1	4783	5
Max value	3	134900	8
Skew	10.517	1.077	-0.528

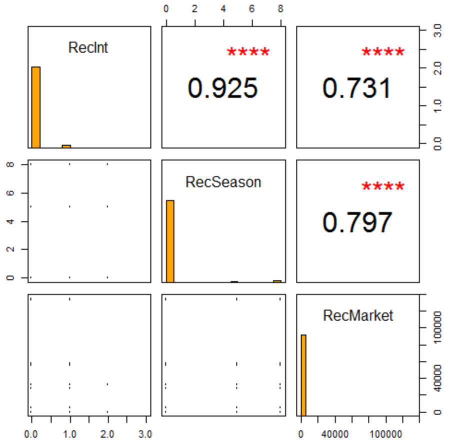


Figure AIII.24. Scatterplots, histograms and Spearman correlation coefficients of three indicators of the Outdoor recreation service. Acronyms of indicators are: RecInt for Intensity of sporting activities, RecSeason for Season length and RecMarket for Revenues from ski passes.

25. Leisure

Table AIII.25. Main statistics of the indicators of Leisure service

	Density of recreational activities Dimensionless
Mean	1.328
Median	1
Standard deviation	0.588
Min value	1
Max value	3
Skew	1.614

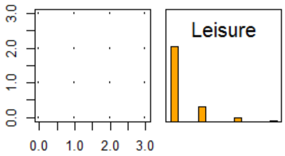


Figure AIII.25. Scatterplot and histogram of Leisure service indicator. Indicator name: Density of recreational activities; acronym: Leisure.