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MAPPING AND ASSESSING MULTIPLE ECOSYSTEM SERVICES IN AN ALPINE REGION: A STUDY IN TRENTINO, ITALY

Ferrari M.*, Geneletti D.

Department of Civil, Environmental and Mechanical Engineering, University of Trento, Italy
Via Mesiano 77 - 38123 Trento, Italy
**Corresponding author: Telephone: +39 3402509240; e-mail: marika.ferrari@unitn.it*

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Abstract – This research aims to identify ecosystem services relevant for Trentino (a region in the Italian Alps), and to assess them through spatial indicators. 51 experts were involved in the identification of relevant ecosystem services and appropriate indicators to represent them. Indicators were computed using the database available at administrative level. Indicators represent the actual or the potential supply of ecosystem services, expressed in terms of either stock or flow. Moreover, indicators may refer to biophysical, economic or socio-cultural values. In total, the experts selected 25 ecosystem services and 57 assessment indicators. Accordingly, the selected indicators were mapped over different spatial units of ecosystem services representation, including land use and forest types. This research was the first attempt to assess a multiple set of ecosystem services for Trentino. The results provide new information that can be used to achieve the objectives of the EU Biodiversity Strategy by 2014. The proposed approach can be reasonably extended to other Alpine areas with similar morphology, land cover and land use.

Keywords: Ecosystem services, Alps, indicators, mapping, GIS

Introduction

The Alps are an important source of ecosystem services for the whole of Europe (MA, 2003; Grêt-Regamey et al., 2013). 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). Alpine ecosystem services contribute greatly to the promotion of human wellbeing both at local and at the regional level. In order to fully understand such contribution, there is a need to identify them, assess their supply, recognize areas where they appear together repeatedly and analyze the interactions that may exist between them (Grêt-Regamey et al., 2012). Most of these activities are also specifically requested by the European Biodiversity Strategy for 2020, which calls on Member States by 2014, to identify key ecosystem services and assess their spatial supply and demand (European Commission, 2011). However, these are difficult tasks and to date they have only been partially executed: existing studies, in fact, are typically focused on a small sub-set of ecosystem services and make use of information that poorly reflects the actual variability of the services distribution across an area.

Focusing on the Trentino area in the Italian Alps, this research aims at identifying the most significant ecosystem services and assessing them through spatial indicators, by exploiting already existing and available data.

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Materials and Methods

Study area

Located in the eastern Alps, Trentino has an area of 6212 km^2 and a population of 524,826 inhabitants, with an average density of 82.5 inhabitants km^{-2}. The area features extreme variability in terms of elevation, ranging from 62 m above sea level to 3343 m a.s.l. Approximately 30% of the territory lies at an altitude of less than 1000 m a.s.l., 50% between 1000 and 2000 m a.s.l., and the remaining 20% lies above 2000 m a.s.l. The latter portion of the territory is mainly covered by glaciers, bare rocks, natural grasslands and pastures. Glaciers and bare rocks constitute about 16% of the Trentino area, while grasslands and pastures cover around 18%. Mountains are scattered throughout the province, creating a mosaic of valleys enclosed by mountain chains. The central part Trentino is crossed by a river of national importance, namely the Adige River, which follows the north-south direction. The area occupies 14 basins and the lateral major rivers follow east-west or west-east directions to the Adige river. The remaining water network is widespread and significantly extended, covering about 1% of the province. More than 300 lakes are located in Trentino, including the northern part of Lake Garda, the largest lake in Italy. Forests cover approximately 56% of Trentino and reach up to an altitude of 1800 m a.s.l.

Forests provide numerous services, such as timber, fuel wood, mushroom, honey and hunting, which are regulated by the local administration, in order to ensure the availability throughout 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 province and the products are renowned (e.g. apples, which correspond to 25% of national production). Tourism is the mainstay of the economy, as Trentino offers many opportunities for leisure activities (such as skiing, trekking, climbing, etc.). In fact, it is renowned for its mountains, including the Dolomites which are an UNESCO site. Urban settlements covering 3.1% of the province and are located mostly along the axis of the Adige River. For each valley there is a major urban settlement, yet several small villages and scattered houses are found throughout the province. Accordingly, Trentino is crossed by dense network of roads and railways, including the north-south network which links Italy to Germany.

Methods

Experts from local administrative offices and research institutes were asked to select important ecosystem services and identify appropriate indicators. The local administrative offices include: the Agriculture Department, Agency for agricultural payments, Forest and Environment Department, Forest Service, Hunting and Fishing Service, Nature Conservation Service, Water Management Service, Planning Department, Geological Survey, Mining Service and Environmental Protection Agency. The local research institutes include: Edmund Mach Foundation, Centro di Ecologia Alpina, Museo tridentino di scienze naturali, Museo di Rovereto, Department of Civil, Environmental and Mechanical Engineering - University of Trento. The Common International Classification of Ecosystem Services (CICES) was adopted as a reference for the selection of ecosystem services (Haines-Young et al., 2010). The list of ecosystem services proposed by Maes et al. (2011) was used as a starting point for the selection of the services. Experts were selected to cover all relevant areas of expertise, and have been engaged through individual interviews.

The experts were asked to identify major ecosystem services, and appropriate indicators that could be computed using the database available at administrative level. During the interviews the experts have disregarded several services from the original list and added a number of new ones. Indicators may represent the actual supply of ecosystem services, expressed in terms of either stock or flow. The actual supply corresponds to the amount of ecosystem services effectively used by people (Haines-Young et al., 2010 and Maes et al., 2012). Stock indicators represent the amount of an ecosystem service that is present in an ecosystem, i.e. the capacity of an ecosystem to deliver a service, while flow indicators correspond to the services provided in a specific time reference (Maes et al., 2012 and Layke, 2009). Indicators may refer to biophysical, economic or socio-cultural values. Biophysical value provides information about the types and location of the biophysical features that affect the capacity to generate/use services. Economic and social information, on the other hand, help to understand the importance ecosystem services for people who get benefits from them (Haines-Young et al., 2010).

Once identified the indicators, an extensive data collation exercise was performed in order to compile a GIS database, consistent in terms of spatial resolution and georeference system. Suitable spatial units of representation were selected for each service. For instance, the water network represents the spatial unit for fishing, water catchments are the units for water supply, habitat for hunting and forests boundaries for carbon storage. Data collected ranged from forest inventories to agricultural cadastral maps, and from habitat models to landscape assets. Some of the indicators were already available in the form requested, whereas others needed further processing, including GIS analysis, such as reclassification, map algebra, and the like. A combination of three GIS software were used to suit different data format and different operation types: ESRI ArcGis 9.2, ILWIS 3.3, and GRASS 6.4.2.

RESULTS

A total of 51 experts from the local administrative offices and local research institutes have been involved. The experts identified 25 ecosystem service "types" that were grouped in nine "classes" (food supply, raw material, energy supply, water supply, water cycle regulation, atmosphere components regulation, natural hazard regulation, opportunities for tourism, opportunities for downtime activities) and 3 "themes" (provisioning, regulating and cultural services). 57 indicators have been proposed to assess the 25 ecosystem services (see Table 1). Indicators have been mapped over different spatial units of representation, like: land use (in cadastral parcels), land cover (CORINE 2003), habitat, hunting districts, forest types, forest parcels, water recharge areas, catchments. For instance, the spatial unit of run-off coefficient is the land cover, while the spatial unit of mushroom production is the forest type.

From the total of 57 indicators, 32 refer to provisioning services, 12 to regulating and 13 to cultural services. Similarly, 29 indicators are measures of stock and 28 indicators of flow. Biophysical and socio-cultural values are measured both by stock and flow indicators. Economic value, on the other hand, is expressed in terms of flow only. In particular, 35, 8 and 14 indicators measure the biophysical, the economic and the socio-cultural values, respectively. For provisioning and cultural services both stock and flow indicators of biophysical, economic and socio-cultural values were identified. In the case of the regulating services, only indicators of biophysical value were adopted. For instance, the ecosystem service "agricultural products" (a provisioning service) was assessed through five indicators: density of stumps and seeds (stock indicator - biophysical value), agricultural production (flow indicator - biophysical value), nutritive value (flow indicators - biophysical value), selling price (flow indicator - economic value) and quality of agricultural products (stock indicator - socio-cultural value). The ecosystem service "Macroclimate regulation" (a regulation service) was assessed through two indicators: carbon storage (stock indicator - biophysical value) and carbon increment (flow indicators - biophysical value).

Spatial units of representation include cadastral parcels, CORINE land cover units, forest parcels, forest types, habitat units, hunting district areas, buffer over water network, water catchments, aquifer recharge buffer. Generally, indicators of the same ecosystem service have the same spatial unit, even though there are exceptions (e.g., hunting and water supply). All details are presented in Table 1. Figures 1 and 2 provide examples of ecosystem services maps: Figure 1 shows the biophysical value in terms of stock of the agriculture production service, and Figure 2 of the macroclimate regulation service.

Table 1. Key indicators of ecosystem services (ES) used in this study. Indicators are both of Stock and Flow (4th column), measures 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	Density of stumps and seeds	S	B	Cadastral parcels
		Quality of agricultural products	S	S-C	Cadastral parcels
		Amount of agricultural products	F	B	Cadastral parcels
		Nutritive value of agricultural products	F	B	Cadastral parcels
		Selling price of agricultural products	F	E	Cadastral parcels
	Hunting production	Density of ungulates	S	B	Habitat units
		Amount of hunting products	F	B	Game reserves
		Nutritive value of hunting products	F	B	Game reserves
		Proportion of ungulates out of the entire hunted population	F	S-C	Game reserves
	Fishing production	Fish biomass	F	B	Fishing zones
		Amount of fishing products	F	B	Fishing zones
		Nutritive value of fishing products	F	B	Fishing zones
		Proportion of key Alpine species out of the entire caught population	F	S-C	Fishing zones

follow →

ES theme	ES type	Key indicators	Stock Flow	Type of indicator	Service spatial unit
Provisioning	Mushroom production	Intensity of mushroom production	S	B	Forest types
		Mushroom quality	S	S-C	Forest types
	Honey production	Intensity of honey production	S	B	Areas of forest types 500 m close to forest ways
		Nectar value	S	S-C	Areas of forest types 500 m close to forest ways
	Inorganic matter extraction	Amount of inorganic matter in quarries	S	B	Quarries
		Amount of inorganic matter extracted	F	B	Quarries
		Selling price of inorganic matter	F	E	Quarries
	Timber production	Wood density in forests	S	B	Forest lots
		Amount of timber harvested	F	B	Forest lots
		Selling price of timber harvested	F	E	Forest lots
	Fuel wood production	Amount of fuel Wood harvested	F	B	Forest lots
		Energy embedded in fuel wood	F	B	Forest lots
		Selling price of fuel wood	F	E	Forest lots
	Water supply from surface water network	Water flow from surface water network	S	B	Sub-Catchments
		Water consumption from surface water network	F	B	Sub-Catchments
		Selling price of surface water supply	F	E	Sub-Catchments
	Water supply from groundwater	Water flow from groundwater	F	B	Buffer of 200m around springs and wells
		Water consumption from groundwater	F	B	Buffer of 200m around springs and wells
		Selling price of groundwater supply	F	B	Buffer of 200m around springs and wells
Regulating	Water quality regulation	Capacity of water ecosystems to reduce pollutants	S	B	Buffer of 30 m around water network
	Water flow regulation	Surface area of lakes, reservoirs and glaciers	S	B	Land cover classes of lakes, reservoirs and glaciers
		Specific discharge coefficient	S	B	Sub-Catchments
	Air quality regulation	Roughness of land surfaces adjacent to roads	S	B	Buffer of 30 m around main roads
		Density of forests adjacent to roads	S	B	Buffer of 30 m around main roads
	Micro-Climate regulation	Ability of forests in mitigating temperature based on shape	S	B	Forest patches
		Ability of forests in mitigating temperature based on density	S	B	Forest patches
	Macro-Climate regulation	Carbon Stock	S	B	Forest types and cadastral parcels of pastures, grasslands and orchards
		Carbon increment	F	B	Forest types and cadastral parcels of pastures, grasslands and orchards
	Hazards protection capacity	Forest watershed protection factor	F	B	Grid cells
		Forest extension	S	B	Forest areas
	Flood prevention capacity	Curve number	S	B	Grid cells

follow →

ES theme	ES type	Key indicators	Stock Flow	Type of indicator	Service spatial unit
Cultural	Cultural heritage	Proximity of cultural heritage sites to road network	S	B	Grid cells
	Scenic beauty	Landscape visibility	S	B	Grid cells
	Hunting	Density of hunters	F	S-C	Game reserves
		Game density	F	B	Game reserves
	Fishing	Fishing intensity	F	S-C	Fishing zones
		Amount of caught fish	F	B	Fishing zones
	Mushroom collection	Availability of mushrooms of good quality	S	S-C	Forest types
		Revenues from permits	F	E	Forest types
	Honey collection	Availability of honey of good quality	S	S-S	Areas of forest types 150 m close to forest ways
	Outdoor recreation	Intensity of sporting activities	S	S-C	Patches of lakes, forest roads and ski slopes
		Revenues from ski passes	F	E	Ski slopes
		Season length	S	B	Patches of lakes, forest roads and ski slopes
	Leisure	Density of recreational activities	S	S-C	Patches of lakes and forest types

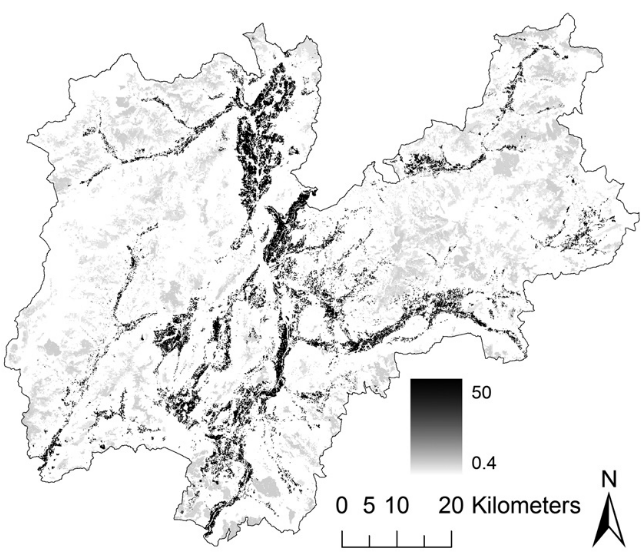

Fig. 1. Amount of agricultural products [t ha^{-1} $year^{-1}$]. The indicator measures the flow of the agriculture production service in terms of its biophysical value. It is mapped over the agricultural cadastral parcels.

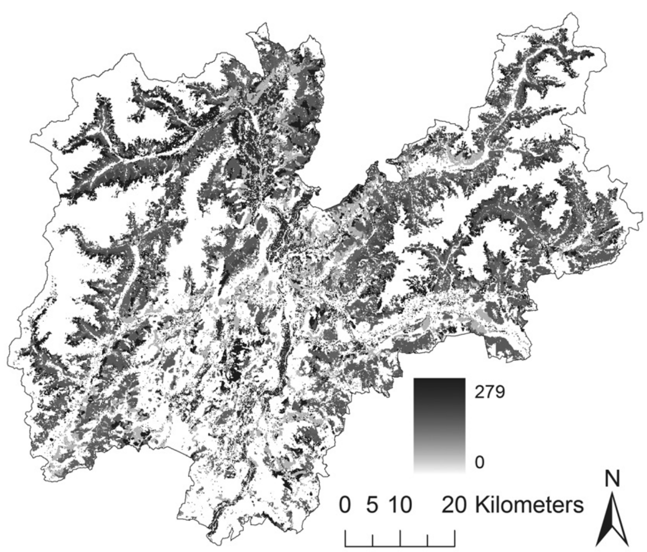

Fig. 2. Carbon stock [t ha^{-1}]. The indicator measures the stock of the macroclimate regulation service in terms of its biophysical value. It is mapped over forest types, and cadastral parcels of pastures/grassland and orchards.

Discussion

Most assessment studies start from an arbitrarily chosen set of ecosystem services and indicators (e.g. Nelson et al., 2009; Raudsepp-Hearne et al., 2010). On the contrary, the present research took advantage of expert knowledge to select the ecosystem services that are likely to be the most important in the study area, and to properly map a wide set of indicators measuring the actual biophysical, socio-cultural and economic value, in terms of stock and flow. Experts selected 25 ecosystem services, that are likely to represent some typical of Alpine regions and of semi-urbanized mountain areas with large forests, such as the capacity of forests to protect from avalanches and ski activity. 18 services are produced by forest ecosystems. The good assortment of provisioning, regulating and cultural services (respectively: 10; 7; 8 ecosystem services (ES) ensures the satisfaction of a wide range of human well-being needs. 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 such services 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 ecosystem services is case specific and that it strongly depends on dwellers needs and on the morphology of the region. Experts selected 57 indicators (up to five indicators for a single service), which were mapped over 20 different spatial units. Indicators measure the actual supply of single ecosystem services, 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 services have a direct market, for the latter the lack of information corresponds to the difficulties in considering such characteristics. 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 ecosystem services.

The major shortcoming of this research is the perceived subjectivity of the selected services. 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 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. Yet, there are some other limitations to the research. Firstly, on the basis of the available data, indicators would only allow us to measure the real supply of ecosystem services, but not the real/potential demand. Secondly, some stock/flow indicators of the biophysical/socio-cultural values are missing, for instance the flow of water quantity and air quality regulation services. Finally, the economic value was computed only for provisioning and cultural ecosystem services with direct market, namely: agriculture, raw material, energy and water supply, mushroom harvesting and ski activity. The present indicators selection should be tested in other Alpine contexts, in order to verify whether other services 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 ecosystem services 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 ecosystem services 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 ecosystem services. 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 ecosystem services 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.

Conclusions

This research was one the first attempts to assess a multiple set of ecosystem services for a rather extended area, only by means of existing and available data and considering the intrinsic spatial heterogeneity of single ecosystem services. 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. The results of this research provide new information that can be used to achieve the objectives of the EU Biodiversity Strategy by 2014, as well as to generate an atlas of ecosystem services for Trentino.

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