Assessing, valuing, and mapping ecosystem services in Alpine forests

ARTICLE *in* ECOSYSTEM SERVICES · AUGUST 2015

DOI: 10.1016/j.ecoser.2015.03.001

4 AUTHORS:

Tiina Häyhä
Stockholm University

Pier Paolo Franzese
Parthenope University of Naples

Alessandro Paletto
Council for Agricultural Research and Agric…

Brian D Fath
Towson University

Ecosystem Services 14 (2015) 12–23

Contents lists available at ScienceDirect

Ecosystem Services

journal homepage: www.elsevier.com/locate/ecoser

Assessing, valuing, and mapping ecosystem services in Alpine forests

Tiina Häyhä [a,b,*], Pier Paolo Franzese [a], Alessandro Paletto [c], Brian D. Fath [d,e]

[a] Laboratory of Ecodynamics and Sustainable Development, Department of Science and Technology, Parthenope University of Naples, Napoli, Italy
[b] Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden
[c] Council for Agricultural Research and Economics, Forest Monitoring and Planning Research Unit (CRA-MPF), Trento, Italy
[d] Biology Department, Towson University, Towson, MD 21252, USA
[e] Advanced Systems Analysis Program, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria

A R T I C L E I N F O

Article history:
Received 19 May 2014
Received in revised form
25 February 2015
Accepted 14 March 2015

Keywords:
Forest
Ecosystem services
Biophysical assessment
Total Economic Value
GIS mapping
Trade-off analysis

A B S T R A C T

Forests support human economy and well-being with multiple ecosystem services. In this paper, the ecosystem services generated in a mountainous forest area in North Italy were assessed in biophysical and monetary units. GIS was used to analyze and visualize the distribution and provision of different services. The assessment of ecosystem services in biophysical units was an important step to investigate ecosystem functions and actual service flows supporting socio-ecological systems. The Total Economic Value (TEV) of all the investigated ecosystem services was about 33 M€/yr, corresponding to 820 €/ha/yr. The provisioning services represented 40% of the TEV while the regulating and cultural services were 49% and 11%. The service of hydrogeological protection, particularly important in areas characterized by a high risk of avalanches and landslides, showed a major importance among the regulating services (81%) and within the TEV (40%). Results from mapping ecosystem services were useful in identifying and visualizing priority areas for different services, as well as exploring trade-offs and synergies between services. Finally, we argue that while a biophysical perspective can ensure a solid accounting base, a comprehensive economic valuation of all categories of forest ecosystem services can facilitate communication of their importance to policy makers.

1. Introduction

Connecting biophysical aspects of ecosystems and human well-being through the notions of natural capital and ecosystem services has been an essential step to recognize the dependence of human societies on natural ecosystems (Braat and de Groot, 2012; Daily, 1997; Folke et al., 2011; MA, 2005). To account for the benefits provided by ecosystems, several assessment and valuation methods have been developed, some using different biophysical approaches while others highlighting the importance of economic values of ecosystem services (Burkhard et al., 2012; Costanza et al., 1997; Farber et al., 2002; Häyhä and Franzese, 2014; Jørgensen, 2010; Seppelt et al., 2012; Ulgiati et al., 2011). Integrating ecosystem services into policy and decision-making also depends on the availability of spatially explicit information on ecosystem service supply and demand (Burkhard et al., 2013; Maes et al., 2012; Schägner et al., 2013). To map ecosystem services, biophysical measures (Burkhard et al., 2012; García-Nieto et al., 2013; Remme et al., 2014; Schröter et al., 2014; Vihervaara et al., 2010), as well as monetary values (Costanza et al., 1997; Kubiszewski et al., 2013; La Notte et al., 2012; van Berkel and Verburg, 2014) have been used.

Monetary valuation has been proposed as a necessary tool to raise awareness and communicate the importance of ecosystems and biodiversity to policy makers. This is because decisions in resource management are mostly affected by ecosystem services for which it is possible to define a market price, while non-marketed ecosystem services are frequently disregarded (Balmford et al., 2002; Costanza et al., 2014; de Groot et al., 2012; TEEB, 2010). In fact, market failures in relation to ecosystem services that are often free public goods can lead to higher exploitation levels providing short-term economic benefits to some stakeholders at the expense of long-term well-being of many others (de Groot et al., 2010; Hardin, 1968). Yet, it should be regarded that economic values of ecosystem services are sensitive to the chosen valuation method and subjective assumptions, whereas considering possible use in decision-making, a limitation is that economic instruments do not address issues of social fairness and equity in ecosystem use (Spangenberg and Settele, 2010).

Ecosystems are complex adaptive systems characterized by non-linearity (Müller, 2005). When reaching a certain threshold, ecosystems can switch into a new equilibrium state, possibly leading to irreversible loss of critical natural capital, after which the ecosystem does not provide ecosystem goods and services (Folke, 2006; Burkhard et al.,

* Corresponding author at: Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden.
E-mail address: tiina.hayha@su.se (T. Häyhä).

http://dx.doi.org/10.1016/j.ecoser.2015.03.001

2011; Holling, 1973). For instance, removing too much forest cover can lead to severe soil erosion driving the forest ecosystem towards a radical change such as desertification. As discussed by Limburg et al. (2002) and Farley (2008, 2012), monetary valuation could assist allocation decisions between conservation and conversion when the stocks of critical natural capital or flows ecosystem services are healthy and resilient. Instead, in the vicinity of thresholds, a small decrease in the physical quantity of ecosystem services can cause a large increase in their marginal economic value, making monetary analysis inappropriate, whereas information about biophysical quantities and quality of ecosystem structure is more relevant.

Forests provide human economy and well-being with a wide range of ecosystem services, from timber and non-wood products to carbon sequestration, watershed protection, and recreation (de Groot et al., 2002; MA, 2005). Concerns about greenhouse gas emissions as well as future shortage and rising prices of fossil fuels and natural resources are leading to a growing interest in wood biomass as renewable material and energy source (Buonocore et al., 2012, 2014). On the other hand, forests are intended to play an important role in carbon storage while also meeting the needs of biodiversity conservation and ecotourism. Moreover, forests in mountain areas are especially important for the protection of human activities against natural hazards such as avalanches, rock falls, and landslides (Dorren et al., 2004). Since ecosystem services are typically highly interlinked, the optimization of one typology of services can affect other services (Bennett et al., 2009), which is why all forest management choices entail trade-offs.

Former studies on forest ecosystem functions and services have focused on a single or few services: timber and bioenergy production in relation to carbon sequestration (Canadell and Raupach, 2008; Seely et al., 2002; Seidl et al., 2007), outdoor recreation (Zandersen and Tol, 2009), and protection against natural hazards (Olschewski et al., 2012; Teich and Bebi, 2009), whereas other authors have studied forest ecosystems by considering multiple services (Croitoru, 2007; Fürst et al., 2013; Grêt-Regamey et al., 2008, 2013; Grêt-Regamey and Kytzia, 2007; Matero and Saastamoinen, 2007; Pearce, 2001; Olschewski et al., 2010; Viglia et al., 2013). With specific reference to the Alpine context of North Italy, Gios et al. (2006) estimated the benefits gained from natural resources focusing on tourism, while Goio et al. (2008) compared standard accounting, green accounting, and total economic value to evaluate the benefits produced by forests in the Province of Trento. In the same region, Notaro et al. (2008) illustrated the economic values of a series of productive and non-productive forest functions, while Notaro and Paletto (2012) performed an economic valuation of the protective function of forest against natural hazards. In addition, Grilli et al. (2014) discussed the importance of Alpine forests for recreation.

In this study, we integrated biophysical assessment and economic valuation to investigate multiple forest ecosystem services in Fiemme and Fassa Valleys (Province of Trento, North Italy). The main services were identified, quantified in their biophysical units, and valued in economic terms, estimating also the Total Economic Value (TEV) of the investigated services. A Geographic Information System (GIS) was used to perform a spatial assessment and map the distribution of selected ecosystem services in the study area. Finally, the spatial information was also used to assess trade-off and synergies between different ecosystem services.

2. Material and methods

2.1. The study area

Fiemme and Fassa Valleys are located in the Province of Trento, North Italy (Fig. 1). These two valleys are divided from administrative point-of-view but they share the same landscape characteristics and geographically they can be considered as one valley. The total area of Fiemme and Fassa Valleys is 73,600 ha of which forests cover 39,970 ha (54% of the total surface), indicating the importance of forest ecosystem in the study area. The main forest types are: Norway spruce (*Picea abies* L.) with 80% of the total area, larch (*Larix decidua* Mill.) with 10%, and Scots pine (*Pinus sylvestris* L.) and beech (*Fagus sylvatica* L.) accounting for 10% of the total area. The stream valleys are occupied by human settlements indicated as 'artificial surfaces' on Fig. 1. The whole area is located in a mountainous region with an altitude ranging from 1000 to 2600 m. The climate is characterized by cold, dry winters and cool, rainy summers. On average the snow period in the valleys lasts from November to March while the higher altitudes have a snow cover until May. The mean annual temperature is 5 °C with a mean annual precipitation of 1110 mm (Marchetti and Panizza, 2001).

Fiemme and Fassa Valleys are renowned for high quality timber production, among which the valuable wood for the manufacture of

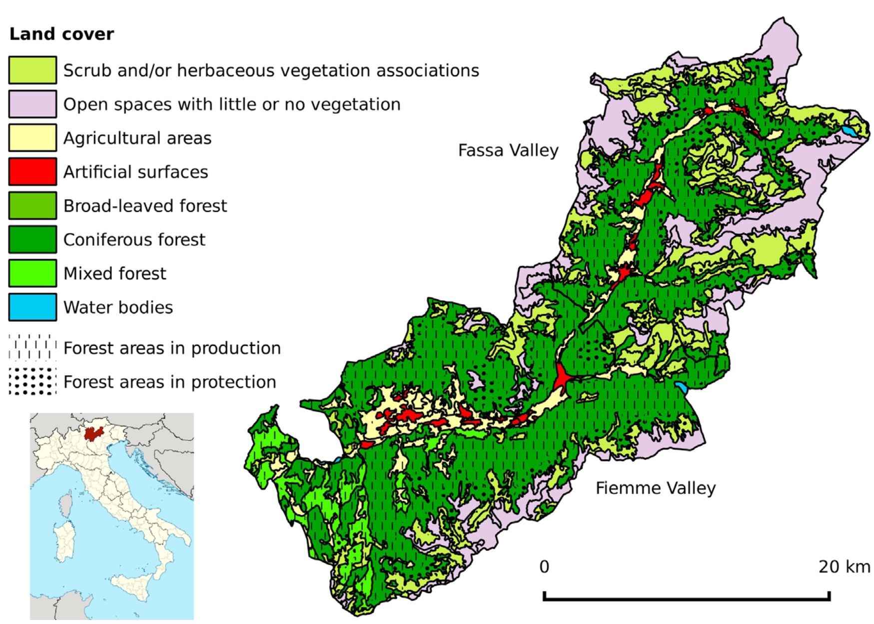

Fig. 1. Land cover and land use map of Fiemme and Fassa Valleys, located in the Province of Trento (North Italy).

the famous Stradivarius violins. All forestry activities in the study area take place according to 10-year forest management plans ensuring the sustainable exploitation of forests. The local forest management is based on the "close-to-nature" forestry approach that recommends selective cutting practices allowing the remaining forest to naturally regenerate over time (Carbone and Savelli, 2009). Based on the forest management plans, the forest area is divided into production and protection areas (Fig. 1) by considering the characteristics of the territory (i.e., morphology, steepness and risk of natural hazards) so that in the protection areas the rate of cutting ranges from 0% to 10% while in production areas it reaches about 65% of the annual increment. Of the total forest cover, 76% belongs to production and 24% to protection areas.

Timber production generates wood residues that are partially (around 50%) chipped and burned (together with wood residues from local sawmills) in local power plants producing heat and electricity (Valente et al., 2011; Buonocore et al., 2014). The demand for wood biomass to power local energy production is growing in the area (Zambelli et al., 2012). Wood biomass is also extensively used as firewood for heating private houses.

Another important economic sector in Fiemme and Fassa Valleys is tourism. The region attracts tourists especially for winter sports and summer trekking, with more than one million visitors per year.

2.2. The ecosystem services assessment framework

There are multiple definitions of the ecosystem service concept, all agreeing that ecosystem services are the benefits humans gain from ecosystem structure and functions but differing in terms of whether only direct benefits are considered (Boyd and Banzhaf, 2007) or also indirect benefits or passively used aspects of ecosystems (Costanza et al., 1997; Fisher et al., 2009). There are also some differences in the use of terms like ecosystem process, ecosystem structure, ecosystem function, and ecosystem benefit (Lamarque et al., 2011; Crossman et al., 2013). According to de Groot et al. (2010), structure and processes of ecosystems are necessary to underpin ecosystem functions that in turn have the capacity or potential to provide services. In this view, ecosystem services are the actual flows of services providing benefits to humans that can be valued in economic terms.

In this study, according to de Groot et al. (2010), the biophysical amount and economic value of the investigated ecosystem services refer to the actual (consumptive) use of services per year. The biophysical indicators used to assess the actual provision of different services, as well as the economic indicators adopted for their monetary valuation, are shown in Table 1. The calculation procedures and data used for assessing each ecosystem service are given in Section 2.4.

2.3. Total Economic Value and economic valuation methods

Total Economic Value (TEV) approach encompasses all components of utility derived from ecosystem services using money or any other market-based unit of account as a common unit of measurement (Pearce, 1993), allowing the comparison of the benefits of various goods and services. TEV of environmental assets consists of different use and non-use values. Whereas use values are based on the actual direct or indirect use of ecosystem services, non-use values are not associated with actual use, not even an option to use, an ecosystem and its services (Pearce, 1993; Merlo and Croitoru, 2005; TEEB, 2010). In this study, we focused on the valuation of direct and indirect use values while non-use values were disregarded due to the lack of sufficient data.

Demand curves for ecosystem services are often difficult to estimate. When assuming that ecosystem services cannot be increased or decreased to a large extent by human actions, their supply curve can be considered almost vertical (Costanza et al., 1997). In this case, a conservative estimate of the economic value of ecosystem services can be defined as:

$$EV = s_i p_i,$$

where s_i is the supply and p_i the price or shadow price of an ecosystem service i. Consequently, the total economic value of ecosystem services can be calculated as:

$$TEV = \sum_{i=1}^{n} s_i p_i.$$

In this study, the methods used for the economic valuation of the investigated ecosystem services were market price method, replacement cost method, and benefit transfer method based on contingent valuation. Market price method was used for the tradable ecosystem services, assuming that the markets are well functioning. Market prices should be still used with caution since in many prices externalities are not taken into account (Dasgupta and Duraiappah, 2012). Instead, for the services without individually observed market prices, non-market valuation methods were used to estimate their marginal shadow prices, which represent the marginal contribution that an ecosystem service makes to human wellbeing when the service does not have a market price (Dasgupta, 2008; Dasgupta and Duraiappah, 2012; Howarth and Farber, 2002).

Replacement cost method is based on the principle that the value of an ecosystem service can be estimated based on the cost of replacing that service with a technological substitute (Dixon et al., 1997). In this study, replacement cost method was applied to value the ecosystem service of hydrogeological protection. The method assumes that a service must be at least worth what people would need to pay to replace the service. Consequently, it is most appropriate in cases where the cost of replacement will be or has already been paid. When applying replacement cost method the following conditions should be met: (1) the human-made system provides the same functions as the original ecosystem (i.e., it is a close substitute for the replaced service), (2) the engineered system is the least costly alternative for the service, and (3) there is a public demand for this alternative, meaning that people would be willing to pay the costs instead of losing the service (Notaro and Paletto, 2012).

The benefit transfer method adapts estimates of ecosystem service benefits from studies already completed in another location with similar characteristics (Richardson et al., 2014; Wilson and Hoehn, 2006). Benefit transfer should be used with caution because the level of validity and reliability of transferred value estimates depends on the adequacy of existing studies. In this study, the benefit transfer method was applied to value the cultural service of tourism by transferring information from a previous study, also located in the Province of Trento, which used contingent valuation approach (Notaro et al., 2008).

Contingent valuation is based on surveys where people are asked to declare how much they would be willing to pay for specific environmental services, instead of deducing values from actual observed choices (Bateman and Willis, 1995). One of the strengths of contingent valuation is that it is capable of estimating in money terms non-use values of ecosystem services that do not involve market purchases or direct participation. However, a weakness is that especially in the case of regulating and supporting services, the general public is not familiar enough with ecosystem functions and services and, moreover, the complexity of the issue makes the survey description very difficult (Nunes and van den Bergh, 2001). In addition, if people were not used to pay for a certain service in the past, they could be unwilling to understand the need to pay for it at present or they might act as free-riders hoping that others would pay for this service. On the

Table 1
Investigated ecosystem services and related biophysical and economic indicators.

Ecosystem service	Biophysical indicator	Economic indicator
Provisioning services		
Timber	Volume of harvest	Market value of timber
Wood chips	Amount of wood fuel for bioenergy	Market value of wood chips
Firewood	Amount of firewood for heating private houses	Market value of firewood
Game	Number of hunted animals	Market value of meat
Mushrooms	Amount of harvested mushrooms	Market value of mushrooms
Berries	Amount of harvested berries	Market value of berries
Fresh water	Water consumption	Market value of domestic water
Regulating services		
Carbon sequestration	Amount of carbon sequestered by tree biomass	Carbon emission permit price
Hydrogeological protection	Forest areas protecting against natural hazards	Cost of bioengineering technologies
Cultural services		
Recreation: tourism	Number of tourists; areas with landscape value	Tourists' willingness-to-pay
Recreation: hunting	Number of hunters	Cost of hunting (permit, license, and insurance)
Recreation: mushroom picking	Number of permits for mushroom picking	Cost of mushroom permits

other hand, due to hypothetical bias, the participants of a valuation survey can overestimate their willingness-to-pay because they do not need to actually pay the amount stated (Riera et al., 2012).

2.4. Data sources and calculation procedures

2.4.1. Wood and non-wood forest products

The data on biophysical amounts of forest wood and non-wood products were collected from the annual reports of Forest and Wildlife Services of Province of Trento (PAT, 2011a, 2014) and field interviews with the chief of local Forest Service in Cavalese municipality and chief of Trento Province Hunting Association. To generate spatially distributed estimates of timber, we used data on actual timber logging based on the local forest management plans (PAT, 2010a).

Market price method was used to assign a monetary value to wood products (including timber, firewood, and wood chips) and to forest non-wood products (including game, mushrooms, and berries). The raw data refer to the year 2010. The monetary value of timber was calculated by using the local average market price of 95 €/m^3 for Fiemme and 98 €/m^3 for Fassa Valley, taking into account tree species and wood assortments (PAT, 2011a). The economic value of firewood was calculated using the average market price of 24 €/m^3 while for wood chips, according to the information from the local power plant, a price of 21 €/m^3 was used. The average price of meat of 4.5 €/kg was used to estimate the economic value of game. The same approach was followed to estimate the money value of mushrooms and berries using an average price of 14 and 6 €/kg, respectively (PAT, 2014).

2.4.2. Fresh water consumption

The presence of forests help to cycle and purify water in many ways: root systems of trees and other plants keep soils porous and allow water to filter through various layers of soil before entering ground water. Through this process, toxins, nutrients, sediment, and other substances are filtered from the water (Brauman et al., 2007). In addition, forests also affect the hydrological cycle through the evapotranspiration process, which could be used as a potential indicator of ecosystem integrity (Müller, 2005). In this study, to estimate the actual service generated from water cycling, the consumption of fresh water was calculated based on the Italian average of 175 l/person/day. The market price of domestic water in the Province of Trento of 1.20 €/m^3 was used to calculate the monetary value of water use. As agriculture and industrial sectors are negligible in the study area, their water consumption was disregarded.

2.4.3. Carbon sequestration

The average carbon sequestration was calculated by using a wood annual increment of 61,923 t C/yr (Tonolli and Salvagni, 2007). To generate a GIS map showing the spatial distribution of carbon sequestration (kg of CO_2) over the study area, the following equation was used:

$$\text{wood biomass}(m^3) \times \text{wood density}(kg/m^3) \times \%\ \text{dry mass} \times \%\ \text{carbon} \times 3.67 \times 120\%(\text{roots})$$

where % of dry mass is a coefficient linked to wood density and 3.67 is the conversion factor from C to CO_2. The net amount of CO_2 sequestered was calculated by substracting from the annual wood increment the CO_2 released when burning firewood, wood chips, and wood residues from sawmills (about 10% of the total CO_2 sequestration). Instead, the carbon stored in timber was assumed to be stocked for a long period of time (e.g., used for buildings, furniture, and musical instruments) and therefore not accounted for. The emission permits regulated by the European Union Emissions Trading Scheme were used to estimate the economic value of carbon sequestration, using an average price of 15 €/t CO_2 (World Bank, 2010).

2.4.4. Hydrogeological protection

Landscape stabilization is one of the main functions of forests in mountainous regions (Brang et al., 2006). Forests provide direct protection for infrastructure and human activities, and indirect protection in terms of watershed protection and soil conservation. We used official GIS data, produced by the Mountain Catchments Service of the Province of Trento, on risk of avalanches and landslides and their spatial location in the study area (PAT, 2010b). The typologies and level of risk take into account the type of risk (i.e., avalanches, landslides, rock falls), direct protection of human activities (e.g., agricultural crops) and infrastructure (e.g., settlements, roads, railway lines), and the site characteristics (i.e., slope, roughness). We used these layers to estimate the hectares for each typology of hydrogeological protection: primary and secondary protection against avalanches and landslides.

The replacement cost method was applied to estimate the monetary value of hydrogeological protection. Four different bioengineering technologies were identified assuming that they would provide a substitute for hydrogeological protection required in the risk areas if the forest did not exist or if a clear-cut occurred. The most cost effective solutions were chosen: simple palisade and cutting terraces for primary and secondary risk of landslides and snow fences and snow stands for primary and secondary risk of avalanches. The price of the selected technologies were 34 €/lm for simple palisade, 23 €/lm for cutting terraces, 265 €/lm for snow fence, and 13 €/piece for snow stand

(PAT, 2011b). An inter-distance of 15 m was assumed for simple palisade and cutting terraces. For snow fences an inter-distance of 20 m was assumed whereas an average of 40 snow stands was assumed to be needed per hectare. To calculate the annual cost c_i of each technology i per hectare during the whole economic lifetime, we used to following formula:

$$c_i = p_i f_i$$

where p_i is the price of each technology per hectare (euro/ha) and f_i is the annuity factor calculated as:

$$f_i = \frac{r(1+r)^{n_i}}{(1+r)^{n_i}-1}$$

where $r=$ interest rate and $n=$ economic lifetime. A conservative social interest rate of 1% and an economic lifetime of 20 years was assumed for all the technologies except for snow stands for which a 10-year lifetime was used. Finally, the annual cost of each bioengineering technology was multiplied by the amount of hectares of forests performing the service of avalanche or landslide protection. This presents the replacement cost that would occur without the presence of the forest.

2.4.5. Cultural services

We accounted for different recreational aspects: landscape value and related tourism, hunting activities, and mushroom picking. Spatial data on areas characterized by particular landscape value were collected from the forest management plans of Province of Trento (PAT, 2010a), whereas data on tourists visiting the area in 2010, accounted as arrivals, were taken from the Statistical Office of Province of Trento.

The recreational value of the forests related to tourism was estimated with the benefit transfer method by updating the outcomes of a former assessment conducted by Notaro et al. (2008). In that study, the recreational and aesthetic value of Lavazè forest, which covers an area of 99 ha and is located in the upper part of Fiemme Valley, was estimated. It can be considered an average situation for Fiemme and Fassa Valleys because its landscape characteristics with conifer forests interspersed with grasslands (i.e., pastures and meadows) and its ownership (public and common owners) as well as socio-economic characteristics are similar to these two valleys.

In their study, contingent valuation was carried out during the summer 2002 through on-site interviews to a random sample of 724 visitors with a return rate of 92.5%. The interviewees were confronted with a proposed modification of the selective cutting practice in a clear cutting approach (i.e., removal of all timber from a stand) in the Lavazè forest. The average willingness-to-pay for not changing to clear cutting practice was 2.58 euro per person in Notaro et al. (2008) and this value was updated to the year 2010 by using national consumer price index for recreation and then up-scaled to the valley level by multiplying by the total number of tourists visiting Fiemme and Fassa.

Hunting includes also a recreational element as for many hunters enjoying nature is an important part of the hunting experience. The data on number of hunters per year were provided by the Trento Province hunting association. The prices of hunting permits, license and insurance were used to estimate the minimum level of willingness-to-pay for hunting activities. Besides hunting, also mushroom picking contains a recreational aspect of enjoying nature. The total cost of permits for mushroom picking, required for people coming from outside Fiemme and Fassa Valleys, was used as an estimation of the recreational value for this activity. As mushroom picking is free of charge for the local population, local inhabitants were not considered in this valuation. The economic value per hectare for mushroom picking was calculated by dividing the total cost of permits by the total forest area.

2.5. Spatial assessment and trade-off analysis

We used QGIS 2.2 to perform spatial assessment of selected provisioning, regulating, and cultural ecosystem services: timber, carbon sequestration, hydrogeological protection, and recreation related to tourism. The GIS layers containing detailed data on annual timber cutting, annual increment of wood biomass, risks of avalanches and landslides, and recreational areas related to beautiful landscapes were used to distinguish the level of the ecosystem services in each polygon (i.e., each forest management area) in the study area. To generate the economic maps, we used the shadow prices per unit of each service, calculated in the earlier step, multiplied by the corresponding biophysical data in each polygon. In the case of the economic recreation map, we distributed the total willingness-to-pay of tourists (calculated earlier) for the specific landscape areas.

The TEV map was calculated by aggregating the layers of economic value of single services in the QGIS using geoprocessing tools. The economic value per ha of services without a spatial analysis were added assuming an equal distribution of the value over the whole forest area.

We performed exploratory data analysis for the mapped ecosystem services to investigate possible trade-offs and synergies between these services. This was done by using graphical technics (in R 3.1.1) to explore whether and to what extent two services exist in the same polygon. For timber and carbon sequestration we used a scatter plot to investigate their correlation. For recreation and hydrogeological protection, we performed an overlap analysis, in which we tested the level of overlapping polygons compared to the areas having only one of those services. For the other service pairs, a frequency distribution, depicted in a histogram, was used.

2.6. Uncertainty analysis

The ecosystem services assessment was based on local biophysical and economic data. However, input data can be affected by non-negligible uncertainty, and therefore, we applied an uncertainty analysis to test how small fluctuations in market prices or calculated shadow prices, and parallel uncertainty in the biophysical input data or calculated values would affect the total economic value. To assess the combined effect of uncertainties, we used the Monte Carlo simulation method (Metropolis and Ulam, 1949; Kroese et al., 2011) based on the distribution functions of input parameters. To set up the Monte Carlo simulation, we used a uniform random function with a range of $\pm 10\%$ for the biophysical amounts and $\pm 20\%$ for the actual prices or shadow prices and an iteration of 10,000 repetitions. According to the maximum entropy theorem (Sivia, 1996), a uniform random function is the best assumption for the probability distribution function when the model describing the variation of input variable is unknown and only its minimum and maximum values can be estimated.

3. Results

Table 2 summarizes the biophysical flows, marginal values (shadow price per unit), the average economic values per hectare, and the total monetary values calculated for different forest ecosystem services in Fiemme and Fassa Valleys. The economic value of provisioning services accounted for 13.06 M€/yr of which 67% was due to timber. The economic value of regulating and cultural services accounted for 16.14 M€/yr and 3.70 M€/yr. The TEV, calculated as the addition of all the investigated ecosystem services, was 32.90 M€/yr (Fig. 2), equivalent to an average value of 820 €/ha/yr. The results of the Monte Carlo simulation showed a mean value of the TEV of 33.08 M€/yr, standard deviation of 0.96 M€/yr, and maximum and minimum value of 35.95 and

Table 2
Total biophysical amounts, marginal values, average economic values per hectare, and total economic values of ecosystem services in Fiemme and Fassa Valleys.

Ecosystem service	Biophysical value	Unit	Shadow price/unit	Economic value[a] (€/ha/yr)	Economic value (€/yr)	% of TEV
Provisioning services						
Timber	89,500	m^3	97	218	8,693,135	26.4
Wood chips	7,326	m^3	21	4	153,855	1.0
Firewood	15,176	m^3	24	9	364,234	0.5
Game	1,429	head	148	5	211,660	0.6
Mushrooms	39,645	kg	14	14	557,233	1.7
Berries	14,197	kg	6	2	83,156	0.3
Fresh water	2,511,394	m^3	1	75	2,999,615	9.1
Regulating services						
Carbon sequestration	201,350	t CO_2	15	76	3,020,246	9.2
Hydrogeological protection	6,946	ha	1,888	328	13,116,047	39.9
Cultural services						
Recreation: tourists	1,094,866	person	3	77	3,090,281	9.4
Recreation: hunting	498	person	774	10	385,425	1.2
Recreation: mushrooming	n.a.	permit	n.a.	6	227,423	0.7
Total Economic Value (TEV)					32,902,310	100.0

n.a.—Not available.

[a] Average value calculated considering the whole forest area.

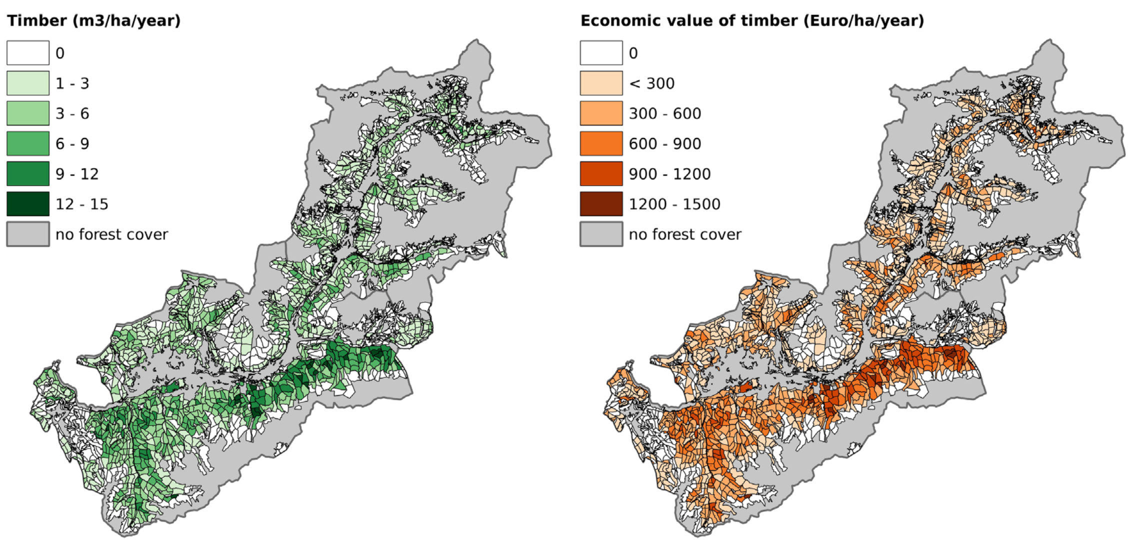

Fig. 2. Biophysical and economic value of timber.

30.37 M€/yr. The provisioning services represented 40% of the TEV while the regulating and cultural services were 49% and 11%. The service of hydrogeological protection showed a major importance among the investigated regulating services (81%) and within the TEV (40%).

Table 3 shows the results of the GIS survey in terms of areas characterized by different natural hazard risk typologies, the cost of different bioengineering technologies per year estimated considering their lifetime, and the resulting economic value of the service of hydrogeological protection.

The value and distribution of selected ecosystem services were also spatially analyzed. In Figs. 2–5, the spatial distribution of timber, carbon sequestration, hydrogeological protection, and recreation related to tourism are shown both in biophysical and monetary units. Finally, the spatially explicit total economic value of the bundle of ecosystem services is presented in Fig. 6.

The results of the trade-off analysis performed for timber, carbon sequestration, hydrogeological protection, and recreation are presented in Figs. 7 and 8. The analysis was based on investigating the coexistence and provision level of ecosystem service pairs in each forest management area. A positive correlation was found between timber and carbon sequestration (Fig. 7). In 63% of the forest management areas with hydrogeological protection there was less than 1 m^3 of timber production per hectare, while the maximum cut was 7 m^3/ha. Instead, in the areas without hydrogeological protection, 50% of the areas had timber production less than 1 m^3/ha, whereas the maximum cut was around 15 m^3/ha. This means that the existence of hydrogeological protection translates into lower level of timber production (Fig. 8). In 68% of areas having a recreational landscape value, timber production was less than 1 m^3/ha, whereas 52% of areas without a specific landscape value had timber cutting more than 1 m^3/ha (Fig. 8). Comparing hydrogeological protection and carbon sequestration, 40% of areas with protection had low rate of carbon sequestration (less than 1 t CO_2/ha) with maximum sequestration rate of 9 t CO_2/ha, while the carbon sequestration rates for non-protection areas resulted higher: 34% of areas with less than 1 t CO_2/ha with a maximum value of 11 t CO_2/ha. Carbon sequestration resulted lower in the areas with recreational landscape value compared to areas without landscape value: 53% and 29% with sequestration rate lower than 1 t CO_2/ha, respectively (Fig. 8). In addition, when comparing areas with recreational landscape value or hydrological protection, in 26% of the cases they both were present in the same polygon.

4. Discussion

In this study, the biophysical amounts, spatial distribution, and economic value of forest ecosystem services in the Italian Alpine region were explored. In addition, some possible trade-offs and synergies between the services were identified. Instead of only using average values for physical flows or benefit transfer for economic values, we produced spatially distributed estimates of ecosystem services based on a specific data collection of local biophysical and economic variables (e.g., actual timber logging based on local forest management units and related plans, and local market prices). Considering the spatial heterogeneity of the investigated forest ecosystem and related services supply, such an approach has capacity to better support local forest planning and management.

Instead of contrasting conservation options and economic activities, the ecosystem services approach aims at showing the added value that ecosystem functions and services provide to human economy (Daily et al., 2009; Primmer and Furman, 2012). As indicated in the Introduction, when the stocks of natural capital are healthy, monetary valuation can be used as a tool to highlight the various benefits humans get from ecosystems. Therefore, initial biophysical assessment is crucial to verify what is the state of ecosystems and natural capital in the study area. In our study area, the growth rate of the forest is more than the annual harvest, one half of the timber production residuals are left in the soil, and selective cutting is the dominant harvest practice. These characteristics give confidence that ecosystem service valuation is relevant to be applied together with biophysical accounting of services.

The assessment showed that forests of Fiemme and Fassa Valleys provide multiple and valuable ecosystem services (Table 2). As shown in Figs. 2–5, the investigated ecosystem services were not equally distributed over the two valleys as different forest areas provided different services with diverse intensity of supply. For timber and carbon sequestration, the most important areas were in Fiemme Valley, located on the left side of the maps in Figs. 2 and 3. Instead, hydrogeological protection played a more crucial role in Fassa Valley, located on the right side of the map in Fig. 4. Recreational areas were identified in both valleys (Fig. 5).

Timber production is often valued above other forest services while in the Alpine regions the control of water streams and soil conservation is a function of primary importance (Dorren et al., 2004; Notaro et al., 2008). Also in this study, due to the presence of human settlements in the forested mountainous areas, the service of hydrogeological protection, concentrated in areas of high risk of avalanches and landslides (Table 3, Fig. 4), showed a major importance accounting for 40% of the TEV, while wood products accounted for 28% of the TEV (Table 2).

The value of hydrogeological protection was estimated using the replacement cost method. It can be argued that replacement cost is not a strict measure of economic value since it is not based on people's willingness to pay. Nevertheless, in the case of protection function, it is reasonable to assume that there would be a demand for this service if the forest cover was removed (Notaro and Paletto, 2012). Therefore, it can be assumed that people would be willing to pay the most cost effective technological solution that could perform the same service, i.e. directly protect infrastructures and human activities and indirectly protect soil and watersheds against natural hazards.

Cultural services were evaluated considering hunting activities, mushroom picking, and local tourism. In the case of hunting and mushrooms picking, the use of permit prices may underestimate the value of these activities, as they are administrative prices rather than being derived from the interaction of supply and demand (Merlo and Croitoru, 2005). In addition, the economic value of carbon sequestration is influenced by the fluctuating carbon price in the European Union's emission trading scheme.

Table 3
Natural hazard risk, replacement costs, and economic value of hydrogeological protection service.

Risk	Area (ha)	Bioengineering technology	Cost (€/ha^{-1}/yr^{-1})	Economic value (€/yr^{-1})
Landslide, primary	3,408	Simple palisade	1,129	483,440
Landslide, secondary	641	Cutting terrace	754	3,849,430
Avalanche, primary	2,297	Snow fence	3,675	8,444,060
Avalanche, secondary	599	Snow stand	566	339,120
Total	6,945		1,888[a]	13,116,050

[a] The average cost, weighted by area.

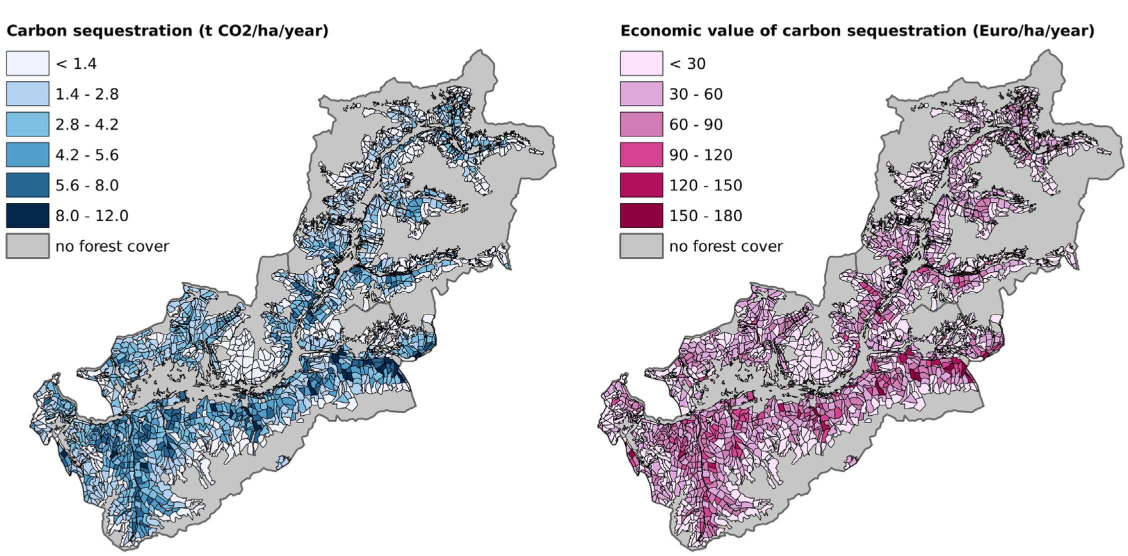

Fig. 3. Biophysical and economic value of carbon sequestration.

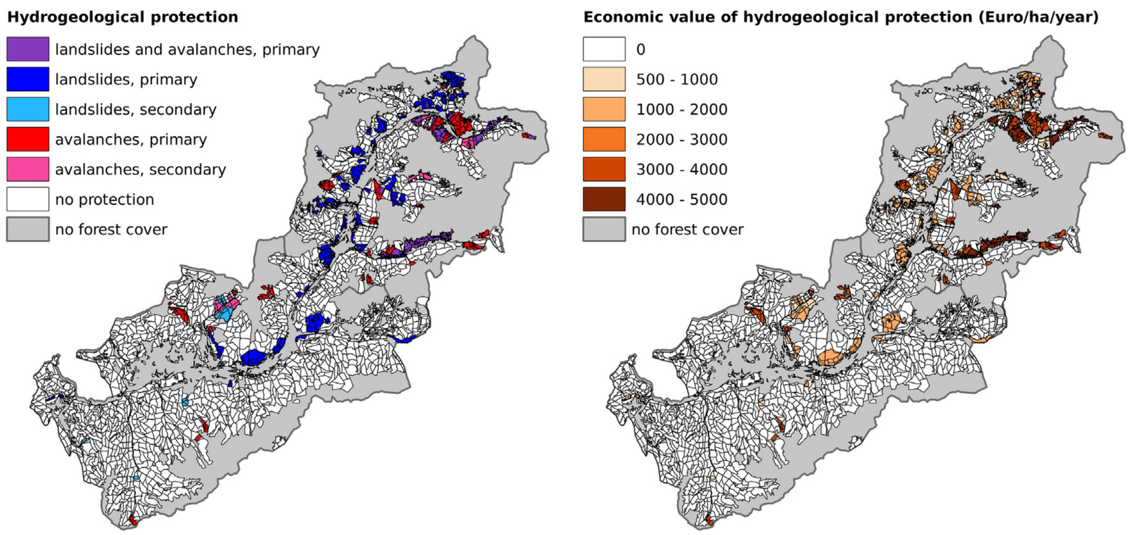

Fig. 4. Biophysical and economic value of hydrogeological protection.

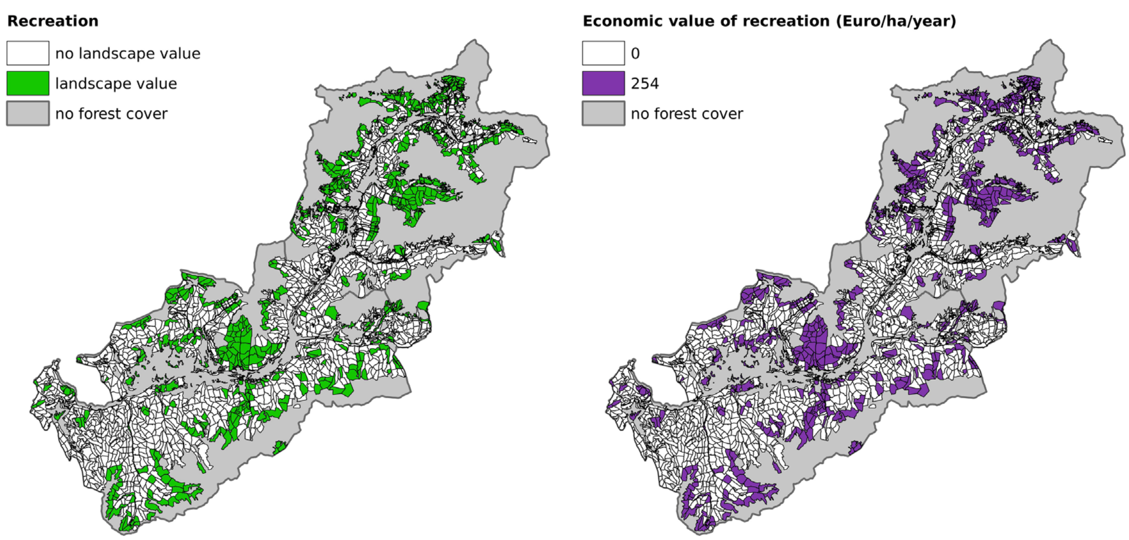

Fig. 5. Biophysical and economic value of recreation and tourism.

The contribution of the investigated services to the local economy (i.e., the amount of money that actually passed through local markets) was about 13 M€/yr, of which timber accounted for 68%. Instead, the total economic value of the investigated forest ecosystem services was about 33 M€/yr (Table 2) when considering also the non-marketed services. This means that about 60% of the economic value was not visible through market transactions. The inclusion of additional ecosystem services (e.g., other regulating ones) that were not considered in this study could further increase this number. It has been argued that shadow prices could be used to reflect the relative importance of natural capital and ecosystem services within national and regional economic accounts (Dasgupta and Duraiappah, 2012; Edens and Hein, 2013). Yet, from a methodological point of view, it should be noted that the monetary values can vary greatly according to the chosen valuation method (Spangenberg and Settele, 2010), and therefore valuation should be explicit about methods used.

In the map of the total economic value (Fig. 6), the areas with higher values are characterized mainly by either high level of timber harvest and carbon sequestration (especially in Fiemme Valley) or hydrogeological protection (in Fassa Valley). Maximizing the TEV of multiple ecosystem services has been proposed as an approach to maximize the benefits received from an optimal exploitation of ecosystem services. A limitation of the TEV approach is that it estimates the total annual value or total value that would be lost if all the services disappeared. The probability of such a supply shock should be considered, and in many cases the marginal value (shadow price/unit of service) is more relevant information to evaluate small changes in the ecosystem service supply. Moreover, being an aggregated indicator, it does not distinguish different ecosystem services or stakeholders receiving the benefits from ecosystems. Different stakeholders and stakeholders at different spatial scales can have diverse interests in ecosystem services (Hein et al., 2006), and these social and equity aspects should be further considered. For example, increased timber production could increase the income of forest owners and companies and induce new labor opportunities but, at the same time, could also decrease the landscape and recreational benefits for local people and tourists.

Maximizing the provision of all ecosystem services simultaneously is often difficult, if not impossible. Fig. 9 describes a generalized functional relationship among different service categories, showing that increasing the use of one service most often

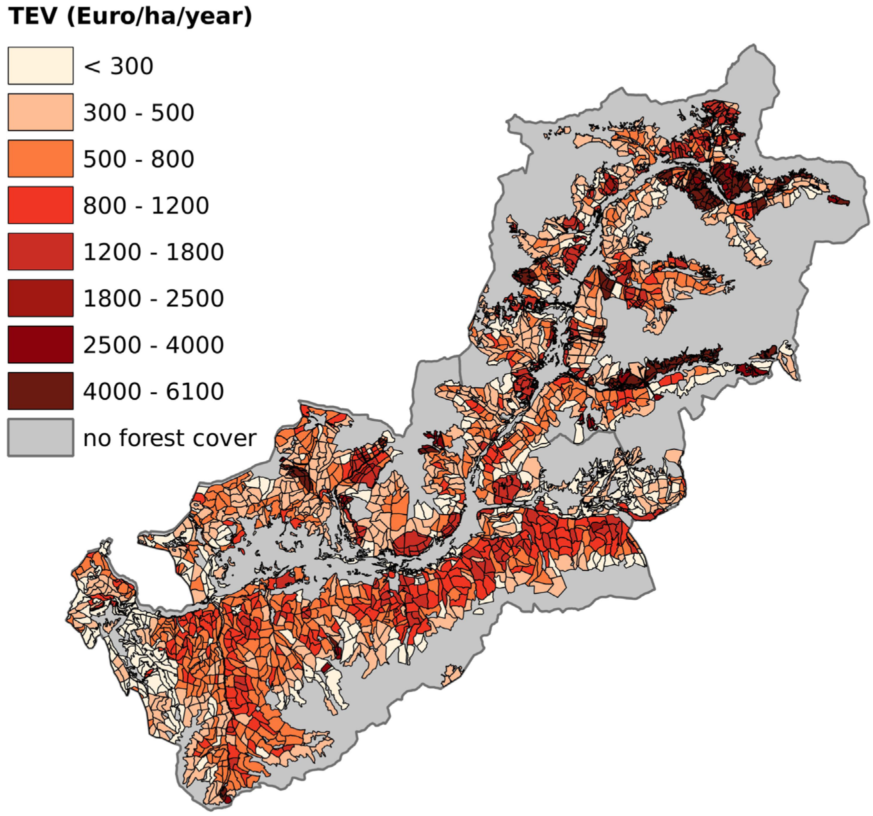

Fig. 6. Total Economic Value (TEV) of all the investigated ecosystem services and its distribution over the Fiemme and Fassa Valleys.

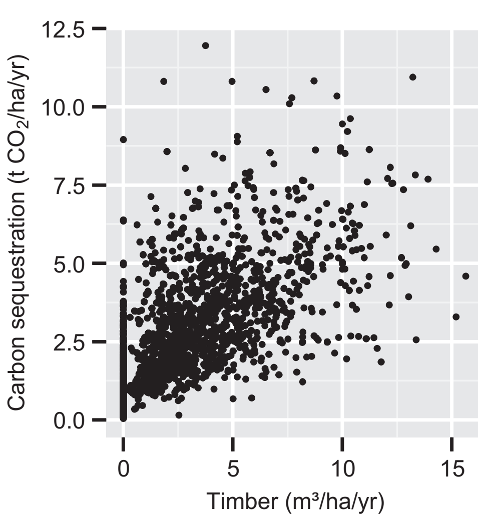

Fig. 7. Scatter plot of timber harvest and carbon sequestration levels.

leads to the decrease of another, although there can be also synergies among different services, for example among the regulating ones (Bennett et al., 2009; Braat and ten Brink, 2008).

Using exploratory data analysis, we assessed trade-offs and synergies between the mapped ecosystem services (Figs. 7 and 8). Timber and carbon sequestration occurred jointly; they both are dependent on the density and annual growth rate characteristics of the forest. Timber production also has a positive relation to wood chips production being a side product. Instead, a trade-off between timber and hydrogeological protection was found. Also carbon sequestration service was lower in areas with hydrogeological protection, which is linked to the lower biomass growth due to higher altitude, lower density of trees, and steepness of the slope. Likewise, timber harvest and carbon sequestration rates were lower in recreational areas with a particular landscape value compared to areas without landscape value.

In Fiemme and Fassa Valleys, forests cover 54% of the total area, representing an important component of the local natural capital. An increasing demand for wood as renewable material and energy source can bring additional future challenges to the sustainable management of the forest ecosystem. In fact, in addition to the conventional wood production and the supply to the local bioenergy sector, forests are also expected to ensure carbon storage and recreational opportunities, among many other functions. The so called "close-to-nature" forest management approach, currently practiced in the study area, mainly uses selective cutting enabling forests to maintain their multifunctionality and a balanced combination of different goods and services. The actual timber and bioenergy production in the area could still be increased within the limits of a sustainable harvest because the annual felling is around 60% of the annual wood increment. However, an increased exploitation of the forests in terms of timber and wood fuel could translate into a lower provision of other services or into a reduction of ecosystem functions (Fig. 9; Kraxner et al., 2013; Sacchelli et al., 2013). For instance, even if wood biomass was used within the limits of the annual increment, an increased use of forest biomass for energy production including roots and log residues could threaten biodiversity and nutrient cycling (Pyörälä et al., 2012). On the other hand, the utilization of wood chips could reduce fossil fuel use in the local power plants, thus improving the environmental performance of energy production (Buonocore et al., 2012, 2014; Häyhä et al., 2011; Sacchelli et al., 2014).

These contradictory aspects call for further research aimed at understanding trade-offs among different categories of ecosystem services, especially provisioning versus regulating and cultural services within alternate forest management regimes. Furthermore, as also emphasized by Grêt-Regamey et al. (2013), decisions in forest resource management are based on assumption of potential future development

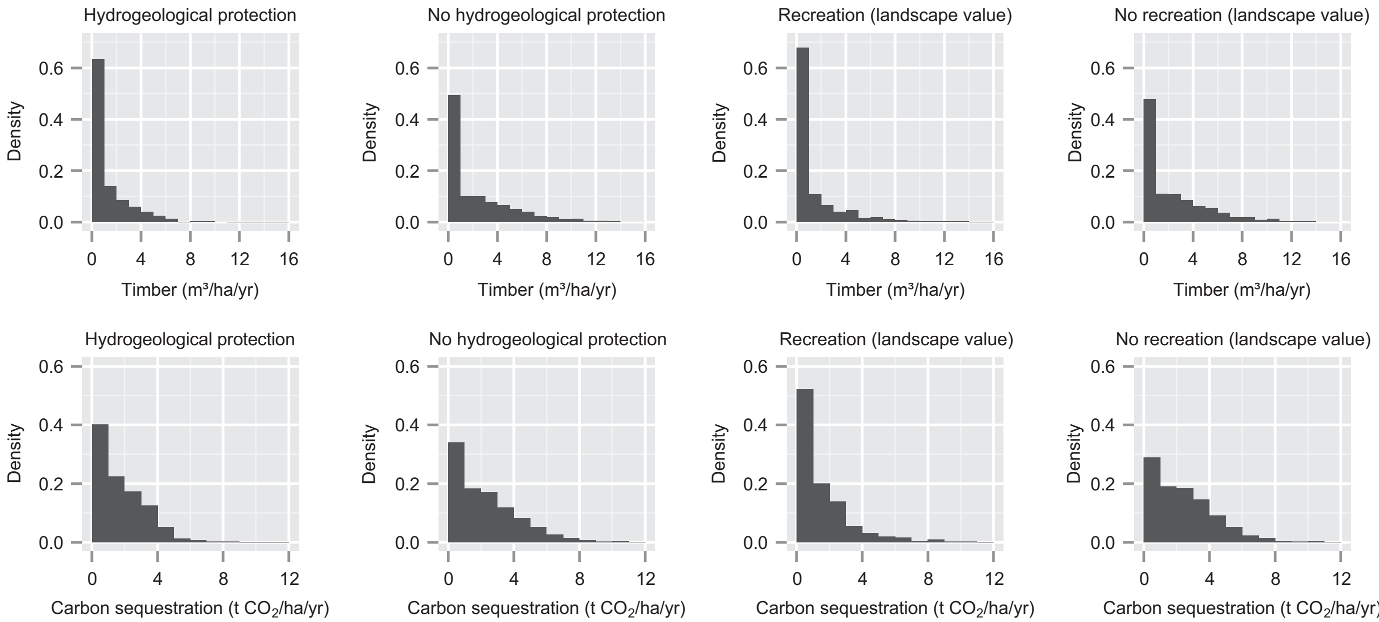

Fig. 8. Density distribution of the mapped ecosystem services against each other.

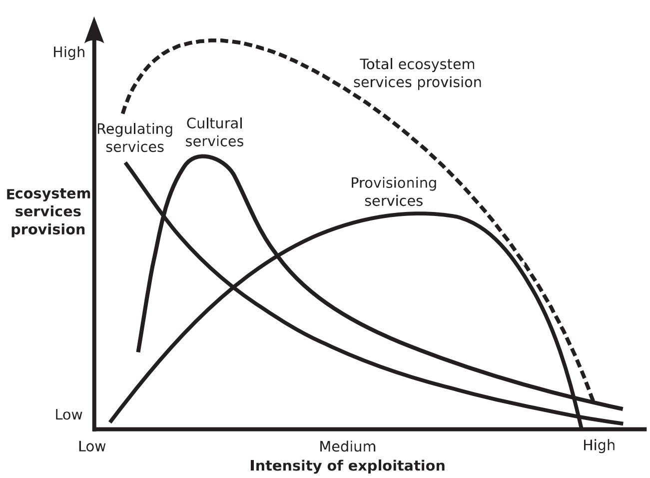

Fig. 9. Generalized functional relationships between different categories of ecosystem services (adapted from Braat and ten Brink, 2008).

and state of ecosystems. Since mountain forests are characterized by long rotation stands and high sensitivity to climate and socio-economic changes, it would be important to analyze also these uncertainties when mapping and assessing bundles of ecosystem services.

5. Conclusion

This study showed that forests in the Alpine context of Fiemme and Fassa Valleys provide humans with a wide range of ecosystem services. Mapping ecosystem services resulted useful in understanding and visualizing the spatial distribution of services, while it also enabled to identify priority areas and possible trade-offs and synergies among different services. A major part of these benefits do not have a direct market value but they are rather public goods, and therefore, valuation was a means to make their economic importance explicit. Our choice of investigated services may have led to an underestimation of the total value, and besides the economic value, there would be other social, ecological, and spiritual values associated with the forests that economic valuation is not able to capture.

We maintain that while a biophysical perspective can ensure a solid accounting base for assessing the stocks of natural capital and flows of ecosystem services, a comprehensive economic valuation of all categories of forest ecosystem services can support the communication of their importance to policy makers. In conclusion, we argue that biophysical and economic assessments can complement each other and they could be used as parts of a broader multi-criteria assessment to provide a comprehensive evaluation of both the ecological and socio-economic dimensions of ecosystems and their services.

Acknowledgements

This research work was supported by the Council for Agricultural Research and Economics, Forest Monitoring and Planning Research Unit, Trento (Italy). Part of the research was developed in the Young Scientists Summer Program at the International Institute for Systems Analysis, Laxenburg (Austria). Authors also wish to thank the Province of Trento for providing statistical data.

References

Balmford, A., Bruner, A., Cooper, P., Costanza, R., Farber, S., Green, R.E., Jenkins, M., Jefferiss, P., Jessamy, V., Madden, J., Munro, K., Myers, N., Naeem, S., Paavola, J., Rayment, M., Rosendo, S., Roughgarden, J., Trumper, K., Turner, R.K., 2002. Economic reasons for conserving wild nature. Science 297, 950–953.
Bateman, I.J., Willis, K., 1995. Valuing Environmental Preferences: Theory and Practice of the Contingent Valuation Method in US, EU, and Developing Countries. Oxford University Press, Oxford, UK 668 pp.
Bennett, E.M., Peterson, G.D., Gordon, L.J., 2009. Understanding relationships among multiple ecosystem services. Ecol. Lett. 12, 1394–1404.
Boyd, J., Banzhaf, S., 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecol. Econ. 63, 616–626.
Braat, L.C., de Groot, R., 2012. The ecosystem services agenda: bridging the worlds of natural science and economics, conservation and development, and public and private policy. Ecosyst. Serv. 1, 4–5.
Braat, L.C., ten Brink, P. (Eds.), 2008. The cost of Policy Inaction: the Case of not Meeting the 2010 Biodiversity 397 Target. Report to the European Commission Under Contract: ENV.G.1./ETU/2007/0044, Wageningen, Brussels, 398 Alterra Report 1718.
Brang, P., Schönenberger, W., Frehner, M., Schwitter, R., Thormann, J.J., Wasser, B., 2006. Management of protection forests in the European Alps: an overview. Forest Snow Landsc. Res. 80, 23–44.

Brauman, K.A., Daily, G.C., Duarte, T.K., Mooney, H.A., 2007. The nature and value of ecosystem services: an overview highlighting hydrologic services. Annu. Rev. Environ. Resour. 32, 67–98.
Burkhard, B., Crossman, N., Nedkov, S., Petz, K., Alkemade, R., 2013. Mapping and modelling ecosystem services for science, policy and practice. Ecosyst. Serv. 4, 1–3.
Burkhard, B., Kroll, F., Nedkov, S., Müller, F., 2012. Mapping ecosystem service supply, demand and budgets. Ecol. Indicat. 21, 17–29.
Burkhard, B., Fath, B.D., Müller, F., 2011. Adapting the adaptive cycle: hypotheses on the development of ecosystem properties and services. Ecol. Modell. 222, 2878–2890.
Buonocore, E., Häyhä, T., Paletto, A., Franzese, P.P., 2014. Environmental costs and impacts of forestry activities: a multi-method approach to environmental accounting. Ecol. Modell. 271, 10–20.
Buonocore, E., Franzese, P.P., Ulgiati, S., 2012. Assessing the environmental performance and sustainability of bioenergy production in Sweden: a life cycle assessment perspective. Energy 37, 69–78.
Canadell, J.G., Raupach, M.R., 2008. Managing forest for climate change mitigation. Science 320, 1456–1457.
Carbone, F., Savelli, S., 2009. Forestry programmes and the contribution of the forestry research community to the Italy experience. Forest Policy Econ. 11, 508–515.
Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S.J., Kubiszewski, I., Farber, S., Turner, R.K., 2014. Changes in the global value of ecosystem services. Global Environ. Change 26, 152–158.
Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.
Croitoru, L., 2007. How much are Mediterranean forests worth? Forest Policy Econ. 9, 536–545.
Crossman, N.D., Burkhard, B., Nedkov, S., Willemen, L., Petz, K., Palomo, I., Drakou, E. G., Martín-Lopez, B., McPhearson, T., Boyanova, K., Alkemade, R., Egoh, B., Dunbar, M.B., Maes, J., 2013. A blueprint for mapping and modelling ecosystem services. Ecosyst. Serv. 4, 4–14.
Daily, G.C., Polasky, S., Goldstein, J., Kareiva, P.M., Mooney, H.A., Pejchar, L., Ricketts, T.H., Salzman, J., Shallenberger, R., 2009. Ecosystem services in decision making: time to deliver. Front. Ecol. Environ. 7, 21–28.
Daily, G.C., 1997. Introduction: what are ecosystem services. In: Daily, G.C. (Ed.), Nature's Services. Island Press, Washington DC, pp. 1–10.
Dasgupta, P., 2008. Nature in economics. Environ. Resour. Econ. 39, 1–54.
Dasgupta, P., Duraiappah, A., 2012. Chapter 1: Well-being and Wealth. In UNU-IHDP and UNEP, 2012. Inclusive Wealth Report 2012. Measuring Progress Toward Sustainability. Cambridge: Cambridge University Press.
de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., ten Brink, P., van Beukering, P., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosyst. Serv. 1, 50–61.
de Groot, R., Alkemade, R., Braat, L., Hein, L., Willemen, L., 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecol. Complex. 7, 260–272.
de Groot, R., Wilson, M.A., Boumans, R.M.J., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecol. Econ. 41, 393–408.
Dixon, J.A., Scura, L.F., Carpenter, R.A., Sherman, P.B., 1997. Economic Analysis of Environmental Impacts. Earthscan Publications, London, UK 210 pp.
Dorren, L.K.A., Berger, F., Imeson, A.C., Maier, B., Rey, F., 2004. Integrity, stability and management of protection forests in the European Alps. Forest Ecol. Manage. 195, 165–176.
Edens, B., Hein, L., 2013. Towards a consistent approach for ecosystem accounting. Ecol. Econ. 90, 41–52.
Farber, S.C., Costanza, R., Wilson, M.A., 2002. Economic and ecological concepts for valuing ecosystem services. Ecol. Econ. 41, 375–392.
Farley, J., 2012. Ecosystem services: the economics debate. Ecosyst. Serv. 1, 40–49.
Farley, J., 2008. The role of prices in conserving critical natural capital. Conserv. Biol. 22, 1399–1408.
Fisher, B., Turner, R.K., Morling, P., 2009. Defining and classifying ecosystem services for decision making. Ecol. Econ. 2009, 643–653.
Folke, C., Jansson, Å., Rockström, J., Olsson, P., Carpenter, S.R., Chapin III, F.S., et al., 2011. Reconnecting to the biosphere. Ambio 40, 719–738.
Folke, C., 2006. Resilience: the emergence of a perspective for social–ecological systems analyses. Global Environ. Change 16, 253–267.
Fürst, C., Frank, S., Witt, A., Koschke, L., Makeschin, F., 2013. Assessment of the effects of forest land use strategies on the provision of ecosystem services at regional scale. J. Environ. Manage. 127, S96–S116.
García-Nieto, A.P., García-Llorente, M., Iniesta-Arandia, I., Martín-López, B., 2013. Mapping forest ecosystem services: from providing units to beneficiaries. Ecosyst. Serv. 4, 126–138.
Gios, G., Goio, I., Notaro, S., Raffaelli, R., 2006. The value of natural resources for tourism: a case study of the Italian Alps. Int. J. Tour. Res. 8, 77–85.
Goio, I., Gios, G., Pollini, C., 2008. The development of forest accounting in the province of Trento (Italy). J. Forest Econ. 14, 177–196.
Grêt-Regamey, A., Brunner, S.H., Altwegg, J., Bebi, P., 2013. Facing uncertainty in ecosystem services-based resource management. J. Environ. Manage. 127, S145–S154.
Grêt-Regamey, A., Bebi, P., Bishop, I.D., Schmid, W.A., 2008. Linking GIS-based models to value ecosystem services in an Alpine region. J. Environ. Manage. 89, 197–208.
Grêt-Regamey, A., Kytzia, S., 2007. Integrating the valuation of ecosystem services into the input–output economics of an Alpine region. Ecol. Econ. 63, 786–798.
Grilli, G., Paletto, A., De Meo, I., 2014. Economic valuation of forest recreation in an Alpine Valley. Baltic Forestry 20, 167–175.
Hardin, G., 1968. The tragedy of the commons. Science 162, 1243–1248.
Hein, L., van Koppen, K., de Groot, R.S., van Ierland, E.C., 2006. Spatial scales, stakeholders and the valuation of ecosystem services. Ecol. Econ. 57, 209–228.
Holling, C.S., 1973. Resilience and stability of ecological systems. Annu. Rev. Ecol. Syst. 4, 1–23.
Howarth, R.B., Farber, S., 2002. Accounting for the value of ecosystem services. Ecol. Econ. 41, 421–429.
Häyhä, T., Franzese, P.P., 2014. Ecosystem services assessment: a review under an ecological-economic and systems perspective. Ecol. Modell. 289, 124–132.
Häyhä, T., Franzese, P.P., Ulgiati, S., 2011. Economic and environmental performance of electricity production in Finland: a multicriteria assessment framework. Ecol. Modell. 223, 81–90.
Jørgensen, S.E., 2010. Ecosystem services, sustainability and thermodynamic indicators. Ecol. Complex. 7, 311–313.
Kraxner, F., Nordström, E-M., Havlík, P., Gusti, M., Mosnier, A., Frank, S., Valin, H., Fritz, S., Fuss, S., Kindermann, G., McCallum, I., Khabarov, N., Böttcher, H., See, L., Aoki, K., Schmid, E., Máthé, L., Obersteiner, M., 2013. Global bioenergy scenarios—future forest development, land-use implications, and trade-offs. Biomass Bioenergy 57, 86–96.
Kroese, D.P., Taimre, T., Botev, Z.I., 2011. Handbook of Monte Carlo Methods. John Wiley and Sons, New York 772 pp.
Kubiszewski, I., Costanza, R., Dorji, L., Thoennes, P., Tshering, K., 2013. An initial estimate of the value of ecosystem services in Bhutan. Ecosyst. Serv. 3, e11–e21.
Lamarque, P., Quétier, F., Lavorel, S., 2011. The diversity of the ecosystem services concept and its implications for their assessment and management. Comptes Rendus Biol. 334, 441–449.
La Notte, A., Maes, J., Grizzetti, B., Bouraoui, F., Zulian, G., 2012. Spatially explicit monetary valuation of water purification services in the Mediterranean biogeographical region. Int J. Bio. Sci. Ecosyst. Serv. Manage. 8, 26–34.
Limburg, K.E., O'Neill, R.V., Costanza, R., Farber, S., 2002. Complex systems and valuation. Ecol. Econ. 41, 409–420.
MA (Millennium Ecosystem Assessment), 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington D.C., World Resources Institute. 137 pp.
Maes, J., Egoh, B., Willemen, L., Liquete, C., Vihervaara, P., Schägner, J., Grizzetti, B., Drakou, E.G., La Notte, A., Zulian, G., Bouraoui, F., Paracchini, M.L., Braat, L.C., Bidoglio, G., 2012. Mapping ecosystem services for policy support and decision making in the European Union. Ecosyst. Serv. 1, 31–39.
Marchetti, M., Panizza, M., 2001. Geomorphology and environmental impact assessment: a case study in Moena (Dolomites—Italy). In: Marchetti, M., Rivas, V. (Eds.), Geomorphology and Environmental Impact Assessment. Swets & Zeitlinger B.V.In: Marchetti, M., Rivas, V. (Eds.), Geomorphology and Environmental Impact Assessment. Swets & Zeitlinger B.V. 235 pp.
Matero, J., Saastamoinen, O., 2007. In search of marginal environmental valuations—ecosystem services in Finnish forest accounting. Ecol. Econ. 61, 101–114.
Merlo, M., Croitoru, L. (Eds.), 2005. Valuing Mediterranean Forests, Towards Total Economic Value. CABI Publishing, Oxford, UK, Cambridge, MA, USA. 406 pp.
Metropolis, N., Ulam, S., 1949. The Monte Carlo method. J. Am. Stat. Assoc. 44, 335–341.
Müller, F., 2005. Indicating ecosystem and landscape organization. Ecol. Indicat. 5, 280–294.
Notaro, S., Paletto, A., 2012. The economic valuation of natural hazards in mountain forests: an approach based on the replacement cost method. J. Forest Econ. 18, 318–328.
Notaro, S., Paletto, A., Raffaelli, R., 2008. The economic valuation of non-productive forest functions as an instrument towards integrated forest management. In: Cesaro, L., Gatto, P., Pettenella, D. (Eds.), 2008. The Multifunctional Role of Forests—Policies, Methods and Case Studies. EFI Proceedings No. 55.
Nunes, P.A.L.D., van den Bergh, J.C.J.M., 2001. Economic valuation of biodiversity: sense or nonsense? Ecol. Econ. 39, 203–222.
Olschewski, R., Bebi, P., Teich, M., Wissen Hayek, U., Grêt-Regamey, A., 2012. Avalanche protection by forests—a choice experiment in the Swiss Alps. Forest Policy Econ. 15, 108–113.
Olschewski, R., Klein, A-M., Tscharntke, T., 2010. Economic trade-offs between carbon sequestration, timber production, and crop pollination in tropical forested landscapes. Ecol. Complex. 7, 314–319.
PAT, 2014. Produzione lorda vendibile dei frutti di bosco (2009-2010-2011)—Valori a prezzi correnti. Statistics Office of the Autonomous Province of Trento.
PAT, 2011a. Relazione annuale sull'andamento della commercializzazione del legname in Provincia di Trento—anno 2010. Camera di Commercio Industria Artigianato e Agricoltura di Trento. Autonomous Province of Trento.
PAT, 2011b. Elenco prezzi della Provincia di Trento. Opere di Valorizzazione Ambientale and Opere di Prevenzione Rischi. Autonomous Province of Trento.
PAT, 2010a. Piani economici forestali. Archivio generale. Autonomous Province of Trento.
PAT, 2010b. Official database of direct protection of forests. Ufficio Pianificazione e selvicoltura, Servizio foreste e fauna, Autonomous Province of Trento.
Pearce, D.W., 2001. The economic value of forest ecosystems. Ecosyst. Health 7, 284–296.

Pearce, D.W., 1993. Economic Values and the Natural World. MIT Press, Cambridge, MA 143 pp.
Remme, R.P., Schröter, M., Lars Hein, L., 2014. Developing spatial biophysical accounting for multiple ecosystem services. Ecosyst. Serv. 10, 6–18.
Richardson, L., Loomis, J., Kroeger, T., Casey, F., 2014. The role of benefit transfer in ecosystem service valuation. Ecol. Econ. http://dxdoi.org/10.1016/j.ecolecon.2014.02.018, in press.
Riera, P., Signorello, G., Thiene, M., Mahieu, P.-A., Navrud, S., Kaval, P., et al., 2012. Non-market valuation of forest goods and services: good practice guidelines. J. Forest Econ. 18, 259–270.
Primmer, E., Furman, E., 2012. Operationalising ecosystem service approaches for governance: do measuring, mapping and valuing integrate sector-specific knowledge systems? Ecosyst. Serv. 1, 85–92.
Pyörälä, P., Kellomäki, S., Peltola, H., 2012. Effects of management on biomass production in Norway spruce stands and carbon balance of bioenergy use. Forest Ecol. Manage. 275, 87–97.
Sacchelli, S., Bernetti, I., De Meo, I., Fiori, L., Paletto, A., Zambelli, P., Ciolli, M., 2014. Matching socio-economic and environmental efficiency of wood-residues energy chain: a partial equilibrium model for a case study in Alpine area. J. Clean. Prod. 66, 431–442.
Sacchelli, S., De Meo, I., Paletto, A., 2013. Bioenergy production and forest multifunctionality: a trade-off analysis using multiscale GIS model in a case study in Italy. Appl. Energy 104, 10–20.
Schröter, M., Barton, D.N., Remme, R.P., Hein, L., 2014. Accounting for capacity and flow of ecosystem services: a conceptual model and a case study for Telemark, Norway. Ecol. Indicat. 36, 539–551.
Schägner, J.P., Brander, L., Maes, J., Hartje, V., 2013. Mapping ecosystem services' values: current practice and future prospects. Ecosyst. Serv. 4, 33–46.
Seely, B., Welham, C., Kimmins, H., 2002. Carbon sequestration in a boreal forest ecosystem: results from the ecosystem simulation model, FORECAST. Forest Ecol. Manage. 169, 123–135.
Seidl, R., Rammer, W., Jäger, D., Currie, W.S., Lexer, M.J., 2007. Assessing trade-offs between carbon sequestration and timber production within a framework of multi-purpose forestry in Austria. Forest Ecol. Manage. 248, 64–79.
Seppelt, R., Fath, B., Burkhard, B., Fisher, J.L., Grêt-Regamey, A., Lautenbach, S., Pert, P., Hotes, S., Spangenberg, J., Verburg, P.H., Van Oudenhoven, A.P.E., 2012. Form follows function? Proposing a blueprint for ecosystem service assessments based on reviews and case studies. Ecol. Indicat. 21, 145–154.
Sivia, D.S., 1996. Data Analysis. A Bayesian Tutorial. Oxford Science Publication 208 pp.
Spangenberg, J., Settele, J., 2010. Precisely incorrect? Monetising the value of ecosystem services. Ecol. Complex. 7, 327–337.
TEEB, 2010. In: Kumar, Pushpam (Ed.), The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundation. Earthscan, Cambridge.
Teich, M., Bebi, P., 2009. Evaluating the benefit of avalanche protection forest with GIS-based risk analyses—a case study in Switzerland. Forest Policy Manage. 257, 1910–1919.
Tonolli, S., Salvagni, F. (Eds.), 2007. InFoCarb—Inventario Forestale del Carbonio della Provincia di Trento. Centro di Ecologia Alpina, Trento 176 pp.
Ulgiati, S., Zucaro, A., Franzese, P.P., 2011. Shared wealth or nobody's land? The worth of natural capital and ecosystem services. Ecol. Econ. 70, 778–787.
Valente, C., Spinelli, R.C., Hillring, B.G., 2011. LCA of environmental and socio-economic impacts related to wood energy production in alpine conditions: Valle di Fiemme (Italy). J. Clean. Prod. 19, 1931–1938.
van Berkel, D.B., Verburg, P.H., 2014. Spatial quantification and valuation of cultural ecosystem services in an agricultural landscape. Ecol. Indicat. 37 (Part A), 163–174.
Viglia, S., Nienartowicz, A., Kunz, M., Franzese, P.P., 2013. Integrating environmental accounting, life cycle and ecosystem services assessment. J. Environ. Account. Manage. 1, 307–319.
Vihervaara, P., Kumpula, T., Tanskanen, A., Burkhard, B., 2010. Ecosystem services—a tool for sustainable management of human–environment systems. Case study Finnish Forest Lapland. Ecol. Complex. 7, 410–420.
Wilson, M.A., Hoehn, J.P., 2006. Valuing environmental goods and services using benefit transfer: the state-of-the art and science. Ecol. Econ. 60, 335–342.
World Bank, 2010. State and Trends of the Carbon Market. World Bank, Washington, DC p. 2010.
Zambelli, P., Lora, C., Spinelli, R., Tattoni, C., Vitti, A., Zatelli, P., Ciolli, M., 2012. A GIS decision support system for regional forest management to assess biomass availability for renewable energy production. Environ. Modell. Software 38, 203–213.
Zandersen, M., Tol, R.S.J., 2009. A meta-analysis of forest recreation values in Europe. J. Forest Econ. 15, 109–130.