Quantification of the total economic value of forest systems: spatial

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Quantification of the total economic value of forest systems: spatial analysis application to the region of Tuscany (Italy)

In forest sector several practical applications need to consider the monetary value of social utility for each specific location and forest function. In this framework the aim of the paper is to implement a spatial analysis model able to link a set of methodologies for the quantification of the total economic value of the forests. The main characteristic of the proposed methodology is the achievement of a geographical dataset with high resolution that can be used for both ex-ante and ex-post Cost-Benefit Analysis and the improvement of spatially explicit forest planning and policy. The results of the application show that spatial analysis methodologies allow the aggregation of several variables and also facilitate the introduction of natural capital concepts into environmental decision-making processes. The analysis is implemented and verified in Tuscany region (central Italy).

Introduction

The Total Economic Value may be strongly diversified in relation to the ecological, geomorphological and geographical characteristics of the forest.

The different methods for the evaluation of the environmental benefits – *hedonic price, travel cost method, contingent valuation* – are generally related, although not in a geo-referred way, to wide forest and territorial areas (see e.g., Bishop and Romano, 1998; Kant, 2003; Signorello, 2007). In addition, the high application cost of these procedures limits their use to just a few forest lands with a recognised high value.

The application of *benefit transfer* procedures represents the first attempt to solve the issue of spatialisation with a high resolution of social utility values. Eade and Moran (1996) and Lovett *et al.* (1997) suggested and applied procedures that use a Territorial Informative System for modelisation of environmental values in an efficacious spatial way. The most advanced applications are based on meta-analysis approaches that also incorporate geographic variables (Nelson and Kennedy, 2009; Zandersen and Tol, 2009). The need to also consider the socio-economic variables, which are generally available on a minimal spatial scale of census data (the municipality), limits the potential spatial disaggregation of the values.

In the most recent applications, the non-monetary evaluation methods (expert systems, Cost-Benefit Analysis, Decision Support Systems) are instead able to assign a cardinal index to evaluation that is geo-referred and diversified on the basis of forest characteristics and the available dataset (Hill and Courtney, 2006; Gimona and Van der Horst, 2007). However, this evaluation cannot be used when the application is the measurement of monetary value, as in the case of the Cost-Benefit Analysis for evaluation of the efficient allocation of public expenditure. Moreover, these methods are often based on empirical-subjective properties and lack explicit descriptions of the uncertainty related to these evaluations.

Recently, the international literature began to give increasing attention to the so-called value of "spatialisation" of social utilities. Spatial disaggregation allows for the appreciation of the geographic distribution of the environmental values and the overlapping of these values with other relevant information at the geographic level (e.g. risk maps). The applicative potentialities of this approach are firstly discussed by Van der Horst (2006). More recently, Baerenklau *et al.* (2010) realised an application for the spatial allocation of the use values for hiking, even though the only variable considered at the territorial level was the width of the panoramic view.

Lastly, it is possible to cite the approach of the "spatial discount", which transfers to the geographic space the traditional concept of the inter-temporal preference rate (Perrings and Hannon, 2001; Brown *et al.* 2002; Heidkamp, 2008); however, the issue related to the determination of the value of that rate remains widely unsolved.

This paper aims at implement a spatial analysis model able to link a set of methodologies for the quantification of the total economic value of the forests systems. The present research focuses on the realisation of an high resolution geographical dataset useful for ex-ante and ex-post cost-benefit analysis and to improve spatially explicit forest planning and policy. The analysis is applied for Tuscany region (central Italy).

Study area

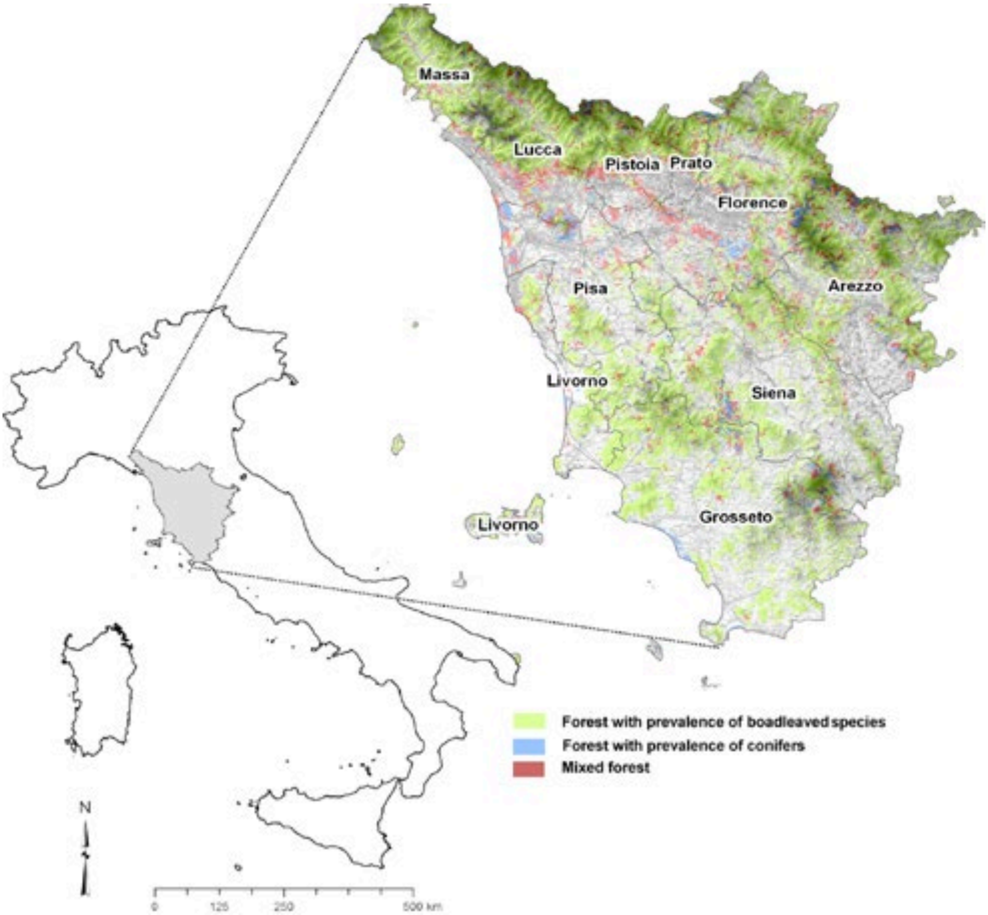
The forest area of Tuscany covers approximately 1,151,539 hectares (INFC, 2005), equal to the 47% of the regional territory (Fig. 1). The species comprised in the forests are mainly deciduous oaks (Turkey oak – *Quercus cerris* L. –, Downy oak – *Quercus pubescens* Willd.) covering 414,000 hectares, equal to 38% of the total forest area. From forest treatment point of view, there is the marked prevalence of coppices compared with high forest, which nonetheless represents more than 176,000 hectares in the mountain stands, most notably in the beech forests of public property.

Approximately 10% of the regional territory in Tuscany (230,000 hectares), is covered by parks and protected areas.

The geographical data used for the evaluation were as follows:

- forest areas extracted from the geo-database of land use Corine Land Cover 2006;
- geo-database of the European, national, regional and local protected areas;
- road maps;
- Digital Elevation Model (DEM) and the Digital Terrain Model (DTM);

Figure 1. Study area and forest typology localisation.



- National Ecological Network;
- geolithological maps;
- population density map.

The geo-databases are organised by a square grid-based spatial model with a side of 100 metres.

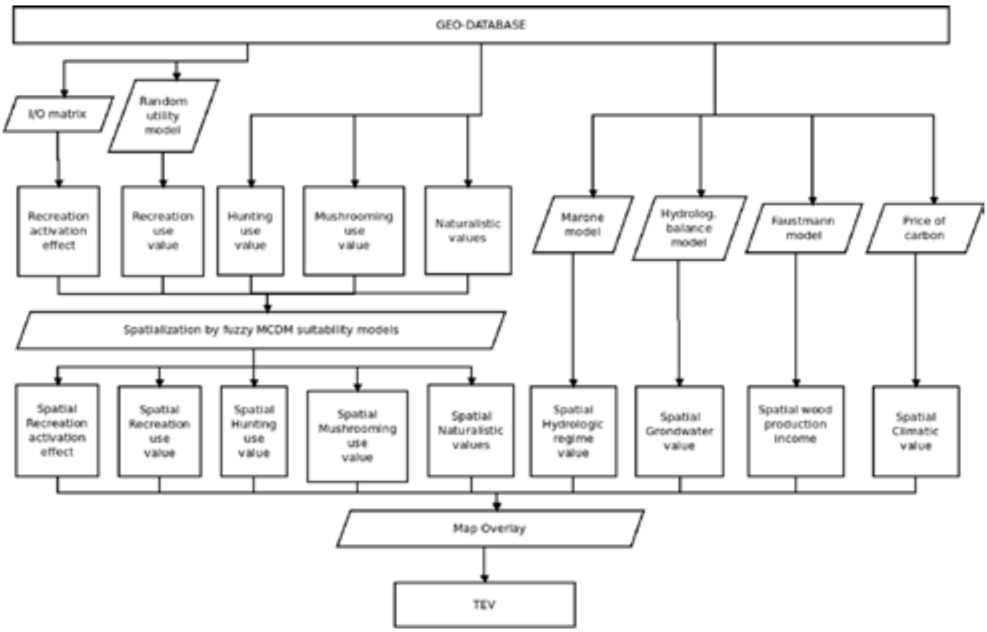
Applied methodologies

Economists typically classify ecosystem goods and services according to how they are used. The main framework used is the Total Economic Value (TEV) approach (Pearce and Warford, 1993). The terminology varies among Authors, but it generally includes: (i) the direct use value; (ii) the indirect use value; (iii) optional value; and (iv) non-use value. Many methods for measuring the utilitarian values of ecosystem services are found in the resource and environmental economics literature (Pearce, 2001; Riera *et al*., 2012). Some evaluation techniques provide values that are already spatialised. Others provide results related to a large spatial area (protected area, administration, etc.). For the latter, the spatialisation is carried out by spreading the monetarily valued results in proportion to the dimensionless spatial fuzzy multiple-criteria suitability model.

Following the approach used in Voces Gonzáles *et al.* (2010) for the estimation of recreational value in forest stands, the applied methodology mainly uses previously available information and results and provides a series of technique for the spatialisation of economic values.

The following sections summarise the procedures used for each evaluation (see the "Supporting information" for more details). The flow chart of the process is showed in Fig. 2.

Figure 2. Flow chart of applied process.



The recreational value

The recreational value of the forests of Tuscany comes from different activities. The main ones are recreational activity and naturalistic tourism in the parks, reserves and other protected areas in addition to hunting and mushrooming activities. Each of these activities requires a different estimation method.

Recreation in the parks and protected areas

Following one of the most recent approaches shown in the existing literature, the estimation of the recreational value in the parks and protected areas is obtained using a Random Utility Travel Cost Method (RUTCM). For the assessment of the multivariate demand functions in each protected area, two probabilistic choice models based on the Random Utility and on the Stochastic Utility realised by Ferrini (2002) were used for the protected areas of Tuscany. The strength of the RUTCM over conventional travel cost models is its ability to account for substitutes in the demand model and, in addition, the valuation of intervening opportunities and capacity issues (Smirnov and Egan, 2012). The implemented procedure is explained in Appendices A.1.1.1 and A.1.1.2.

The impact of the tourist expenditure on the local economy

Considering the research on the impact determined by the tourist demand linked to the presence of a park, it was verified that the structure of the *regional matrixes* gives the best results (Casini and Marone, 1996). The regional matrixes, in addition to being available for the entire national territory, allow the complete evaluation of the effects of the visitors' consumption. They consider both local products and services and products that are not necessarily associated with the site but that are most likely linked to the regional economic system (for instance, the consumption of wine and oil, which are not produced on site in the parks of Tuscany).

In this case, on one hand, the use of the matrixes for the description of the productive structure linked to smaller territories is able to show the effects on the local economy with a greater accuracy. On the other hand, there is a risk related to the non-evaluation of the effects of extra-local consumption. However, studies on several expenditure vectors in the parks relative to different locations in the national territory showed that consumption is linked to the productive area. This area generally coincides with the region in which the park is located (Bernetti and Marone, 2000). Thus, the validity of choosing the regional matrixes is confirmed.

On the basis of the data obtained by the above mentioned study, it was possible to determine the multiplicative coefficients for the expenditure unit and for the number of visits in relation to both the direct and indirect effects and the induced effects. The multiplicative coefficients for the expenditure unit and the spatialisation methodology of indirect and induced effects of the recreational expenditure are reported in Appendix A.1.1.3.

The value of hunting activity

The total value of hunting activity for the regional agro-forest resources was calculated using the results of a study on the willingness to pay (WTP) per hunter and per year in the province of Florence (Tuscany) (Romano *et al.*, 2005). The value derived from that study was adjusted for the current year and was then multiplied by the number of operant hunters in Tuscany (Bidini, 2010). Thus, the total value of the social utility of hunting activity was spatialised proportionally to the ecological suitability of the species of interest, which were calculated by aggregating the geo-databases obtained through the project National Ecological Network (Boitani *et al.*, 2002) (see Appendix A.1.1.4).

The recreational value of mushrooming

The first phase of the evaluation was, as for the previous case, the identification of the total value of the social utility for the entire region. This derived from the multiplication among total mushroom hunters in Tuscany, the average working days per person spent gathering and the willingness to pay per workday (this last value was estimated on the basis of the daily cost for the gathering authorisation, taking into consideration the enforced regional regulations). The spatialisation of the total value was performed on the basis of a fuzzy suitability map for the different fungal species of the genre *boletus* that can be gathered in Tuscany (approach of ecological niche detection). The result is an index of the ecological suitability for mushrooms production. The fuzzy functions used are based on climate, forest typology and geomorphology parameters. The fuzzy functions and the spatialisation method were reported in the Appendix A.1.1.5.

The naturalistic value

Simplifying the extensive national and international literature for the aim of this paper (Randall and Stoll, 1983; Fisher and Raucher, 1984; Boyle and Bishop, 1987; Ten Brink *et al.*, 2000; Freeman, 2003; Menghini, 2006), the estimation of the naturalistic value with a monetary measurement unit represents a "non use" value related to ethical motivations. As such, within a contingent valuation, it cannot be detected with high-resolution spatial reference. However, the landscape and spatial ecology demonstrate how the naturalistic and environmental aspects of a forest can be evaluated on the basis of numerous indicators that take into account the effects of the geographic characteristics linked to each localisation (see e.g., Cornes and Sandler, 1986; Brun, 2002).

In an attempt to valorise the informative contents of the two approaches and to consider the present and available information, the proposed methodology is based on the following hypotheses:

- the willingness to pay for the preservation of the biodiversity of the regional forest ecosystems can be estimated based on results described in the existing European literature. Specific regional studies are not available, and few studies at the national level have been carried out;
- this individual willingness to pay is assigned without distinction to the regional forest resources as a whole;
- the existing value per hectare – unknown – of a single location depends on the ecological and geomorphologic characteristics of the location itself and on the geographic surroundings.

On the basis of these hypotheses, the estimation of the naturalistic value can be handled by spatialising the total willingness to pay of the resident population of Tuscany as a function of the value of an adequate set of indicators for the ecological value, which are available in the literature.

The main review on the willingness to pay for biodiversity's conservation in Europe has been performed in the *Technical Report on Biodiversity in Europe* presented within the project *"European Environmental Priorities: an integrated economic and environmental assessment "* (Ten Brink *et al.*, 2000).

Based on this reference, the naturalistic value of the forest resources is broken down according to the following taxonomy: (i) biodiversity value; (ii) ecological value; (iii) value given to endangered species. The full methodology for naturalistic value estimation is highlighted in Appendix A.1.2.

The evaluation of service for water flow control

The evaluation of the hydrologic regime service has been extensively studied (Asciuto *et al.*, 1988; Corrado, 1988; Guo *et al.*, 2001; Merlo and Croitoru, 2005; Brauman *et al.*, 2007). The most used approaches, besides the direct methods, are: i) the cost value referred to the damages from a disaster that may be prevented and ii) the subrogation value calculated in relation to the damage prevention efforts that would be necessary to "subrogate" the effect of the forest cover.

In the present paper, the chosen methodology was the subrogation cost, which was easier to determine and had a broader applicability on a regional scale. The hypotheses at the basis of the estimation are as follows:

- the presence of the forest determines the potential for flood retention; in the case of the absence of forest, specific hydraulic engineering measures should be implemented to protect overflowing areas;
- the hydraulic structure of the reference was the dry detention basins. Thus, the social utility value is calculated as a yearly cost that should be paid to subrogate the presence of the forest with an adequate system of expansion cases.

At methodological level, the phases are as follows (see Appendix A.1.3 for more details):

- for each catchment basin, the surface runoffs were calculated with and without forest. Surface runoffs are related to exceptional events registered by the network of weather stations of the Regional Agency for Agricultural Development and Innovation of Tuscany;
- for each catchment basin, determination of the approximate size of a system of expansion cases in the overflowing areas, capable of draining the difference in the flow due to the forest, was carried out;
- the total yearly cost (expropriation, construction, maintenance, loss of incomes) for the system of cases was calculated;
- the total subrogation cost and the yearly cost were assigned to each pixel in proportion to the quantity of water retention due to the presence of the forest.

The estimation of the value of the drinking water service

The literature analysis stresses a set of quantitative and qualitative application for the drinking water service estimation (see e.g., Cordero Camacho, 2008). In the present paper the applied method is based on the hypothesis that the best alternative to the water-bearing stratum is the water supply stored in artificial basins. The spatialisation of the water storage service was carried out on the basis of the contribution of the forest cover water balance to the production of the drinkable water. The process was achieved in two phases (see Appendix A.1.4). Firstly, using the method of the reversed water balance, the water balance of a single forest location was calculated (Civita *et al.*, 1999). Then, in order to calculated drinking water service value, the subrogation price per cubic meter was applied. For the estimation of the subrogation price, a recent review of the applications for the evaluation of the social utility relative to the recovery cycle for the service of the water bearing stratum was carried out by Pettenella and Secco (2006). The Authors present many valuations, with relevant studies based on direct approaches (contingent valuation), defensive expenses, production costs and subrogation value. The range of results obtained is quite wide: from 0.0009 to 260 €/m^3. In this case study, on the basis of data available in CISPEL (2008), the storing cost of water in the new catchment basins in Tuscany can be estimated as 0.33 €/m^3.

Wood production

The net income value of the wood production was calculated by converting the capital value of the forest cover, obtained with the classic Faustmann formula, into a yearly value. To achieve the estimation with automatic procedures that could be applied quickly to the entire regional area, the following simplifications were adopted. As for the coppice stands the capital value was calculated on the basis of only the final cut, without considering intermediate thinning.

As for the high forests of public property and those inside parks and reserves, the realisation of a curative cutting with a periodicity *c* and natural reproduction was considered.

Lastly, for the high forests on private properties, not located in protected areas, intermediate cuttings were not considered, but only the reproduction expenses.

The stumpage value was estimated on the basis of the potential timber assortments from the forests of the referred area, as a function of the productive processes and of the silvicultural and forest utilisation interventions, as well as on the basis of the selling prices registered in the internal market. For this purpose, not only the ecological characteristics were taken into account, but also the technical, logistic and economic variables were considered on the basis of the methodology presented in Bernetti *et al*. (2009).

The values of the forest were then capitalized (see Appendix A.1.5).

Protection from climatic change

Forests are of great importance in the reduction of carbon dioxide present in the atmosphere and, as a consequence, in climate change mitigation (Binkley *et al.*, 2002). The function of protection from climatic changes can be quantified through the fixing activity of the stored carbon inside the trees and thus not freed in the atmosphere. The catching of carbon dioxide is described in terms of the yearly amount of collected CO_2 in the aerial and underground parts of the plant (Trexler, 1991). Therefore the caught quantity depends on growth and on mortality, which in turn depend on the species, the age, the structure and on degree of health of the forest. The spatialisation of the annual benefits, in terms of CO_2 fixation, was developed considering the wood biomass increment, the Biomass Expansion Factor – BEF (Garzuglia and Saket, 2003) and the price of carbon (Euro-Mediterranean Centre for Climate Change, 2011) (see Appendix A.1.6).

Results

Spatialised value per forest function

Fig. 3a shows the economic value of the tourist-recreational function for Tuscany forests. The quantification was achieved by summing the tourist values in the protected areas and the recreational values related to hunting and mushrooming. The legend of the map is based on the quantiles of the frequency distribution (see Appendix A.2).

As evidently shown by the percentile diagram, the distribution is strongly asymmetrical, with a long tail pointing towards the highest values, representing the forests in the protected areas. These zones are mainly located in areas with high tourist activity (low slope, suitable typology of stand and proximity to roads).

Total recreational value shows a difference for the forests located in protected and non-protected areas, with a median value equal to 467 and 56 €/ha*year^{-1}, respectively.

Fig. 3b shows the graphs regarding the statistics of the distribution of the naturalistic values. In spite of a range of possible variation fluctuating from a minimum of 3 and a maximum of approximately 400 €/ha*year^{-1}, most of the values are centred around the range of 93 and 168 €/ha*year^{-1}, with the median value shifted towards 105 €/ha*year^{-1}. The frequency distribution is quite asymmetrical with a greater tail toward the higher values.

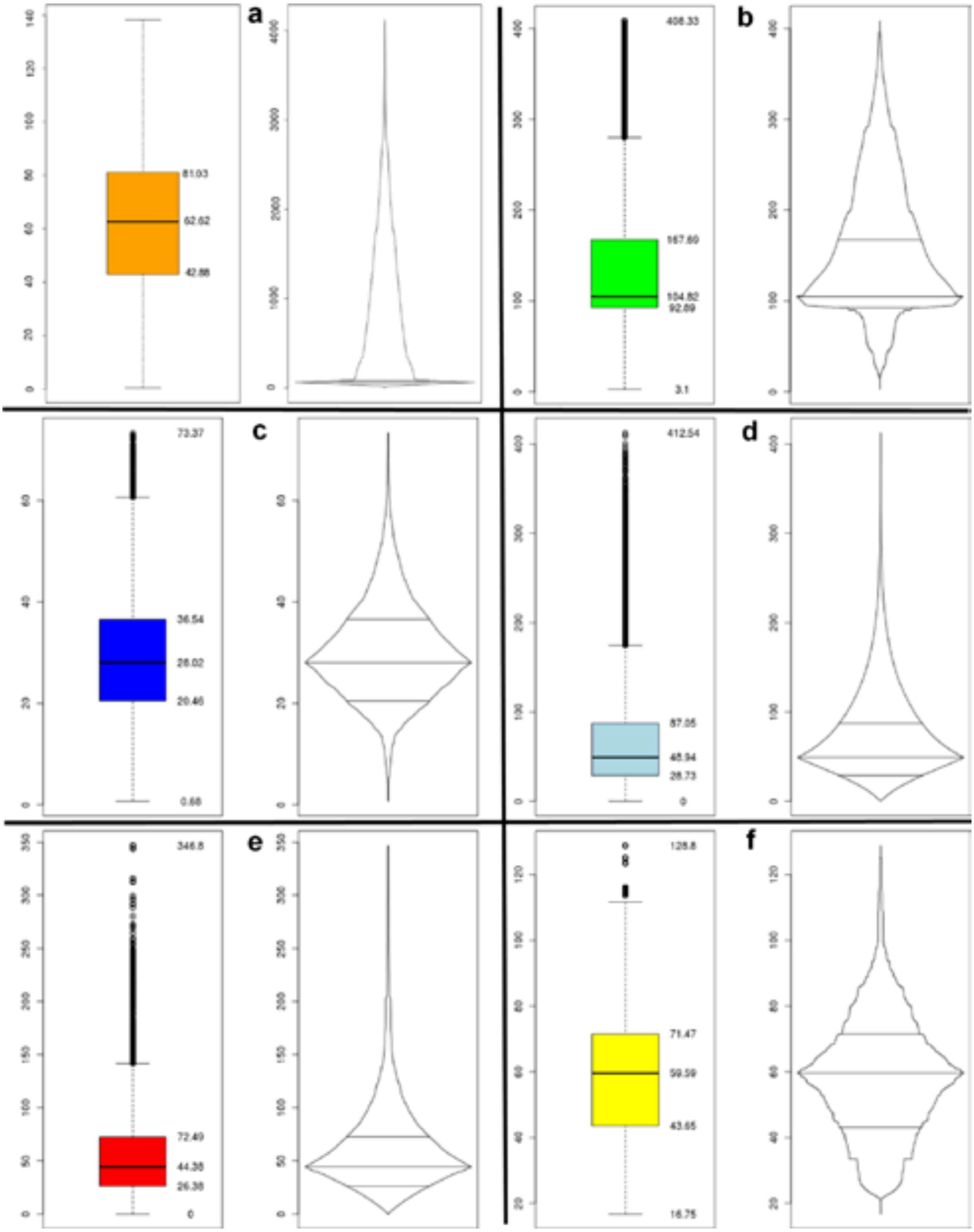
Most of the water flow regime values of Tuscany forests belong to the range 20-37 €/ha*year^{-1}, with a median value of approximately 28 €/ha*year^{-1} (Fig. 3c) and, as consequence, a quite symmetrical distribution.

The most of the values of drinking water production in Tuscany forests are centred between 29 and 87 €/ha*year^{-1}, with a median value of 49 €/ha*year^{-1} and a maximum value of over 400 €/ha*year^{-1} (Fig. 3d).

The frequency distribution of the wood production values is characterised by the following parameters: 1st and 3rd quartile 26 and 72 €/ha*year^{-1}, respectively with a median of 44 €/ha*year^{-1} (Fig. 3e).

Finally, the frequency distribution of the protection from climatic change value is quite symmetric, with a median of approximately 60 €/ha*year^{-1} and 1st and 3rd quartile of 44 and 71 €/ha*year^{-1}, respectively (Fig. 3f).

Figure 3. Frequency distribution of economic value for single forest function (€/ha*year^{-1}).

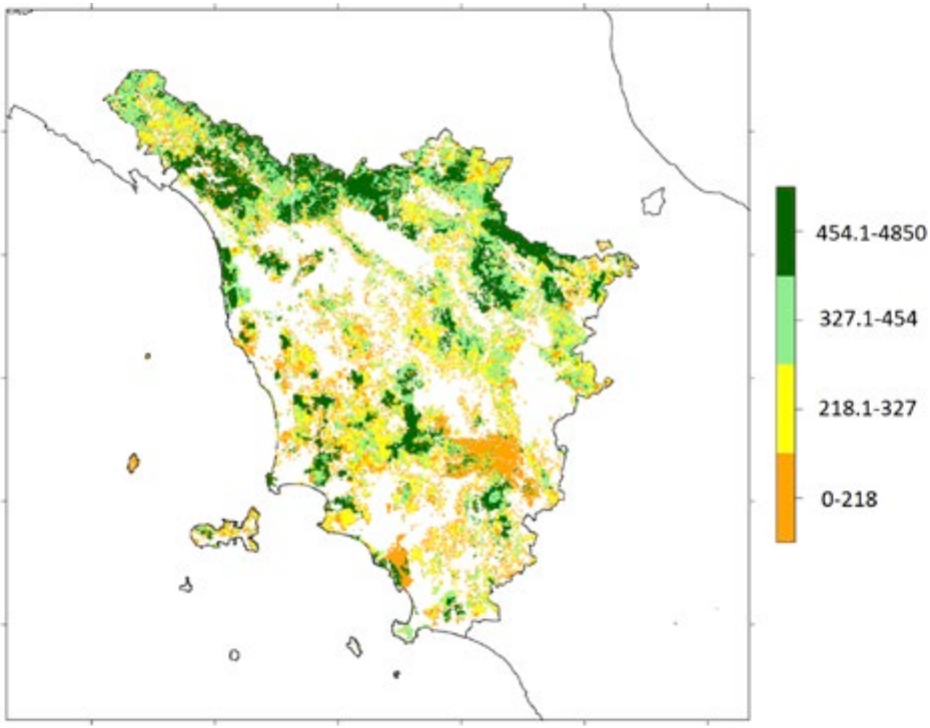


Total Economic Value

The calculation of TEV for each localisation was performed by summing the previous forest function's values through a map overlay. The hypothesis of additive components of total economic value derives from the utilitarian theory, which is the most common in the literature. It is derived from the neoclassical economic paradigm of the Cost-Benefit tools (for a critique of the pros and cons of Cost-Benefit Analysis in the context of ecosystem services see Randall, 1991 and Wegner and Pascual, 2011).

Fig. 4 highlights the overall ranged spatialisation obtained from a raster geodatum with a resolution of 100 metres.

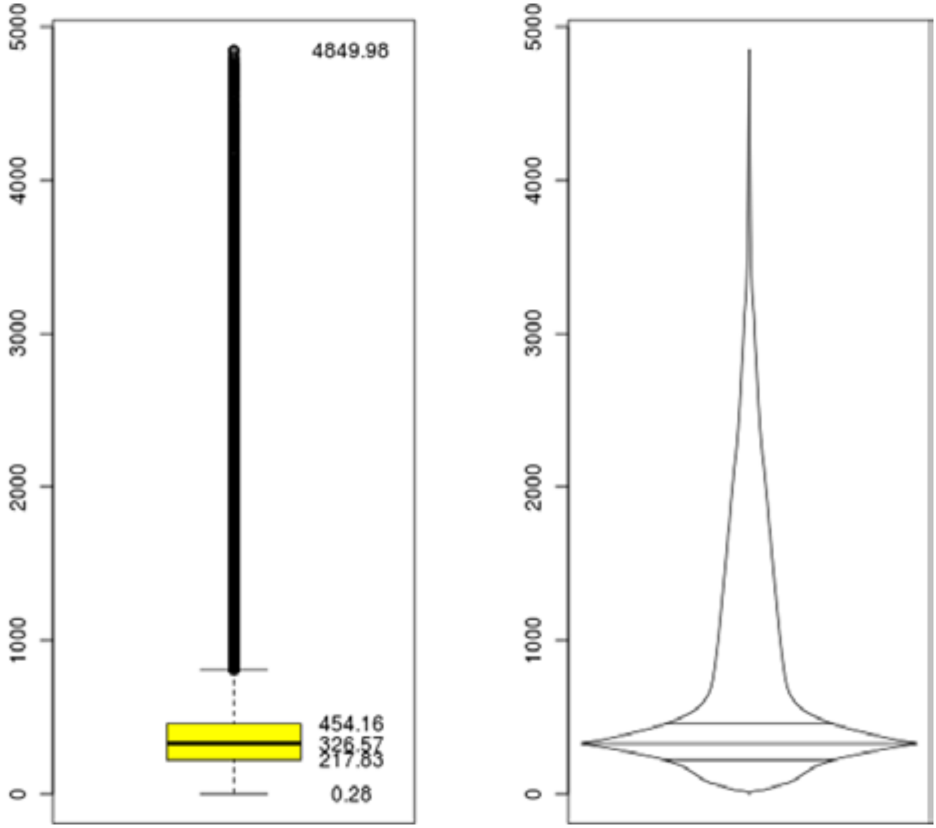
Figure 4. Map of the Total Economic Value (€/ha*year^{-1}).



The spatial analysis highlights how the main part of TEV is localised in the Apennines (mountains in the North of the region) and other mountainous area. An additional component is concentrated in hilly and planar forests characterized by high recreational and naturalistic value.

As a whole, the Tuscany forests produce services of social utility for a total amount of 547,832,636 €/year (1st, 2nd and 3rd quartile equal to 218, 327 and 454 €/ha*year^{-1}, respectively – Fig. 5).

Figure 5. Frequency distribution of the Total Economic Value (€/ha*year^{-1}).



From Table 1, it is possible to observe that the greater contribution to TEV is given by the recreational values (47%, subdivided in 22% from visits to protected areas, 15% from economic activation effect and 10% from hunting and mushrooming activities). Naturalistic value reaches 24% of TEV. The wood production value, the main value perceived by the owner of the forest, represents only 4% of TEV. The composition of TEV is quite different for the protected area if compared to the non-protected territory: in the first case, the recreational values prevail (80%), while in the non-protected territory, the greatest contribution is given by the naturalistic (34%), the climatic (16%) and the groundwater (15%) values. As for the median value per hectare, it is possible to confirm that the protected areas mainly have a recreational function.

From a forest typology viewpoint, the greater TEV contribution is given by the hill forests of oaks (Turkey oak and Downy oak), chestnut (*Castanea sativa* Miller) and mixed forests of conifers and broadleaved trees. In terms of value per hectare, the forests with a higher TEV are the fir stands with a median value of approximately 780 €/ha*year-1, followed by the beech (*Fagus sylvatica* L.) forests with a median of 534 €/ha*year-1.

Table 1. TEV per species and per function.

		Total forest			Protected area		Non protected area	
		€	%	Median €/ ha*year-1	%	Median €/ ha*year-1	%	Median €/ ha*year-1
Forest typology	Beech	82,199,298	15.0	534	21.7	2189	9.3	459
	Chestnut	119,671,952	21.8	445	21.4	1951	22.3	424
	Firs	5,937,514	1.1	780	1.5	2838	0.7	653
	Hill oaks	137,350,777	25.1	309	13.2	888	35.1	303
	Mediterranean oaks	51,970,221	9.5	275	11.6	557	7.7	238
	Mediterranean pines	22,267,526	4.1	480	5.7	2899	2.7	405
	Mixed woods	118,252,031	21.6	365	22.9	1976	20.5	342
	Mountain pines	9,237,038	1.7	511	1.8	1965	1.6	455
	Others	946,279	0.2	633	0.2	1722	0.2	568
Functions	Wood production	22,157,684	4.0	44	0.8	40	7.2	45
	Hydrological regime	26,507,562	4.8	28	1.6	27	7.5	28
	Groundwater	56,733,780	10.4	49	4.1	60	15.2	48
	Climatic	51,999,621	9.5	60	3.2	58	15.9	60
	Naturalistics	131,076,407	23.9	105	10.5	154	33.6	101
	Recreation	120,109,618	21.9	224	41.6	467	4.1	56
	Recreation induced effect	83,603,540	15.3	0	35.2	204	0.6	0
	Hunting	21,062,436	3.8	21	1.2	20	6.0	21
	Mushrooms	34,581,988	6.3	32	1.9	18	9.9	35

Discussion

The comparison among the above spatialised values and other published works demonstrate how recreational value are substantially consistent with the (scarce) national and international case history (Table 2). For the national case history, the value per hectare was obtained by dividing the total yearly benefit by the surface area: it must be noted that this value is not homogeneous with the results of the spatialisation, which take into account the local geographic specificities. The results presented by Baerenklau *et al.* (2010), even if obtained through a spatial analysis procedure that differs from the one applied in this paper, are more comparable. The estimation carried out in the above mentioned study produced relatively higher results, especially as for the median value. It takes into account only the social utility value, while in this application, the values relative to hunting, mushrooming and, above all, the indirect and induced effects of the tourist expenses are also considered. The values regarding only the tourist use are quite similar in this work and in Barenklau *et al.* (2010) with the only exception being the maximum value, which is much higher for the California estimation.

Table 2. Recreational value comparison among regional quantification and the National and International available data (€/ha*year^{-1}).

Area	Quantile				
	0%	25%	50%	75%	100%
Total forest area (Tuscany)	0	43	63	81	4,122
Protected area (Tuscany)	28	78	467	1,698	4,122
Protected area (Tuscany): only tourist value	0	0	133	782	2,319
National data	1	11	53	170	2,214
South California (Baerenklau et al. 2010)	29	--	121	751	7,258

It is not possible to make a comparison with other spatialisation of naturalistic value because these data are not available in literature. The only national study for which it is possible to determine a value per hectare related to a sufficiently defined geo-ecological situation is the one carried out by Romano (2002) for the existence value of the Bosnian Pine (*Pinus leucodermis* Antoine) in Parco del Pollino (Calabria region, Italy). This evaluation was performed through the direct detection of the WTP among the visitors of the park. By applying at that forest ecotype the same procedure used for the regional analysis, it is possible to obtain a naturalistic value of 1,977 €/ha*year^{-1}, that is considerably higher than the ones identified in this study. These differences are justifiable because Romano's research considers a unique and symbolic forest resource of very limited area as case study, while the application in Tuscany distributes the individual WTP over the entire regional area.

In an application of the subrogation value of water flow control on a limited area in the Simeto catchment basin (Sicily, Southern Italy), Asciuto *et al.* (1988) determined a capital value (not annualised) of 2,000 €/ha corresponding to approximately 40 €/ha*year^{-1} using a discount rate of 2%. This value is higher respect of our results but still comparable if keeping the same estimative conditions. It seems justifiable considering the foreseen subrogation interventions, which aim to also control erosion. In an application in China, Guo *et al.* (2001) report much lower values of approximately 2.6 US$/ha*year^{-1}. In a recent literature review Lele (2009), reports a range of extremely diversified values at the international level: from 4 to 2,000 US$/ha*year^{-1}.

The values of other forest functions seem not to be comparable with other case studies because of the absence of spatialised value in national and international literature.

Eventually, high forests seem to reach a greater median TEV than coppices: this aspect confirms results of other forest multifunctionality evaluation carried out in Italy (Paletto *et al.*, 2012).

The single TEV functions show a percentage contribution in the forest typology as follows (Fig. 6).

Mediterranean pines (Umbrella pine – *Pinus pinea* L., Maritime pine – *Pinus pinaster* Aiton, Aleppo pine – *Pinus halepensis* Mill.) reach their highest value for wood production and recreation (tourist visit). In these formations, the first function (wood production) is mainly concentrated in hilly stands, whereas tourist importance is associated to coastal forest (in particular in the Umbrella pine forests).

Spatial results highlight a great importance of the naturalistic value for Mediterranean oak (Holm oak – *Quercus ilex* L., cork oak – *Quercus suber* L.) forests, particularly if located in protected areas.

It is possible to define that, even though the runoff coefficient depends on soil permeability, slope and natural land use, the value of water flows control service also appears strictly related to areas with high population density. This is a consequence of the cost linked to the increasingly frequent works of construction and maintenance for the protection of local communities. Therefore, hydrogeological regime highlights high percentage on TEV for oak formations (Mediterranean and hilly oaks) due to the high value of population density near these stand typologies.

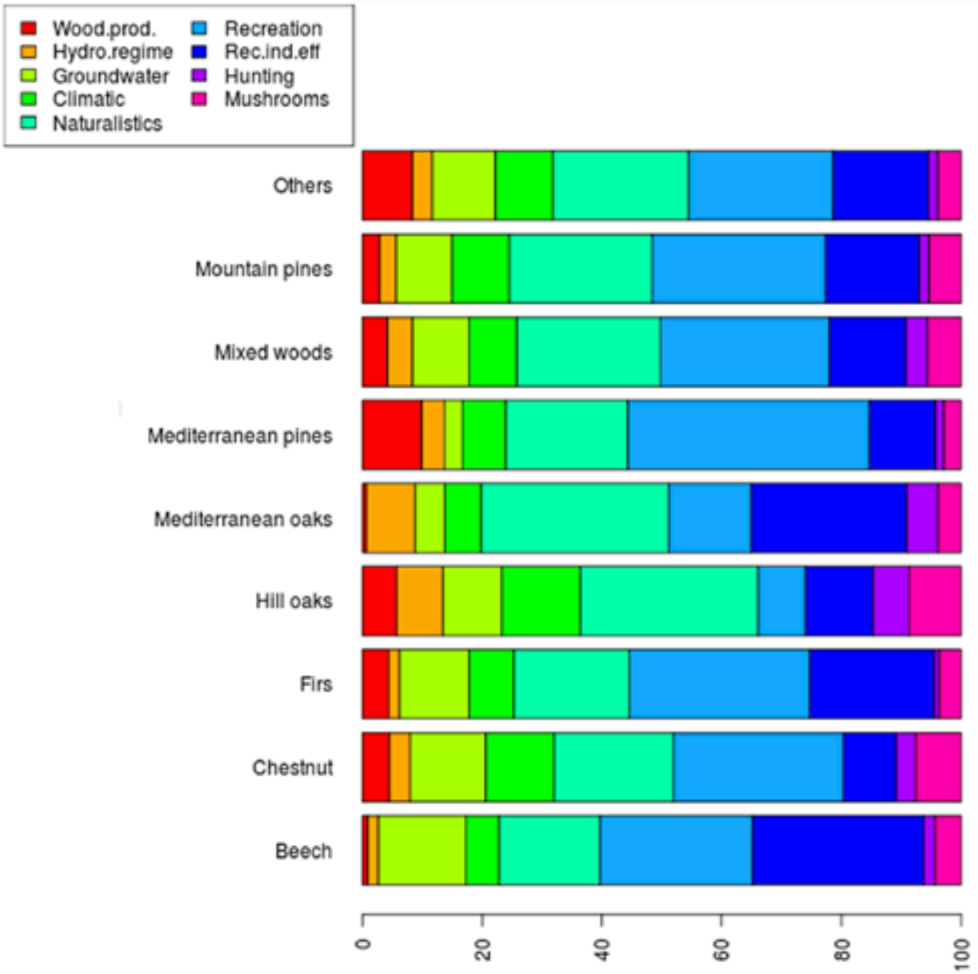
The combination between Biomass Expansion Factor and annual increase of forest typology is the fundamental parameter for the quantification of the value for climate change protection. This parameter appears consistent in hill oaks and chestnut forests according to their physiological characteristics. In these formations, mushroom production reaches the highest values too.

The drinking water production function seems to be a relevant issue in the Apennine forests, and in particular in beech stands. In these formations, a high contribution for induced tourist value is also evident.

The total economic value as decision support for forest policy: an example

The integration of TEV map with other map layers can form the kernel of a decision support system for forest policy and planning. The here presented example is the assessment of forest operations for climate change mitigation, through Cost-Benefit Analysis. The interventions will be efficient if the present value of benefits exceeds the present value of costs for damage prevention. In this case, given the great uncertainty about the effects of climate change, the benefits are the expected present value of avoided losses (in terms of total annual flow of economic value):

Figure 6. Percentage distribution of TEV components for forest typology.



$$EPV_i = p_i \cdot TEV_i \cdot \frac{(1+r)^x - 1}{r(1+r)^{x+c}} - C_i \quad (1)$$

where:
EPV_i: expected present value of avoided losses for the location *i*;
p_i: probability of losing the stand for effect of climate change;
TEV_i: total economic value;
r: interest rate;
c: year of forest loss;

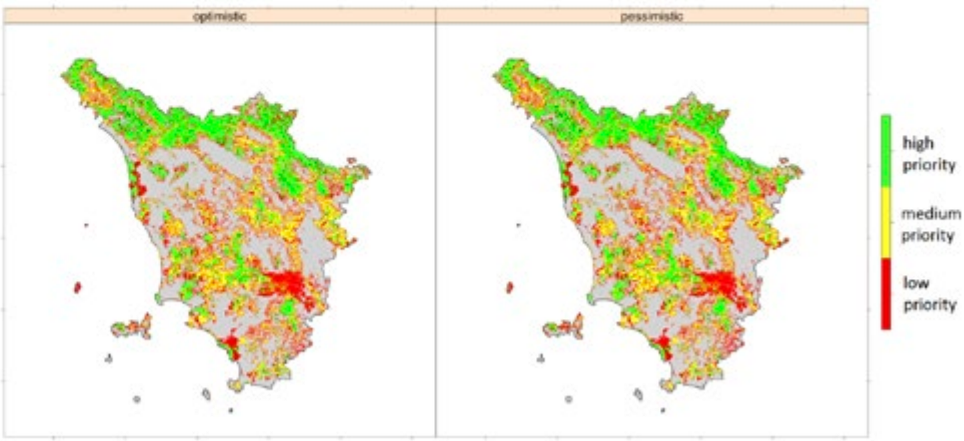
x: years required to restore the efficiency of the forest in terms of flow of total economic value;
C_i: cost of mitigation actions (e.g. thinning to avoid overstocked stands susceptible to increased mortality from drought, insects disease and wildfire) (Anderson and Chmura, 2009).

The map of forest loss probability for the Tuscany region was calculated according to methodology proposed by Bernetti *et al.* (2011). The probability referred to IPCC climate scenario for the year 2036. Regarding the two unknown parameters *x* and *c*, two scenarios were defined with respect to the present:

- pessimistic scenario: loss of forest at 2024 (c = 12 and x = 60 years);
- optimistic scenario: loss of forest at 2036 (c = 24 and x = 30 years).

For both scenarios, the locations with positive EPV were split, according to the 66th and 33th percentile in high, medium and low intervention priorities areas. Figure 7 shows that the two scenarios are basically identical. This is positive because the decisions of action do not seem to be sensitive to the most uncertain parameters (*x* and *c*), but depend on the spatial distribution of TEV and on the risk of climate change. The highest priority in both cases is located in the Apennine mountains.

Figure 7. Priority forest action in the climate change framework.



Conclusions

The spatial dimension of the total economic value of forestry has been investigated. The adoption of a spatial approach to economic valuation appears to be useful in terms of: i) producing more accurate economic valuation figures, ii) providing a repository for benefits estimates and iii) examining spatial sustainability of forest policy and interventions.

Several forest functions and potential application for Tuscany region have been examined. The results show that the greater contribution to TEV is given by non-market value (e.g. naturalistic and recreational values), particularly in protected forests. In addition, according to the relationship between species composition and forest management, high forests seem to reach a greater median value than coppices. The application of spatialisation for forest investment analysis highlights how the methodology can be useful for policy evaluation. This aspect shows how different regional forest policy and related silvicultural issues can be analysed using the TEV approach. For example, in addition to the assessment of forest operations for climate change mitigation, the potential management conversion from coppice to high forest for particular medium-low fertility stand could be analysed. Furthermore, treatment choice and re-naturalization of artificial conifer forests such as Douglas fir or mountain pines forests seem to be an interesting topic. In this framework, a scenario analysis can be developed by the comparison between current and potential future management in terms of TEV, making the spatial model a useful Decision Support System. Additional evaluations can be applied to non-protected forests with high naturalistic and tourist value, in order to analyse the potentiality for parks and reserves regime introduction.

In order to better implement this approach, some aspects of this work could be improved: an in-depth policy analysis is necessary to determine indicators to establish the effects of the investments in fire fighting actions, hydrogeological regimes, protection from climatic change and improvement of the tourist-recreational function. These evaluations should be comparable with the spatial resolution of TEV achieved in this paper. Other forest functions, such as additional innovative or traditional tourist aspects, can be introduced into the economic analysis. Finally, other direct use values related to medicinal plants, berries and truffles production can be quantified.

In conclusion, spatial analysis methodologies allow to aggregate all of the above variables and also facilitate the quantification of economic value for natural capital stocks in environmental decision-making processes.

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Appendix

A.1. Details of the methods used for the assessment of each TEV component

A.1.1 Recreational value

A.1.1.1 Recreational value in parks and protected areas: the Random Utility Models

Following the model proposed by Ferrini (2002), the consumer behaviour is studied through two probabilistic choices:

- the decision of making a recreational visit to a protected area, dependent on the socio-economic characteristics of the visitor;
- the decision regarding the recreational site to visit, as a function of the geographic, infrastructural and environmental characteristics of the area.

For each choice, a probabilistic binomial logit model has been identified. Tables A.1 and A.2 show the estimations for the parameters of the regressors detected by Ferrini.

Table A.1. Logit model for the decision to a visit to a protected area (Ferrini, 2002).

	Relevant statistical value
LogL	-329
LogL°	-374
χ^2	89
Degrees of Freedom	7
Regressors	Logit model parameters estimation and t-student statistic (in brackets)
Constant	-1.71949 (-2.655)
Age	-0.103749E-01 (-1.682)
Education	0.39144 (3.474)
Consumption	-0.24687E-04 (-0.300)
FSMAR	0.43679 (4.567)
FSMOC	0.99056E-01 (1.316)
Footing	0.63781 (1.994)
Outdoor	0.65811 (3.195)

Table A.2. Logit model for the choice of the recreational site to visit (Ferrini, 2002).

	Relevant statistical value
LogL	-455
LogL°	-1402
R^2	0.6756
Adjusted R^2	0.6754
Regressors	Logit model parameters estimation and t-student statistic (in brackets)
Cost	-0.26074E-04 (-15.514)
Surface	0.23682E-02 (2.491)
Sport	-0.76479 (-9.462)
Animal	0.22565E-01 (6.059)
Facilities	1.15703 (13.363)
Campings	0.31272E-01 (2.342)

The variables that influence the choice of the area are the following:

"AGE: discrete variable indicating the age of the respondent expressed in years.

EDUCATION: ordinal discrete variable that it is assumed as proxy of the cultural level; can have a value included between 0 and 3, indicating that the interviewed is not holding any educational qualification (0), he ended the obligatory school (1), he took the high school diploma (2) or he took the university degree (3).

CONSUMPTION: value in Italian lire (converted in Euro) of the average monthly family consumption. The choice of an index of family wealth, against a per-capita one, is based on the hypothesis that the expenditure of the recreational trip weights on the family budget as a whole and only on the income of the respondent.

FSMAR: ordinal discrete variable indicating the number of days averagely spent each year at the sea during the week-ends and the official holidays.

FSMOC: ordinal discrete variable indicating the number of days averagely spent each year at the mountain and in the hillsides during the week-ends and the official holidays.

FOOTING: dummy variable that assumes value 1 if the interviewed states that habitually does footing, jogging, etc., in the town of residence. This variable can be interpreted as an index of interest towards activity to be performed in the open air.

OUTDOOR: dummy variable that assumes value 1 if the interviewed frequently does sport activities in natural environment in protected areas.

COST: the cost, expressed in Italian lira (converted in Euro), for the visit.

SURFACE: continuous variable that expresses the total surface in hectares of the forest area.

SPORT: it is the weighted sum of 6 dummies, each indicating, respectively the possibility of walking, mountain biking, horse riding, skiing, boat riding and going around with excursion guides. SPORT is a proxy of the park attractiveness, as a place in which to carry out sport activities.

N_SPECIE: discrete variable which gives the number of the different species living in the area.

TOT_AV: ordinal variable that detect the presence or not of totem animals and rare avifauna.

ANIMAL: the variable N_SPECIE is multiplied by the variable TOT_AV get a weighted variable for the number of species living in the protected area.

FACILITIES: sum of 7 dummies which detect the presence of botanical gardens, naturalistic museums, naturalistic libraries, herbarium, visit centres, picnic areas and spa water. Thus, a proxy regarding the available infrastructures in the area supporting the visit is obtained.

EMERARCH: sum of two dummies, one indicating the presence of monumental and/or historical wooded formations, the second the existence in the territory of archaeological, historical and/or architectural proofs.

CAMPINGS: discrete variable reporting the number of camping present in the municipalities in which the protected area falls.

ACCOMODATION: discrete variable reporting the number of hotels present in the municipalities in which the protected area falls.

N_SPECIE: discrete variable which gives the number of the different species living in the area.

TOT_AV: ordinal variable that detect the presence or not of totem animals and rare avifauna.

variable for the number of species living in the protected area.

N_AREEAT: number of recreation areas in the park. (Ferrini, 2002; pp. 48, 51-52)".

The variables "EMERARCH", "ACCOMODATION" and "N_AREEAT" were not introduced into the model because of the high relation with the "SURFACE" parameter and consequent multicollinearity problems.

The Random Utility Models were implemented by following steps:

1. the regional territory was divided into raster cells with a resolution of 100 metres;
2. the resident population density (European Environment Agency, 2012) and the average provincial values of the variables that influence the choice of making at least one visit to a protected area were assigned to each cell. Then, using a map-overlay operation, the probability π_V that the residents of the cell would make at least one visit was calculated.
3. For each protected area, a map of the choice probability $\pi_{s/V}$ respect to the resident population was created on the basis of the area characteristics and of the travel cost.
4. A map of the expected visits to the area from the cell was calculated using the following equation:

   $E(V)_i = \pi_V \bullet \pi_{s/V} \bullet P_i$ (A.1)

   where:
   P_i: resident population in each cell.

   By summing all of the values of the map dataset, it was possible to estimate the number of visits in the examined area.
5. The travel cost was increased by a discrete value and steps 3 and 4 were reiterated, thus providing the consumer surplus R relative to the increase in the travel cost:

   $$R_{\Delta Cs} = \left(E\left(V\right)_{i,Cs+\Delta Cs} + E\left(V\right)_{i,Cs}\right) \cdot \Delta Cs / 2 \qquad \text{(A.2)}$$

   where:
   Cs: initial travel cost;
   ΔCs: increase of cost.

6. $Cs_{+1} = Cs + \Delta Cs$ was determined, and step 5 was reiterated until the unimportant contribution to the consumer surplus was reached.
7. The sum of the consumer surpluses R^a obtained in all of the iterations from step 5 to step 6 represented the social utility value of the recreation service of the examined area a belonging to the set of protected areas A.

The spatialisation of the achieved values for each area was completed on the basis of the estimated suitability to the recreational activity through a fuzzy multicriteria analysis. This methodology was chosen according to its capacity of relate variables characterized by different unit of measures (Munda, 1995). In addition both quantitative and qualitative parameters can be aggregated such as forest typology and subjective perception of the forest typology. This is particularly important in sector where subjective opinion of forest visitors reaches an high weight (e.g. for recreational and tourist issues). Taking into account the existing literature (Loomis, 2005), the model was detected on the basis of the following criteria:

- type of forest: greater suitability for the high forest vegetation with thin undergrowth;
- geomorphology: greater suitability for localisation with an open view;
- slope: greater suitability on slight slopes;
- distance from roads: greater suitability for localisations next to roads.

The parameters of the adopted fuzzy functions are listed in Appendix A.1.1.2. The aggregation of the different criteria was made through the method of the linear combination to attribute a recreation suitability index <<05_Eq_08.pdf>> to each pixel. The linear combination method seems to be one of the most suitable application for the aggregation of highly differentiated parameters. In this case the linear combination permits to simplify the model output analysis as a simple input summarize. Therefore the forest characteristic result easily comparable. The tourist value in the protected areas, spatialised for each *i-th* pixel, is derived from the following formula:

$$R_i^a = R^a \cdot Irec_i / \sum Irec_i \qquad \text{(A.3)}$$

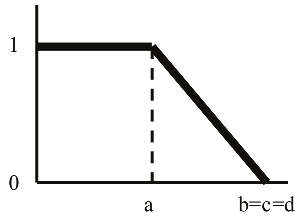
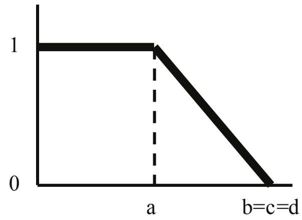
A.1.1.2 Recreational value in parks and protected areas: fuzzy linguistic evaluators

The estimation of economic value of different recreational component deal to the semi-quantification of several variable through the fuzzy methodology. In the present work fuzzy values were performed using the method of linguistic operators, proposed by Chen and Hwang (1992). The fuzzy linguistic operators are strictly related to the fuzzy logic functions.

These represent a methodology that allows to obtain a numeric quantification of qualitative opinions given by the experts of the sector for particular decisional processes, through an evaluation performed using specific functional shapes, generally triangular or trapezoidal. Thus, with a fuzzy linguistic operator, we can convert the verbal evaluation (i.e. the high influence of a geomorphological variable on touristic function) into a number, maintaining the intrinsic uncertainty of the expert estimation.

Chen and Hwang identified 8 scales of linguistic terms. The evaluation was then implemented through a linguistic term set resulting in Scale 4 from Chen and Hwang, which works with five linguistic terms derived from the numeric quantification ascribed to each variable through a fuzzy linguistic evaluator of five

Table A.3. Fuzzy functions for the recreational value in parks and protected areas.

Criterion	μ_k	Control point			
Slope (%)		0	10	10	10
Distance from roads (m)		150	1,500	1,500	1,500

values (low, medium-low, medium, medium-high, high).The linguistic terms were converted into the following fuzzy values using a de-fuzzification methodology: low: 0.115, medium-low: 0.3, medium: 0.5, medium-high: 0.7, high: 0.885.

Table A.4. Linguistic evaluation for the recreational value in parks and protected areas.

Corine Land Cover class	Linguistic evaluation	Corine Land Cover class	Linguistic evaluation
311	medium	313	medium
3111	medium	3131	medium
3112	medium	31311	medium
3113	medium	31312	high
3114	high	31313	high
3115	high	31314	medium
3116	high	31315	medium
3117	high	31316	medium-high
312	medium	3132	medium
3121	high	31321	medium
3122	medium-high	31322	medium
3123	medium-high	31323	medium
3124	medium-high	31324	medium
3125	medium	31325	medium

A.1.1.3 Recreational value in parks and protected areas: impact on the local economy

The multiplicative coefficients were calculated using the 44 Branches Total Flows Tuscan matrix and the 44 Branches Internal Production Tuscan matrix (Casini and Marone, 1996).

Table A.5. Multiplicative coefficients for expenditures and visit units.

	Internal production matrix		Total production matrix	
	Direct and indirect effects	Induced direct and indirect effects	Direct and indirect effects	Induced direct and indirect effects
Average multiplier for an expenditure unit	1.42	1.89	2.16	4.36
Average multiplier for visit	18.77	25.10	28.62	57.82

Table A.5 shows that for each euro spent on recreational activities in the protected areas, it is possible to produce a multiplicative effect that varies from 1.40 to 2.10 € according to the use of an internal production matrix or a total production matrix. The effect can varies from 1.90 to 4.40 € if the induced effects are considered in addition to the direct and indirect effects. In the application under consideration, a multiplier *Mult* equal to 57.82 €/visit has been used.

To spatialise the indirect and induced effects of the recreational expenditure, first of all the visits ($Visits^a$) to each protected area were estimated using the cited probabilistic choice model. Then, applying the coefficients presented in Table A.5 and the recreational suitability $Irec_i$, the activated regional economy could be estimated.

$$R.ind.eff._i^a = 57.82 \cdot Visits^a \cdot Irec_i / \sum Irec_i \quad \text{(A.4)}$$

A.1.1.4 Hunting activity: spatialisation methodology

The total value H_i of the social utility of hunting activity was spatialised proportionally to the ecological suitability of the species of interest, which were calculated by aggregating the geo-databases obtained through the project National Ecological Network (Boitani et al. 2002) using the following formula:

$$H_i = \frac{h_i}{\sum h_i} \cdot Htot \quad \text{(A.5)}$$

where:

H_i: hunting value per hectare and per year for the location *i*;

h_i: dimensionless fuzzy index for the ecological suitability of the species of interest.

A.1.1.5 Mushrooming activity: fuzzy linguistic evaluator and spatialisation methodology

Regarding the geomorphology, the geology, the forest cover and climatic parameters the linguistic evaluation for mushrooming activity were defined as in Tables A.6, A.7, A.8 and A.9.

Table A.6. Linguistic evaluation for geomorphology.

Geo-morphology	Linguistic evaluation
Planar	medium
Pit	medium-low
Channel	low
Pass (saddle)	high
Ridge	high
Peak	medium-high

Table A.7. Linguistic evaluation for the geological substratum

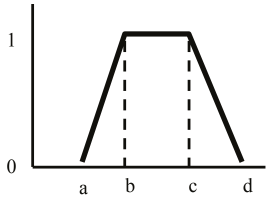
Geological substratum	Linguistic evaluation
Beach and coastal dune sands; recent and current.	medium-low
Recent alluvial deposits and current filled deposits, swamp deposits, and peat soils.	medium-low
Current and recent travertine, limestone debris and organogenic material.	medium-low
Fluvial, lacustrine and marine antique, terraced.	low
Polygenic conglomerates with interbedded sands and clays, sedimentary polygenic breccias.	medium
Clay deposits of fluvial-lacustrine or marine origin, with intercalation of sand, gravel and other materials.	medium
Sandy deposits of fluvial-lacustrine or marine origin, with interbedded clays, gravels and other materials, recently cemented sandstone "bench", ancient dunes, molasses.	medium
Marls, shales, clayey (clay varicolori, multicolored shale), sometimes interbedded with other rock types.	low
Quartz-feldspathic sandstones, often turbid with interbedded marls and shales (Boulder Chianti "in Boulder," Pietraforte, sandstones of Monte Senario, Marl-sandstone formation).	medium-high
Silty shale, marl, shales and sandstones, often turbid (Londa Boulder, Boulder Mugello "Boulder Bed").	medium-high

Geological substratum	Linguistic evaluation
Alternations of limestones, calcarenites, marly limestones and marls are often graded, calcareous Breccioli (Grosseto, calcarenites of multi-coloured shales, "Breccioli nummulitiche", limestones and Breccioli of Monte Senario, training of Sillano).	medium-low
Limestone, massive or crudely stratified (massive limestone, marble, limestone saccharoidal, ceroid limestone) with rare intercalations.	medium-low
Well-stratified limestones with interbedded, lithographic limestone, flint limestone, subject calcarenites, marly limestone).	medium-low
Laminated limestones, nodular marly limestones with marly intercalations (red ammonitic, Marne at Posidonia, to limestone aviculare).	medium-low
Cavernous limestone (limestone and dolomite vacuolar), anhydrite, dolomite and dolomitic limestone (Grezzoni).	medium-low
Jaspers, radiolarites and siliceous shales.	high
Metamorphic schists, phyllites, anagen (Verrucano formation of Tocchi).	high
Acid intrusive igneous rocks: granite, granodiorite, quarzomonzoniti, apliti; filoniane rocks.	high
Extrusive acid igneous rocks: ignimbrites, reoignimbriti, volcanic tuffs, volcanics (Lipari, trachytes, quarzolatiti, tephrites fonolitiche).	medium-high
Ophiolitic rocks: diabase, gabbro, serpentine, peridotite, pillow lavas, extrusive basic igneous rocks: trachy, Bashan leucitites.	high
Gypsum, anhydrite intercalated with clays, marls, sands (chalky-sulphurous).	medium-low
Complex chaotic masses disordered matrix encompassing clay marly limestones, ophiolitic breccias, calcarenites, limestones (scaly clays) and undifferentiated Complex: alternation of clayey (marl) and siliceous limestone (palombini) sometimes mixed together at random, with the presence of interbedded calcareous sandstones, limestones marly, argilliti. Karstified areas	low

Table A.8. Linguistic function of forest cover

CLC class	Linguistic evaluation	CLC class	Linguistic evaluation	CLC class	Linguistic evaluation
311	High	3122	high	31315	medium-high
3111	medium-low	3123	medium-high	31316	medium-low
3112	Medium	3124	medium	3132	high
3113	Medium	3125	medium-low	31321	low
3114	medium-high	313	high	31322	medium
3115	medium-high	3131	high	31323	high
3116	medium-low	31311	low	31324	medium
3117	medium-low	31312	high	31325	medium-low
312	high	31313	high		
3121	low	31314	medium-high		

Table A.9. Fuzzy functions of climate.

Criterion	μ_k	Control point			
Autumn rainfall (mm)		293	377	699	962
Spring rainfall (mm)		203	256	432	572
Summer rainfall (mm)		119	150	206	243
Average temperature (°C)		8	10	13.1	14
Summer temperature (°C)		16	18	21	22
Autumn temperature (°C)		9	11	14	15
Water Surplus (rainfall - evapotranspiration)		0	187	1,106	1,811

The result of the ecological niche detection approach was an index m_i of the ecological suitability for mushroom production based on the above fuzzy functions (climate, forest typology and geomorphology parameters). The spatialisation of total mushrooming activity value *Mtot* was performed using the following equation:

$$M_i = \frac{m_i}{\sum m_i} \cdot Mtot \tag{A.6}$$

A.1.2 Naturalistic value

The average naturalistic value per hectare can be estimated through the following equation:

$$WTP^{nat} = WTP^{nat}_{fam} \cdot F \tag{A.7}$$

where:
WTP^{nat} : total willingness to pay per typology of a naturalistic function *nat*{biodiversity, ecological value, endangered species};
WTP_{fam}^{nat}: individual (per family) willingness to pay naturalistic function *nat*;
F: number of resident families in Tuscany.

The values for the individual per family willingness to pay are shown in Table A.10.

Table A.10. Willingness to pay of the resident population of Tuscany (Ten Brink et al., 2000).

Typology	WTP_{fam} (€/family*year^{-1})
Biodiversity value	28.60
Ecological value	1.80
Endangered species value	120.90

On the basis of the cited literature (Ten Brink et al., 2000), the fuzzy indicators that affect the probabilities relative to the three aspects of the naturalistic value were considered:

- the value of the fuzzy function relative to biodiversity was hypothesised as directly proportional to the value of the Simpson index. The Simpson index was matched - through fusion operation - with the percentage of habitat with a global valuation A (excellent) or B (good) within the Natura 2000 sites;
- the fuzzy function of ecological value was considered to be proportional to the number of vertebrates species expected in the localisation, derived from the geodatum of the National Ecological Network (Boitani et al., 2002);
- the fuzzy function of the endangered species preservation's value was estimated as a function of the proportional percentage of habitat with a specific value for endangered species preservation (evaluated in class A – excellent – or B – good – within the Natura 2000 sites). This value was aggregated through a linear combination with the fuzzy index of the number of endangered vertebrate species in the National Ecological Network.

The parameters of the fuzzy functions used are shown in the Table A.11. The aggregation of the different criteria was made using the linear combination method.

The spatialisation of the naturalistic value N_i can be calculated through the following formula:

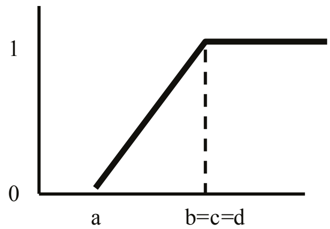
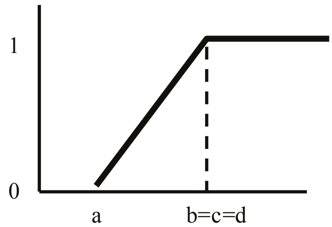
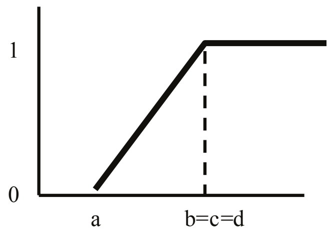
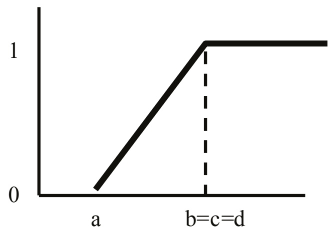
$$N_i = \frac{n_i^{biodiv}}{\sum n_i^{biodiv}} \cdot WTP^{biodiv} + \frac{n_i^{ecol}}{\sum n_i^{ecol}} \cdot WTP^{ecol} + \frac{n_i^{species}}{\sum n_i^{species}} \cdot WTP^{species} \tag{A.8}$$

where:
N_i: naturalistic value per hectare and per year for the location *i*;
n^{biodiv}: dimensionless fuzzy biodiversity value index;
n^{ecol}: dimensionless fuzzy ecological value index;
$n^{species}$: dimensionless fuzzy index for the aspects related to the preservation of the endangered species.

A.1.3 Evaluation of water flow control

For the calculation of the surface runoff, the so-called "Kennessey" method (Kennessey, 1930) was used. Through this method, it is possible to classify a catch-

Table A.11. Fuzzy functions for the naturalistic value

Criterion	μ_k	Control point			
		a	b	c	d
Biodiversity value: Simpson index		2	4	4	4
Conservation value for the endangered species: percentage habitat Natura 2000		0	15%	15%	15%
Conservation value for the endangered species: number of vertebrate species present in the cell "endangered" (REN)		0	36	36	36
Ecological value: number of vertebrate species present in the cell (REN)		126	157	157	157

ment basin on the basis of the physiographic and climatic data. Using this approach, it is possible to calculate the average yearly runoff coefficient CK_i of the studied area by analysing three parameters:

$$CK_i = CA_i + CP_i + CV_i \tag{A.9}$$

where:
CK_i: yearly runoff coefficient;
CA_i: slope;
CP_i: permeability;
CV_i: plant cover.

High values for CK_i suggest high surface runoff values, while low values of CK_i suggest high values of deep infiltration. To calculate the runoff coefficient, the values of the parameters were standardised by expressing them relative to the aridity index (AI) and normalising them to values between 0 and 1, as shown in Table A.12.

Table A.12. Partial coefficients

Permeability	AI<25	25≤AI<40	AI≥40
1- Very low	0.21	0.26	0.30
2- Low	0.16	0.21	0.25
3- Medium	0.12	0.16	0.20
4- High	0.06	0.08	0.10
5- Very high	0.03	0.04	0.05
Slope	AI<25	25≤AI<40	AI≥40
1- ≥35%	0.22	0.26	0.30
2- 10%≤s<35%	0.12	0.16	0.20
3- 3,5≤s<10%	0.01	0.03	0.05
4- ≤3,5%	0.00	0.01	0.03
Natural land use	AI<25	25≤AI<40	AI≥40
Rocks	0.26	0.28	0.30
Pastures	0.17	0.21	0.25
Agriculture - Shrubs	0.07	0.11	0.15
Forest	0.03	0.04	0.05

The volume of the expansion cases needed to subrogate the presence of the forest was approximately estimated by applying the so-called Marone's formula. Marone's formula (De Martino et al., 2002) expresses the rolling ratio η between the peak outflow Q_{max} and the peak inflow Q_c as a function of the maximum storage volume W and of the entering flood wave $W.flood$:

$$\eta = 1 - \frac{W}{W.flood} \tag{A.10}$$

In this case study, for each catchment basin *b*, we considered an entering wave with the same peak discharge calculated using the inflows-outflows model, caused by a precipitation of critical duration with height *h* derivable from the rainfall intensity-duration curves. The volume of the entering wave is equal to:

$$W.flood^{b} = h \cdot \sum CK_{i} \cdot 10000 \tag{A.11}$$

Hypothesising a maximum flow discharge of the basin equal to Q_{max} = 25 m^3/sec, the rolling ratio was calculated:

$$\eta_{Marone} = \frac{Q_{max}}{Q_{c}} \tag{A.12}$$

The volume of the basin system is be given by:

$$W^{b} = W.flood^{b} \cdot \left(1 - \eta_{Marone}\right) \tag{A.13}$$

Hypothesising a cases with a height of approximately 4 metres, the case area WA^b needed to store an increase in rainfall height due to the absence of forest Δh is equal to:

$$\begin{aligned} WA^{b} &= \left(W.flood^{forest} - W.flood^{bare\_soil}\right) \cdot \left(1 - \eta_{Marone}\right) = \\ WA^{b} &= \left[\sum \left(CK_{i}^{forest} - CK_{i}^{bare\_soil}\right) \cdot h_{i}\right] \cdot \left(1 - \eta_{Marone}\right) \end{aligned} \tag{A.14}$$

The yearly cost of construction of the cases $Whyd^b$ was calculated through a weighted average of the expropriation costs, the construction costs, the maintenance costs and the loss of income. This parameters refer to the overflowing areas of each catchment basin. The result was then divided proportionally to the runoff coefficient for all pixels representing each catchment basin in order to define the water flow control value $Whyd_i$:

$$Whyd_{i} = \left[\frac{\left(CK_{i}^{forest} - CK_{i}^{bare\_soil}\right) \cdot h_{i}}{\sum \left(CK_{i}^{forest} - CK_{i}^{bare\_soil}\right) \cdot h_{i}}\right] \cdot Whyd^{b} \tag{A.15}$$

A.1.4 Evaluation of the drinking water service value

The spatialisation of the water storage service was carried out on the basis of the contribution of the forest cover water balance to the production of the drinkable water. The process was achieved in two phases. Firstly, using the method of the reversed water balance, the water balance of a single forest location App_i, was calculated (Civita et al. 1999):

$$App_i = Aff_i - CK_i \cdot Aff_i - Defl_i - ETR_i \tag{A.16}$$

where:
Aff_i: average yearly inflows;
CK_i: runoff coefficient as defined in Appendix A.1.3;
$Defl_i$: groundwater runoff + the minimum vital runoff;
ETR_i: evapotranspiration.

Then, in order to calculated drinking water service value $W.drink_i$, the subrogation price *DP* per cubic meter was applied:

$$F_i = Vm_i / (q^t - 1) - s_i / r \tag{A.17}$$

A.1.5 Evaluation of wood production

The spatialisation of the wood production value was performed by converting the capital value of the bare soil, obtained with the classic Faustmann formula, into a yearly value.

The value for coppices was calculated according to formula A.18.

$$F_i = Vm_i / (q^t - 1) - s_i / r \tag{A.18}$$

where:
F_i: Faustmann value;
Vm_i: net stumpage value;
r: interest rate;
q: 1+r;
t: rotation period;
s_i: annual expenses.

The value for high forests of public property and those inside parks and reserves was estimated as follows:

$$F_i = Vm_i / (q^c - 1) - s_i / r \tag{A.19}$$

where:
c: periodicity of curative cutting.

The value for the high forests on private properties, not located in protected areas, was calculated according to formula A.20.

$$F_i = (Vm_i - R_i \cdot q^t) / (q^t - 1) - s_i / r \tag{A.20}$$

where:
R: regeneration cost.

Finally, the yearly values of the forest soils localized in *i-th* area were calculated on the basis of the following formula:

$$Wood_i = F_i \cdot r \tag{A.21}$$

A.1.6 Evaluation of protection from climatic change

The spatialisation of the annual benefits, in terms of CO_2 fixation ($Diox_i$), was developed considering the wood biomass increment, the Biomass Expansion Factor – BEF (Garzuglia and Saket, 2003) and the price of carbon (Euro-Mediterranean Centre for Climate Change, 2011) (Eq. A.22).

$$Diox_i = Y_{i,t} \cdot BEF_t \cdot Pdiox \tag{A.22}$$

where:
$Y_{i,t}$: wood biomass annual increment of *t-th* forest typology (m^3/ha*year^{-1});
BEF_t: Biomass Expansion Factor of *t-th* forest typology (t/m^3; conversion coefficient from the volume of wood biomass, given in cubic meters, into aerial arboreal biomass, given in tons of dry matter). Applied BEFs are shown in Table A.13 (Garzuglia and Saket, 2003);
Pdiox: price in tons of carbon (€/t) (Euro-Mediterranean Centre for Climate Change, 2011).

Table A.13. Biomass Expansion Factor – BEF (t/m^3)

Forest cover	BEF
Broadleaved forest	0.90
Coniferous forest	0.60
Mixed forest	0.75
Mediterranean maquis	1.00

A.2. Statistical descriptive diagrams

The box-plot (*box-and-whisker diagram*) is a type of representation that provides an indication of the symmetry or asymmetry of a distribution. The box-plot is a box whose extremes represent the 1st and 3rd quartile (Q1, Q3) and the box is divided by the median with a whisker at the minimum and maximum values. In the case of *outliers* (anomalous values), that is values that fall outside of the range [Q1-1.5(Q3-Q1),Q3+1.5(Q3-Q1)], the whiskers are set next to the observations nearest to the extremes of that range and internal to it. Elaboration were developed by R that is an open source programming language and software environment for statistical computing and graphics. In R outputs the outliers are highlighted with small points.

The percentile diagrams or *percentile plots* contain information that completes the *box-plot.* The horizontal lines are set at the 25th, 50th and 75th percentile, but the width of the plot is proportional, in each value, to the percentile if it is over the median and at 100 minus the percentile if it is under the median (Esty and Banfield, 2003).