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Effects of different thinning systems on the economic value of ecosystem services: A case-study in a black pine peri-urban forest in Central Italy

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Abstract. Sustainable Forest Management (SFM) should be able to produce an optimal level of bundle of Ecosystem Services (ES), thus ensuring more resilient forest ecosystems and creating benefits for local population and human well-being. Yet, choosing between alternative forest management practices is not straightforward as it necessarily involves ES trade-offs. Forest management decisions have to reconcile the socio-economic and ecological contributions of forest ecosystems by fostering a synergistic relation between multiple ES while lowering ES trade-offs. The aim of the study is to analyze different forest management practices (selective and traditional thinning) in black pine peri-urban forest in Central Italy, by investigating their contribution in terms of provisioning (wood production), cultural (recreational benefits) and regulating (climate change mitigation) ES. For each management option was performed: (1) a biophysical assessment of selected ES by using primary data and calculating indicators for wood production with special regard to biomass for energy use (living trees and deadwood volume harvested), recreational benefits (tourists' preferences for each forest management practice), climate change mitigation (carbon sequestration in above-ground and below-ground biomass), and (2) an economic valuation of wood production, recreational benefits and climate change mitigation ES using direct and indirect methods (environmental evaluation techniques). The results show that the effects of the selective thinning on ES are higher that the effects of the traditional thinning. The economic value of the three ES provided by traditional and selective thinning are respectively: bioenergy production 154.2 € ha^{-1} yr^{-1} and 223.3 € ha^{-1} yr^{-1}; recreational benefits 193.2 € ha^{-1} yr^{-1} and 231.9 € ha^{-1} yr^{-1}; carbon sequestration 29.0 € ha^{-1} yr^{-1} and 36.2 € ha^{-1} yr^{-1}. The integrated (biophysical and economic) assessment of ES in addition to the trade-off analysis can provide multi-perspective insights for forest policy makers and can be included as a part of the local forest management plans.
Keywords forest management, thinning, ecosystem services, biophysical accounting, trade-off, economic valuation

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Introduction

In the 90s of the twentieth century the concept of Sustainable Forest Management (SFM) emerged in the forest sector, based on sustainability principles and focusing on the maintenance of the economic, social and environmental values of forests, for the benefit of present and future generations (Putz 1994, Luckert & Williamson 2005, Paletto et al. 2014).

One of the key elements of SFM is the awareness that forest ecosystems are able to perform a multiplicity of functions and, consequently, to provide several ecosystem services (ES) to society (Führer 2000).

ES represent the goods and services provided by ecosystems and ecological processes to society (Costanza et al. 1997, De Groot et al. 2002). In 2005, the Millennium Ecosystem Assessment (MEA 2005) listed a classification of ES, based on their functions: provisioning services, regulating services, cultural services and supporting services. With special regard to forest ecosystems (Fisher et al. 2009, Kumar & Wood 2010, UK NEA 2011): (1) provisioning services include food (non-wood forest products), water, timber, fiber, and genetic resources provision; (2) regulating services consist of water purification, soil conservation, carbon sequestration, flood and disease control; (3) supporting services include biodiversity, soil formation and structure, soil fertility, nutrient cycling and the provision of water; and (4) cultural services include recreational, spiritual and cultural benefits provided by forests. Subsequently, the TEEB classification substituted supporting services with habitat services, which include lifecycle maintenance and gene pool protection (TEEB 2010). Other authors have excluded the supporting services or habitat services from the ES classification because they could give rise to double counting in economic evaluation (Hein et al. 2006, Rodríguez García et al. 2016).

SFM should be able to produce an optimal level of bundle of ES, thus ensuring more resilient forest ecosystems and creating benefits for local population and human well-being. Yet, choosing between alternative forest management approaches is not straightforward, as it necessarily involves ES trade-offs. ES trade-offs take place when the provision of one ES is reduced as a result of an increased use of another ES. In the forestry context, forest management decisions can unintentionally generate trade-offs when interactions among ES are little known or incomplete (Ricketts et al. 2004, Walker et al. 2002). In particular, forest management practices are capable to sustain biological diversity and ecosystem functionality by intervening on tree species composition, stand density and structure (horizontal and vertical), canopy cover and amount and distribution of deadwood (Kimmins et al. 2005, Carnol et al. 2014). Forest management decisions that affect the provision of ES are mainly: choice of tree species and silvicultural system (high forest or coppice), thinning regime, optimal rotation age. Silvicultural treatments affect water cycle components - such as rainfall interception, transpiration, soil moisture and deep infiltration - influencing the water quality and quantity ES (Fernandes et al. 2016). In addition, silvicultural treatments affect the level of biodiversity but also recreational ES. In fact by intervening on forest tree ages, species, stand structure, open areas, and tourist facilities the recreational ES is modified (Wunder et al. 2014).

In order to assess the effects of forest management practices on ES, the three domains identified by De Groot et al. (2002) must be taken into account: ecological (biophysical), socio-cultural and economic (monetary). Biophysical assessment focuses on biological and ecological relationships between ES and effects of forest management on their provision, while socio-economic assessment address market and non-market priced ES in order to uncover socially desirable levels for their provision (Filyushkina 2016). Biophysical and socio-economic assessments of ES - which aim to quantify the importance of ecosystems for human well-being - serve as support for designing better policies aiming at conserving and ensuring sustainable management of ES (TEEB 2010, UK NEA 2011). In addition, these ES evaluations are the basis for analyzing the efficiency of the different forest management practices to influence the provision of ES.

Starting from these considerations, the aim of the present study is to analyze the effects of two forest management practices (selective thinning and traditional thinning) on provisioning (wood production), cultural (recreational benefits), and regulating (climate change mitigation) ES. The two forest management practices were applied in an Austrian black pine forest located in Central Italy (Monte Morello peri-urban forest in Tuscany region) and characterized by a high level of multifunctionality.

Materials and methods

Study area

The study area is Monte Morello forest (43°51'20''N; 11°14'23''E), located in Central Italy close to the urban area of Florence (Tuscany Region). Taking into account the geographical location and the high tourist attraction of this area, Monte Morello can be considered a peri-urban forest, in accordance with Blazevska et al. (2012) who define as peri-urban forests the forest stands with amenity values situated near urban areas.

The Monte Morello peri-urban forest is a reforestation realized from the first of 1909 until 1980 for protection purpose, with a density of about 2,700 trees per hectare. The total surface of reforestation in Monte Morello is 1,035 ha. The main tree species used are black pine (*Pinus nigra* J.F.Arnold), Calabrian pine (*Pinus brutia* Ten. subsp. *brutia*), cypress (*Cupressus spp.*), flowering ash (*Fraxinus ornus* L.), Turkey oak (*Quercus cerris* L.) and Downey oak (*Quercus pubescens* L.).

Over the last fifty years no silvicultural treatments were applied in the Monte Morello peri-urban forest. Currently the forest is degraded and characterized by a large scale forest instability with poor regeneration, high mortality and marked susceptibility to adversities, in particular fires. In reason of its proximity to the city of Florence, Monte Morello peri-urban forest has an important recreational function for trekking, jogging, picnicking and biking.

In 2016, to restore the ecological stability and enhance the resistance and resilience of the forest, silvicultural treatments have been applied. In particular, both traditional and selective thinning were applied, with the aim to investigate their effects (economical, ecological and social) on the various ES and to compare forest evolution with unmanaged areas (*status quo*). The main characteristics of the two silvicultural treatments applied in the study area are the following:

Selective thinning: the choice of the trees to be cut is based on a positive selection (thinned 30-40% of basal area). During cutting, all crown-volume competitors trees are harvested, standing dead trees and lying deadwood slightly decomposed are removed (1st and 2nd decay classes). The selective thinning is the silvicultural treatment proposed by the Project LIFE14 CCM/IT/905 FoResMit in order to improve the tourist attractiveness of the area and to increase the positive effects of forest on the climate change mitigation;

Traditional thinning: the choice of trees is based on a negative selection (thinned from below 15-20% of basal area). During cutting only small and leaned trees and standing dead trees are harvested, while the lying deadwood is not removed during the silvicultural treatments. The traditional thinning is the common silvicultural treatment applied in Central Italy in the forest management of coniferous forests. Both selective and traditional thinning were applied in three forest parcels (each one of 1 hectare surface) randomly located in the Monte Morello peri-urban forest. Consequently, the effects of the selective and traditional thinning on ES were analyzed in six hectares of forest.

Research framework

The effects of selective and traditional thinning in the forest parcels were assessed from biophysical and economic point of view considering the following three ES: wood production (provisioning services); recreational benefits (cultural services); and climate change mitigation (regulating services).

The biophysical assessment was realized by using primary data and calculating one or more indicators, while the economic valuation of bioenergy production, recreational benefits and climate change mitigation was based on both direct and indirect methods (environmental evaluation techniques).

Wood production

Wood production was estimated considering the local market prices (year 2016) and wood volumes harvested during the silvicultural treatments. In accordance with the characteristics of black pine trees in Monte Morello forest, 100% of the harvested volume - living trees, standing dead trees and lying deadwood of 1st and 2nd decay classes - is intended for bioenergy production (woodchips), while 0% is for timber production intended for sawmills.

Bioenergy production in Monte Morello peri-urban forest was calculated through the field measurement of the volume of wood (m^3 ha^{-1}) harvested with the traditional thinning and the volume of wood (m^3 ha^{-1}) harvested with the selective thinning. Woodchips production (q ha^{-1}) was then calculated taking in consideration black pine wood basic density. Woodchips were finally transformed in energy at the Calenzano heating power plant, located in a municipality closed to the study area.

The economic value of bioenergy production was evaluated through the direct calculation of profit from the annual income derived from the sale of woodchips (€ ha^{-1} yr^{-1}) considering the local price of woodchips and a rotation period of 15 years (eq. 1):

$$R = \frac{Vt_0}{\frac{(1+i)\cdot\left[1-(1+i)^{-t}\right]}{i}} \quad (1)$$

where: R - the annual income derived from the sale of woodchips at the time t_0 (€ ha^{-1} yr^{-1}), Vt_0 is the total current value derived from the sale of woodchips (€ ha^{-1}), i is the average inflation rate in Italy for the period 2002-2016 (1.7%), t is the rotation period (15 years).

Recreational benefits

Recreational benefits provided by Monte Morello peri-urban forest were assessed through the administration of a semi-structured questionnaire to a sample of visitors. The aim of the questionnaire is to analyze visitors' preferences for the two forest management options (selective thinning and traditional thinning) and to investigate the costs for the trip to the Monte Morello peri-urban forest.

A preliminary version of the questionnaire was developed in February 2016 and pre-tested with four visitors in early March 2016, with the main objective of assessing the clarity of wording. The final version of the questionnaire was face-to-face administered to 201 visitors (75% of 269 visitors contacted) of the Monte Morello forest in the period from April to July 2016 (four months). The visitors were selected in a systematic way, selecting one out of two visitors who arrived in three previously identified sampling points (two rest areas and one parking). The number of visitors counted in the sampling points during the survey days - both weekend and working days - was used to estimate the theoretical total annual visitors of the Monte Morello peri-urban forest (18,475 visitors per year).

The final version of the questionnaire consists in a mix of open-ended and closed-ended questions divided in some thematic sections ("Personal information", "Recreational use of forest", "Benefits provided by peri-urban forest", "Preferences and perceptions towards the peri-urban forest" and "Cost expenditures"). The first thematic section ("Personal information") focuses on the personal information of the respondent such as gender, age, level of education, actual job and place of residence. The second thematic section ("Recreational use of forest") focuses on visitors' behavior during their visit to the Monte Morello peri-urban forest such as day of visit (weekend or working days), visiting time (hours) and reasons of visit (hiking, sport activities, non-wood forest products-NWFP collection, relaxing into the nature, picnicking, and eating local products). The third thematic section ("Social benefits provided by forest") focuses on the benefits provided by peri-urban forests to the society such as benefits involving aesthetic enjoyment and relaxation, and benefits involving sports and social contact. The forth thematic section ("Preferences and perceptions towards the peri-urban forest") considers three aspects related to forest management for recreational purpose: tourist facilities, characteristics of forest stand (tree species composition, horizontal and vertical stand structure, deadwood), silvicultural treatments. With particular reference to the last point, the visitors' aesthetic perception of the effects of silvicultural treatments was assessed by showing to visitors three images (scenarios) of the Monte Morello forest. Images represent the forest both unmanaged and after the thinning: Image 1-*status quo* scenario, Image 2-traditional thinning scenario and Image 3-selective thinning scenario. The respondents compared the three images of Monte Morello peri-urban forest in pairs (pairwise comparison), according to the scheme in Figure 1.

The collected data were processed using the Analytic Hierarchy Process (AHP) approach, a hierarchical weighted decision analysis method aimed at solving complex decision problems and making accurate decision and judgment for complex system (Saaty 1987). The image preferred by the visitors was identified with the calculation of the priority value of each image using the eigenvalue method. The distribution of visitors' aesthetic preferences for the three images was used to estimate the potential number of visitors in the three forest scenarios and the changes from the *status quo* scenario.

In the last thematic section ("Cost expenditures"), the key information to estimate the recreational value of Monte Morello peri-urban forest were collected such as location of the visitor's home, how many times in the past year they visited the site, the length of the trip, the amount of time spent at the site (hours), travel expenses (e.g., lodging, meals and transportation). Starting from these data, the recreational value was indirectly calculated using the Travel Cost Method (TCM) and considering individual total cost expenditures for the trip to the Monte Morello forest.

TCM is a non-market valuation technique, used to estimate recreational values, based on revealed preferences (Hanley & Barbier 2009). This technique assumes that people are travel cost sensitive, meaning that the expected number of trips to a certain site is lower when the cost sustained to reach the destination increases (Garrod & Willis 1999). The demand function, to model the number of trips Y_i an individual is likely to make in a certain time span, is the following (eq. 2):

Image A	5	3	1	1/3	1/5	Image B

Figure 1 Scheme of pairwise comparison for the images of Monte Morello peri-urban forest

$$Y_i = f(TC_i, M_i, C_i) \quad (2)$$

where: TC_i - the cost sustained to reach the destination, M_i - a vector of motivations to visit the area (i.e. hiking, sport activities, NWFP collection, relaxing into the nature, picnicking, and eating local products) and C_i - a vector of socio-demographic characteristics (i.e. gender, age, level of education).

The dependent variables is the number of trips, which takes only integer non-negative values, therefore count data models are often used to estimate the above-described function. Once the model is estimated, the usual welfare measure that is estimated is Consumer Surplus (CS), which is the negative inverse of the travel cost coefficient (Ram et al. 2002). Most common count data model are the Poisson and Negative Binomial (NB) regressions (Martínez-Espiñeira et al. 2008). In particular, NB is usually preferred to Poisson, because the latter assumes the distribution mean to be equal to the variance (Greene 2003). In many cases, it has been shown that the variance is higher than the mean number of trips because of the presence of both very frequent and non-frequent visitors, thus NB is used to account for overdispersion of the data. In addition, it has been shown that TCM data collected with on-site interviews may suffer of truncation and endogenous stratification of the sample (Martínez-Espiñeira & Amoako-Tuffour 2008).

Truncation refers to the fact that people not visiting the site (i.e. with zero trips) are not considered. Endogenous stratification, on the other hand, indicates that, when collecting data in the study area, the probability of interviewing a very frequent visitor is much higher than tourists making only few trips per year. In the presence of overdispersion, truncation and endogenous stratification of the data, estimates might be biased (Shaw 1988). To account for these three features of on-site data, we used a modified version of the NB model that accounts for truncation and endogenous stratification (Hilbe and Martinez-Espineira 2005), whose likelihood function is the following (eq. 3):

$$\mathrm{P}\gamma\left[Y = y \middle| Y > 0\right] = y_i \frac{\gamma\left(\alpha^{-1} + y\right)}{\gamma(\alpha^{-1})\gamma(y+1)} \alpha_i^{\,y_i} \mu_i^{\,y_i - 1} (1 + \alpha\,\mu)^{-(y_i + \alpha_i^{-1})} \quad (3)$$

where: y_i - respondents' number of trips per year, r - the gamma function, α - the parameter that accounts for overdispersion, μ_i - the distribution mean, which is composed by the linear combination of dependent variables and the coefficients to be estimated (Table 1). The typical welfare measure that you can estimate from a TCM is Consumer Surplus (CS), which is a proxy for the benefit people derive from visiting. CS is calculated as the negative inverse of the travel cost coefficient (Price 1989).

Climate change mitigation

The climate change mitigation benefits resulting from carbon sequestered in trees and soils is dependent on silvicultural treatments (Sing et al. 2015). Therefore, the contribution of Monte Morello peri-urban forest in terms of climate change mitigation was quantified as difference in carbon sequestration after the two forest management practices (selective thinning and traditional thinning).

The annual forest capacity to transform atmospheric carbon into biomass was estimated considering two carbon pools (above-ground biomass and below-ground biomass), while the other three carbon pools (litter soil, and deadwood) were not considered as the changes in the annual increment of carbon stock are negligible. The biophysical assessment of carbon sequestration (C) in above-ground and below-ground biomass of the Monte Morello peri-urban forest was estimated using the following formula (eq. 4):

$$C = \left[(I \cdot BEF \cdot WBD) + (I \cdot R \cdot WBD)\right] \cdot 0.5 \cdot 3.67 \quad (4)$$

where: I - the annual increment of trees vol-

Table 1 Dependent variables included in the demand function of the present study

Variable	Code	Description	Expected effect*
Tc	EUR/Trip	Amount paid for fuel per round-trip	-
Tuscany	1 0	From Tuscany Otherwise	+
Image1_2	5-point-Likert scale	1 = Image 1 really preferred, 5 = Image 2 really preferred	-
Image1_3	5-point-Likert scale	1 = Image 1 really preferred, 5 = Image 3 really preferred	-
Picnicking	5-point-Likert scale	1 = motivation not important, 5 = motivation very important	+
NWFP collection	5-point-Likert scale	1 = motivation not important, 5 = motivation very important	+
Relaxing	5-point-Likert scale	1 = motivation not important, 5 = motivation very important	+
Sport activities	5-point-Likert scale	1 = motivation not important, 5 = motivation very important	+
Age	Classes from 1 to 5	1 is the youngest class, 5 the oldest	-
Gender	1 0	Female Male	-
Education	Classes from 1 to 6	1 is elementary education, 6 is for PhD holders	+

Note. Abbreviation: * is the expected effect of the independent variables on number of trips.

ume (m^3 ha^{-1} yr^{-1}), *BEF* - the biomass expansion factor to take into account not only stem but also tops and branches, *WBD* - the wood basic density of black pine (kg m^{-3}), *R* - the root-to-shoot ratio of black pine, *0.5* - carbon content coefficient), and *3.67* - coefficient from C to CO_2.

The carbon sequestration was estimated using as variables the annual increment of volume before thinning (I_b), the annual increment of volume after the traditional thinning (I_t) and the annual increment of volume after the selective thinning (I_s). Annual increments of volume were estimated by taking few wood samples with a Pressler borer from the trees in the forest parcels.

The changes in carbon sequestration before and after the two types of thinning were calculated using the following equations (eq. 5 and eq. 6):

$$\Delta_{c_t} = C_t - C_b \qquad (5)$$

$$\Delta_{c_s} = C_s - C_b \qquad (6)$$

where: C_b - the annual carbon sequestration before thinning (tCO_2 ha^{-1} yr^{-1}), C_t - the annual carbon sequestration after the traditional thinning (tCO_2 ha^{-1} yr^{-1}), C_s - the annual carbon sequestration after the selective thinning (tCO_2 ha^{-1} yr^{-1}), Δ_{ct} - the change of carbon sequestration in the traditional thinning scenario, Δ_{cs} - the change of carbon sequestration in the selective thinning scenario.

Finally, the economic evaluation of carbon sequestration was estimated in both scenarios using the average voluntary carbon market price (9.1 € tCO_2^{-1}) in 2015 for the agro-forestry project (Hamrick & Goldstein 2016).

Results

Wood production

The growing stock in Monte Morello peri-urban forest is about 590.4 m^3 ha^{-1}, while the total deadwood (lying deadwood, standing dead trees and stumps) volume is 75.1 m^3 ha^{-1}. Deadwood is distributed in the five decay classes in the following way: 9.8% in 1st decay class, 26.6% in 2nd, 50.0% in 3th, 12.0% in 4th, and the remaining 1.6% in the 5th decay class. For the bioenergy production only the first two classes were used, while the other three decay classes cannot be used due to the high moisture content (M% more than 100%) and to the difficulties in harvesting operations. The amount of deadwood volume to be used for bioenergy production is influenced by site conditions (i.e. temperature, rainfall, exposure, elevation).

In forest parcels managed with traditional thinning 141.7 m^3 ha^{-1} of living trees volume and 9.5 m^3 ha^{-1} of deadwood (1st and 2th decay classes) was removed with the silvicultural operations. Conversely, in the forest parcels managed with selective thinning was removed 200.7 m^3 ha^{-1} of living trees volume and 18.2 m^3 ha^{-1} of deadwood (1st and 2th decay classes) (Table 2).

As above-mentioned, all the volume removed during the silvicultural operations is intended for bioenergy production. The results show that the selective thinning provides a slightly higher quantity of woodchips for bioenergy production compared to the traditional thinning: respectively 1374.3 q ha^{-1} and 1989.9 q ha^{-1}.

From the economic point of view, the total economic benefits as bioenergy production provided by traditional thinning is 2061.4 € ha^{-1} and by selective thinning is 2984.8 € ha^{-1}, while the annual economic benefits are 154.2 € ha^{-1} yr^{-1} and 223.3 € ha^{-1} yr^{-1}.

Consequently, the results show that the economic value of wood production in the selective thinning scenario is higher that the economic value of this ES in the traditional thinning scenario. This difference is mainly due to the percentage of living trees volume harvested in the two thinning: 34% of growing stock volume in the selective thinning and 24% of growing stock volume in the traditional thinning, according to the different silvicultural criteria adopted in selective thinning. In addition, the selective thinning tends to maximize deadwood as biomass for energy use - 24.4% of total deadwood volume is removed for bioenergy production - while the traditional thinning (which removes only standing dead trees) uses for energy only 12.7% of total deadwood volume.

Recreational benefits

Concerning recreational benefits provided by Monte Morello peri-urban forest, the results of pairwise comparison highlighted that the visitors prefer the forest scenario after selective thinning (priority score of 0.5034) to the scenario after traditional thinning (priority score of 0.2873). In addition, results show that visitors prefer managed peri-urban forests (selective thinning scenario or traditional thinning scenario), while unmanaged peri-urban forests (*status quo* scenario) are evaluated negatively from the aesthetic point of view by the sample of respondents (Table 3). *CR* is the consistency ratio that measure how consistent the judgments have been relative to large samples

Table 2 Wood production in the Monte Morello peri-urban forest

Production issues	Selective thinning	Traditional thinning
Removed living tree volume (m^3 ha^{-1})	200.7	141.7
Removed deadwood volume (m^3 ha^{-1})	18.2	9.5
Woodchips (q ha^{-1})	1989.9	1374.3
Rotation period (t) (years)	15	15
Inflation rate (r) (%)	1.7	1.7
Total current value woodchips (Vt_0) (€ ha^{-1})	2984.8	2061.4
Annual income (R) (€ ha^{-1} yr^{-1})	223.3	154.2

of purely random judgments. *CR* is calculated as a ratio between *CI* (consistency index) and *RI* (expected consistency index obtained from generated comparisons). *CR* value should be lower or equal to 0.1 (10%) in order to have consistency of the matrix; in the present study *CR* is equal to 0.000793.

The visitors' preferences for the different images were used to estimate the change in the number of visitors in the selective and traditional thinning scenario. Currently, the annual visitors of Monte Morello peri-urban forest (*status quo* scenario) are estimated in 18,475 visitors yr^{-1}. Therefore, after the traditional thinning is assumed an increase of visitors by 7.8% (19,916 visitors), while after the selective thinning is assumed an increase of visitors by 29.4% (23,908 visitors).

The estimated CS is 10.04 € per visit. Consequently, the total social surplus in terms of recreational benefits in the Monte Morello peri-urban forest is equal to 179.2 € ha^{-1} yr^{-1} (*status quo* scenario), while in future years the social surplus could increase to 193.2 € ha^{-1} yr^{-1} in the case of traditional thinning scenario and to 231.9 € ha^{-1} yr^{-1} in the case of selective thinning scenario.

The results of the Negative Binomial (NB) regression model are showed in Table 4. As a general measure of the goodness of fit of the econometric model, McFadden's pseudo-R^2 might be considered, because it attempts to replicate the information provided by the r^2 of the linear regression. However, the value is usually much smaller than that of a linear regression and, usually, an r^2 between 0.2 and 0.4 is an indication of an excellent model fit (McFadden 1979). In our case, McFadden's r^2 is 0.22 (Table 4), indicating that the NB model that accounts for endogenous stratification and truncation is good in explaining the data.

Table 3 Priority scores for the images of the Monte Morello peri-urban forest after the silvicultural treatments

Image	Total (n = 201)
Image 1 - *Status quo* scenario	0.209300
Image 2 - Traditional thinning scenario	0.287300
Image 3 - Selective thinning scenario	0.503400
CI	0.000416
CR	0.000793

The results of NB regression highlight that the most important variables to describe the number of trips were the motivations for visiting the site (activities such as sports activities and NWFP collection are preferred to relaxing and picnicking). The travel cost coefficient (tcost) is negative, consistently with the economic theory. This means that as travel cost increases, the number of trips decreases, as expected from the travel-cost sensitivity assumption (Hellerstein 1991). The positive and statistically significant coefficient for Tuscany indicates that people living in Tuscany region are more likely to visit Monte Morello peri-urban forest, which is reasonable since the study area is in the same region.

Coefficients for Image1_2 and Image1_3 indicate tourists' preferences for a silvicultural treatment alternative to the current situation (*status quo* scenario). As it can be seen, both coefficients are negative, thus people preferring different forest management options, compared to the *status quo*, are more likely to visit the destination. This means that a switch in the forest management might increase the number of visitors. Image1_2 is not statistically significant; therefore this treatment might not be effective. Conversely, Image1_3 is significant and larger in module compared to Image1_2. For this reason, there is evidence that probably the selective thinning scenario would be the best management solution to increase the number of visitors in Monte Morello forest.

Among reasons to visit the study area, we considered relaxing into the nature, picnicking, sport activities and NWFP collection. All these variables are statistically significant, meaning that each of these have an explanatory pow-

Table 4 Results of the NB regression model

Parameter	Coefficients	Std. error	*t* statistics	*p*-value	Significance
tcost	-0.09962	0.018209	-5.47	0.000	****
Tuscany	4.35023	0.825304	5.27	0.000	****
Image1_2	-0.05389	0.051898	-1.04	0.299	
Image1_3	-0.16585	0.077421	-2.14	0.032	**
Picnicking	-0.16337	0.051898	-3.15	0.002	****
NWFP	0.23371	0.082484	2.83	0.005	****
Relaxing	-0.39668	0.077061	-5.15	0.000	****
Sport activities	0.17411	0.056233	3.10	0.002	****
Gender	-0.15625	0.168285	-0.93	0.353	
Age	0.30608	0.069444	4.41	0.000	****
Education	-0.23498	0.07506	-3.13	0.002	****
Constant	-29.15380	70.13275	-0.42	0.678	
Alpha	2.64e+08	4.70e+10			
-LL			849.83		
McFadden r^2			0.22		
Observations			201		

er in modelling the number of trips. However, the negative signs for picnicking and relaxing suggest that these motivations are inversely related with the number of annual trips. Conversely, sport activities and NWFP collection are motivations likely to increase the number of visit. This indicates that, probably, visitors consider the destination as a site for doing sport and other active recreational activities, rather than for relaxing and enjoying the nature.

Among personal characteristics of respondents that influence the number of trips, gender seems not to play a significant role in explaining the number of trips. This suggests that males and females are equally likely to visit the area. Age of the respondents shows a positive and statistically significant effect on the response variable, indicating that elder people compute a higher number of trips per year. Conversely, the coefficient for individual education is negative, suggesting that people with a larger number of yearly trips has a lower educational background, compared to sporadic travelers. The joint analysis of respondents' age and educational background may suggest that most of the visitors are quite old and maybe retired. Finally, the constant term, although being quite large in absolute value, is not statistically significant. This suggests that the included variables have good explanatory power. Unfortunately, it was not possible to include among the independent variables the individual income, because most of respondents refused to answer to the income question. However, most of the TCM studies reported a non-significant effect of income in explaining the number of trips, therefore this missing variable might be considered not very important in the quality of the model. The estimated CS is 10.04 € per visit, which is in line with similar studies about recreation (Grilli et al. 2014, Herath & Kennedy 2004, Martínez-Espiñeira & Amoako-Tuffour 2008).

Carbon sequestration

The annual increment of volume before thinning is 9.6 m^3 ha^{-1} yr^{-1}, while the annual increment of volume is 13.0 m^3 ha^{-1} yr^{-1} after the selective thinning and 10.4 m^3 ha^{-1} yr^{-1} after the traditional thinning (Table 5).

Starting from these data, the carbon sequestration estimated in the three forest management scenarios is the following: 2,939 tCO_{2eq} ha^{-1} yr^{-1} in *status quo* scenario (C_b), 3,184 tCO_{2eq} ha^{-1} yr^{-1} in traditional thinning scenario (C_t), and 3,980 tCO_{2eq} ha^{-1} yr^{-1} in selective thinning scenario (C_s). Consequently, the change in carbon sequestration after the traditional thinning is +245 tCO_{2eq} ha^{-1} yr^{-1}, while the change in carbon sequestration after the selective thinning is +1,041 tCO_{2eq} ha^{-1} yr^{-1}. Both forest management practices increase carbon sequestration compared to the *status quo* scenario, but selective thinning allows a greater carbon sequestration in the short-medium term than the traditional thinning. This difference is due to the silvicultural criteria adopted with the selective thinning: in this case are selected candidate trees which are vigorous and with high growth capacity, moreover there is a greater removal of growing stock volume (34% in selective and 24% in traditional) so that leaved trees have more space and less competition.

From the economic point of view, the value of carbon sequestration ES in the three scenarios is: 26.7 € ha^{-1} yr^{-1} in *status quo* scenario, 29.0 € ha^{-1} yr^{-1} in traditional thinning scenario, and 36.2 € ha^{-1} yr^{-1} in selective thinning scenario.

Discussion

Synthesizing the results for the three ES, we can assert that the selective thinning has a greater positive effect on all ES than the traditional thinning (Figure 1). In particular, in the traditional thinning scenario the total economic value of three ES is distributed as follows: 41.0% wood production, 51.3% recreational benefits, and 7.7% carbon sequestration. In the selective thinning the total economic values of three ES is distributed as follows: 45.4% wood production, 47.2% recreational benefits, and 7.4% carbon sequestration. Therefore, in both scenarios the recreational benefits are the most important ES, but the selective thinning enhances wood production more than the traditional thinning.

The results of the present study are comparable with the results evidenced in other studies in Europe. With regard to the recreational benefits provided by forests, the estimated CS in this study (10.04 € per visit) is slightly lower that the mean CS estimated considering eighteen TCM studies specific for forest ecosystems (14.13 € per visit) (Glück & Kuen 1977, Boatto et al. 1984, Tosi 1989, Cesaro 1991, Merlo 1992; Romano & Carbone 1993, Garrido et al. 1994, Bettinazzi 1995, Tempesta 1995, NIER 1991, Bravi & Curto 1996, Bellu & Cistulli 1997, Montagné et al. 2005, Getzner 2010). The TCM model also highlighted that people preferring the image associated with

Table 5 Carbon sequestration in the Monte Morello peri-urban forest

Characteristics	*Status quo*	Selective thinning	Traditional thinning
Annual increment of volume (I) (m^3 ha^{-1} yr^{-1})	9.6	10.4	13.0
Carbon sequestration (C) (tCO_{2eq} ha^{-1} yr^{-1})	2,939.0	3,980.0	3,184.0
Change in carbon sequestration (Δ) (tCO_{2eq} ha^{-1} yr^{-1})	-	+245.0	+1,041.0
Voluntary carbon market price (pr) (€/tCO_{2eq})	9.1	9.1	9.1
Value carbon sequestration (V_c) (€ ha^{-1} yr^{-1})	26.7	29.0	36.2

the selective thinning scenario are more likely to visit Monte Morello. This means that managing forests in Monte Morello with a selective thinning might increase the number of annual trips and therefore its recreational value.

The value of carbon sequestration is strongly related to the current carbon price, however this analysis in the case study converges to other similar contributions. In Monte Morello peri-urban forest, the value of carbon sequestration is similar to the results highlighted by other European case studies (Italy, the Netherlands, Czech Republic) that showed values for the above-ground biomass included in a range between 6 € ha^{-1} yr^{-1} and 40 € ha^{-1} yr^{-1} (Goio et al. 2008, Hein 2011, Šišak 2013). In addition, in a case study in the Austrian Alps (Leiblachtal in Vorarlberg), Paletto et al. (2015) estimated a value of carbon sequestration in above-ground and below-ground biomass of 21.1 € ha^{-1} yr^{-1}. In Italy, Rodríguez García et al. (2016) estimated a value of carbon sequestration in above-ground and below-ground biomass of 48 € ha^{-1} yr^{-1} in a case study in Piedmont region (Gesso-Vermenagna Valley), while Grilli et al. (2015) estimated that the economic value of carbon sequestration of the Non valley's forests (Trentino region) is 16.8 € ha^{-1} yr^{-1}.

Conclusions

The present research confirms that the integrated (biophysical and economic) assessment of ES in addition to the trade-off analysis can provide multi-perspective insights for forest policy makers and can be included as a part of the local forest management plans.

The applied methodology has the advantage of considering forest values from a multiple perspective, even thought there are possibilities to improve the analysis. For example, future interesting developments might be represented by the assessment of additional ES - such as biodiversity, landscape, protection against natural hazards (landslides, flooding, rockfalls), water quantity and quality – and by the comparison of different forest management practices. This will allow a more comprehensive picture of the effect of each forest management alternative on ES provision and a more detailed evaluation of the most effective management practice.

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