



ADVANCED EARTH OBSERVATION APPROACH FOR MULTISCALE FOREST ECOSYSTEM SERVICES MODELING AND MAPPING (MIMOSE)

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ABSTRACT – In the last decade ecosystem services (ES) have been proposed as a method for quantifying the multifunctional role of forest ecosystems. Their spatial distribution on large areas is frequently limited by the lack of information, because field data collection with traditional methods requires much effort in terms of time and cost. In this contribution we propose a methodology (namely, MultiScale Mapping Of ecoSystem servEs - MIMOSE) based on the integration of remotely sensed images and field observation to produce a wall-to-wall geodatabase of forest parcels accompanied with several information useful as a basis for future trade-off analysis of different ES. Here, we present the application of the MIMOSE approach to a study area of 443,758 hectares coincident with the administrative Molise Region in Central Italy. The procedure is based on a local high resolution forest types map integrated with information on the main forest management approaches. Through the non-parametric k-Nearest Neighbors techniques, we produced a growing stock volume map integrating a local forest inventory with a multispectral satellite IRS LISS III imagery. With the growing stock volume map we derived a forest age map for even-aged forest types. Later these information were used to automatically create a vector forest parcels map by multidimensional image segmentation that were finally populated with a number of information useful for ES spatial estimation. The contribution briefly introduces to the MIMOSE methodology presenting the preliminary results we achieved which constitute the basis for a future implementation of ES modeling.

KEYWORDS: ECOSYSTEM SERVICES, EARTH OBSERVATION, REMOTE SENSING, MIMOSE PROJECT, FORESTS, MAPPING

INTRODUCTION

Ecosystems, through their functioning, provide a range of goods and services important for human well-being, which are collectively called ecosystem services (ES). The ecosystem

service concept in contemporary science has an increasing popularity (Seppelt et al., 2012; Fisher et al., 2009). ES may be intended as flows of value to human societies as a result

of the state and quantity of natural capital (TEEB, 2010; EEA, 2011). Thus maintaining stocks of natural capital allows the sustained provision of future flows of ES, and thereby helps to ensure enduring human well-being. As a consequence of global increase of economic and societal prosperity, ecosystems and natural resources have been substantially exploited, degraded, and destroyed in the last century (MA, 2005).

The ecosystem services concept is becoming a central issue in conservation planning and environmental impact assessment (Burkhard et al., 2010; Fisher & Turner, 2008). Methods for the practical application of this concept are urgently needed to support sustainable natural resource management (Daily et al., 2009; Burkhard et al., 2010). Distinctively, forests deliver multiple ES (Barbati et al., 2010): provisioning (timber, non-wood products and bioenergy, habitats), regulating (carbon sequestration, water-flow, erosion prevention, biodiversity conservation), cultural (opportunities for recreation and tourism, as well as landscape aesthetic values). Non-timber goods provisioning and the other mentioned services are distinctively relevant under Mediterranean environmental and socioeconomic conditions (Merlo & Briaies, 2000; Merlo & Croitoru, 2005). ES provisioning is inherently a territorial concept, that is linked inextricably to the place where goods/services provision takes place; this holds for all the types of forest ES. Some services are delivered at specific spatial scale: e.g. supporting services like flood control or soil protection impacting on downstream areas are linked to the catchment scale. Because of the spatial peculiarity of ecosystem services, mapping their distributions and changes over time has the potential to aggregate complex information. The spatial visualization of ecosystem services can be used by decision makers, e.g. land managers, as a powerful tool to support landscape sustainability assessment (Swetnam et al., 2011). The explicit quantification and mapping of ecosystem services are considered as one of the main requirements for the implementation of the ecosystem services concept into environmental institutions and decision making (Daily & Matson, 2008; Marchetti et al., 2012). In addition repeatability and reproducibility of mapping procedures would allow spatio-temporal analysis of changes in ES provision, a key issue in a monitoring perspective.

In recent years, many new ES mapping approaches have been developed and applied at different spatial scales and for different biomes by several authors. Referring to ES specifically provided by forest ecosystems we refer to Burkhard et al. (2009) for a more detailed review of recent approaches. These methods are based on the availability of forest maps depicting a number of variables which are then used for assessing and estimating the provisioning of ES. These information may be collected directly in the field through stand-wise forest inventories, which are usually

created at local forest management scale level. Such an approach is expensive and it can be applied only in small areas: for this reason it usually cannot be routinely updated in short times. On the other hand, mapping forest ecosystem services is especially useful when the information is provided wall-to-wall in large areas, at limited costs, allowing fast track monitoring. However, forest ecosystem inventory and mapping can be suitably integrated (Corona, 2010).

Remote sensing techniques are seen as a valuable source of information for mapping forest attributes (tree species composition, stand biomass, stand density, etc.) since these variables are linked to relevant spectral responses collected by Earth Observation (EO) platforms (McRoberts & Tomppo, 2007). The potential of EO for the spatial quantification of ecosystem services is, however, incompletely known, since the utilization of these data is often complicated by the existence of several interacting factors which contemporaneously affect the spectral signatures of the observed forest surfaces (differences in tree species, age and density, canopy closure, etc.) (Chirici et al., 2008).

Further complications arise in environmentally complex areas because of topographic irregularities and variable soils and under-storey vegetation. The situation is particularly problematic in most Mediterranean environments, where, due to climatic and edaphic limiting factors, the canopy closure is often low, there are complex patterns of plant species composition, densities, ages and sizes also resulting from long term intensive forest management (Chirici et al., 2008). The aim of this contribution is to present a research study carried out in the administrative Region of Molise in Central Italy for the spatial modeling and mapping of ecosystem services on the basis of high resolution multispectral satellite remotely sensed data. We called this approach MultIscale Mapping Of ecoSystem servicEs (MIMOSE). Non-parametric prediction methods are used to create wall-to-wall maps of forest variables which were then processed on the basis of an object-based segmentation for creating input information for well-known models for the integrated evaluation of ES, like the InVEST one (Tallis et al., 2013).

MATERIALS AND METHODS

Study area

The study area is coincident with the administrative boundary of Molise Region, in Central Italy, it covers about 443,758 ha. The elevation ranges between the sea level on the Eastern Adriatic coast to 2050 m a.s.l. of the Matese massif. The

climate is Mediterranean and Temperate. Forests and other wooded lands in Molise cover the 35% of the total region and are mainly constituted by deciduous broad leaved formations (Gasparini & Tabacchi, 2011).

Earth observation data

The dataset we used is made of the four spectral bands acquired between 0.52 and 1.70 μm of a cloud free IRS LISS III imagery acquired in summer 2006, the image is available at 20 m spatial resolution, more information of pre-processing steps are available in Müller et al. (2009). Digital panchromatic orthophotos (ADS40) acquired in spring and summer 2007 having a resolution of 0.5 m were also available.

Forest types map

The forest types map of Molise Region was used for deriving spatial information about the distribution of the different forest types and forest management approaches. This map was created at a nominal scale of 1:10,000 by manual delineation of ADS40 images supported by a field survey (Chirici et al., 2011); a minimum mapping unit of 0.5 ha was adopted. The system of nomenclature was originally based on 13 forest categories (compatible with the European Forest Types nomenclature system, see Barbati et al., 2013), subdivided into 40 forest types. The FAO forest definition was adopted resulting a total of 151,235 ha of forest and Other Wooded Land (OWL) area, consistently with NFI estimates (Gasparini & Tabacchi, 2011).

In this study we used only those parts of the map related to forest types which are usually managed as even-aged formations, they account 128,402 ha (the 85% of the total forest area).

Field data

Field data were acquired on the basis of a local two-phase forest inventory sampling design (Cochran, 1977) tha was based on the following steps. 1) The inventory area coincident with the administrative boundary of Molise Region was adopted. 2) The first-phase sample for the inventory area was created on the basis of a tasseled sampling design (TSS) with sampling units randomly located within an hexagonal systematic grid of 1 km^2 (Fattorini, 2003). 3) First-phase sample units were classified in forest and non-forest, forest units were further stratified on the basis of forest categories, 4) From the first-phase sample we randomly selected 304 second-phase sample points. Around each second-phase point we created a circular plot of 13 m

radius where all tree stems with a diameter at breast height (DBH) greater than 3 cm were measured in DBH and height. For each plot the growing stock (GS) was then calculated using specific allometric models (Castellani et al., 1984).

Growing stock volume map

We used the non-parametric multivariate k -Nearest Neighbour (k -NN) to estimate the growing stock volume combining the data acquired in the 304 field plots of the local forest inventory with the IRS LISS III multispectral images. The method is extensively described in Chirici et al. (2008), here we recall only the main basics of it. Given a reference pixel set (r) for which both the IRS LISS III spectral values and field observed growing stock values (Y_r) are available, and the set of target pixels (t) for which spectral values are available and growing stock volume (denoted as the target variable Y_t) is unknown, we estimated the growing stock for each pixel t as follows:

$$\hat{Y}_t = \frac{\sum_{r=1}^k W_{t,r} Y_{rNN}}{\sum_{r=1}^k W_{t,r}}$$

where Y_{rNN} are growing stock values for pixels located on the k -nearest neighbor units of the target pixel t and W is a weight inversely related with the multidimensional distance between the pixel t and rNN measured on the fourth - dimensional IRS LISS III spectral band space.

The estimation was carried out with the freely available software “K-NN FOREST” (Chirici et al., 2012). After a preliminary optimization phase we decided to use the Euclidean distances in determining the six nearest neighbors. The final growing stock volume map has the same spatial resolution of the input IRS images, 20 m. We validated the growing stock volume map against a totally independent dataset of field observation available in 442 forest stand units, which covers 4,959 ha, resulting in a Root Mean Squared Error (RMSE) of 81.47 m^3 per forest stand unit (the 2.97% of the real observed values per forest management unit).

Forest age map

We estimated the forest age for each pixel of the growing stock volume map by applying for each even aged forest category a specific inverted yield equation. A detailed description of the method we used is presented in Frate et al. (pers. Comm.). The method was applied to even-aged forests only.

We validated the forest age map with the same approach used for the growing stock volume, this time we used 305 stand

units which covers 3,137 ha, resulting in a Root Mean Squared Error (RMSE) of 15.78 years (the 30% of the real values observed per forest management unit).

Segmentation

One of the most important decision that have to be taken when mapping ES is the definition of the mapping unit used for aggregating and representing the different services. Two options are possible: pixels or forest parcels. In this work we created forest parcels as polygon objects through a segmentation algorithm available in the GIS software IDRISI Selva Edition. The input layer was formed by polygons homogeneous by forest category and management approach and the segmentation was performed on the basis of the growing stock volume map and the age map. The algorithm is based on a watershed delineation process applied to variance images calculated on the basis of input layers with a 3 x 3 moving window. The watershed approach is a modification of that proposed by Jenson & Domingue (1988). Variance images are used as input because we assume that polygons have to be delineated when a local change is encountered in the input images, because in these regions the variance values are higher. The final parcels are created merging adjacent image segments according to their similarity. In so doing average and standard deviation of separate and merged polygons are compared before and after the possible merge. Only if the overall heterogeneity introduced to form a new segment through merging is above a given threshold, the merging is retained. For more information we refer to Eastman (2012). The method was demonstrated to give valuable results in similar activities in boreal forest conditions (Egberth & Nilsson, 2010).

InVEST and management scenario

In order to assess and mapping the Net Present economic Value (NPV) of timber production obtainable from the regional forest resources we planned to use the Managed Timber Production tool, which is a part of the InVEST model toolboxes developed by the Natural Capital Project. InVEST is a set of models spanning terrestrial, freshwater, and marine environments, that use production functions to estimate changes in ES under different demographic, land-use, and climate scenarios. The model runs on a vector GIS dataset that maps parcels on the landscape that are, or are expected to be, used for legal timber harvest over a user-defined time period. Each timber harvest parcel is described by its harvest levels (harvested mass), frequency of harvest, mean price of achievable products and harvest and management costs. Further information on the InVEST

models are available at <http://naturalcapitalproject.org/>.

In order to prepare the information basis for the InVEST use we associated to each forest parcel obtained by segmentation the dominant forest type, the total amount of growing stock, and the average forest age using the relative maps previously created.

In order to assess the potential harvestable wood volume per forest parcel, the management need to be consistent with limitation to forest logging legally imposed to maintain the protective function of forest against hydrological diseases in steep terrains and mountain environments. For this reason on the basis of a local Digital Elevation Model (DEM) with a spatial resolution of 20 m we associated elevation and slopes to each forest parcel delineated by segmentation. In order to take into consideration nature conservation aims we also classified parcels on the basis of their inclusion in the core area of the local National Park - Parco Nazionale di Abruzzo, Lazio e Molise.

RESULTS AND DISCUSSION

The segmentation process produced 47,909 forest parcels covering about 152,000 ha. The average surface of each parcel is approximately 3.2 ha, with a range of variation between 0.5 and 145 ha and a standard deviation of 5 ha.

The average growing stock volume in each parcel is 107 m³ ha⁻¹ ranging between 0 and 829 m³ ha⁻¹ with a standard deviation of 86 m³ ha⁻¹ (Figure 1).

The average age in each forest parcel ranges between 0 and 191 years, the average is 25 years with a standard deviation of 20 years (Figure 2).

The most represented forest categories in terms both of area and growing stock are those forests dominated by deciduous oaks (*Quercus cerris* and *Q. pubescens*), both prevalently managed as coppice with standards for firewood production (Figure 3).

Together they cover the 67% of the forest area and represent the 54% of the total growing stock volume. Beech forests, which are mainly high forest stands represent the 10% of the area and the 24% of the volume (Figure 4).

First results highlighted that despite the majority of forest parcels is yet ascribable to coppices, most of them have already passed the maximum cutting rotation age allowed by local forest regulations and should necessarily be converted to high forest. This may requires the stretching of harvesting period and the impossibility to use such forest resource in the short time.

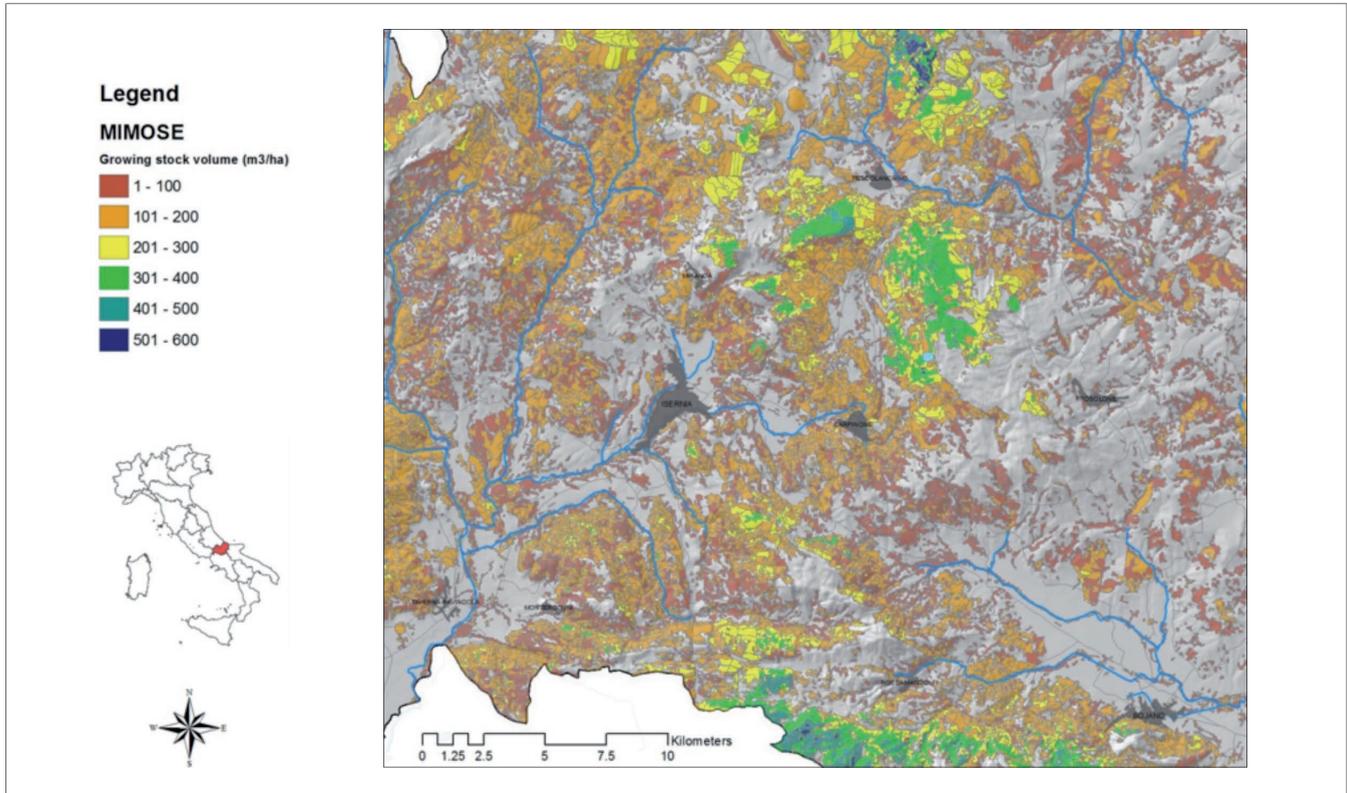


Figure 1. Averaged growing stock volume (m³/ha) of the forest parcels created by segmentation in the south west part of Regione Molise.

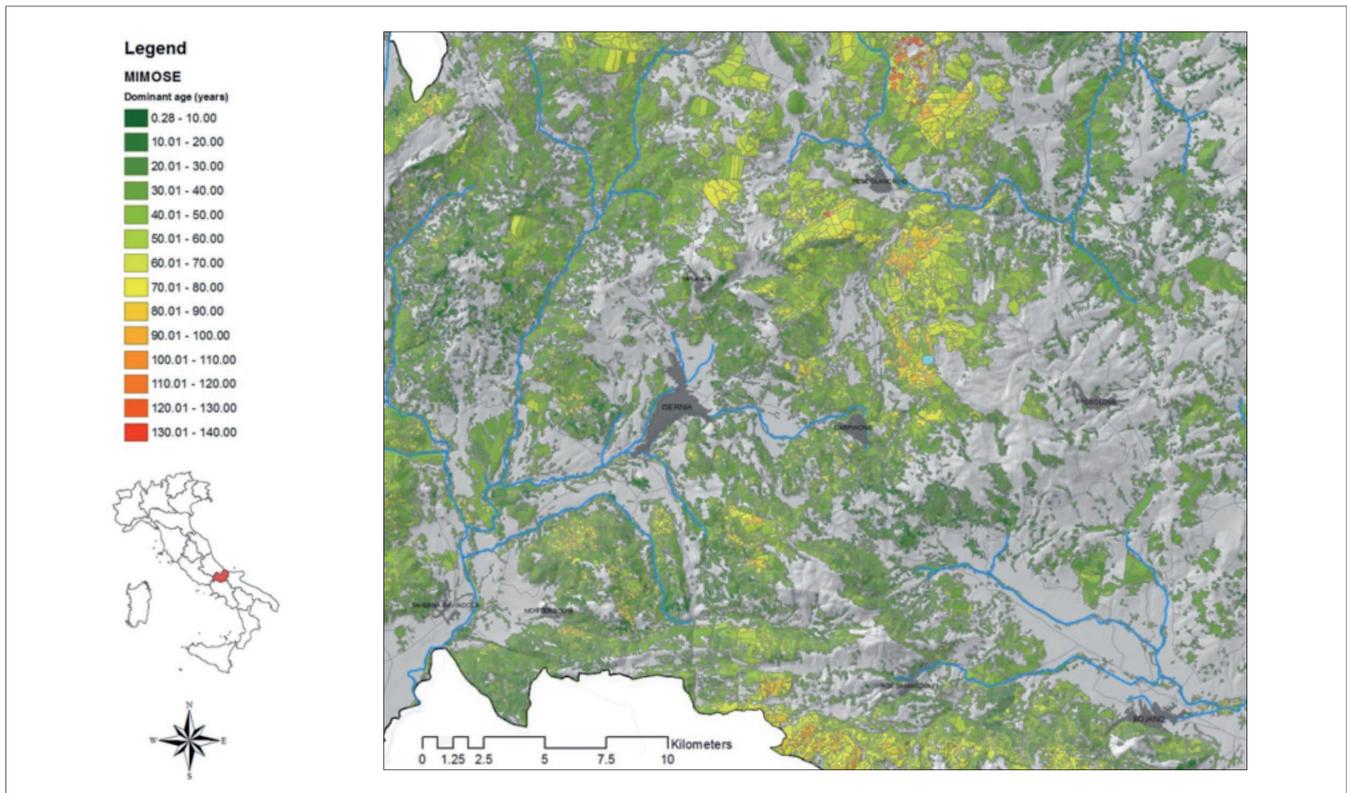


Figure 2. Dominant forest age (years) of the forest parcels created by segmentation in the south west part of Regione Molise.

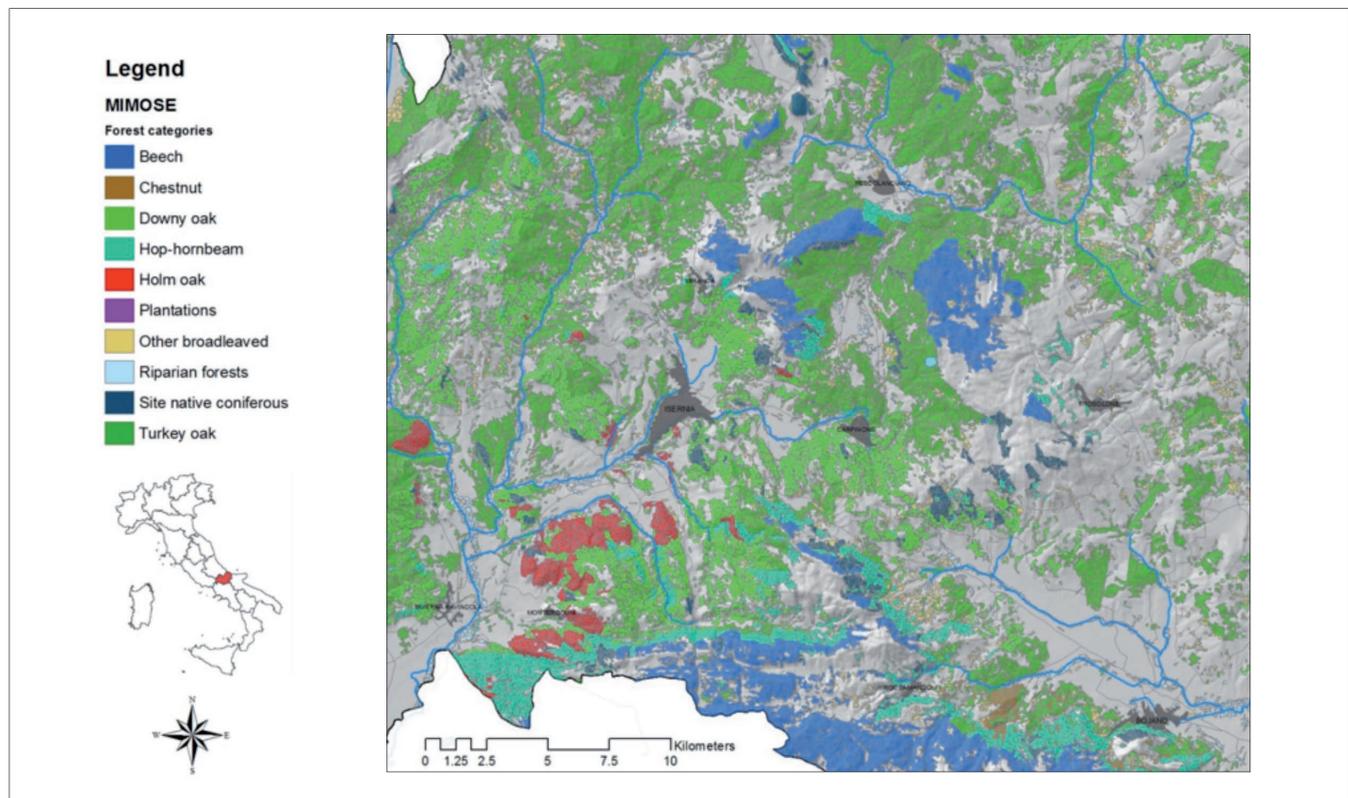


Figure 3. Forest categories of the forest parcels created by segmentation in the south west part of Regione Molise.

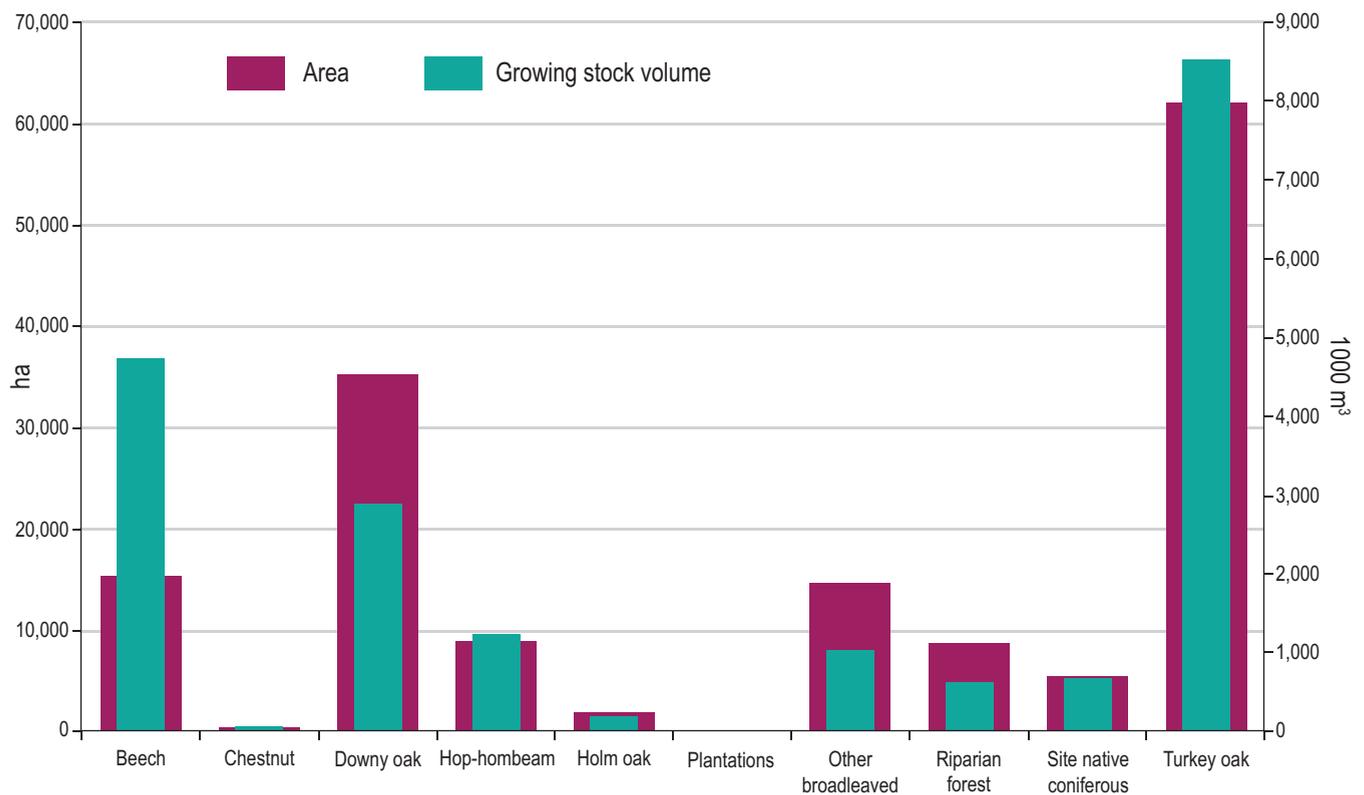


Figure 4. Total area (hectares, on the left) and growing stock volume (thousands of m³, on the right) of the forest categories in the study area.

CONCLUSIONS

In the last decade ecosystem services have been proposed as a method for quantifying the multifunctional role of forest ecosystems (Corona & Marchetti, 2007; Corona et al., 2011). Their spatial representation on large areas is limited by the availability of information, that, when collected in the field with traditional methods typical of forest management practices, are expensive.

In this contribution for the first time we propose the MIMOSE approach which integrates remotely sensed images and field observation to produce a wall-to-wall geodatabase of forest parcels accompanied with several useful information, such as forest categories, growing stock volume, increments, forest age. Other ancillary information useful to model forest management scenarios such as the inclusion in protected areas, slope, and elevation are considered. Even if only preliminary results are here presented, the procedure demonstrated to be able to provide valuable spatially explicit information to support the implementation of models, like the InVEST one, on large geographical areas with a limited cost. We hope that the MIMOSE approach will facilitate the stakeholders participation and the inclusion of ES evaluation in decision-making processes.

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