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Methods for biomass stock estimation in Mediterranean maquis systems

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As a result of Kyoto Protocol agreements, the scientific community increased its efforts to enhance the availability of biomass and organic carbon stock data in forest ecosystems. Nevertheless, a considerable data shortage has been recognized in estimating the stock of above-ground biomass (AGB) in Mediterranean maquis systems. This work aims at contributing in addressing such shortage by testing quick and non-disruptive methods to estimate the AGB stock in maquis species. Two methodologies were tested in three widespread sclerophyllous evergreen species (*Pistacia lentiscus*, *Euphorbia dendroides*, and *Cystus monspeliensis*). Both methodologies were based on the estimation of the apparent volume (AV): the first one assumed the shrub shape (or canopy) to be similar to a regular tridimensional solid, while the second method was based on plant digital images analysis. Results showed some differences in AV values estimated through the two methodologies, although a high correlation was found between them (R^2 = 0.92-0.98) and with the AGB weight obtained from plant samples (R^2 = 0.89-0.96). As a consequence, the shrubs apparent density values (*i.e.*, weight/AV) vary depending on the method used for AV estimation. This should be taken into account when AV is used for AGB estimation. Besides, measurements of above-ground biomass were carried out to characterize the studied area. Results showed high variability in AGB values, ranging from 7.04 to 48.05 Mg ha^{-1} of dry matter.

Keywords: Shrubland, Allometric Equations, Above Ground Biomass, Apparent Volume

Introduction

In the recent past an increase of surfaces covered by maquis was observed in Europe due to a reduction in cultivated areas (Rühl et al. 2005). However, in southern Europe, most of the Mediterranean maquis surfaces are secondary successions of forested areas as consequence of human activities (*e.g.,* utilization for timber, fires, grazing) and climatic stress factors (elevated summer temperatures and drought), which cause the conversion from forests to maquis and slow down the transition of maquis to forest.

The assessment of carbon stock of these surfaces plays a key role in evaluating the ecosystem resources, both for traditional goods production (such as timber or food, biodiversity assessment – Corona et al. 2011a, or related services such as soil protection, water and nutrients cycling, biodiversity, and pollution control) as well as in function of climate regulation. After the Kyoto protocol (KP), the role of shrub species was highlighted in 2005 during the Marrakech summit (Lumicisi et al. 2007); recently, the international challenges related to the carbon issue were renewed following the Doha agreements in 2012, when the KP objectives to pursue the reduction and constraint of greenhouse gases emission at global level were extended to 2020. New environmental policies and carbon market mechanisms are being developed in southern Europe (Boisgibault 2012), including the improvement of forest ability to sequester carbon with proper silvicultural practices (Corona & Marchetti 2007) and fire management (Botequim et al. 2015, Corona et al. 2015). In most of these cases, the biomass stock assessment plays a key role (Barbati et al. 2007).

The "Good Practice Guidance for Land Use, Land Use Change and Forestry" (GPG-LULUCF – Penman et al. 2003) is the official guide developed by the IPCC National Greenhouse Gas Inventories Programme to estimate the carbon stock and its changes in relation to the KP (Nabuurs et al. 2003, Schlamadinger et al. 2003). It defines five terrestrial carbon pools: above- and below-ground biomass, dead wood, litter, and soil organic matter. In forestry systems, the above-ground biomass (AGB) stock and changes are mostly assessed through a combination of inventory data and the use of allometric equations that relate plant dendrometric measurements (trunk diameter at breast height, tree height, etc.) to the AGB weight. However, the application of the GPG-LULUCF protocols is difficult when Mediterranean maquis is involved. In such ecosystems, the quantification of the AGB stock is challenging due to the high variability in species composition and because of the shrub architecture (Costa & La Mantia 2005), which limits the application of traditional techniques developed for forestry tree species. As a consequence, there is still little information on the carbon stock capacity and changes in such ecosystems (Navarro Cerrillo & Blanco Oyonarte 2006). This fact is particularly vexing in Italy, where the maquis ecosystem is one of the most represented forest categories (3.34%

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of the national surface and 8.05% of forested area, with more than 1 million ha), denoting a critical issue in the context of the carbon credits market (Alisciani et al. 2011). In addition, the available AGB data are also characterized by a wide range of variability and uncertainty; this has been demonstrated by recent efforts to harmonize, at international level, the allometric equations available for supporting volume and biomass assessment in tree/forestry systems (Somogyi et al. 2008, Henry et al. 2013).

Currently, different methods are used to estimate the AGB in the maquis species. The destructive sampling method is accurate but time consuming and not always applicable (*e.g.,* in protected areas - Gratani et al. 1980). Most used methods are based on allometric equations relating AGB to its proxies, such as the shrub height (Gratani et al. 1980, Sternberg & Shoshany 2001, Bianchi et al. 2002, Coomes et al. 2002, Scarton et al. 2002, Corona et al. 2011b) or the crown diameter (Gratani et al. 1980, Lledò et al. 1992, Quideau et al. 1998, Sternberg & Shoshany 2001, Coomes et al. 2002, Ogaya et al. 2003, De Luis et al. 2004, Saglam et al. 2008, Corona et al. 2011a). Gratani et al. (1980) estimated the apparent volume (AV) from the crown diameter and height measurements, while Catarino et al. (1982) used plant height and stem diameter measurements. The shrub AV can be also used as a proxy of the AGB stock. Montès et al. (2000) proposed a computerized methodology to estimate the AV based on orthogonal-view digital images of the shrub. Other authors (Whittaker & Woodwell 1968, Chapman 1986, Azmi et al. 1991, Usó et al. 1997, Sternberg & Shoshany 2001, De Luis et al. 2006) developed a methodology where the AV is estimated assuming the shrub shape to be similar to a 3D regular solid (*i.e.,* cylinder, sphere, rotation paraboloid, etc.). In all cited cases, reliable data on the specific apparent density of the shrub (*i.e.,* weight/AV, kg m^{-3}) are needed.

Chirici et al. (2009) and Bacciu (2009) applied an expeditious method to estimate a "volume index" as the product between the vegetation coverage degree and shrub height, while in recent years a growing interest was addressed to the application of the Light Detection And Ranging (LiDAR) systems which estimates the AGB stock from the relationship between plant weight and canopy height or volume (Garcìa et al. 2010, Maselli et al. 2011, Corona et al. 2012).

The aim of this paper is to contribute in evaluating methodologies able to estimate the AGB stock in Mediterranean maquis systems. In particular, this work explores the potential application of two expeditious and non-disruptive methodologies to be applied for three of the most representative maquis species of the Mediterranean basin: *Pistacia lentiscus* L., *Cystus monspeliensis* L. and *Euphorbia dendroides* L. Additional measurements of AGB were carried out in order to characterize the study area and to evaluate the two applied methodologies, thus increasing the availability of such data within the scientific community.

Materials and methods

Study site

The work was carried out in Sardinia (Italy), the second largest island (24 090 km^2) of the Mediterranean Sea, where approximately half of the land surface is covered by forests and Mediterranean maquis. The site is located in the National Park of Asinara (40° 59′ - 41° 07′ N; 8° 12′ - 8° 21′ E; 51.2 km^2), an island used as a State prison until 1997 (Forteleoni & Gazale 2008). The climate is typically Mediterranean, with relatively mild winters, and warm and dry summers. The mean annual temperature is 16.1 °C (coldest month: February with 10 °C; warmest month: August with 23 °C). The climatic annual rainfall is 476 mm, among the lowest in Sardinia. More than 80% of the soil substrate consists of metamorphic rocks with sedimentary and volcanic origins, mainly represented by schist and sporadic granitic lithologies.

The vegetation is characterized by a mosaic of secondary Mediterranean maquis communities as a consequence of frequent fires in the past (frequently used during the penal colony period for agricultural purposes) and over-grazing (by goats, horses, and wild boars). The establishment of the National Park and the subsequent abandonment of agricultural activities favored the recolonization of these areas by Mediterranean maquis species, mainly *Pistacia lentiscus* L., *Cystus monspeliensis* L. and *Euphorbia dendroides* L. A detailed description of Asinara Island vegetation can be found in Pisanu et al. (2014).

Application of two methodologies for above-ground biomass estimation

AGB estimation is based on the relationships between AV and the plant dry weight. Preliminary height and crown diameter measurements were carried out in different areas to characterize the structural variability of the plant community. Shrubs with different sizes of the three most diffuse species in the area (18 for *C. monspeliensis*, 12 for *E. dendroides*, and 8 for *P. lentiscus*) were randomly sampled to estimate the AV using the two methodologies described below.

- *Methodology 1*. The AV was estimated assuming the shrub shape to be similar to a regular 3D solid. Measurements of plant height (H), maximum crown diameter (MD) and diameter orthogonal to MD (OMD) were used to calculate regular solid volumes (circular and elliptical cylinder, sphere, paraboloid, ellipsoid, and half ellipsoid).
- *Methodology 2*. The AV was estimated using a methodology adapted from Montès et al. (2000). The methodology includes the following steps (Fig. 1): (i) a digital camera was used to take two orthogonal view pictures in correspondence of plant MD and OMD sides; (ii) the software Microsoft Power Point® ver. 2013 was used to manually digitize the plant contour displayed in the pictures; (iii) a worksheet (Microsoft Excel® ver. 2013), with cells previously organized in a grid of 0.1 × 0.1 m, was used to place the plant digital contour on the grid and to calculate the apparent volume for each shrub layer. The AV of each shrub was

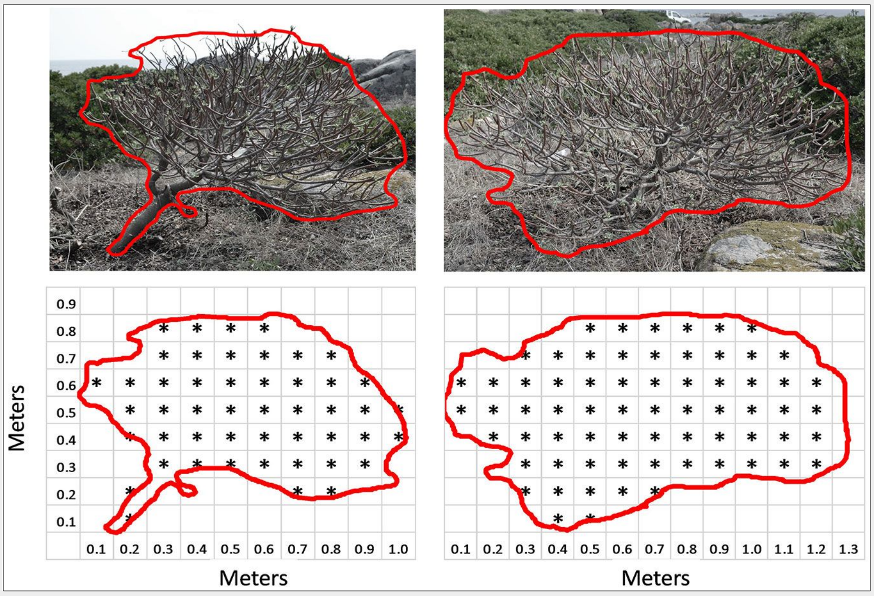

Fig. 1 - The apparent volume estimation with Methodology 2: digital photos and contouring (upper panels); a view of Excel worksheet for the volume calculation (lower panels). The apparent volume of the shrub is obtained summing the volume of each layer of 0.1 m height.

obtained through the sum of each layer's volume.

The sampled shrubs were cut and oven-dried in a laboratory at 65 °C to obtain the dry weight.

The regressions between the AV estimated with the two methodologies and the dry weight were then calculated for each species. The AD values (dry weight/AV ratio) for each species were also obtained both with Methodology 1 and 2.

Field measurements: AGB stock estimation

The findings of the above analysis were applied to a case study. Three areas characterized by a different degree of soil cover and mean shrubs height (identified as low, medium, and high recolonization degree) were identified on the Asinara Island. In each area, three plots of 3.0 × 3.0 m were demarcated, where sub-plots of 0.5 × 0.5 m were further delimited. In each sub-plot and for each species, the basal area and the canopy height were measured (at 0.1 × 0.1 m points) to estimate the AV as the product of specific soil cover and plant height. This method was chosen since shrubs were highly intermingled. Given the small size of the sub-plots, it was assumed that the estimated AV for each plot was comparable to the AV of the single shrubs obtained with Methodology 2. Finally, the AGB was estimated by the product of the AV and the AD obtained from the Methodology 2.

In order to better characterize the site, the litter and dead wood stock were also calculated. Ten aluminum frames of 0.1 × 0.1 m were randomly distributed in each plot to estimate the litter amount, and all the dead wood material inside each plot was collected. Both litter samples and dead wood were oven-dried (65 °C) and then weighed in the laboratory.

Tab. 1 - Attributes of the sampled plants. (MD): maximum crown diameter; (OMD): diameter orthogonal to MD; (AV): apparent volume; (AD): apparent density.

Parameter	Statistics	*C. monspeliensis* (n = 18)	*E. dendroides* (n = 12)	*P. lentiscus* (n = 8)
Height (m)	average	0.763	1.453	1.203
	maximum	1.200	2.200	1.800
	minimum	0.340	0.730	0.480
	standard dev.	0.277	0.489	0.475
MD (m)	average	0.999	1.653	2.406
	maximum	1.530	2.400	3.000
	minimum	0.310	0.800	1.930
	standard dev.	0.357	0.599	0.299
OMD (m)	average	0.804	1.664	2.088
	maximum	1.400	2.620	3.100
	minimum	0.270	0.650	1.640
	standard dev.	0.302	0.610	0.606
AV (m^3) *Methodology 1*	average	0.43	2.80	3.32
	maximum	1.04	7.21	6.53
	minimum	0.02	0.20	0.86
	standard dev.	0.33	2.42	2.04
AV (m^3) *Methodology 2*	average	0.26	1.59	2.63
	maximum	0.60	5.10	4.90
	minimum	0.01	0.06	0.71
	standard dev.	0.21	1.65	1.61
Dry weight (kg)	average	0.68	5.25	8.85
	maximum	1.48	15.16	13.77
	minimum	0.12	0.31	3.39
	standard dev.	0.45	5.35	4.13
AD (kg d.m. m^{-3}) *Methodology 1*	average	2.18	1.67	3.02
	maximum	7.95	2.66	4.74
	minimum	1.20	0.86	2.08
	standard dev.	1.60	0.59	0.98
AD (kg d.m. m^{-3}) *Methodology 2*	average	4.04	3.44	3.81
	maximum	15.00	4.84	5.76
	minimum	1.79	2.34	2.77
	standard dev.	3.13	0.87	1.06

Results and discussion

Application of two methodologies for above-ground biomass estimation

The main attributes of the sampled shrubs are reported in Tab. 1. The lowest and highest mean height was found in *C. monspeliensis* and *E. dendroides*, respectively, while *P. lentiscus* showed the mean highest crown diameters. *C. monspeliensis* and *P. lentiscus* showed the lowest and highest mean dry weight and AV per shrub, estimated with both Methodology 1 and 2.

Differences in the AV depend not only on the methodology used for its estimation but also on the species. In this analysis, higher differences were found for *C. monspeliensis* (62%) and *E. dendroides* (60%) than for *P. lentiscus* (26%), mainly due to the more irregular crown contour of the first two species with respect to *P. lentiscus*.

Results also confirm that the method used for the AV estimation should be appropriately considered when AD values are used, since the two terms are strictly related. In Methodology 1 the shrub shape is assumed to be regular (*i.e.,* the plant contour irregularities are not considered), while in Methodology 2 the canopy contour is more detailed. Consequently, AVs calculated with Methodology 1 show higher values than those obtained by Methodology 2 (Tab. 1). This result highlights the importance to have specific AV-AGB relationships for a reliable biomass stock assessment.

Results from the two methodologies were compared and a strong relationship between the AV estimated with Methodology 1 and 2 (R^2 = 0.95-0.98 – Fig. 2) was

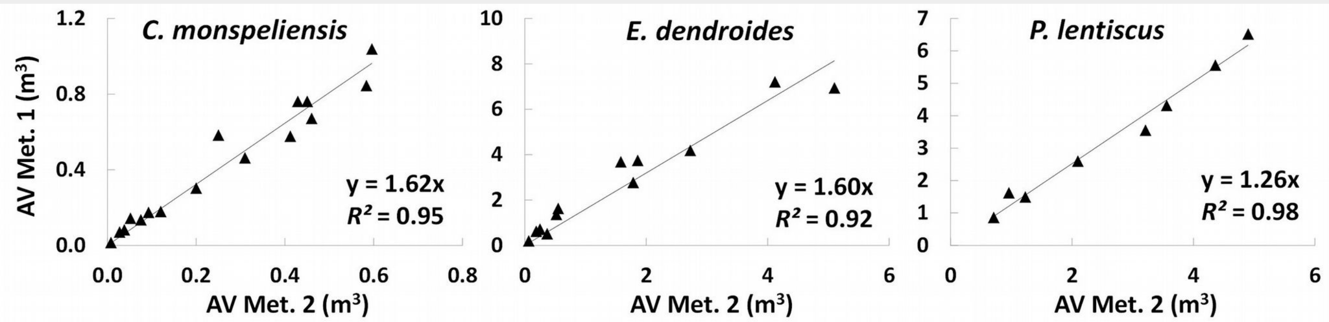

Fig. 2 - Relationships between the apparent volume (AV) estimated with Methodology 1 (Met.1) and Methodology 2 (Met. 2).

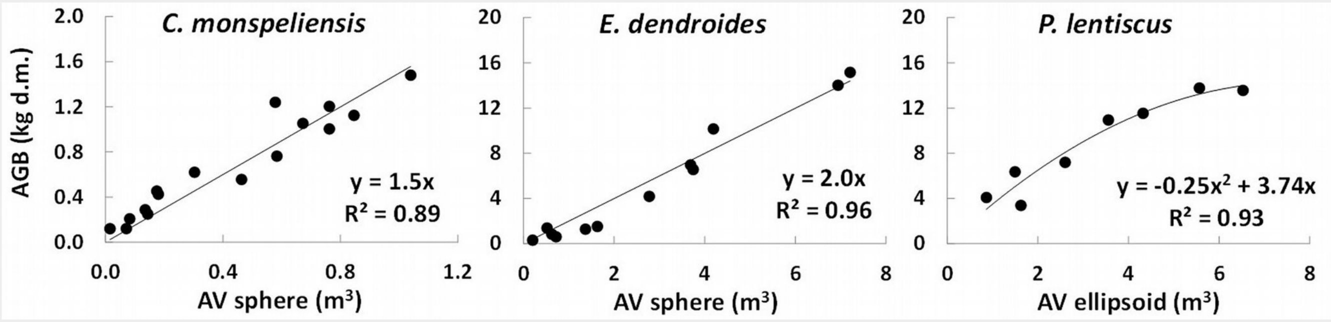

Fig. 3 - Relationships between the apparent volume (AV) estimated with Methodology 1 and the above-ground biomass (AGB).

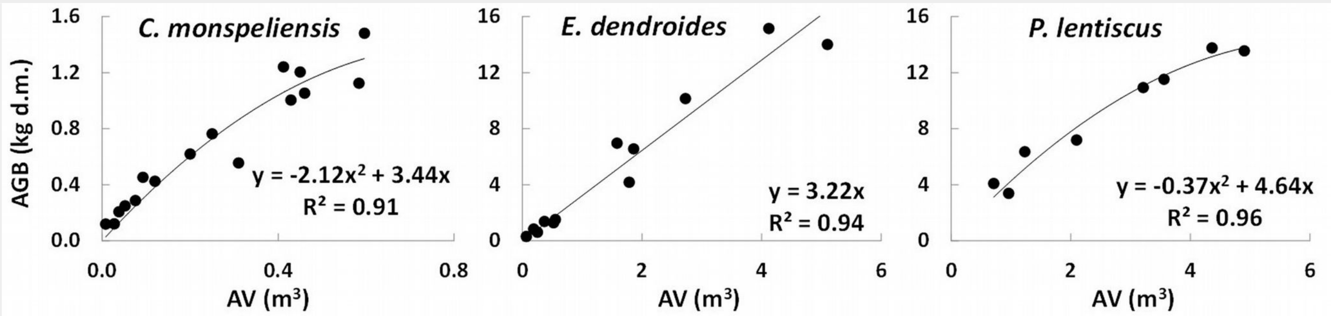

Fig. 4 - Relationships between the apparent volume (AV) estimated with Methodology 2 and the above-ground biomass (AGB).

found. This confirms that reliable AGB assessments based on AV estimates can be obtained both with Methodology 1 and 2, when appropriate AD values are used.

The corresponding AD values for Methodology 1 and 2 are reported in Tab. 1. The AV estimation methodology also affects the distribution of the apparent density values between species. Higher AD values for each species were found when AV was obtained with Methodology 2 (*Cystus* +85.3%, *Euphorbia* +106.0%, *Pistacia* +26.2%). With Methodology 1, the highest mean AD value was found for *P. lentiscus*, followed by *C. monspeliensis*, but the opposite was obtained using Methodology 2. The lowest mean AD value was obtained for *E. dendroides* with both methodologies.

Furthermore, simple relationships between the estimated AV and the dry weight of the sampled plants were calculated. The R^2 value ranged from 0.89 to 0.96 (Fig. 3) with Methodology 1 (AV estimated as 3D shape) and the best 3D shape (higher R^2 value) is different depending on the species (sphere for *C. monspeliensis* and *E. dendroides*, and ellipsoid for *P.lentiscus*). Comparable R^2 values between species were indeed obtained when AV was estimated with Methodology 2 (R^2 = 0.91-0.96 – Fig. 4).

Previous studies did apply similar methods to maquis species. Gratani et al. (1980) obtained a R^2 value of 0.85 for *P. lentiscus* by estimating the AV as $D^2 \cdot H$ (D: diameter, H: height). Usó et al. (1997) did not find statistical differences in using the circular cylinder, elliptical cylinder, and paraboloid of rotation as proxies of the AGB stock in *Cistus albidus, Thymus vulgaris,* and *Rosmarinus officinalis*. A similar approach was used in a study conducted in arid sites in Israel, where Sternberg & Shoshany (2001) calculated the AV for more than 20 shrub species using the formula of several solids (as inverted cone, spheroid, cylinder, etc.). However, no indication about the solid shape showing the best fit with the AGB stock values was reported by the authors.

Our results confirmed that AV can be used as a proxy of the AGB weight with quick field measurements, but providing appropriate AV-AGB relationships is crucial. Although this analysis was based on a limited number of samples, results are promising also in view of the growing interest on proximal sensing techniques (*e.g.,* LiDAR) for the AGB assessment.

Field measurements: AGB stock estimation

Previous results were applied for estimating the AGB in the same area, with the aim of increasing the limited availability of AGB data in maquis systems within the scientific community. Tab. 2 shows the structural

Tab. 2 - Main structural characteristics of the sampled areas. (AV): apparent volume; (AGB): above-ground biomass); (*): the soil cover is above 100% due to the partial overlapping of the species.

Recolonization degree	Species	Cover* (%)	AV (m^3 m^{-2})	Height (m)			AGB (Mg d.m. ha^{-1})
				mean	max	min	
low	*C. monspeliensis*	32.9	0.104	0.27	0.50	0.08	4.209
	P. lentiscus	22.7	0.074	0.27	0.55	0.10	2.830
	baresoil	44.7	-	-	-	-	-
medium	*E. dendroides*	8.9	0.082	0.75	1.30	0.38	2.832
	P. lentiscus	69.5	0.332	0.43	0.80	0.10	12.644
	baresoil	25.1	-	-	-	-	-
high	*C. monspeliensis*	6.3	0.047	0.71	0.90	0.50	1.907
	E. dendroides	43.7	0.833	1.34	1.80	0.80	28.636
	P. lentiscus	49.4	0.460	0.76	1.75	0.25	17.506
	baresoil	13.9	-	-	-	-	-

Tab. 3 - Above-ground biomass (AGB), litter and dead wood stock (Mg d.m. ha $^{-1}$) of the sampled areas.

Recolonization degree	AGB	Litter	Dead wood	Total
low	7.04	21.18	3.46	31.68
medium	15.48	23.48	1.36	40.32
high	48.05	19.88	1.24	69.17
Average	23.52	21.51	2.02	47.06

characteristics of the areas where the woody stocks were estimated. On average, the AV ranged from 0.18 m^3 m^{-2} to 1.34 m^3 m^{-2} from low to high recolonization degree sites. The AGB of *C. monspeliensis* inversely decreased with respect to the recolonization degree (Tab. 2), with values ranging from 1.91 to 4.21 Mg d.m. ha^{-1}. An opposite trend was observed both for *P. lentiscus* (2.83-17.51 Mg d.m. ha^{-1}) and *E. dendroides* (2.83-28.64 Mg d.m. ha^{-1}), whose AGB values increased from low to high recolonization degree. These results are in accordance with the patterns of vegetation dynamics related to secondary succession models (also conceptualized as vegetation series – Farris & Filigheddu 2011), already described for north-western Sardinia (Biondi et al. 2001) and for the Asinara National Park (Farris et al. 2007, 2010, Bacchetta et al. 2009, Pisanu et al. 2014). Due to these succession dynamics, and to the consequent species distribution and structure, the AGB ranged from 7.04 (low recolonization degree) to 48.05 Mg d.m. ha^{-1} (high recolonization degree – Tab. 3).

Results were also compared with findings from a literature survey, even if this comparison may be affected by a certain degree of uncertainty due to different reasons: the reduced size of the surveyed area, the low number of replicates in our analysis, and the high variability in species, structural characteristics, and methodologies used in different studies. Only a few papers reported results related to a single species. For *P. lentiscus,* Gratani et al. (1980) found an AGB value ranging from 0.90 to 2.17 Mg d.m. ha^{-1}, while Peressotti et al. (1999) reported a value of 1.30 Mg d.m. ha^{-1}, lower than our findings. More similar results were reported for *P. lentiscus* (19.67 Mg d.m. ha^{-1} – Navarro Cerrillo & Blanco Oyonarte 2006; 5.80 to 9 Mg d.m. ha^{-1} – Corona et al. 2011b). For *E. dendroides*, Corona et al. (2011b) reported a value ranging from 3.60 to 11.30 Mg d.m. ha^{-1}.

Less marked differences within the investigated areas were observed for the litter and dead woody material. In particular, the litter load ranged from 19.9 to 23.5 Mg d.m. ha^{-1}. In Greece, Dimitrakopoulos (2002) found that the average litter load in an evergreen-sclerophyllous shrubland, with height up to 1.5 m, was 2.51 Mg d.m. ha^{-1}, and slightly higher (3.38 Mg d.m. ha^{-1}) in the same vegetation with height up to 3 m. In California, Countryman (1982) collected dry weight of litter ranging from 6.77 to 49.60 Mg d.m. ha^{-1}. These extreme differences are not only related to different structural and vegetation characteristics, but also to sampling methodologies: according to Countryman (1982) litter included all dead organic material above the mineral soil in the surface layer, whereas Dimitrakopoulos (2002) supposedly considered only the freshly fallen leaves and spines. In our sampled areas, the dead woody material load was relatively low compared with AGB and litter, and it decreased from low to highly recolonized plots. This fact is partially due to the grazing pressure (mainly by horses and goats), causing mechanical damages to the *Cystus* vegetation in low recolonized areas. Overall, the sum of living and dead mass ranged from 31.68 to 69.17 Mg d.m. ha^{-1} from low to high recolonization degree (Tab. 3).

Conclusions

Consistent and wider datasets of carbon stock in Mediterranean forests are essential for studies related to nutrient cycles, ecology, global change impact assessment, and for management purposes. This is a critical issue especially for Mediterranean maquis systems, where the quantification of the above-ground biomass is challenging. Our results showed that expeditious measurements of the apparent canopy volume can be used for assessing the above-ground biomass of these ecosystems. The two applied methodologies performed well in estimating AV. Results showed that the apparent canopy density values depend on the methodologies used for the apparent volume estimation. In addition, the combination of data related to shrubs volume and density can be of great help in other studies where plant volume assessment is made using different methods (*e.g.,* LiDAR scanner).

This study confirms the high degree of heterogeneity of these systems, and highlights that species and applied methodologies are factors that should be taken into account in order to generalize the results from different studies. Moreover, it provides AGB data and equations for AGB estimation in three widespread shrub species, thus contributing to enhance the limited datasets and information for these ecosystems.

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