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SHORT COMMUNICATION

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# Basic wood density and moisture content of 14 shrub species under two different site conditions in the Chilean Mediterranean shrubland

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## Abstract

*Aim of study:* The aim of this study is to provide information on species-specific basic wood density (g cm$^{-3}$) and moisture content (%) in Mediterranean shrublands.

*Area of study:* The study covers two sites of the sclerophyllous shrubland in central Chile, Cortaderal (34°35'S 71°29'W) and Miraflores (34°08'S 70°37'W), characterized by different climatic and topographic conditions.

*Materials and methods:* The sampling area covers 4,000 m$^2$ over four plots at two sites. Shrub species were identified and size-related attributes such as height and crown size measured. A total of 322 shrubs were sampled at 0.3 m aboveground to determine basic wood density and moisture content. Species-specific differences and similarities were analyzed by multiple pairwise comparisons (post-hoc tests) and by ordination and hierarchical clustering.

*Main results:* We found high variation across species in wood density (0.46-0.77 g cm$^{-3}$) and moisture content (41.6-113.1%), with many significant differences among species in wood density and among sites in moisture content. Because intraspecific variability could not be explained by shrub size and pronounced differences in wood density (0.49-0.64 g cm$^{-3}$) also occurred between species of the same genus (*e.g.*, *Baccharis linearis* and *Baccharis macraei*), our results suggested that phylogenetic affinity may be less important than adaptation to local conditions.

*Research highlights:* The values presented here were variable according to the type of species and environmental conditions, necessitating the determination of basic wood density (BWD) and moisture content at site – and species-specific level. The provided BWD estimates allow converting green volume to aboveground biomass in shrubland areas and are an essential source of information for estimating the carbon stocks.

**Additional key words:** wood properties; water content; shrub size; shrubland ecology; sclerophyllous vegetation.

**Abbreviations used:** BWD (Basic Wood Density); CD (Crown Diameter); CL (Crown Length; DCH (Diameter at Collar Height); HT (Total Height); MC (Moisture Content); NS (Number of Stems).

**Authors' contributions:** EK, MEO, and MZ wrote the paper. MZ and EK performed the statistical analysis. JGu selected the study area and carried out the field measurements. EK and JGa processed the samples at the laboratory. EK, MZ, JGa, FP, DC, TA and YR analyzed the results and reviewed the manuscript. MEO revised English grammar and style. All the authors contributed to improve and approved the final version of the paper.

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# Introduction

Sclerophyll Mediterranean shrubland is one of the most extensive vegetation types in Chile, covering 1,631,441 hectares (11.1% of the national territory) between the regions of Coquimbo and Bio Bio (INFOR, 2020). This ecosystem is of great importance in nutrient cycles, carbon sequestration, soil erosion control, biodiversity and endemic species conservation, and water regulation (Schulz *et al.*, 2010; Ruiz-Peinado *et al.*, 2017). Despite this great importance, it is beset by anthropogenic fires, over-grazing from livestock, agricultural expansion, and logging for firewood, which have occurred historically from the Euro-Chilean settlement, and as a result have reduced shrubland cover in central Chile (Schulz *et al.*, 2011). To promote effective strategies of protection, restoration, and sustainable management of this ecosystem and to estimate the services it might provide (*e.g.*, carbon stock and sink), it is crucial to measure both its aboveground biomass as well as its wood density, which is necessary to convert wood volume to dry biomass. However, quantitative information on the Chilean Mediterranean shrubland is scarce in the international literature. Most studies on aboveground biomass, basic wood density (BWD) and moisture content (MC) in Chile have focused on temperate rainforests (*e.g.*, Gayoso *et al.*, 2002). Among the few studies conducted on Mediterranean shrubland, Cruz *et al.* (2015) reported mean values of BWD and MC for four shrub species in central Chile, such as *Acacia caven* Mol., *Lithraea caustica* Mol., *Cryptocarya alba* (Mol.) Looser, and *Quillaja saponaria* Mol., which are among the most common species. However, the available information for other shrub species is scant.

Wood density and moisture are highly variable across species (Barajas Morales, 1987; Chave *et al.*, 2009), underscoring the need to document as many species as possible. In some cases, due to the absence of species-specific information, values from closely related species or under similar ecological conditions are used as a substitute. However, because BWD can vary markedly even between closely related species and among the species of the same community, such extrapolations must remain highly tentative. Such information is key in multispecies and generalized models, where BWD is an important covariate for predicting dry biomass (Chave *et al.*, 2005).

In this study, we investigated species in the sclerophyllous Mediterranean shrubland in central Chile. To our knowledge, no information on BWD and MC of these species has been previously reported in the international literature or databases such as the Global Wood Density Database (Zanne *et al.*, 2009) or GlobAllomeTree (Henry *et al.*, 2013). The main aims were (1) to obtain species-specific BWD and MC and shrub attributes, (2) to evaluate whether species of the same genus or family have similar BWD and MC, and (3) to analyze the relationship between BWD and MC within and between species.

# Material and methods

The study was carried out in the central region of Chile, in the O'Higgins region, between the provinces of Colchagua and Cachapoal (Fig. S1 [suppl]), including the sampling sites Cortaderal (34°35'S 71°29'W) and Miraflores (34° 08'S 70° 37'W). The two sites have different topographic and climatic conditions (Fick & Hijmans, 2017). Cortaderal is near the Coastal Mountain Range and is characterized by a higher annual precipitation, while Miraflores is in the foothills of the Andes and is characterized by higher temperatures and a steeper slope facing south (Table S1 [suppl]). Soils also differed between sites, with Cortaderal having clay loam, while in Miraflores the soils were derived from alluvial deposits and thus are characterized by a sandy loam texture (CIREN, 1996). Given these characteristics, water availability is lower at Miraflores than Cortaderal.

During summer 2018 (January and February), shrubs in two plots of 1000 $m^2$ at each site (Fig. S1 [suppl]) were identified, measured and then cut, weighed, and further sampled for determination of BWD and MC. Before shrubs were cut, attributes such as diameter at collar height (DCH), total height (HT), crown diameter (CD), crown length (CL) and number of stems (NS) were assessed with a caliper and a measuring tape (Table S2 [suppl]). In total 322 shrubs were cut, 233 at Cortaderal and 89 at Miraflores. 322 stem samples for BWD and 644 stem samples (two per individual) for MC were obtained through a destructive sampling (wood disks) at the base 0.3 m aboveground (Martínez-Cabrera *et al.*, 2009) in order to standardize the protocol of sampling and avoid values for BWD and MC being affected by sampling height (*e.g.*, Martínez-Cabrera *et al.*, 2011). We measured green weight using a field balance.

In the laboratory, we saturated samples for BWD and used the water displacement method based on Archimedes' principle in order to estimate green volume. Then, the samples were dried at 103±2°C for approx. 48 hours to reach constant mass. The dry basic density (eq. 1) was calculated according to ISO 13061-2-2014:

$$BWD_{0.3} = \frac{m_d}{v_g} \quad (1)$$

where $BWD_{0.3}$ is the basic wood density (g $cm^{-3}$) of the stem sample taken at 0.3 m aboveground, $m_d$ is the dry mass (g) and $v_g$ is the green volume ($cm^3$).

MC was calculated as the ratio between the green weight measured in the field and dry weight measured in the laboratory (eq. 2) according to ISO 13061-1-2014 using a digital balance with a precision of 0.1 g.

$$MC_{0.3} = \frac{w_g - w_d}{w_d} \cdot 100 \quad (2)$$

where $MC_{0.3}$ is moisture content (%) of the stem sample taken at 0.3 m aboveground, $w_g$ is the green weight and $w_d$ is the dry weight of the stem sample.

We analyzed the data in R (R Core Team, 2021). Because variance homogeneity could not be confirmed for the species-specific values of BWD and MC, we used the nonparametric Kruskal-Wallis tests for analysis of variance. Based on the evidence that at least one species differed significantly from the others in its BWD and MC, we then used Dunn's test for multiple comparisons with a correction to control for the experiment-wise error rate with R package 'dunn.test' (Dinno, 2017) to determine which species differed significantly from one another. Pearson's product moment correlation coefficient was computed along with its 95% interval using R function 'cor.test'. To analyse site-specific differences in the relationship between MC and BWD, local polynomial regression fitting as well as correlation ellipses were computed using the 'pairs.panels' function in from R package 'psych' (Revelle, 2021). To elucidate associations between attributes related to shrub size (CD, CL, HT, DCH, NS) and species classification, a principal component analysis of mixed data, *e.g.* including quantitative and qualitative variables, was conducted using the R function 'PCAmix' in the R package 'PCAmixdata' (Chavent *et al.*, 2017). Prior to analysis, quantitative variables were log transformed (to ensure linearity among co-variables and avoid distorted calculations that are otherwise seen as horseshoe effects in the biplot) and scaled (to avoid variables with high variance are dominating the results) (Zwanzig *et al.*, 2020). To classify shrub species with similar size-related characteristics, a hierarchical cluster analysis was applied based on a matrix of Mahalanobis distances computed for pairwise comparisons of species-specific means of the variables DCH, HT, CD, CL and NS. The R function 'pairwise.mahalanobis' in the package 'HDMD' (McFerrin, 2013) was used to calculate the Mahalanobis distances and the agnes-algorithm from the 'cluster' package (Maechler *et al.*, 2021) to construct the hierarchy of clusterings. Additional graphs such as boxplots were constructed using the 'ggplot2' package (Wickham, 2016).

# Results and discussion

Our sampling revealed a different species composition and species richness at the two sites, with 10 shrub species at Cortaderal and 4 species at Miraflores. Site conditions such as insolation, water and nutrient availability are known to affect plant diversity in Mediterranean areas (Fernández-Moya *et al.*, 2011), where the species diversity decline when water availability decreases (Segura *et al.*, 2003). Here, more favorable soil and climate conditions at Cortaderal seem to support higher shrub biodiversity. The species spanned a wide range of shrub size attributes (Fig. 1A), with clear differences between species such as *T. bicolor* and *L. hirsuta* regarding shrub height and stem diameter.

A principal component analysis showed that the multidimensional data can be reduced to one axis loaded with the variables CD, CL, DCH and HT, which explains around 20% of the variance, and a second axis loaded with number of stems that is explaining around 10% (Fig. 1B). The ordination of species along these gradients (axis 1: increasing size, axis 2: increasing stem number) indicates shrub species with similar habits. This grouping is further confirmed and refined by the results of the hierarchical clustering (Fig. 1C). The strongest dissimilarity was found between the cluster of *C. salicifolia, G. foliosa* and *P. mitique,* which have the highest numbers of stems, to all other shrub species. A cluster of *M. obtusa* and *R. trinervia*, both quite tall and wide, were also highly dissimilar from all other species. In addition, *T. bicolor,* which is very short and has a small crown, was dissimilar to all other species. These size-specific clusters of species were not consistently recovered when analyzing their MC and BWD. Similar to our results for shrubs, Preston *et al.* (2006) and Kenzo *et al.* (2017) reported that tree size had only negligible effects on BWD and MC. Martínez-Cabrera *et al.* (2011) showed negative relationship between maximum height and wood density in trees, but not in shrubs.

The BWD of the shrubs varied between 0.46 and 0.77 g $cm^{-3}$ (Table 1), with significant differences between some species (Fig. 2). However, no difference was observed between the two sites. Our results extend the range of BWD from 0.59 to 0.72 g $cm^{-3}$ reported by Cruz *et al.* (2015) for four dominant species of the sclerophyllous shrubland of central Chile. Because wood density integrates many wood properties associated to different growth strategies (Chave *et al.*, 2009), such variability suggests different adaptations of sclerophyllous shrubland species to local conditions. This probably also results from niche partitioning, where shrubs with lower wood density represent short-lived, fast growing and colonizing species, as reported for other ecosystems (Ter Steege & Hammond, 2001; Muller-Landau, 2004).

Mean MC differed significantly between species and sites, with lower values in Miraflores than in Cortaderal (Fig. 2) in line with differing environmental conditions at the two sites (Table S1 [suppl]). Species-specific estimates ranged from 41.6 to 113.1% (Table 1), representing a wider range as compared to the values reported by Cruz *et al.* (2015) (69.4-92.6%) for samples collected in the same season (summer) for four other shrub species in Chile. Our finding suggests that MC tends to be higher at moister sites conditions. However, previous studies by Kenzo *et al.* (2017), have reported that MC in wood increases in trees from forests with higher drought stress. The large differences in both BWD (> 50% between the two species at the distribution extremes) and MC (> 100%) among the studied species underscore the importance of our species-specific investigation. Using one value for all species would cause large under − or over − estimations and thus biases in the assessment of shrubland biomass and carbon stock.

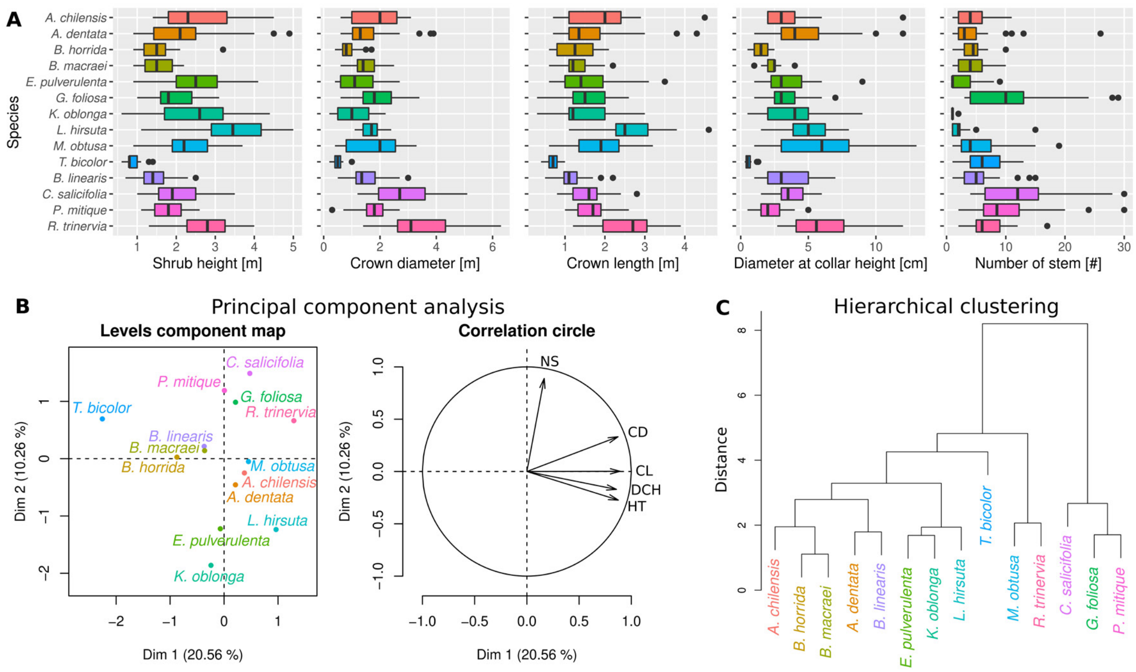


**Figure 1.** Species-specific growth habitat and the correlation and clustering of species according to these traits. **A:** Boxplots of shrub height (HT), crown diameter (CD), crown length (CL), diameter at collar height (DCH), number of stems (NS) by species. **B:** Results of the principal component analysis on the centered and scaled shrub attribute data shown in A; axes 1 and 2, which explain together 30% of the variance, distinguish shrub species according to the number of stem (axis 2 loaded with NS) and the expression of the other traits (axis 1 loaded with HT, CD, CL, and DCH). **C:** Dendrogram showing the hierarchical clustering of species according to the shrub attributes shown in A. The distance represents the average of the dissimilarities between the species in one cluster and the species in the other cluster.

**Table 1.** Genus, species, authorities, common names, and summary statistics of BWD (g cm$^{-3}$) and MC (%) for 14 shrub species of the Mediterranean shrubland in central Chile

| Species | Basic wood density (g cm$^{-3}$) | | | | | Moisture content (%) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | n | Mean ± SD | Max | Min | CV | Mean ± SD | Max | Min | CV |
| **Cortaderal site** | | | | | | | | | |
| *Aristotelia chilensis* (Mol.) Stuntz (Maqui) | 21 | 0.519 ± 0.044 | 0.606 | 0.405 | 0.085 | 101.9 ± 16.1 | 134.3 | 62.1 | 0.158 |
| *Azara dentata* Ruiz & Pavon (Corcolen) | 42 | 0.562 ± 0.032 | 0.617 | 0.501 | 0.056 | 92.2 ± 9.0 | 113.0 | 66.7 | 0.097 |
| *Baccharis macraei* Hook. & Arn. (Vautro) | 21 | 0.648 ± 0.034 | 0.703 | 0.574 | 0.053 | 55.6 ± 10.6 | 69.9 | 31.6 | 0.191 |
| *Berberis horrida* Gay (Michay) | 20 | 0.622 ± 0.038 | 0.690 | 0.525 | 0.061 | 68.6 ± 7.9 | 85.3 | 53.0 | 0.115 |
| *Escallonia pulverulenta* (Ruiz et Pav.) Pers. (Corontillo) | 23 | 0.582 ± 0.047 | 0.682 | 0.488 | 0.080 | 93.1 ± 8.7 | 105.0 | 72.4 | 0.094 |
| *Gochnatia foliosa* D.Don (Mira Mira) | 21 | 0.550 ± 0.066 | 0.699 | 0.408 | 0.119 | 72.1 ± 23.8 | 140.9 | 19.4 | 0.330 |
| *Kageneckia oblonga* Ruiz et Pav. (Bollen) | 21 | 0.636 ± 0.064 | 0.843 | 0.563 | 0.101 | 86.3 ± 8.1 | 99.4 | 70.8 | 0.094 |
| *Lomatia hirsuta* (Lam.) Diels ex J.F. Macbr. (Radal) | 20 | 0.518 ± 0.039 | 0.582 | 0.436 | 0.075 | 101.2 ± 18.2 | 137.6 | 58.7 | 0.180 |
| *Myrceugenia obtusa* (DC.) O. Berg (Arrayancillo) | 23 | 0.514 ± 0.031 | 0.572 | 0.441 | 0.061 | 113.1 ± 15.7 | 148.5 | 85.6 | 0.139 |
| *Teucrium bicolor* Sm. (Oreganillo) | 21 | 0.465 ± 0.094 | 0.651 | 0.295 | 0.202 | 73.2 ± 33.9 | 199.1 | 21.1 | 0.462 |
| Total | 233 | 0.561 ± 0.074 | 0.843 | 0.295 | 0.131 | 86.6 ± 23.0 | 199.1 | 19.4 | 0.266 |
| **Miraflores site** | | | | | | | | | |
| *Baccharis linearis* (Ruiz & Pav.) Pers. (Romerillo) | 24 | 0.497 ± 0.046 | 0.602 | 0.428 | 0.092 | 58.0 ± 22.9 | 111.1 | 9.5 | 0.395 |
| *Colliguaja salicifolia* Gillies & Hook. (Colliguay) | 23 | 0.601 ± 0.036 | 0.667 | 0.497 | 0.059 | 45.0 ± 7.0 | 54.5 | 28.9 | 0.156 |
| *Podanthus mitique* Lindl. (Mitique) | 22 | 0.600 ± 0.058 | 0.741 | 0.473 | 0.097 | 62.4 ± 14.1 | 79.8 | 27.2 | 0.227 |
| *Retanilla trinervia* (Gillies & Hook.) Hook. & Arn. (Tevo) | 20 | 0.772 ± 0.127 | 1.274 | 0.654 | 0.165 | 41.6 ± 13.3 | 60.5 | 8.4 | 0.319 |
| Total | 89 | 0.611 ± 0.121 | 1.274 | 0.428 | 0.198 | 52.1 ± 17.6 | 111.1 | 8.4 | 0.338 |

n = number of samples (to be doubled for MC as two samples per individual were processed). SD = standard deviation. CV = coefficient of variation

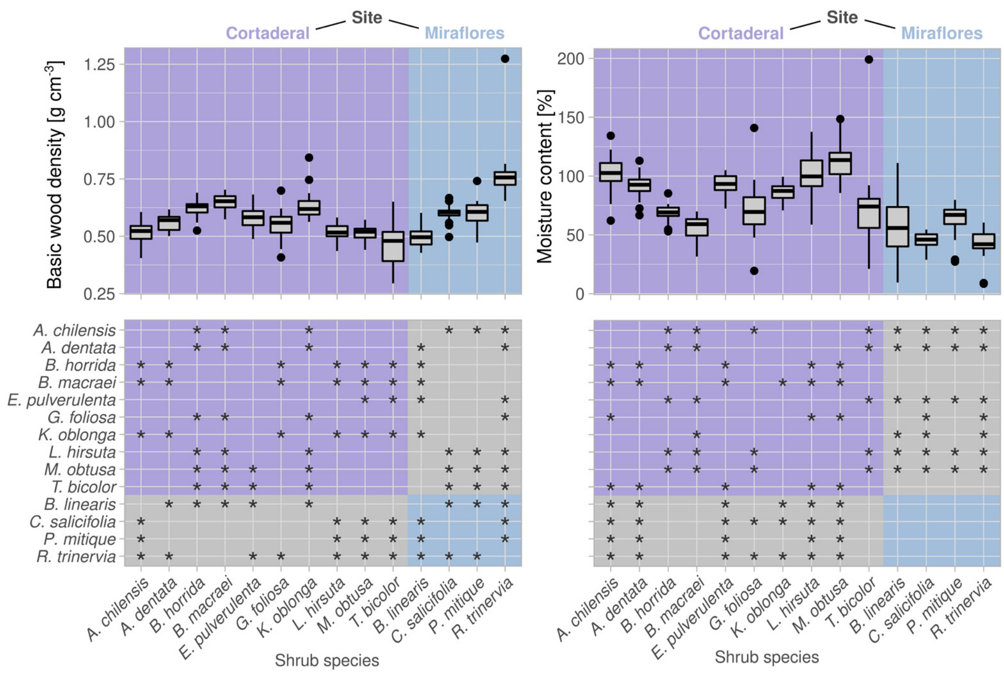


**Figure 2.** Relationship between basic wood density (g cm$^{-3}$) and moisture content (%) of the 14 shrub species. Top: boxplots show median, 25- and 75%- quantiles and outliers (distance to the box greater than 1.5 times the interquartile range). Bottom: *indicates significant differences between species as determined by Dunn's test (after a Kruskal-Wallis test confirming the overall significant effect of species).

While there are some tendencies for phylogeny to predict BWD (Chave *et al.*, 2006), our results indicate that large differences among closely related species may be frequent. We found large differences in BWD even between four species of the same family, *Asteraceae*, at the same site. Also, BWD means were significantly different in the two species of the genus *Baccharis*, one from each site. Therefore, these results remark the importance of specific studies of wood density to get more reliable carbon stock quantifications. Our findings illustrate that the same genus can have a wide range of BWD values and that assigning BWD values to one species based on the values of another will often prove unreliable. This conclusion is supported considering other studies documenting similarly wide ranges in shrubby species, *e.g* 0.45-0.67 g cm$^{-3}$ between six species of *Teucrium* (Lamiaceae) in the eastern Mediterranean zone in Europe (Crivellaro & Schweingruber, 2013), and 0.49-0.67 g cm$^{-3}$ across three species of *Escallonia* (Escalloniaceae) (Zanne *et al.*, 2009).

For MC, we also found large differences between species from the same family. The range between the four *Asteraceae* species was from 55.6 to 72.1%, while the range between the two *Baccharis* species was very similar, from 55.6 to 58.0%.

As expected from previous studies (Fromm *et al.*, 2001; Longuetaud *et al.*, 2016; Kenzo *et al.*, 2017), our data showed a negative relationship between MC and BWD across species, which is much more pronounced at Cortaderal than at the drier Miraflores site (Fig. S2 [suppl]). Within species, BWD and MC rarely showed a clear negative correlation, which may also reflect that similar wood density can be associated with different anatomical traits (Preston *et al.*, 2006). Considering that MC is related to seasonal variations that are also associated with water availability (Castro *et al.*, 2003), and our sample collection was performed in January and February, the described relationship is valid for summer, and not for winter.

We believe that the new information on BWD and MC provides insights into the wood properties of species of the Chilean sclerophyllous Mediterranean shrublands. Our study also contributes to knowledge of group of species scantly represented in global datasets such as Global Wood Density Database (Zanne *et al.*, 2009) or GlobAllomeTree (Henry *et al.*, 2013). Considering the high variability of BWD and MC, species-specific information is crucial to reliably convert green volume, which today can be assessed over large areas thanks to photogrammetry and laser scanning, to aboveground biomass. This information is essential for sustainable management and for estimating the carbon stocks of the Mediterranean shrubland ecosystems.

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