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Aboveground phytomass models for major species in shrub ecosystems of western Andalusia

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Abstract

This paper reports the first results of a project aimed at estimating aboveground biomass in shrub ecosystems of Western Andalusia. Models for predicting of dry phytomass (ms) from apparent biovolume (v) values were constructed by simple regression analysis, using shrub height, and maximum and minimum crown diameter as the specific data. Models obtained for the 31 selected species in these ecosystems were power, linear and logarithmic functions with determination coefficients (R^2) between 0.751 and 0.989. The statistical significance of the results confirms the accuracy of the regional estimates provided by these models.

Keywords: aboveground biomass, biovolume, individual models, Mediterranean shrub lands.

Resumen

Modelos para la determinación de biomasa aérea de las especies dominantes de ecosistemas de matorral en Andalucía occidental

Presentamos los primeros resultados de la estimación de biomasa aérea en matorrales y arbustedos de Andalucía Occidental. Se han calculado modelos de predicción *fitomasa seca* (*MS*) en función del *biovolumen aparente* (*V*) mediante análisis de regresión simple con datos sobre distintas variables biométricas: altura, y diámetro máximo y mínimo correspondientes a 832 plantas. Los modelos específicos obtenidos para 31 de las especies más representativas de estos ecosistemas han sido en su mayoría de tipo potencial, lineal y logarítmico, con coeficientes de determinación (R^2) entre 0,751 y 0,989. La bondad de los ajustes y la solidez estadística confirman su aptitud para llevar a cabo estimaciones de carácter regional.

Palabras clave: biomasa aérea, biovolumen, regresión simple, modelos individuales, matorrales mediterráneos.

Introduction

Those ecosystems where the dominant species are more or less woody and smaller than trees are known as shrub ecosystems. Defining and characterizing shrubs is a complex task, particularly, in the Mediterranean climate ecosystems, as shown by the many papers devoted to their definition and classification (both physiognomic and also ecological) (Valle, 1990, Font Quer, 1977). Of special significance in this context is the study by Ruiz de la Torre (1981), who identifies shrub formations as a type of vegetal group with a specific structure or appearance. This non-tree, woody formations are of great significance to biophysical and biodynamic processes in Mediterranean ecosystems (Di Castri, *et al.*, 1981), on account of both of impact on ecosystem dynamics and function, and of the great expanses of land they cover. With the exception of especially stable ecosystems, shrubs are intermediate stages in the regressive and progressive dynamics towards desertification or mature wooded formations. This fact is particularly obvious in the fire-prone formations of the genus *Cistus*, and strengthens their prominent role in the natural resource management of the region.

As with all vegetal formations, biomass or phytomass (a better descriptive term) is a key structural variable in research into the dynamics of these ecosystems, the level and types of biodiversity they sustain, their role in the carbon cycle, and their sustainability (Waring and Running, 1996). Also, much functional ecology work (especially that concerned with nutrient cycle, productivity or space-time processes) relies on estimates of this variable (Mary *et al.*, 2001; Rapp *et al.*, 1999; Terradas, 1991). In addition, the quantification of aboveground biomass resources is a pre-requisite for many studies of

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interest in forest management, including models and mapping of characteristics of forest fuels (e.g. Nuñez-Regueira *et al.*, 2000), support of hydrological-forest defence planning (e.g. Pastor-López and Martin, 1995), forest models for sustainable exploitation (e.g. Gónzalez, 1989), analysis of fixed emissions of CO_2 (Price *et al.*, 1998; Nabuurs and Mohren, 1995), and stockbreeding for plans of forest-pastoral management (e.g. Patón *et al.*, 1999; Robles *et al.*, 1994).

Traditionally, biomass estimates for forest ecosystems have been obtained using *Direct* (destructive or extractive) or *Indirect Methods* (dimensional analysis) (Wharton and Griffith, 1993; Etienne, 1989; Uresk *et al.*, 1977). Indirect methods provide estimates that can be as accurate as those of direct methods while allowing the analysis of more samples and hence encompassing a large number of observations at a relatively low cost (Montes *et al.*, 2000; Castro *et al.*, 1996). The approach of Whittaker and Woodwell (1968), with some variations, has so far been the most widely successfully accepted for this purpose. This is a *Mixed Method* that estimated the biomass of a species by using a destructive procedure on a relatively small number of samples. The samples are used to construct a prediction function that relates a characteristic parameter for the plant structure (or a group of biometric variables) to phytomass production by the plant for subsequent analysis.

A number of studies have used the apparent phytovolume as an explanatory variable for predictive models (Passera *et al.*, 2002; Montes *et al.*, 2000; Marti and Badia, 1999; Castro *et al.*, 1996). The specification of mathematical prediction models is normally tested using simple regression models (Murray and Jacobson, 1982). For shrubs, the relation between biomass and structural measurements is usually a power function of the form $Y = aX^b$ (Robledo *et al.*, 1991; Castro *et al.*, 1996). The relation is often established by logarithmic transformation of the power equation into a linear equation ($logY = a + blogX$) despite the potential of overestimation associated with this practice (Castro *et al.*, 1996). The determination coefficient (R^2) of the function has frequently been used to comparatively assess several functions for the same species. However, some authors analyse values obtained from the sum of the residual squares and the distribution of the residues to construct solid prediction models (Castro *et al.*, 1996).

In response to the interest in acquiring territorial data of this structural variable in Andalusia forests, prediction models for aboveground phytomass for 31 typical species of shrubs of western Andalusia were developed. The aim was to establish the most appropriate function for each species by using the apparent biovolume for wide territorial range as the explanatory variable.

Material and methods

Ecosystems and sampling plots

The study area, western Andalusia, constitutes no self-contained geological or climatic, thus no ecological unit. The presence of climatic gradients and soil mosaics, together with traditional agriculture, forest and pasture exploitation, shape the diversity of Mediterranean environments land make the study area an ideal place for undertaking this type of description on a regional scale.

This study used the typology of shrub ecosystems proposed by Ruiz de la Torre (1990), this physiognomic classification is quite consistent with the forest landscape of the region. In addition, it is geographically represented in the Andalusia forest map (Junta de Andalusia, 1999), a digital 1:50,000 map containing important information about the specific composition and structure of each land unit where these formations constitute uniform masses.

In response to the interest in developing an efficient technique, the 32 species listed in Table 1, designated «reference species», and were selected as it was impractical to derive equations to estimate biomass for the majority of species in western Andalusia shrub formations. Species were selected according to two criteria, namely:

— The significance of the specific composition of the different formations (i.e. the dominant species).

— Flexibility in the models to allow application to individuals of the same genus or with similar morphological characteristics and for which no specific model had been constructed (Wharton and Griffith, 1993).

The GIS analysis of the maps for the shrub ecosystems, which were produced from the database associated with the Forest Map of Andalusia, facilitated placement and distribution of the sampling plots in the four major geomorphological units of the study area. Therefore, sampling sites were located in the following areas:

— In Sierra Morena, on Precambrian and Paleozoic materials (quartzite and gneiss), plants being collected in Huelva and Córdoba.

Table 1. Ranges of biometric variables and morphotypes of the selected species in shurb ecosystems of western Andalusia

Species	Heigth (m)	Diameter (m)	Cover (m^2)	Morphotype	Volume (m^3)	Dry biomass (g)
Adenocarpus telonensis (Loisel.) DC.	0.52–2.30	0.33–1.38	0.08-1.72	4	0.29-4.97	53.92-887.53
Arbutus unedo L	0.37-4.49	0.15-2.03	0.02-3.22	1	0.01-4.82	15.37-35.759.74
Calycotome villosa (Poiret) Link.	0.85-1.82	1.44-3.25	1.65-8.30	2	1.94-20.13	1.785.80-17.937.70
Chamaerops humilis L.	0.41-0.85	0.62-1.79	0.30-2.50	2	0.20-2.27	224.21-5.734.59
Cistus albidus L.	0.72-1.58	0.38-0.87	0.30-2.50	2	0.03-0.30	74.62-761.97
Cistus ladanifer L.	0.63-2.70	0.21-2.60	0.03-5.31	1	0.01-4.42	26.82-5.058.60
Cistus monspeliensis L.	0.75-1.30	0.54-1.53	0.22-1.83	1	0.06-0.64	177.49-2.776.24
Crataegus monogyna Jacq.	0.88-2.90	0.51-3.08	0.20-7.43	1	0.06-5.32	112.43-7.419.40
Cytisus striatus (Hill) Rothm.	0.85-2.05	0.60-1.97	0.28-3.03	1	0.31-6.47	267.07-3.456.03
Daphne gnidium L.	0.63-1.54	0.32-1.41	0.08-1.55	2	0.08-2.19	42.00-1.258.18
Erica arborea L.	0.34-2.60	0.15-1.42	0.02-1.89	2	0.01-1.21	6.30-1.859.60
Erinacea anthyllis Link.	0.08-0.33	0.25-0.93	0.05-0.68	1	0.01-0.21	170.52-3.787.43
Genista cinerea (Vill.) DC.	0.35-1.49	0.59-1.73	0.27-2.76	3	0.13-4.64	307.86-6.745.06
Genista hirsuta Vahl.	0.45-1.13	0.38-1.10	0.11-0.95	2	0.07-1.14	164.20-1.198.50
Genista umbellata (L'Her.) Poiret	0.86-1.30	1.38-2.17	1.48-3.68	2	1.84-6.38	1.841.3-8.169.45
Juniperus oxycedrus L.	0.79-2.25	0.45-1.51	0.16-1.79	2	0.05-1.13	117.89-5.392.00
Juniperus phoenicea L.	0.90-1.88	0.83-1.63	0.53-2.07	1	0.17-1.14	1.402.67-8.153.19
Juniperus phoenicea L.	0.71-1.43	0.68-1.44	0.36-1.61	1	0.09-1.04	109.73-1.852.07
Lavandula stoechas L.	0.36-1.41	0.25-0.98	0.05-0.75	1	0.03-0.92	49.47-636.75
Myrtus comunis L.	0.46-1.65	0.82-2.95	0.52-6.83	2	0.38-12.76	203.04-5.379.77
Phillyrea angustifolia L.	0.87-2.50	0.35-1.63	0.10-2.07	2	0.09-4.46	45.21-1.919.73
Pistacia lentiscus L.	0.75-2.35	1.28-3.44	1.28-9.29	4	0.97-11.99	1.492.45-47.533.67
Pistacia terebinthus L.	1.66-2.88	1.30-3.88	1.33-11.82	2 & 3	4.51-37.05	1.665.56-24.860.72
Retama sphaerocarpa (L.) Boiss.	0.75-4.00	0.99-4.45	0.77-15.55	2	0.83-82.95??	594.00-27.386.50
Rhamnus oleoides L.	1.06-2.98	0.30-2.60	0.07-5.31	2	0.10-12.74	30.00-9.277.76
Rosmarinus officinalis L.	0.54-1.33	0.31-2.12	0.07-3.51	4	0.08-5.67	46.54-1.827.61
Teline linifolia (L.) Webb & Berth.	0.64-1.63	0.32-1.30	0.08-1.33	2	0.07-2.39	64.40-923.40
Teucrium fruticans L.	0.51-1.20	0.45-1.00	0.16-1.26	2	0.04-0.46	16.00-81.52
Teucrium fruticans L.	0.77-1.28	0.07-0.51	0.01-0.20	1	0.01-0.99	4.40-51.69
Thymus zygis L.	0.12-0.35	0.16-0.42	0.02-0.14	4	0.01-0.04	16.00-107.23
Ulex parviflorus Pourret	0.67-1.22	0.60-1.50	0.28-1.77	4	0.19-1.94	368.31-1.664.60
Vella spinosa Boiss.	0.14-0.33	0.30-0.80	0.07-0.50	4	0.01-0.18	196.78-1.080.00
Viburnum tinus L.	1.42-4.25	0.75-2.21	0.45-3.84	2 & 3	0.24-5.18	105.08-2.617.17

— On Paleozoic and Triassic substrata in the Baetica mountain range (limestone and sandstone), samples being taken both in Baetica (Málaga) and in Subbaetica locations (Málaga and Cádiz).

— In Campo de Gibraltar (Cádiz).

— An area with the typical woody flora of the sandy coastal areas of the Atlantic dominion (Huelva), which are representative of the similar formations in the Guadalquivir depression.

Sampling Method

Based on the distribution of the study sites and, in response to the initial need to use at least two different sources per species, a random sampling of at least 10 specimens per reference species was conducted in each plot (2 plots per location). The size of the plots varied from 0.001 to 1 ha depending on the structure and distribution of the different vegetation groups examined. This experimental design provides adequate sampling density (Patón *et al.*, 1998).

Three standing biometric variables were measured, namely maximum height, larger crown diameter and smaller crown diameter. Measurements were made on every plant sampled with a tape measure according to the size of the specimen (between 0 and 5 m, unit: 1 cm, appreciation error ± 1 cm). After measurements, plants were cut at ground level and weighed *in situ*, with no distinction between wood and leaves (PHI-

LLIPS ESSENCE HR2388-0; maximum weight 5,000 g, unit 1 g, appreciation error 5 g). Several specimens of each species were then taken to the laboratory for drying in a forced-air chamber (P SELECTA) at 70ºC for 72 hours. The dry material was weighed to construct regression models for dry weight (W_d).

The apparent biovolume was determined by fitting the plant shape to the shape of a specific solid body (Passera *et al.*, 2002; Robles *et al.*, 1997; Etienne, 1989), using equations (1), (2), (3), and (4), where the mean crown diameter (D_m) was used as the average of the maximum and minimum diameters.

— Conical morphotype: $V = 1/3 * \pi * [D_m/2]^2 * h$ (1)

— Semi-spherical morphotype: $V = 4/3 * \pi * [D_m/2]^2 * h$ (2)

— $V = 4/3 * \pi * [D_m/2] * h^2$ (3)

— Cylindrical morphotype: $V = \pi [D_m/2]^2 * h$ (4)

Samples were taken during the springtime peak production period (May and June). Further sampling was done in November and December with the aim of including the influence of seasonal variations in the models.

Regression Analysis

Specific *phytomass-apparent biovolume* relations were established by simple regression analysis in a preliminary interpretation of the field data, using the SPSS 8.0 statistical software suite.

The means and standard deviations of the variables, and their logarithmic transformations, were obtained, and Spearman's correlation coefficients for dry phytomass, apparent biovolume and transformed data were calculated in order to select the parameter to be used in the regression model. The process involved developing linear, potential, exponential, logarithmic, square and cubic models. *A priori* and *a posteriori* analyses of the population sample were carried out for the specification of valid explanatory models (Ferrán, 1997).

— Residues to the normal were established from the «P-P normal regression» which compares expected and observed cumulative probability. The distribution must be approximated to a straight line of unity slope intersecting the source.

— Relative measures based on the correlation coefficient of determination R^2, and standard estimation error, *SE*.

— Analysing of variance to check the significance of R^2 by calculating the statistic *F* statistic and its significance level *p*.

— Hypothesis tests about the statistical significance of each explanatory variable, using Student's *t*.

— Presence or absence of self-correlation of errors as determined using the Durbin Watson test.

— Homoscedasticity of the model, or constant variance of the error, determined from a «typified residue regression–typified predicted value» graph.

Results

Models for predicting aboveground phytomass for the 31 reference species studied were developed (Table 1) from 832 plants**.** With the exception of *Pistacia terebinthus*, *Daphne gnidium***,** *Myrtus communis* and *Teucrium fruticans*, the minimum density sampling required (10 specimens per study area) was achieved. For *Erica arborea*, *Cistus ladanifer*, *C. monspeliensis* and *Arbutus unedo*, the sampling density was higher than that required by experimental design It should be noted that 13 of the models were constructed using data from three study areas with clearly different environmental factors: 9 with data from two areas and the other 9 with data from only one.

Table 1 shows the wide range of biometric values used in this study; ranges were especially broad for *Arbutus unedo* (heights from 0.37 to 4.49 m, volumes from 0.01 to 4.82 m^3, and dry weights from 0.015 to 3.76 kg), *Cistus ladanifer* (heights from 0.63 to 2.70 m, volumes of 0.01-4.42 m^3, and dry weights of 0.03-5.06 kg), and *Retama* sp. (heights of 0.75-4 m, volumes of 0.83-82.95 m^3, and dry weights of 0.59-27.39 kg).

We have found no substantial within-species differences in morphotype (see Table 1). Their shape uniformity has facilitated establishment of the regression functions and development of unique models through assimilation of their apparent biovolume to that of a specific solid body. *Teucrium fruticans* required various models owing to marked differences in morphotype and weight between its young (cylindrical) and mature (inverted conical) specimens. We also had to develop new models for *Juniperus phoenicea*, whose common conical morphotype exhibited variable morphological characteristics.

The development of specific estimation models (Table 2) allowed the derivation for more than one half of the species (20) of a power relation between dry phytomass and apparent biovolume. The remaining 11 species fitted a linear function without transformation. In

Table 2. Number of plants used in the phytomass analysis (NP), humber of outliers (NO), sampling location (NL) and regression model for each species

Species	NP	NO	NL*	Regression model
Adenocarpus telonensis (Loisel.) DC.	30	0	MA, HU, CA	$Y = 393.83 * X^{0.604}$
Arbutus unedo L.	46	2	MA, HU, CA	$Y = 1.114.9 * X^{0.725}$
Calicotome villosa (Poiret) Link.	14	1	CA	$Y = 956.96 * X – 636.5$
Chamaerops humilis L.	13	1	MA, HU, CA	$Y = 1.650.06 * X^{1.073}$
Cistus albidus L.	26	2	MA, CA	$Y = 2.026.4 * X^{0.875}$
Cistus ladanifer L.	39	6	MA, HU, CA	$Y = 1.976.7 * X^{0.884}$
Cistus monspeliensis L.	40	6	MA, HU, CO	$Y = 3.468.6 * X^{1.113}$
Crataegus monogyna Jacq.	26	3	MA, CA	$Y = 1.280.7 * X^{1.087}$
Cytisus striatus (Hill) Rothm.	21	1	HU, CO	$Y = 680 * X^{0.880}$
Daphne gnidium L.	19	1	CO, CA	$Y = 510.5 * X^{1.045}$
Erica arborea L.	50	6	MA, HU, CA	$Y = 1.090.8 * X^{0.812}$
Erinacea anthyllis Link.	10	0	MA	$Y = 214 + 16.659.3 * X$
Genista cinerea (Vill.) DC.	23	3	MA, CO	$Y = 1.168.02 * X^{0.820}$
Genista hirsuta Vahl.	32	4	MA, HU, CA	$Y = 785.28 * X^{0.701}$
Genista umbellata (L'Her.) Poiret	10	0	MA	$Y = 1.404.3 * X – 815.1$
Juniperus oxycedrus L.	22	2	MA	$Y = 4.800.9 * X – 152.7$
Juniperus phoenicea L.	10	0	MA	$Y = 6.674 + 8.226 * \log X$
Juniperus phoenicea L.	12	2	CA	$Y = 1.803 + 1.567 * \log X$
Lavandula stoechas L.	12	1	HU	$Y = 33.23 + 586.96 * X$
Myrtus comunis L.	26	2	MA, HU, CA	$Y = 480.84 * X^{0.884}$
Phillyrea angustifolia L.	35	3	MA, HU, CA	$Y = 402.83 * X^{0.930}$
Pistacia lentiscus L.	30	1	MA, HU, CA	$Y = 2.479.76 * X^{0.985}$
Pistacia terebinthus L.	18	3	MA, CA	$Y = 323.49 * X^{1.130}$
Retama sphaerocarpa (L.) Boiss.	31	2	MA, HU, CA	$Y = 1.361.6 + 341.1 * X$
Rhamnus oleoides L.	36	3	MA, HU, CA	$Y = 763.2 * X – 144.4$
Rosmarinus officinalis L.	20	2	HU	$Y = 418.55 * X^{0.822}$
Teline linifolia (L.) Webb & Berth.	17	0	CA	$Y = 352 * X^{0.842}$
Teucrium fruticans L.	14	3	CA	$Y = 21.41 + 147.49 * X$
Teucrium fruticans L.	8	0	CA	$Y = 5.385 + 174.02 * X$
Thymus zygis L.	33	1	MA, CA	$Y = 17.68 + 2.717.6 * X$
Ulex parviflorus Pourret	30	4	MA, HU, CA	$Y = 278.7 + 717.9 * X$
Vella spinosa Boiss.	10	0	MA	$Y = 162.8 + 4.240.4 * X$
Viburnum tinus L.	20	1	CO, CA	$Y = 1.052 + 1.878 * \log X$

* MA: Málaga. HU: Huelva. CO: Córdoba. CA: Cádiz.

three species, the relation was a logarithmic function of the explanatory variable. None of the tested exponential, linear without constant, power, square or cubic models provided consistent results.

As can be seen from table 3 proposed the equations for each species meets the requirements of the graphic analyses performed to detect uncommon distribution problems. No self-correlation or heteroscedasticity in the distribution of residues was observed. R^2 was high in all the cases: it ranged from a minimum for *Ulex parviflorus* (0.751) to a maximum for *Rhamnus oleoides* (0.989). Note that 91% of the models had a determination coefficient higher than 0.8, 38% one between 0.8 and 0.9, and 53% one higher than 0.9.

The average number of outliers data detected in establishing the regression models for each species was 7.5% of the total number of the field data. The greatest number were those for *Cistus ladanifer* and *Cistus monspeliensis* (both with 6 outliers observations), and the smallest (no outliers observations) for *Adenocarpus telonensis*, *Chamaerops humilis*, *Erinacea anthyllis*, *Genista umbellate*, *Juniperus phoenicea*, *Teline linifolia*, *Teucrium fruticans*, and *Vella spinosa*.

We should emphasize the typical estimation errors for the different models which were tested for species of different structural characteristics spanning wide intra-specific ranges of volumes and weights, were highly variable, with a minimum of 3.25 g for *Philly-*

Table 3. Determination coefficient (R^2) squared standard estimation (SE). F-ratio of ANOVA (*** $p < 0.001$) test (F)

Species	R^2	SE	F
Adenocarpus telonensis (Loisel.) DC.	0.880	102.34	206.135***
Arbutus unedo L.	0.934	361.07	591.157***
Calicotome villosa (Poiret) Link.	0.967	832.31	318.811***
Chamaerops humilis L.	0.907	664.30	107.626***
Cistus albidus L.	0.894	205.49	135.55***
Cistus ladanifer L.	0.869	367.74	106.123***
Cistus monspeliensis L.	0.947	483.10	666.951***
Crataegus monogyna Jacq.	0.806	375.88	158.013***
Cytisus striatus (Hill) Rothm.	0.898	730.60	184.695***
Daphne gnidium L.	0.921	592.59	220.216***
Erica arborea L.	0.914	199.50	170.794***
Erinacea anthyllis Link.	0.967	318.79	1.420.555***
Genista cinerea (Vill.) DC.	0.987	135.36	587.904***
Genista hirsuta Vahl.	0.957	546.66	153.150***
Genista umbellata (L'Her.) Poiret	0.775	247.13	103.090***
Juniperus oxycedrus L.	0.869	788.13	46.320***
Juniperus phoenicea L.	0.961	340.47	422.750***
Juniperus phoenicea L.	0.860	961.54	36.976***
Lavandula stoechas L.	0.863	223.55	50.384***
Myrtus comunis L.	0.935	47.08	130.449***
Phillyrea angustifolia L.	0.936	894.83	349.191***
Pistacia lentiscus L.	0.829	223.59	159.820***
Pistacia terebinthus L.	0.870	7.564.41	180.093***
Retama sphaerocarpa (L.) Boiss.	0.815	4.630.81	66.134***
Rhamnus oleoides L.	0.946	1.267.97	503.668***
Rosmarinus officinalis L.	0.989	171.60	2.957.532***
Teline linifolia (L.) Webb & Berth.	0.972	157.50	634.52***
Teucrium fruticans L.	0.905	179.38	142.962***
Teucrium fruticans L.	0.837	7.57	61.492***
Thymus zygis L.	0.962	3.25	152.816***
Ulex parviflorus Pourret	0.854	10.79	180.982***
Vella spinosa Boiss.	0.751	158.85	81.526***
Viburnum tinus L.	0.914	68.82	85.359***

* Morphotypes: 1 (conic), 2 and 3 (semi-spherical), and 4 (cylindrical).

rea angustifolia and a maximum of 7.56 g for *Pistacia lenstiscus*.

Discussion

The results derived from this study allowed us to develop phytomass estimation models (regional application) for species in the different Mediterranean shrub ecosystems of the study area. It allowed a greater number of species to be studied than other, similar studies on the same environment dealing with different formations (Castro *et al*., 1996;) or specific communities (Passera *et al*., 2002; Patón *et al*., 1998).

As can be seen, the target number of harvested individuals per placement as defined under Material and Methods was exceeded for some species. There were three main reasons for this increase in sampling density, namely:

— The intention to preserve the initial maximum number of 10 per source as outliers potentially arising in constructing the prediction models would have to be discarded.

— The need to cover, with models developed from only one o two species (*Erica arborea, Cistus ladanifer, C. monspeliensis*), the estimation of a number of taxons of the same genus in a wide range of sizes and morphological characteristics.

— The presence of several clearly distinguishable morphotypes within the same species, which was the case with *T. fruticans* (with assimilation to cylinders in the juveniles and to inverted cones in adults).

Nevertheless, the number of individuals used to develop models was similar to those employed in other studies involving the estimation of phytomass in shrub species. Thus, Martí and Badía (1999) used 20 specimens to model phytomass *Cistus albidus;* Patón *et al*. (1998) employed 25 and 15 individuals for *C. albidus* and *C. ladanifer* respectively, Passera *et al*. (2002) used data volume of 10 to 20 specimens per species; and Castro *et al*. (1996), in an experiment similar to ours, used a variable number of data comparable to the previous ones and those used in this study for *Cistus albidus, Cytisus striatus, Genista hirsuta, Retama sphaerocarpa* and *Thymus zygis*, but much smaller than our choice for *Cistus ladanifer*. This was a result of the sampling method used in this study (plots of definitive size) and to the density of this species in the studied shrub ecosystems. These numbers, however, are not comparable to the data volume used in non-destructive works such as that of Montes *et al.* (2000) on *Juniperus* sp., where they used photo interpretations of more than 100 specimens.

On the other hand, the intended number of specimens was not reached for the species of interest because of:

— The absence or shortage of certain species in some of the provinces studied (e.g. *Juniperus phoenica* in Córdoba, *Juniperus* sp. and *Pistacia terebinthus* in Huelva; and *Teline linifolia, Erinacea anthyllis* and *Genista umbellata* in Huelva and Córdoba). Similarly, *Calycotome villosa* and *Teline linifolia* were only found in sampling sites of the Campo de Gibraltar unit.

— Temporal and economical constraints on the conduct of field work (*Junperus phoenica, Viburnum tinus, Lavandula stoechas, Daphne gnidium* and *Thymus zygis*) due to the labour-intensive and expensive nature of this type of research (Uresk *et al*., 1977).

The number of sources per species was equivalent to that used by Pastor-López and Martín (1995) in their equations for the estimation of biomass for reforestation with *Pinus halepensis* in the Levante region or that of sampling sites employed by Castro *et al*. (1996) to cover ecological gradients in the Iberian Central Mountains. Therefore, we believe the estimation functions used in this study encompass the environmental diversity of the region, even though the models for *Lavandula stoechas, Phyllirea angustifolia, Cistus albidus, Pistacia terebinthus* and *Crataegus monogyna* more sources could have been further refined if more specimens had been available (Table 3).

The studied species were assimilated to apparent biovolumes, which are frequently used in shrub research (Etienne, 1989; Passera *et al*., 2002). No substantial differences in the morphotypes associated to each species were observed, however.

The proposed models provide results consistent with the previously reported in the literature particularly for Mediterranean species. For example, Passera *et al*. (2002) estimated phytomass in fodder areas of the Castril mountains (Granada), and Castro *et al*. (1996) developed models for *C. albidus* and *C. ladanifer*, that show coefficients similar to those obtained in this work. We also found linear models for Mediterranean species of the genus *Cistus* (Martí and Badía, 1999) and other taxa (Castro *et al.*, 1996) that confirm the models for the species studied here. No precedents were found, however, for models based on the logarithmic transformation of biovolume, which was necessary in some cases to linearize its relationship with dry phytomass.

The correlation coefficients obtained within the ranges reported by other authors for shrub species (Uresk *et al*., 1977; Rittenhouse and Greva, 1972) and either higher or lower than those reported by Martí and Badía (1999), Patón *et al*. (1988) and Castro *et al*., (1996). On the other hand, the outliers detected in the developing the models, and the typical estimation errors obtained, confirm the high heterogeneity of the populations from where the specimens were obtained (Patón *et al*., 1998).

We therefore conclude that our equations can be generalized since the high correlation exhibited by the specific models, the full fillment of the statistical requirements leading to solid predictions, and the high variability of the data used in this study (different environmental conditions, types of soil, precipitation, phenological status and sizes within the same species). These equations can be used to estimate dry phytomass from apparent biovolume values for the most representative taxa of the western Andalusia shrub ecosystems, both at the individual and at the formation level. These results lay the groundwork for future estimation of aboveground biomass in the different ecosystems under study in western Andalusia, and for the simultaneous evaluation of the error associated with the proposed method, both at the individual and at the community level. Therefore, this study represents the first step towards the development of an effective, flexible method for the determination of aboveground biomass in Mediterranean shrub ecosystems. Also, it facilitates large-scale evaluation and mapping. This has strategic value as a necessary precedent with a view to improving available knowledge and accurately modelling of the dynamics of these ecosystems.

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