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Composition and structure of Mediterranean shrublands for fuel characterization

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Key message
We present a relational database containing compositional and structural characteristics of 575 permanent 100 m^2 shrubland plots distributed in the NE of Iberian peninsula. The datasets provide valuable information about shrubland fuels to improve fire danger prediction, study vegetation dynamics in relation to drought and fire or test aerial-based methodologies with ground-based information. Dataset access is at : https://doi.org/10.5281/zenodo.7685487 and associated metadata are available at https://metadata-afs.nancy.inra.fr/geonetwork/srv/fre/catalog.search#/metadata/f55fcde4-113e-40f9-9a35-a2e65b0ee951.

Keyword Fire danger, Fuel characteristics, Mediterranean shrublands, Shrub biomass, Shrub cover and height

1 Background

Mediterranean shrublands are among the worldwide vegetation types most likely to be negatively impacted by climate change: the projected hotter and drier climate with higher frequency of extreme droughts will increase the number fire danger days and will shorten fire intervals (Enright et al. 2012). Mediterranean shrublands represent 1% of Earth surface (Di Castri et al. 1981). In the west of the Mediterranean basin, they are characterized by the dominance of woody-shrubby plants, in general less than 2–3 m tall, with evergreen, broad and small, stiff, and thick leaves (San Miguel-Ayanz et al. 2004). There can be an overstorey of short trees, as well as an understory of herbs. Mediterranean shrublands are found primarily in the xerothermic range of the Mediterranean region as permanent formations where physical or chemical soil characteristics or climate impede the establishment of dense tree cover. Shrublands also include intermediary successional communities resulting from historic intensive forest management and pastoral activities and, more recently, because of wildfires or woody encroachment of abandoned fields and pastures. Mediterranean shrublands are among the most fire-prone vegetation types due to their high fuel load, high fine fuel particle content, low fuel moisture content in summer (Gabriel et al. 2021), and high volatile organic compound concentrations (Pellizzaro et al. 2007; Santana et al. 2011). Therefore, the characteristics of shrub formations are usually of concern to fire risk prevention agencies.

Information on composition and structure of forestland supports stand-oriented management plans, provides the basis for adjusting management options and is useful for the understanding of ecosystem functioning (Herrick et al. 2005). Ground-based data is also essential to inform remote sensing techniques to continuously map forest resources and ecosystem services over large areas. In the long term, the data collected can help to redefine ecological models. Whereas systematic regional or national inventories are common in forests of the Mediterranean Basin, systematic information in shrub-like formations is scarce despite their interest for better accounting

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ecosystem services or fire hazard. The main objective of this article is to present a new database issued from two field sampling projects, containing detailed and accurate information of woody composition and structure of shrub-like formations in the NE of Iberian Peninsula.

2 Database geographical scope

The database covers shrub-like formations in the NE of Iberian Peninsula (Catalonia, 40° 34′ to 42° 26′ N and 0°10′ to 3°10′ E; Fig. 1). The region is highly mountainous except for the southwestern plains of the Ebro basin. The distribution of altitudes ranges from sea level up to 3000 m a.s.l., with an average altitude of about 700 m. The dominant climate is Mediterranean with a wide array of local microclimates depending on the altitude, continentality and topography. In the Pyrenees, temperate and alpine climates can also be found. Mean annual temperature ranges between 2 °C and 17 °C (average 11.6 °C) and annual rainfall varies between 350 and 1600 mm (average 680 mm). The most common soil parent materials are limestones and marls, though low metamorphic schists and granodiorites are also frequent in the north and north-east, while in the south-west there are more evaporitic rocks. Forested land occupies 20,744 km^2 (64.6% of the Catalan region), of which 4654 km^2 (22.4% of the forest area) are shrub-like formations according to the Land Cover Map of Catalonia (MCSC) v1.0–2018 (ICGC, https://www.icgc.cat/en/Downloads/Maps-in-image-format/Cobertes-del-sol).

3 Methods

To fill the gap in shrubland fuel information, the Catalan Forest Fire Prevention Service (SPIF) and the Forest Science and Technology center (CTFC) designed a cost-effective sampling protocol to provide fire danger evaluation with ground information regarding fuel amount, and characteristics of shrub-like fuel complex. The resulting database includes information gathered in two projects: Combuscat and MatoSeg. Combuscat aimed to characterize shrubland structure and fuel load in Catalonia and was carried out by forest specialist members of Catalan Forest Rangers (Cos d'Agents Rurals, Generalitat de Catalunya). MatoSeg aimed to complement the database with information on vascular plant composition at different

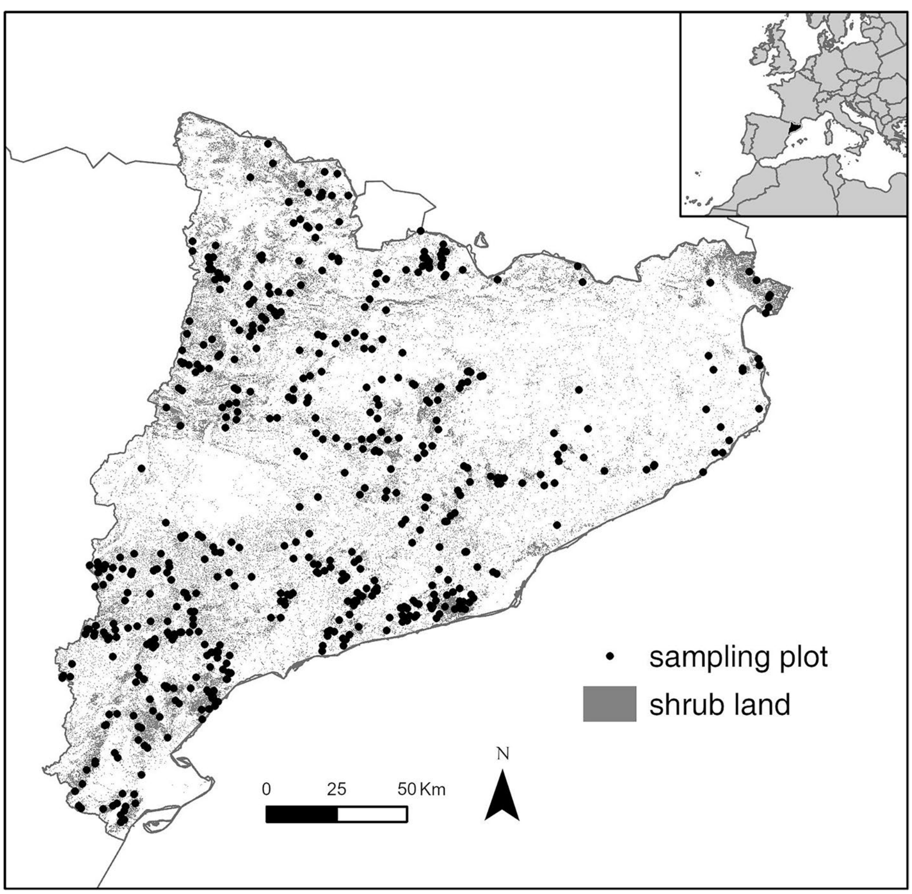

Fig. 1 Location of the study area (Catalonia, NE of Iberian peninsula) and spatial distribution of the shrubland plots sampled so far in the Combuscat project

scales collected in a set of 24 plots: 13 plots in Catalonia, and 11 in the nearby regions of Aragon and Valencia.

3.1 Definition of objectives and methodology elaboration

The two projects began with the definition of monitoring objectives and the development of protocols to obtain precise and methodologically well-defined information on the location, composition, structure, and fuel characteristics of shrublands (Table 1). Protocol design and methods were inspired by the Étienne and Rigolot (2001), Herrick et al. (2005), and Bohham (2013) manuals. The methodology was tested the first year with forest rangers at two pilot sites to determine its understanding, accuracy, and effectiveness in terms of information collected and time. The time required for plot establishment and measurements was between 1.5 and 2.5 h.

3.2 Forest rangers' training

The training of forest rangers lasted 4 years, starting with the teams from the counties (administrative subdivisions of Catalonia) with the greatest percentage of wildland covered by shrublands and ending with those in counties with lowest percentage of shrublands. Each year, in early spring, we carried out the training of the new teams, which included both theoretical and field sessions. In addition, the first monitoring on each county was performed by the forest rangers with the support of CTFC and SPIF technicians; and, at the end of the campaign, one plot per county was revisited and sampled again to assess the robustness of the methodology (see "5" section) and discuss in the field the differences in the measurements between both sampling visits. Each year, the results obtained in the previous campaigns and problems detected were jointly discussed.

3.3 Location selection

At the beginning of the project, we randomly distributed one location per km^2 of the shrub-like formations layer of the Catalan land cover map (CREAF 2009, http://www.creaf.uab.cat/mcsc/). Selection was restricted to a minimum distance between them of 400 m and slope lower than 55% (30º) and to the 33 Catalan counties with a significant cover of shrub-like formations. We finally sent between 30 and 100 random localities (the number depends on the shrubland cover in the county) to each county team of forest rangers. Each team chooses, every year, between two and six localities per county to be visited and sampled.

3.4 Plot location, field monitoring, and data uploading

Forest rangers followed a standard operating procedure (SOP, Appendix 1) that detailed step-by-step the instructions to select or reject the plot, to physically characterize it, and upload the collected information to a shared-point web. The tasks were grouped in three blocks, according to whether they are conducted *before*, *during*, or *after* the field work. Briefly, before going to the field, forest rangers checked the land ownership, decided the best access, and inspected the suitability of the location using available cartography. They arrived at the location using a GPS and again assessed the suitability of the plot. The criteria to reject a given location was clearly stated in the SOP and discussed during the training sessions. If the initial location is rejected, they try to find a new location moving 50-m around. If accepted, they set-up a 10×10 m plot and a belt transect of 20 m×1 m following a "L" shape, along two sides of the plot (Fig. 2, left). In the plot and in each 20 1-m^2 squares of the transect, they visually estimated the cover of vegetation and surface strata and measured the height of low scrubs and herbs and the thickness of litter (see "3.7" section). They also recorded the species name, crown orthogonal diameters and height of each plant, taller than 0.3 m, covering the transect (Fig. 2, right). After the field work, they uploaded the data in a web server together with the images and the scanned field data form sheets.

3.5 Plot description

Each plot was described by their geographic coordinates, altitude, aspect, and slope. Based on its location, each

Table 1 Objectives of the monitoring and measurements at plot and transect scales[a] in the Combuscat and MatoSeg projects. Figure 2 provides detail of plot and transect arrangement

Objective	Measurement	Scale[a]	Project(s)
General information	General description, geographic coordinates, photographs, and field notes	Plot	Both
Semi-quantitative information on shrubland structure	Visual cover and height per strata	Plot	Both
Quantitative information on fuel load and characteristics	Crown diameters and height of woody individuals	L-shaped belt transect	Both
	Herb height and litter thickness	L-shaped belt transect	Both
Quantitative information on woody composition	List of woody plant species in the L-shaped 20 m^2 transect	L-shaped belt transect	Both
Quantitative information on species-area composition	List of vascular plant species in the 20 1-m^2, 20 m^2, and 400-m^2 areas	Plot and belt transect	Matoseg

[a] Plot scale: 100 m^2 in Combuscat and 100 m^2 and 400 m^2 in MatoSeg; transect scale: 20 m^2 in Combuscat and 1-m^2, and 20 m^2 in MatoSeg

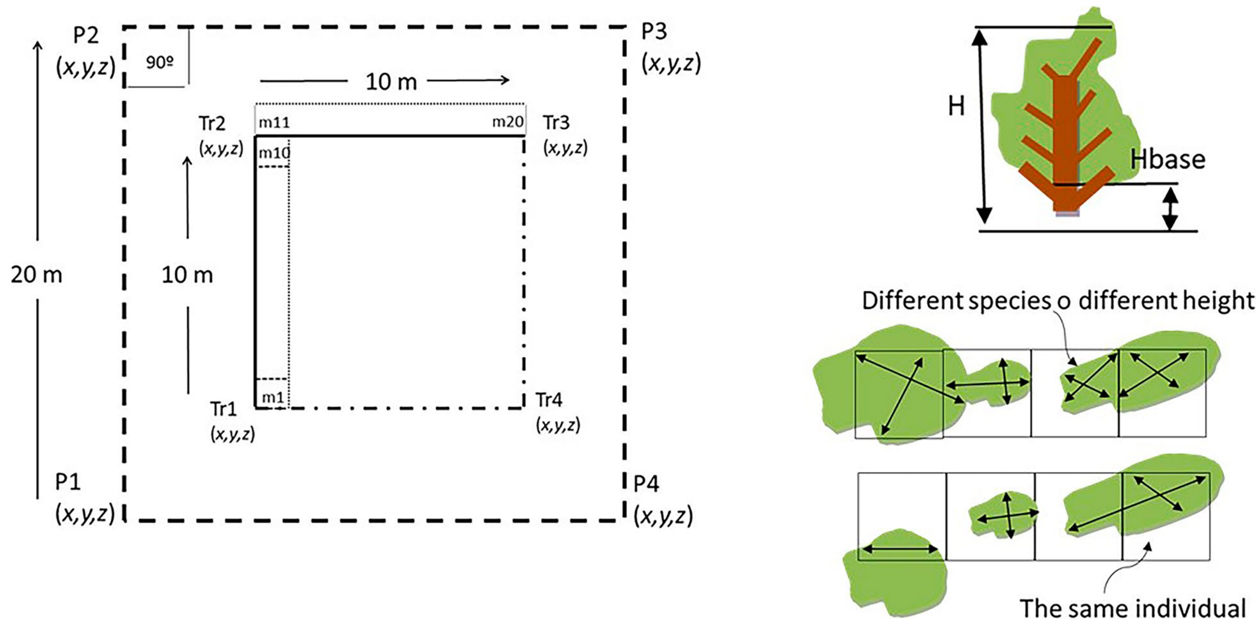

Fig. 2 Scheme of the plot and transect set-up (left) to characterize the composition and structure of shrublands; and schema of woody plant measurements in squares along the L-shaped transect (right). The outer 20 × 20 m plot on the left figure was only implemented in the MatoSeg project (24 plots)

plot was associated to a Catalan habitat map unit (Carreras et al. 2015). As the habitat map allows for three possible typologies in some polygons, the final habitat category was refined using the transect woody composition. The CORINE biotope was obtained from the correspondence between the CORINE and the Catalan habitat units (Carreras et al. 2015). For each plot, we calculated the minimum, maximum and mean annual temperature and mean precipitation over the period 1990–2020 using the R package 'meteoland' (De Cáceres et al. 2018).

3.6 Species composition

Plants were identified to species level. Species nomenclature and life-form classification (sensu Raunkiaer 1934) followed Bolòs et al. (2005) criteria. Here we use the term "woody plant species" to refer the group plant species with a *Macrophanerophyta*, *Nanophanerophyta*, or *Chamaephyta* life form, although some species may be essentially herbaceous (e.g., *Brachypodium retusum*). Plants species were grouped into functional groups according to their response to fire (resprouters and non-resprouters), based on our expert knowledge and using the information compiled in the BROT database (Tavsanoglu and Pausas 2018). We calculated the richness of woody species, potential N-fixing woody species, and woody species of each fire response group growing in the transect (species number in 20 m^2). With the MatoSeg subset of plots we also calculated total vascular and woody species richness in the 400-m^2 plot, 20-m^2 belt transect, and the median species richness in 20 1-m^2 transect squares.

3.7 Shrubland structure

Shrubland structure was described at the plot and transect levels. At plot level, structure information included the visual estimation of the cover and height per vegetation strata and the cover of plot surface without vegetation. Using the structure information recorded in each 20 1-m^2 of the belt transect, we calculated the median of the percent cover of each stratum: overstory ($h > 3$ m), shrub (3 m > h > 0.3 m), low scrub ($h < 0.3$ m), herb, litter, rock and bare soil; the median height of scrub and herb strata; and the median thickness of litter. The cover of woody individuals (i.e., macro-, nano-phanerophytes, and chamaephytes) taller than 0.3 m growing in the belt transect was calculated from crown orthogonal diameters, assuming an ellipse shape of the crown. Using this cover and the height of each woody individual in the transect we calculated the weighted median height of the shrub strata (3 m > h > 0.3 m). In addition, per each woody species in the transect, we calculated the percent cover, summing up the cover of each individual, and the weighted mean crown height. Total and fine fuel loads per each woody species ($kg \cdot m^{-2}$ of species' dry weight) in the transect were calculated summing up the loads obtained using specific allometric equations on the crown diameters and height of the species' individuals in the transect (De Cáceres et al. 2019).

4 Database structure and design

4.1 Datasets description

A relational database was designed to store shrubland data (Casals et al. 2023) in a format ensuring long-term integrity and a flexible access to data (Fig. 3). The description and units of each variable in the data tables can be found in the *Readme.csv* file. Whereas *plotID* is the primary key between the five tables, *SamplingDate* is an additional primary key to allow for future sampling of plot structure and composition. The available tables in the current version are (Fig. 3):

(i) *Plot_description.csv*—contains information about the plot reference, datum, zone and coordinates, altitude, slope, and aspect; and the project name with which the data was obtained.
(ii) *Habitat.csv*—contains the Catalan habitat unit and the corresponding CORINE biotope, and the minimum, maximum and mean annual temperature and mean precipitation.
(iii) *Structure.csv*—contains information about the cover and height visually estimated at plot (variables starting with P) or transect (starting with T) scales. Plot and transect shape and area are included to allow future sampling changes or different records.
(iv) *Species_Fuel.csv*—contains the species binomial Latin name of each woody species (i.e., macrophanerophyte, nanophanerophyte, or chamaephyte) covering the 20 m belt transect and the pooled cover, weighted mean height and total and fine fuel loads per each woody species.
(v) *Richness.csv*—contains information about the richness of woody species, potential N-fixing woody species, and woody resprouters and non-resprouters in the 20 m belt transect of the Combuscat subset. It also includes the total vascular and woody plant species richness in the 400-m^2 plot, 20-m^2 transect, and median richness in 1-m^2 recorded in the MatoSeg subset ($n = 24$ plots).

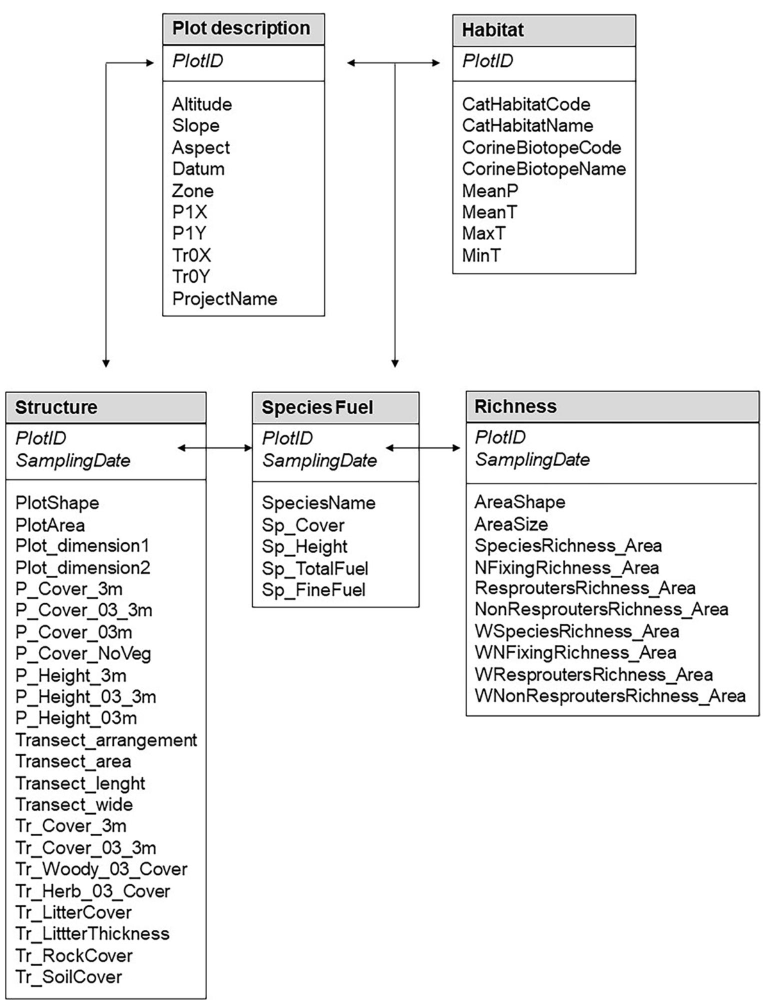

Fig. 3 Relational data model of shrubland database showing the attributes and primary (in cursive) and foreign keys

4.2 Data accessibility and metadata description

A public version of the database is available through Zenodo (Casals et al. 2023, https://doi.org/10.5281/zenodo.7685487) and includes the five main datasets: *Plot_description.csv*, *Habitat.csv*, *Structure.csv*, *Species_Fuel.csv*, and *Richness.csv*; and description of the variables in the *Readme.csv* file. Associated metadata are available at https://metadata-afs.nancy.inra.fr/geonetwork/srv/fre/catalog.search#/metadata/f55fcde4-113e-40f9-9a35-a2e65b0ee951.

5 Database validation

5.1 Database error detection

Related variables were examined for inconsistencies based on their correlations. Variable records were revised in relation to the expected range of values, and anormal data was checked with field sheets and, if necessary, corrected or deleted the value or the plot.

5.2 Robustness of sampling to different field teams

A total of 26 localities were revisited about 6 months after to check the robustness of measurements to the differences between technician pairs. Original and revisited records were visually checked and compared by means of correlation analyses. The most robust variables were the mean cover and means height of the shrub layer calculated from transect measurements, whereas the correlations between both visits were significant but weak for the visual estimation of mean height and the cover of different strata at the plot scale (Appendix 2).

5.3 Validation of fuel estimates against alternative equations

The total fuel load of each plot was compared with the estimations using the equations obtained by Pasalodos-Tato et al. (2015) for shrubland in the south of Iberian Peninsula. Briefly these authors provided equations that related the fuel load obtained destructively to the mean shrub cover and height in 20-m^2 plots of different shrubland formations. To compare both estimates we assimilated their formations to the CORINE habitats of our plots (Table 5 in Appendix 3). Scatter plots showed in general a good agreement between both estimates (Fig. 10 in Appendix 3).

6 Database exploration

The database contained, in March 2023, information from 575 localities, distributed across the NE of Iberian peninsula (Fig. 1). This included the 24 localities sampled in the MatoSeg project.

6.1 Plant composition of shrublands

The database includes information of 43 different CORINE habitats. The most represented habitats are calcicolous shrublands, kermes garrigue, maquias and garrigue, and box formations. Pooling all the transect data, we recorded 164 woody species: 47 macrophanerophytes, 55 nanophanerophytes, 47 chamaephytes, and 15 vine-like species. The number of woody species with a predominant resprouting strategy after fire was twice that of species with a non-resprouter strategy (87 vs 37 species), although the strategy is unknown in 24% of the recorded woody species. In the 20-m^2 transects, woody plant richness ranged from 1 to 17 species (median = 7, IQR = 6), depending on the shrubland typology. In the MatoSeg plots ($n = 24$), the woody plant richness recorded in the 20-m^2 transect was similar and slightly lower than the number of woody species in the 400 m^2 plot (paired mean difference = 1.4 species; Table 2). This supports that the belt transect produces an acceptable estimate of the richness of woody species in the shrublands. As expected, the richness of vascular species was clearly higher in the 400-m^2 plot than in the 20-m^2 transect (Table 2).

6.2 Structure of shrublands

The woody cover of the shrub strata (3 m > h > 0.3 m) in the transect ranged from 3 to 100% (median = 56%) and the shrub height from 0.5 m to 2.40 m (median = 0.97 m) (Fig. 4). The cover of the shrub strata visually estimated at the plot and the transect were positively correlated ($r = 0.69$), while the correlation is slightly weaker for the shrub height ($r = 0.51$), suggesting (i) different height at plot and transect scales or (ii) the difficulty to visually estimate the height in comparison to weighted mean height calculated from individuals in the transect.

6.3 Fuel load and characteristics

Total fuel load ranged from 0.02 kg m^{-2} to 3.93 kg m^{-2} (median = 0.83 kg m^{-2}, $n = 575$ plots) (Fig. 4). The ratio between fine and total fuel load ranged from 0.73 to 0.90 (interquartile range; median = 0.81; $n = 3841$ species and plots). We estimated the following fuel flammability characteristics per transect using species shrub loadings as weights (Fernandes 2009): (i) bulk density (BD, kg m^{-3}); (ii) surface area-to-volume ratio (SAV; m^2 m^{-3}); (iii) high heat content (Heat; kJ kg^{-1}); (iv) minimum fuel moisture content (FMC; % of dry weight) combining the information in the *Species-Fuel* table and species-specific values included in the R package 'medfate' ver. 2.7.3 (De Cáceres et al. 2015). Fuel characteristics by species or species groups are detailed in Sanchez-Pinillos et al. (2021, Appendix 2). Fuel load and characteristics showed different spatial arrangement patterns (Fig. 5).

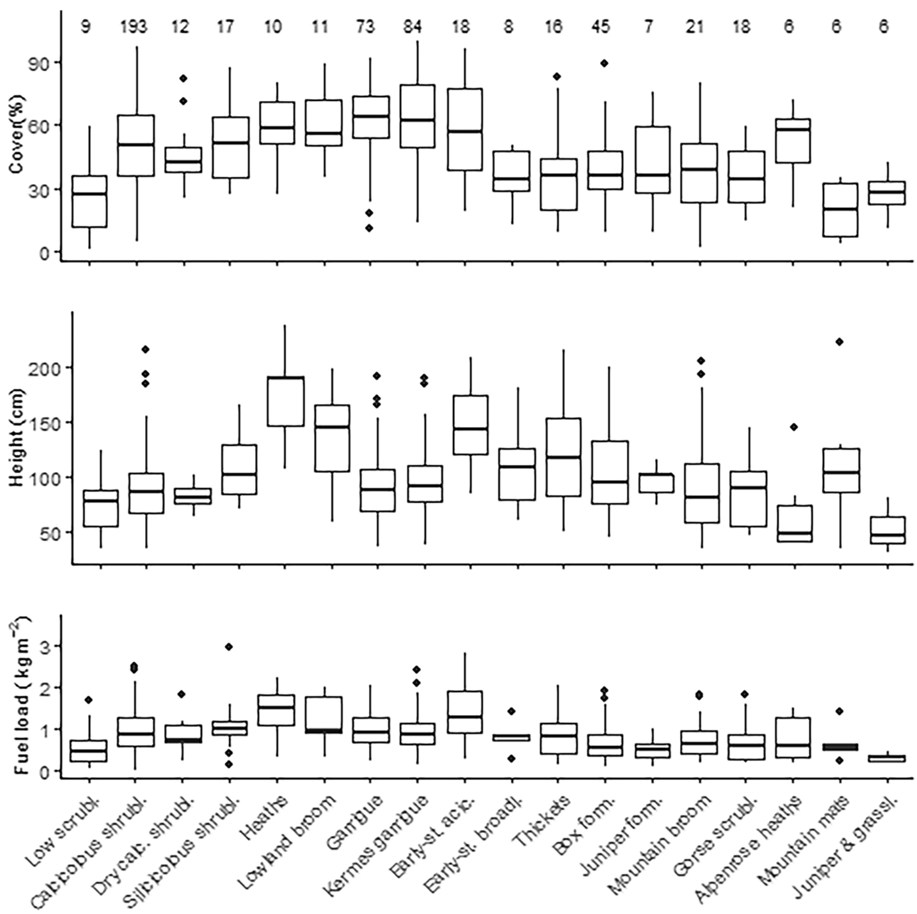

Fig. 4 Cover, weighted mean height, and total fuel load of woody plants in the 0.3 m to 3.0 m strata estimated in the 20-m belt transect grouped into CORINE biotope groups (see Table 5 in Appendix 3 for CORINE group description). The number of plots in each group is indicated in the top. Only habitat groups with more than five plots were represented

Table 2 Woody and all vascular species richness in the Combuscat and in the MatoSeg transects (20-m^2) and plots (400-m^2). The Student's paired-t test differences between plot and transect is indicated for the richness of woody or vascular species in the MatoSeg subset

	Combuscat (*n* = 551 plots)	**MatoSeg subset (*n* = 24 plots)**			
	Woody species	**Woody species**		**Vascular species**	
	Transect	**Plot**	**Transect**	**Plot**	**Transect**
Median	7	8	8	36	23
Min–max	1–17	4–18	3–17	18–58	14–42
Paired *t* test					
Estimated mean difference		1.4		11.3	
Confiance interval (95%)		(0.36–2.39)		(8.0–14.6)	
t statistics		2.795		7.093	
p value		0.010		< 0.0001	

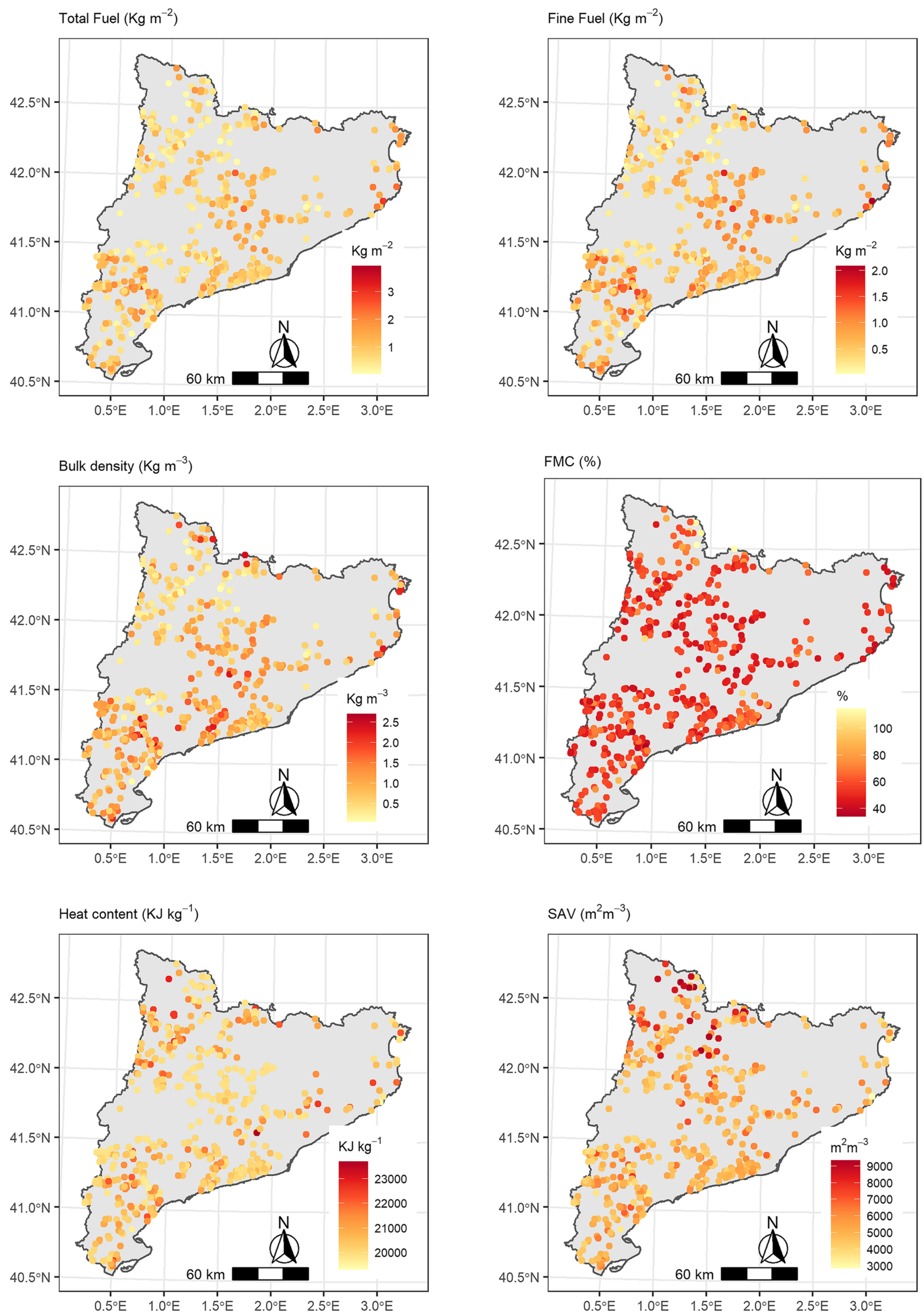

Fig. 5 Spatial distribution of fuel characteristics

7 Potential use and limits

The SPIF currently uses the database to complement the static fuel load maps for wildfire risk assessment with information on shrubland composition and structure. The database provides valuable information for estimating aboveground biomass and describing fuel characteristics to improve operational fire danger prediction protocols. We expect the database will be useful for research on wildfire risk analysis and on the effects of drought or wildfires on shrublands. In particular, detailed georeferenced information on permanent plots can be used to detect changes after severe droughts or forest fires, and in combination with process-based models of forest function and dynamics (e.g., De Cáceres et al. 2015, 2023), to predict the effects of severe droughts in the structure and composition of Mediterranean shrublands. In addition, the database can be useful for wildfire risk assessment, plant flammability prediction, and fire spread rate in combination with fine fuel moisture data sets (e.g., Martin-StPaul et al. 2018; Gabriel et al. 2021). Additionally, the database could be used to test aerial methodologies for mapping carbon stocks or fuel models and inform the development of remote sensing data products with accurate information from georeferenced ground data.

Appendix 1

Standard operating procedures for plot set-up, description and characterization of shrubland formations at plot and transect levels

This section describes step-by-step the instructions to guide Forest rangers in the tasks to perform before going to the field (previous work), in the field (field work), and after the field. A checklist was provided to help follow the steps in the order they are normally completed (Table 3 in Appendix 1). The instructions for each step are detailed below.

Table 3 Check list for operating procedure validation

1. Pre-field work
Check the locality suitability using available geographic information
Check the ownership
Find the best access to the plot locality
Collect the material for plot set-up and sampling
Print the field datasheets and cartography if necessary
Check the correctness of coordinates in the GPS
2. Field work
Plot localization and general description
Find the location using GPS
Check the suitability of the locality or reject it and move to a new one
Plot and transect set-up
Fill the general information (date, plot id, Forest rangers id)
Annotate the coordinates and datum of each plot corner
Mark each transect vertex with a wooden stake
Take general photographs of the plot and of each transect
Annotate the reference of each image in the datasheet
Plot and transect measurements
Annotate per strata the visual characterization of plot structure
Annotate per strata the visual characterization of the structure in each 20 1-m^2 in the transect
Annotate the species name and crown diameters and height of each woody individual in each 20 1-m^2 in the transect
Take photographs of plants from which the species name is unknown
Check that all the information is recorded in the datasheets
3. Post-field work
Upload the field data to the database in the share-point
Upload scanned field datasheets and photographs
Download the information and check it with field datasheets
Archive field data sheets

Previous work

Locality suitability inspection

Using available cartography, check the suitability of the plot location, inspecting for the presence of electric lines, forest roads or perturbations such as recent wildfires and forest works. Determine the ownership of the field and inform and ask for permission if necessary. Assess the best access to the locality to save travel time.

Collect the field material

A checklist was used to prepare and collect the material required for the field work (Table 4 in Appendix 1).

Table 4 Check list of the material required for field sampling

Check	Material	Minimum quantity
	Field data sheets	Several copies
	Pencils	Several
	GPS	1
	Photograph camera, battery, and memory card	1
	Compass	1
	Clinometer	1
	Measure tape of 3–5 m	1
	Measure tapes of 30 m	2
	Wooden stakes	4
	Surveying rod	4
	Metallic bars to fix the tapes in the transect	3
	Hammer	1

Field work

Plot localization and representativeness

Get to the locality using a GPS to locate the coordinates with a precision of ± 2 m. This will be the initial point of the transect (Tr0). Visualize the plot and check their suitability. In case of rejection, describe the reason. The reasons can be the following: proximity of a power line or forest road; high density of tall trees; recent forest activity; recent wildfire; a rock or rocky outcrop covering more than 50% of the plot. If the localization is suitable, proceed with the next step, otherwise, search for a new location by moving 50 m around.

Plot and transect set-up

The left-bottom corner (Tr0) coincided with the coordinates used to locate the plot. From this point, the 20 m × 1 m belt transect follow a "L" shape (Fig. 2). In steep areas, the first 10-m transect is arranged parallel to the maximum slope and the 10 to 20 m transect following the ground level. In flat sites, the first 10-m transect is *N* oriented, and the next 10–20 m transect, E oriented. The 1-m belt transect is arranged in the inner part of the plot in the first 10-m transect and in the external part in the 11–20 m transect (Fig. 2).

Plot general description

Record the date, plot reference and forest rangers identity. Annotate the transect coordinates in the meter 0, 10, and 20, with a conventional GPS, and the datum and precision of GPS measurements. Record the slope and orientation of each 10-m transects. Took plot and transect photographs, and annotate image references in the field sheet.

Visual estimation of plot structure per strata

In the 10 m × 10 m plot, estimate by eye the percent cover (the cover of strata can overlap) and height of the following strata:

- Overstory cover (%): plants with the crown above 3 m height
- Shrub cover (%): plants with the crown between 3 m and 0.3 m height
- Herb cover (%): small scrubs and herbs with the crown below 0.3 m height (both small woody and herbaceous plants together because, in general, it is difficult to estimate their cover separately in the field)
- Surface cover (%): plot surface without vegetation or organic matter (i.e., bare soil, stones or rocky outcrops)
- Overstory height (cm): weighted average height of overstory stratum
- Shrub height (cm): weighted average height of shrub stratum
- Herb height (cm): weighted average height of herb stratum

To estimate the cover of each stratum in the plot we recommend to use a jerarquic protocol (Fig. 6 in Appendix 1).

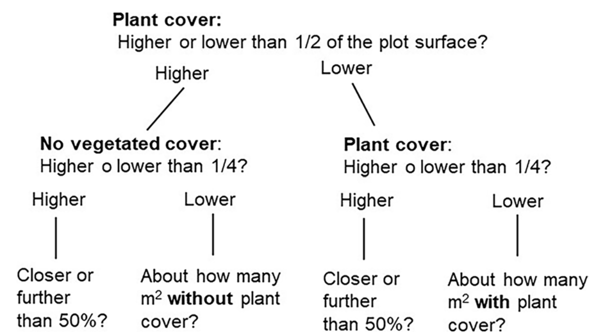

Fig. 6 Flow chart to visually estimate the cover per strata in the plot

Visual estimation of the structure per strata in each 20 1-m² transect

In the each 20 1-m² of the belt transect, estimate by eye the percent cover and height of the following strata:

- Overstory cover (%): plants with the crown above 3 m height
- Shrub cover (%): plants with the crown between 3 m and 0.3 m height
- Low scrub cover (%): small woody plants with the crown below 0.3 m height
- Herb cover (%): herbs with the crown below 0.3 m height
- Litter cover (%): recent fallen leaves and small branches
- Bare soil cover (%): bare soil and small stones (ca. < 10 cm diameter)
- Rock cover (%): rocks and rochy outcrops cover
- Overstory height (cm): weighted average height of overstory stratum (precision ± 25 cm)
- Low scrub height (cm): weighted average height of shrub stratum (precision ± 5 cm)
- Herb height (cm): weighted average height of herb stratum (precision ± 5 cm)
- Litter thickness (cm): thickness of recent fallen leaves and small branches (precision ± 1 cm)

Per each 1-m^2 follow the protocol in Fig. 6 in Appendix 1 to estimate the cover.

Measurements of cover and height of woody individuals in the transect

Per each woody individual, taller than 0.30 m, with the crown in the 20 m^2 belt transect annotate the following information (Fig. 2, right):

- Species name
- Crown longest and normal diameters (D1, D2 in cm, precision ± 5 cm)
- Crown height (H, cm, precision ± 5 cm)
- Distance from the crown base to ground (Hbc, cm, precision ± 10 cm). We define crown base as the height where most of the leaves and fine branches become dominant.

Post-field work

Upload field data to the Combuscat share-point web

Soon as possible after the field work upload the field data to the Combuscat share-point following the instructions and upload scanned field data sheets and photographs. After, download the file and check for errors between the information in the database file and field data sheets.

Appendix 2

Robustness of woody structure characterization

To assess the robustness of recorded field data on the main structure variables by different teams we revisited 26 plots. Thus, each year between 2017 and 2021, we randomly selected between 4 and 8 plots among those sampled by the forest rangers during the spring to be resampled by an independent team three to 6 months after first sampling. In general, the visit was in Autumn. The sampling followed the same methodology.

In general, the comparison between samplings showed a good agreement for the visual overstory and shrub covers in the plot or in the transect (Figs. 7 and 8 in Appendix 2), with correlations (*r*) above 0.7, except for the overstory cover estimated in the transect ($r = 0.55$, Fig. 8 in Appendix 2, left). Low agreement resulted from different perception of the cover in woody individuals above 3 m in the 20 1-m^2 transect squares. The mean height of shrubs in the transect, obtained from the measurement of each shrub individual weighted by their cover, highly correlated between repetitions ($r = 0.86$), while the correlation between the visual estimation of the shrub layer in the plot was worse ($r = 0.74$, Fig. 9 in Appendix 2).

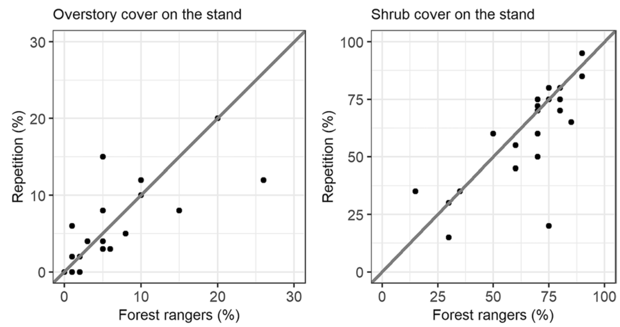

Fig. 7 Scatterplots comparing the visual cover of overstory and shrub layers in the stand between original and revisited samplings ($n = 26$ pairs, $r = 0.74$ and $r = 0.78$, left and right graphs respectively). Note the different scale between graphs

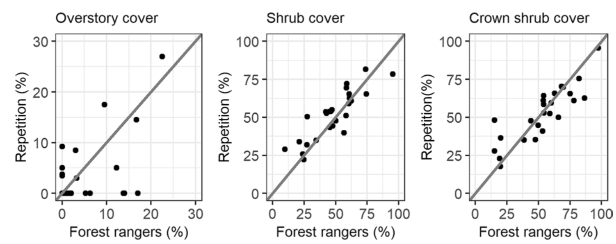

Fig. 8 Scatterplots comparing original and revisited samplings for the cover of overstory and shrubs visually estimated in the transect (left and center) and estimated averaging the individual shrub crown obtained from crown diameters in the transect (right) ($n = 26$ pairs, $r = 0.55$, $r = 0.87$, and $r = 0.85$, from left to right graphs). Note the different scale between graphs

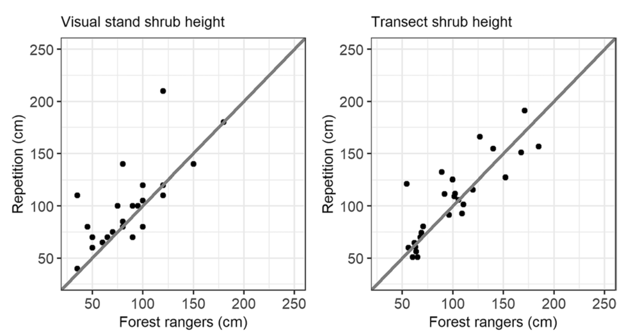

Fig. 9 Scatterplots comparing original and revisited samplings for the height of shrub layer visually estimated in the stand and the average of the measures of each woody indiviual in the transsect wheigthed by their crown cover ($n = 26$ pairs, $r = 0.74$ and $r = 0.85$, stand and transect respectively)

Appendix 3

Fuel estimations

In this section, we compared the fuel estimates compiled in our database with those estimated using the log-linear equations of Pasalodos-Tato et al. (2015) for shrubland formations in the south of Iberian Peninsula. In our study, we estimated the total fuel load of each plot summing up the individual fuel of the woody individuals in the 20-m^2 transect using the specific allometries described in Cáceres et al. (2019). The Pasalodos-Tato and coworkers' equations allow to estimate the fuel load of shrubland formations using visual estimates of the canopy cover and mean height of woody vegetation. Their equations were obtained for a total of 834 plots grouped into 10 categories of the Spanish Forest Map 1/25,000 (SFM 25). The equations were obtained relating the visual percentage of the ground covered by the projection of the shrub crowns per species (FCCm) and the mean height per species (Hm, expressed in dm). The total biomass (dry weight) was obtained by clearing and weighting 4 m×5 m plots. Pasalodos-Tato et al. (2015) used log-linear equations with a Bliss transformation on the cover fraction:

$$\ln(Y) = bo + b1 * \ln(Hm) + b2 * \ln(FCCbliss)$$

$$FCCbliss = \arcsin(\mathrm{sqrt}(FCCm/100))$$

To use the PasaLodos-Tato's equations we assimilated their 9 shrub-like formations to the Corine habitats of our plots (Table 5 in Appendix 3).

Table 5 Correspondence between the Corine biotopes of our database and the formations studied by Pasalodos-Tato et al. (2015) used to compare the fuel load estimate using their equations and the estimations in the current study

Corine group	Corine ID	Corine name	Pasalodos-Tato et al. 2015
Gorse scrublands	32.4811+	Lowland and montane *Genista scorpius* formations	Formation 240. Leguminous gorse shrubs and related groups
Calcicolous shrubland	32.431	Lowland rosemary scrubs	Formation 250a. Mixture of *Lamiaceae* and thyme sward (*Rosmarinus officinalis*)
	32.432	Thermo-Mediterranean *Cistus clusii* formations	
	32.4L+	Dry calcicolous scrubs with *G. biflora*	
Heaths	32.322+	*Erica arborea* heaths	Formation 210. Heathers, *Erinaceae* bushes and related groups
	45.2162+	Heaths with corn-oak	
	45.2163+	Heaths with corn-oak and pines	
Alpenrose heaths	31.42	Alpenrose heaths	
Silicicolous shrublands	32.3442+	Montane silicicolous shrublands	Formation 220b. Rockrose shrubs and Cistaceae bushes. Big-size Cistaceae bushes
	32.341	Lowland silicicolous shrublands	Formation 220a. Rockrose shrubs and Cistaceae bushes. Small-size Cistaceae bushes
	32.351	Silicicolous *Cistus* shrublands	
	32.376+	Silicicolous shrublands	
Kermes garrigue	32.41	Kermes oak garrigue	Formations 170 and 180. Associations dominated by Kernes oak, thicket of mastic trees
Thickets	31.8111	Montane mesophile thickets	
	31.891	Lowland dry thickets	
Box formations	31.8123	*Amelanchier* and box thickets	
	32.641+	Montane box formations	
Garrigue and maquis	42.8412+	Maquis with Aleppo pine	Formations 140, 150, and 160. Machias, terebinth, garrigues
	32.123	Thermo-medit. garrigue	
	32.23	Thermo-medit. garrigue with *Ampelodesmos*	
	32.1151+	Everg. and decidiuos oak maquis	
	45.345	Q. rotundifolia maquis	
Early pine stages	32.B+	Shrubby early stages of Aleppo pine	
	42.8414+	Scrubland with Aleppo pine	
	42.8417+	Aleppo pinewoods	
Juniper formations	31.881	Mountain Juniperus communis f	
	32.1311	*J. oxycedrus* maquis	
	32.1321	*J. phoenicea* formations	
Early deciduous stages	31.8D	Early stages of mixed forest regeneration	
Lowland broom	32.A	*Spartium* broom fields	Formation 230. Mixture of broom leguminous bushes
	32.261	*Retama* broom fields	
	31.8414	Mesophile *Cytisus* broom	
Mountain broom	31.84221+	Montane *Genista balansae* formations	
	31.84222+	Subalpine *G. balansae* formations	
Low scrublands	32.47	Low calcicolous scrublands	Formation 250b. Mixture of *Lamiaceae* and thyme sward (Thyme sward, lavender shrubland, and *Phlomis purpurea* association)
	15.921	Open scrubl. in gypseous soils	
	34.32614+	Semi-dry grassland	
	32.631+	*Aphyllanthes* grassland	
	62.32+	Rocky outcrops	
Mountain mats	32.66+	*Arctostaphylos* mats	
	31.412	*Calluna* heaths	

Scatter plots showed a good direct relation although the estimations obtained in the present study tend to be lower than those obtained with the equations provided by Pasalodos-Tato and coworkers (Fig. 10 in Appendix 3).

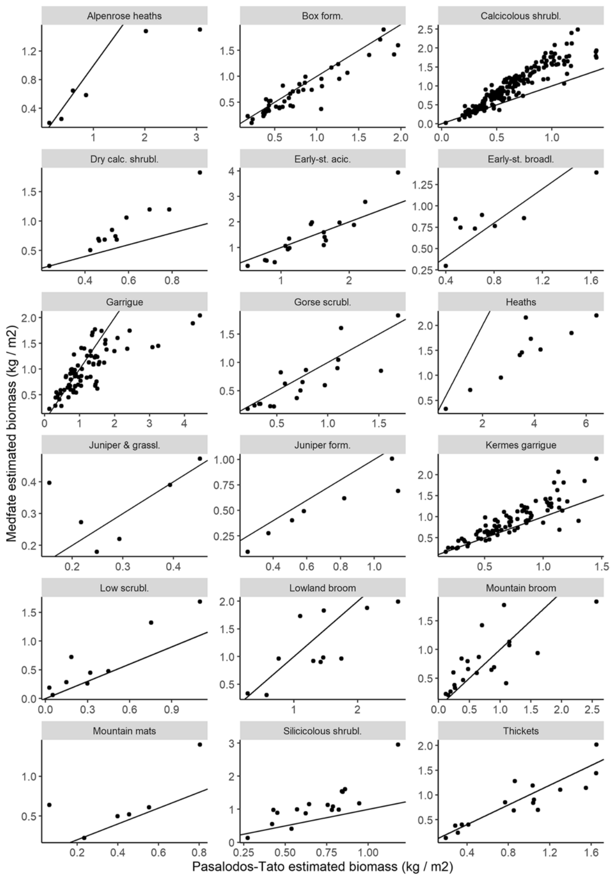

Fig. 10 Scatterplots comparing plot fuel estimates applying Pasalodos-Tato and coworkers equations and the specific allometries of Medfuels (De Cáceres et al. 2019). The correspondence between the shrubland formations used to compare both estimates is described in Table 5 in Appendix 3

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Code availability
Not applicable.

Authors' contributions
PC and EG are co-first authors. PC, EG, AR, and XC designed the study. PC, EG, and AR coordinated the field work and database management. PC, EG, and MDC designed the database and conducted data quality controls. PC, EG, and MDC led manuscript writing, with inputs from all co-authors. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets generated during the current study are available at the ZENODO repository: https://doi.org/10.5281/zenodo.7685487.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no conflict of interest.

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