D 1.1 Fuel type classification and national fuel dataset

Work Package: WP1

Work Package leader: UNITO
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Executive summary

This deliverable presents the national fuel type classification and the updated national fuel dataset developed within WP1 of the FIREBOX project. Together, these outputs provide the conceptual and empirical basis for the subsequent products of WP1, namely the national Fuel Type Map and the national Fuel Model Map. In particular, the deliverable defines a harmonised framework to describe Italian surface fuels and assembles the quantitative information needed to characterise them consistently at the national scale.

The proposed classification is organised into three hierarchical levels: Fuel group, MacroFuelType, and FuelType. Fuel groups distinguish the main burnable vegetation formations, including grasses, shrubs, broadleaved forests, conifer forests, agricultural burnable fuels, and special fuels. These are further subdivided into 23 MacroFuelTypes and 51 FuelTypes according to ecological context, litter characteristics, phytoclimatic setting, and relative flammability. A four-digit Univocal Code was also assigned to identify each FuelType unambiguously and ensure consistency in both mapping and database applications.

The updated national fuel dataset integrates the surveys published by Ascoli et al. (2020) with 759 new unpublished surveys collected by FIREBOX partners, reaching a total of 1342 fuel surveys. This substantially improves the geographic and ecological representativeness of the database, including new vegetation types and previously underrepresented areas. Each survey was harmonised, assigned to the new classification, and enriched with additional variables needed for the FIREBOX framework.

Overall, the deliverable provides a reproducible and nationally coherent system for fuel description in Italy. By linking a hierarchical classification with a harmonised quantitative database, D1.1 establishes the reference framework for fuel mapping, fuel model calibration, and future wildfire hazard and risk applications.

Keywords

Fuel type; classification; national dataset; surface fuel

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1. Introduction

Deliverable D1.1 provides the national fuel type classification and the updated national fuel dataset developed within WP1 of the FIREBOX project. These two outputs represent the conceptual and empirical basis for the subsequent mapping activities of WP1, i.e. the national Fuel Type Map and Fuel Model Map. The objective of this deliverable is therefore twofold: first, to establish a harmonised classification framework for surface fuels across Italy; second, to assemble a consistent national database of quantitative fuel observations supporting the definition and description of fuel types.

A nationally coherent fuel classification is a necessary prerequisite for wildfire risk assessment and fuel mapping, because Italian vegetation spans very different ecological and phytoclimatic conditions, ranging from alpine and subalpine environments to temperate and Mediterranean systems. Existing land cover and vegetation classifications were not specifically designed to represent fire-related fuel properties and therefore require translation into a fuel-oriented framework. In this context, D1.1 proposes a hierarchical classification articulated into Fuel group, MacroFuelType, and FuelType, designed to organise Italian burnable vegetation according to dominant fuel structure, ecological setting, and relative flammability. This structure makes it possible to link vegetation categories to quantitative fuel attributes for subsequent spatial applications.

The second pillar of the deliverable is the updated national fuel dataset. This database integrates the harmonised fuel surveys published by Ascoli et al. (2020) with new unpublished field observations collected during the FIREBOX project by project partners. The resulting dataset substantially expands both the number of surveys and the ecological representativeness of the database, improving the coverage of vegetation types and geographic areas that were previously underrepresented. The updated dataset provides the empirical basis for assigning quantitative fuel characteristics to the classification system and for describing variability in fuel loads, cover, and depth across fuel types.

Overall, D1.1 establishes the reference framework on which the entire WP1 workflow is built. By combining a reproducible classification logic with a harmonised national fuel database, the deliverable provides a robust basis for fuel type mapping, fuel model calibration, and future wildfire hazard and risk applications in Italy.

2. Classification of national fuel types

2.1. Classification structure

The classification of fuel types consists of three levels: fuel group, macro fuel type, and fuel type (Figure 1). The first classification level, called **Fuel group**, is defined based on the type of vegetation, distinguishing between grass fuels, shrub fuels, forest fuels (subdivided into broadleaved and coniferous, i.e., Broadleaved Forest and Conifer Forest), agricultural burnable fuels, and special fuels. The Special fuel group includes surface fuels that cannot be mapped in the Fuel Types map (see Deliverable 1.2) because of their dynamic nature (e.g., forestry residues) or because they represent a particular habitat (e.g., reed beds), they are not considered in the land use maps used as a basis for the development of the Fuel Type Map, namely the Forest Map of Italy (Mattioli et al. 2025)[1] and Corin Land Cover 2018.

The second level of classification divides fuel groups into **macro fuel types** (MacroFuelType). A total of 23 Macro Fuel Types have been defined. Specifically, I) the Grass and Shrubs fuel groups are divided into 3 MacroFuelTypes each based on the phytoclimatic region (alpine, temperate, and Mediterranean); II) the Broadleaved Forest fuel group has been subdivided into 5 MacroFuelTypes using the following criteria: i) distinguishing between deciduous and evergreen forest stands, ii) observing the degree of litter porosity (low, medium, or high); III) the Conifer Forest fuel group has been divided into 5 MacroFuelTypes using the following criteria: i) distinguishing forest stands according to the phytoclimatic region to which they belong (i.e., subalpine conifers, temperate conifers, Mediterranean conifers), ii) observing the degree of litter porosity (low, medium, or high); IV) the Special fuel group is divided into 5 MacroFuelTypes, including shredding and forestry residues, deadwood resulting from natural disturbances (e.g., windthrow) or insect infestations (e.g., bark beetles in Trentino-Alto Adige), high-load reed beds, and eucalyptus plantations.

[1] [1] https://cfi-sinfor.crea.gov.it/Home/CartaForestale

The third level of classification associates each fuel macrotype with 1 to 3 **fuel types** (FuelType). Specifically, the Grass and Shrubs macrotypes have been divided into 2 classes of fuel types (low and high flammability). The Broadleaves and Conifer MacroFuelTypes have both been divided into 3 classes of fuel types (low, medium, and high flammability). The same applies to agricultural macrotypes. A total of 51 Fuel Types have been defined (Figure 1).

Finally, a **unique code** (Univocal Code) was generated from the combination of MacroFuelType and FuelType to identify each Fuel Type at the cartographic level in the creation of the Fuel Type Map (see Deliverable 1.2) and to assign a Fuel Type to each fuel survey in the national fuel database (see paragraph 3). The Univocal Code consists of 4 digits (e.g., 0101), where the first two represent the MacroFuelType and the last two represent the FuelType (Table 1).

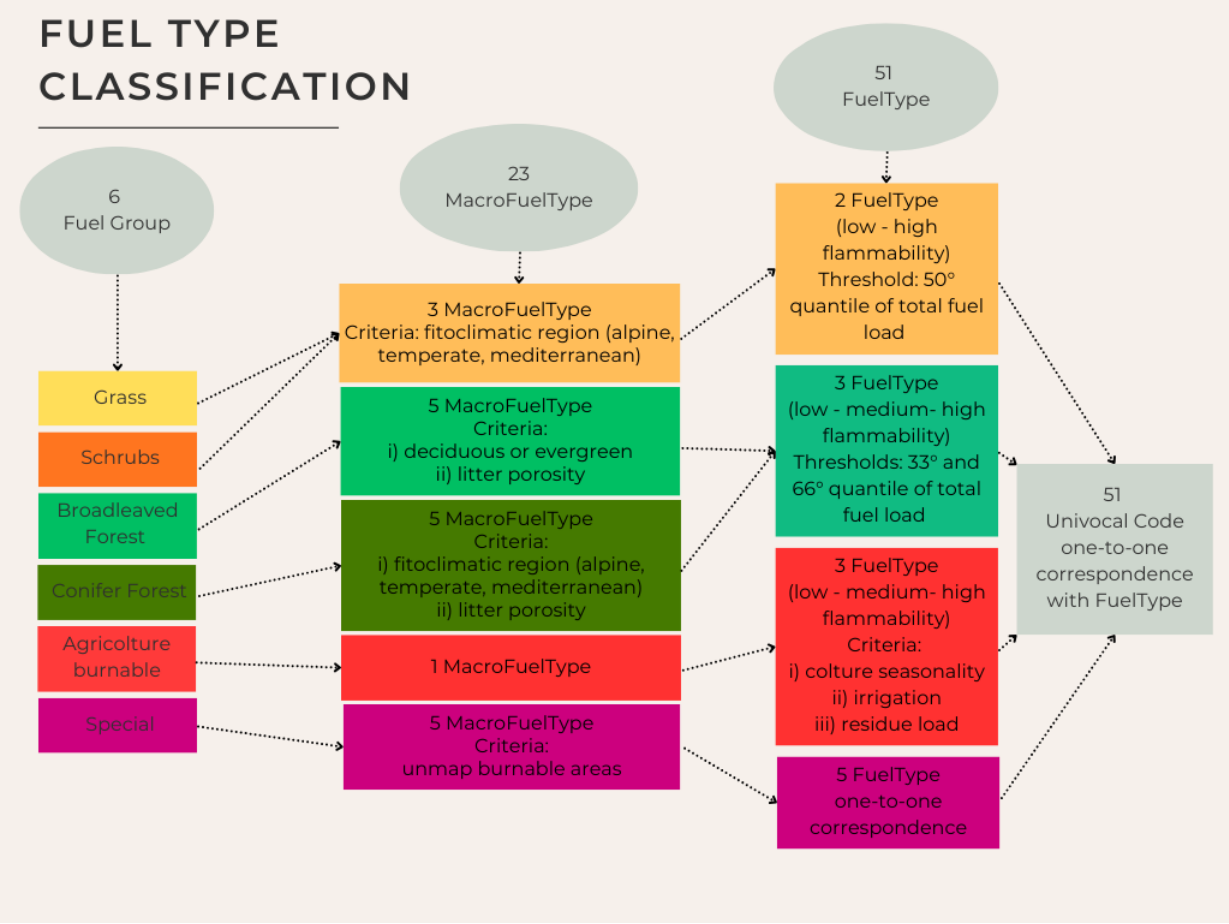

Figure 1. Flow chart of the classification of national fuel types.

Table 1. Classification of surface fuels into Fuel group, MacroFuelType, FuelType, and Univocal Code.

Fuel group	NMacroFuelType	MacroFuelType	NFuelType	FuelType	Univocal Code
Grass	01	Prateria alpina	01	Prateria alpina continua con erbe ad infiammabilità bassa	0101
Grass	01	Prateria alpina	02	Prateria alpina discontinua con erbe ad infiammabilità alta	0102
Grass	02	Prateria temperata	01	Prateria temperata continua con erbe ad infiammabilità bassa	0201
Grass	02	Prateria temperata	02	Prateria temperata discontinua con erbe ad infiammabilità alta	0202
Grass	03	Prateria mediterranea	01	Prateria mediterranea continua con erbe ad infiammabilità bassa	0301
Grass	03	Prateria mediterranea	02	Prateria mediterranea discontinua con erbe ad infiammabilità alta	0302
Schrubs	04	Arbusteti subalpini	01	Arbusteti subalpini a infiammabilità bassa	0401
Schrubs	04	Arbusteti subalpini	02	Arbusteti subalpini a infiammabilità media	0402
Schrubs	05	Arbusteti temperati	01	Arbusteti temperati a infiammabilità media	0501
Schrubs	05	Arbusteti temperati	02	Arbusteti temperati a infiammabilità alta	0502
Schrubs	06	Macchia mediterranea bassa	01	Macchia mediterranea a infiammabilità media	0601
Schrubs	06	Macchia mediterranea alta	02	Macchia mediterranea a infiammabilità alta	0602
Broadleaved Forest	07	Lettiera di caducifoglie temperate a porosità bassa	01	Lettiera di caducifoglie temperate a porosità bassa con sottobosco a infiammabilità bassa	0701
Broadleaved Forest	07	Lettiera di caducifoglie temperate a porosità bassa	02	Lettiera di caducifoglie temperate a porosità bassa con sottobosco a infiammabilità media	0702
Broadleaved Forest	07	Lettiera di caducifoglie temperate a porosità bassa	03	Lettiera di caducifoglie temperate a porosità bassa con sottobosco a infiammabilità alta	0703
Broadleaved Forest	08	Lettiera di caducifoglie temperate a porosità media	01	Lettiera di caducifoglie temperate a porosità media con sottobosco a infiammabilità bassa	0801
Broadleaved Forest	08	Lettiera di caducifoglie temperate a porosità media	02	Lettiera di caducifoglie temperate a porosità media con sottobosco a infiammabilità media	0802
Broadleaved Forest	08	Lettiera di caducifoglie temperate a porosità media	03	Lettiera di caducifoglie temperate a porosità media con sottobosco a infiammabilità alta	0803
Broadleaved Forest	09	Lettiera di caducifoglie termofile a porosità media	01	Lettiera di caducifoglie termofile a porosità media con sottobosco a infiammabilità bassa	0901
Broadleaved Forest	09	Lettiera di caducifoglie termofile a porosità media	02	Lettiera di caducifoglie termofile a porosità media con sottobosco a infiammabilità media	0902
Broadleaved Forest	09	Lettiera di caducifoglie termofile a porosità media	03	Lettiera di caducifoglie termofile a porosità media con sottobosco a infiammabilità alta	0903
Broadleaved Forest	10	Lettiera di caducifoglie termofile a porosità alta	01	Lettiera di caducifoglie termofile a porosità alta con sottobosco a infiammabilità bassa	1001
Broadleaved Forest	10	Lettiera di caducifoglie termofile a porosità alta	02	Lettiera di caducifoglie termofile a porosità alta con sottobosco a infiammabilità media	1002
Broadleaved Forest	10	Lettiera di caducifoglie termofile a porosità alta	03	Lettiera di caducifoglie termofile a porosità alta con sottobosco a infiammabilità alta	1003
Broadleaved Forest	11	Lettiera di latifoglie sempreverdi mediterranee a porosità bassa	01	Lettiera di latifoglie sempreverdi mediterranee a porosità bassa con sottobosco a infiammabilità bassa	1101
Broadleaved Forest	11	Lettiera di latifoglie sempreverdi mediterranee a porosità bassa	02	Lettiera di latifoglie sempreverdi mediterranee a porosità bassa con sottobosco a infiammabilità media	1102
Broadleaved Forest	11	Lettiera di latifoglie sempreverdi mediterranee a porosità bassa	03	Lettiera di latifoglie sempreverdi mediterranee a porosità bassa con sottobosco a infiammabilità alta	1103
Conifer Forest	12	Lettiera di conifere subalpine a porosità bassa	01	Lettiera di conifere subalpine a porosità bassa con sottobosco a infiammabilità bassa	1201
Conifer Forest	12	Lettiera di conifere subalpine a porosità bassa	02	Lettiera di conifere subalpine a porosità bassa con sottobosco a infiammabilità media	1202
Conifer Forest	12	Lettiera di conifere subalpine a porosità bassa	03	Lettiera di conifere subalpine a porosità bassa con sottobosco a infiammabilità alta	1203
Conifer Forest	13	Lettiera di conifere subalpine a porosità media	01	Lettiera di conifere subalpine a porosità media con sottobosco a infiammabilità bassa	1301
Conifer Forest	13	Lettiera di conifere subalpine a porosità media	02	Lettiera di conifere subalpine a porosità media con sottobosco a infiammabilità media	1302
Conifer Forest	13	Lettiera di conifere subalpine a porosità media	03	Lettiera di conifere subalpine a porosità media con sottobosco a infiammabilità alta	1303
Conifer Forest	14	Lettiera di conifere temperate a porosità media	01	Lettiera di conifere montane a porosità media con sottobosco a infiammabilità bassa	1401
Conifer Forest	14	Lettiera di conifere temperate a porosità media	02	Lettiera di conifere montane a porosità media con sottobosco a infiammabilità media	1402
Conifer Forest	14	Lettiera di conifere temperate a porosità media	03	Lettiera di conifere montane a porosità media con sottobosco a infiammabilità alta	1403
Conifer Forest	15	Lettiera di conifere mediterranee a porosità media	01	Lettiera di conifere mediterranee a porosità media con sottobosco a infiammabilità bassa	1501
Conifer Forest	15	Lettiera di conifere mediterranee a porosità media	02	Lettiera di conifere mediterranee a porosità media con sottobosco a infiammabilità media	1502
Conifer Forest	15	Lettiera di conifere mediterranee a porosità media	03	Lettiera di conifere mediterranee a porosità media con sottobosco a infiammabilità alta	1503
Conifer Forest	16	Lettiera di conifere mediterranee a porosità alta	01	Lettiera di conifere mediterranee a porosità alta con sottobosco a infiammabilità bassa	1601
Conifer Forest	16	Lettiera di conifere mediterranee a porosità alta	02	Lettiera di conifere mediterranee a porosità alta con sottobosco a infiammabilità media	1602
Conifer Forest	16	Lettiera di conifere mediterranee a porosità alta	03	Lettiera di conifere mediterranee a porosità alta con sottobosco a infiammabilità alta	1603

Continued of Table 1.

Fuel group	NMacroFuelType	MacroFuelType	NFuelType	FuelType	Univocal Code
Agriculture burnable	17	Colture agrarie	01	Colture agrarie a infiammabilità bassa	1701
Agriculture burnable	17	Colture agrarie	02	Colture agrarie a infiammabilità media	1702
Agriculture burnable	17	Colture agrarie	03	Colture agrarie a infiammabilità alta	1703
Special	30	Canneto a carico elevato	01	Canneto a carico elevato	3001
Special	31	Lettiera di caducifoglie a porosità alta	01	Eucalipteti	3101
Special	32	Residui di trinciatura	01	Residui di trinciatura	3201
Special	33	Residui di utilizzazione diffusi	01	Residui di utilizzazione diffusi	3301
Special	34	Necromassa diffusa a seguito di incendi e schianti	01	Necromassa diffusa a seguito di incendi e schianti	3401
Special	35	Necromassa derivante da attacchi da bostrico	01	Necromassa derivante da attacchi da bostrico	3501

For each of the 51 fuel types, descriptive sheets were generated as shown in **Annex A**, based on the template shown in Figure 2.

CODICE TIPO COMBUSTIBILE	1001
NOME	Lettiera di caducifoglie termofile a porosità alta con sottobosco a infiammabilità bassa
DESCRIZIONE	Castagneti cedui gestiti
CATEGORIA CFI	
TIPI FORESTALI	

Foto 1 PANORAMICA

Foto 2 LETTIERA

Foto 3 COPERTURA

PIANO DOMINANTE ARBOREO

Piano arboreo		Governo	CEDUO	TRANSIZIONE	FUSTAIA	NEOFORMAZIONE
PRESENTE					x	

	chiome > 70%	chiome 30% - 70%	chiome < 30%	altezza (m)	inserzione (m)	diametro (cm)	basimetrica (m2/ha)
Struttura						25	32
Specie	conifere 100%	80% - 20%	60% - 40%	50% - 50%	40% - 60%	20% - 80%	latifoglie 100%
							x

STRUTTURA COMBUSTIBILE SUPERFICIE

Componente	Copertura (%)	Altezza (cm)	Specie
Necromassa 1-10 h	62.7	4.8	
Strato erbaceo	17.0	12.4	
Strato arbustivo	15.8	37.3	

CARICO DI COMBUSTIBILE

Componente	Media	Min	Max	Std
Suolo organico	26.6	1.9	99.3	26.6
Lettiera (1h)	2.1	0.1	6.8	2.1
Necromassa (10 h)	2.0	0.2	7.1	1.7
Strato erbaceo	0.3	0	1.7	0.4
Strato arbustivo	0.5	0	3.2	0.8
Carico totale	5.5	2.0	8.0	1.6

NOTE	

Figure 2. Description of one of the 51 types of fuel covered by the FIREBOX Project.

2.2. Comparison between different Italian and European vegetation classifications

A comparison was made between the fuel classifications in Fuel group, MacroFuelType, FuelType, and Univocal Code and the various fuel classifications used in Italy and at European level. Table 2 shows the associations between the Firebox surface fuel classifications and the classifications in:

- Fuelbed, as defined by the publication by Ascoli et al. (2020)
- European Forest Fire Information System (EFFIS) classes
- Corine Land Cover IV level classes of 2010 (CLC)
- European Forest Types (EU Forest Types) classes
- Forest categories of the National Forest Inventory (INFC)

A value of 'na' was assigned to the association when no suitable matches were found between the different classifications; for example, there is no class for herbaceous and shrubby fuels within the EU Forest Types and INFC classifications, just as there are no classes corresponding to the Fuel group Agriculture burnable in the Fuelbed, EFFIS, EU Forest Types and INFC classifications. As regards the Fuel group Special, the classification by Ascoli et al. (2020) does not have any corresponding classes, with the exception of '19. Aquatic marshes' and '12. Eucalyptus litter'; furthermore, for MacroFuelType:

- "30. Heavy-load reed bed": no association with CLC, EU Forest Types, and INFC classifications
- "31. High-porosity deciduous litter": no association with EFFIS and INFC classifications
- "32. Chipping residues": no association with any of the classifications examined.

It was found that some MacroFuelTypes could be assigned a unique class with almost all other classifications (e.g., MacroFuelType "08. Temperate deciduous litter with medium porosity" corresponds uniquely to Fuelbed "07. Montane beech litter," to CLC class "3115. Beech forests" and the INFC category "Beech forests"). However, several MacroFuelTypes and FuelTypes can be associated with the same vegetation class and, conversely, several vegetation classes can be associated with the same fuel class description (e.g., as in the case of MacroFuelTypes 15 and 16, which can be associated with both Fuelbed 16 and 17).

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Table 2. Association of Fuel groups, MacroFuelType, FuelType, and Univocal Code to the Fuelbeds in the publication by Ascoli et al. (2020), the fuel map classes of the European EFFIS, the Corine Land Cover classes (level IV), the European Forest Types, and the forest categories of the National Forest Inventory (INFC). A value of "na" was assigned when no suitable matches were found between the classifications.

Fuel group	MacroFuelType	FuelType	Univocal Code	Fuelbed (Ascoli et al. 2020)	EFFIS fuel map class	Corine LC IV level	EU Forest Types	INFC Categories
Grass	01. Prateria alpina	01. Prateria alpina continua con erbe ad infiammabilità bassa	0101	01. Sparse and very short grasslands	4. Sparse grasslands	3212. Discontinuous grassland	na	na
Grass	01. Prateria alpina	02. Prateria alpina discontinua con erbe ad infiammabilità alta	0102	01. Sparse and very short grasslands	4. Sparse grasslands	3212. Discontinuous grassland	na	na
Grass	02. Prateria temperata	01. Prateria temperata continua con erbe ad infiammabilità bassa	0201	02. Continuous short grasslands	5. Mediterranean grasslands and steppes; 6. Temperate, Alpine and Northern grasslands	3211. Continuous grassland	na	na
Grass	02. Prateria temperata	02. Prateria temperata discontinua con erbe ad infiammabilità alta	0202	02. Continuous short grasslands	5. Mediterranean grasslands and steppes; 6. Temperate, Alpine and Northern grasslands	3211. Continuous grassland	na	na
Grass	03. Prateria mediterranea	01. Prateria mediterranea continua con erbe ad infiammabilità bassa	0301	03. Continuous tall Mediterranean grasslands	5. Mediterranean grasslands and steppes	3211. Continuous grassland	na	na
Grass	03. Prateria mediterranea	02. Prateria mediterranea discontinua con erbe ad infiammabilità alta	0302	03. Continuous tall Mediterranean grasslands	5. Mediterranean grasslands and steppes	3211. Continuous grassland	na	na
Schrubs	04. Arbusteti subalpini	01. Arbusteti subalpini a infiammabilità bassa	0401	04. Temperate and Alpine heathlands	8. Temperate, Alpine and Northern moors and heathlands	322. Moors and heathlands	na	na
Schrubs	04. Arbusteti subalpini	02. Arbusteti subalpini a infiammabilità media	0402	04. Temperate and Alpine heathlands	8. Temperate, Alpine and Northern moors and heathlands	322. Moors and heathlands	na	na
Schrubs	05. Arbusteti temperati	01. Arbusteti temperati a infiammabilità media	0501	04. Temperate and Alpine heathlands	8. Temperate, Alpine and Northern moors and heathlands	322. Moors and heathlands	na	na
Schrubs	05. Arbusteti temperati	02. Arbusteti temperati a infiammabilità alta	0502	04. Temperate and Alpine heathlands	8. Temperate, Alpine and Northern moors and heathlands	322. Moors and heathlands	na	na
Schrubs	06. Macchia mediterranea bassa	01. Macchia mediterranea a infiammabilità media	0601	05. Short Mediterranean shrublands and garrigues	9. Mediterranean open shrublands (sclerophyllous)	3232. Low maquis and garrigues	na	na
Schrubs	06. Macchia mediterranea alta	02. Macchia mediterranea a infiammabilità alta	0602	06. Tall Mediterranean shrublands and heathlands	10. Mediterranean shrublands (sclerophyllous)	3231. High maquis	na	na
Broadleaved Forest	07. Lettiera di caducifoglie temperate a porosità bassa	01. Lettiera di caducifoglie temperate a porosità bassa con sottobosco a infiammabilità bassa	0701	18. Riparian vegetation	39. Riparian vegetation	3116. Hygrophilous forests	12.1 Riparian forest	Boschi igrofili
Broadleaved Forest	07. Lettiera di caducifoglie temperate a porosità bassa	02. Lettiera di caducifoglie temperate a porosità bassa con sottobosco a infiammabilità media	0702	08. Compact mesophytic broadleaved litter	31. Mesophytic broadleaved forest	3241. Young tree plantations for wood production; 3112. Deciduous oak forests; 3113. Mesophilous broad-leaved forests; 3117. Non-native broadleaved forests	5.1 Pedunculate oak-hornbeam forest; 5.9 Other mesophytic deciduous forests; 8.2 Turkey oak, Hungarian oak and Sessile oak forest; 14 Introduced tree species forest	Boschi a rovere, roverella e farnia; Cerrete, boschi di farnetto, fragno, vallonea; Ostrieti, carpineti
Broadleaved Forest	07. Lettiera di caducifoglie temperate a porosità bassa	03. Lettiera di caducifoglie temperate a porosità bassa con sottobosco a infiammabilità alta	0703	08. Compact mesophytic broadleaved litter	31. Mesophytic broadleaved forest	3241. Young tree plantations for wood production; 3112. Deciduous oak forests; 3113. Mesophilous broad-leaved forests; 3117. Non-native broadleaved forests	5.1 Pedunculate oak-hornbeam forest; 5.9 Other mesophytic deciduous forests; 8.2 Turkey oak, Hungarian oak and Sessile oak forest; 14 Introduced tree species forest	Boschi a rovere, roverella e farnia; Cerrete, boschi di farnetto, fragno, vallonea; Ostrieti, carpineti
Broadleaved Forest	08. Lettiera di caducifoglie temperate a porosità media	01. Lettiera di caducifoglie temperate a porosità media con sottobosco a infiammabilità bassa	0801	07. Montane beech litter	33. Montane beech forest; 38. Mixed beech with conifers forest	3115. Beech forests	7.1 South western European mountainous beech forest; 7.3 Apennine-Corsican mountainous beech forest	Faggete
Broadleaved Forest	08. Lettiera di caducifoglie temperate a porosità media	02. Lettiera di caducifoglie temperate a porosità media con sottobosco a infiammabilità media	0802	07. Montane beech litter	33. Montane beech forest; 38. Mixed beech with conifers forest	3115. Beech forests	7.1 South western European mountainous beech forest; 7.3 Apennine-Corsican mountainous beech forest	Faggete
Broadleaved Forest	08. Lettiera di caducifoglie temperate a porosità media	03. Lettiera di caducifoglie temperate a porosità media con sottobosco a infiammabilità alta	0803	07. Montane beech litter	33. Montane beech forest; 38. Mixed beech with conifers forest	3115. Beech forests	7.1 South western European mountainous beech forest; 7.3 Apennine-Corsican mountainous beech forest	Faggete
Broadleaved Forest	09. Lettiera di caducifoglie termofile a porosità media	01. Lettiera di caducifoglie termofile a porosità media con sottobosco a infiammabilità bassa	0901	09. Porous thermophilous broadleaved litter	30. Thermophilous broadleaved forest	3112. Deciduous oak forests; 3113. Mesophilous broad-leaved forests	8.1 Downy oak forest; 8.2 Turkey oak, Hungarian oak and farnia; Cerrete, boschi di farnetto, fragno, vallonea; 8.8 Other thermophilous deciduous forests	Ostrieti, carpineti
Broadleaved Forest	09. Lettiera di caducifoglie termofile a porosità media	02. Lettiera di caducifoglie termofile a porosità media con sottobosco a infiammabilità media	0902	09. Porous thermophilous broadleaved litter	30. Thermophilous broadleaved forest	3112. Deciduous oak forests; 3113. Mesophilous broad-leaved forests	8.1 Downy oak forest; 8.2 Turkey oak, Hungarian oak and farnia; Cerrete, boschi di farnetto, fragno, vallonea; 8.8 Other thermophilous deciduous forests	Ostrieti, carpineti
Broadleaved Forest	09. Lettiera di caducifoglie termofile a porosità media	03. Lettiera di caducifoglie termofile a porosità media con sottobosco a infiammabilità alta	0903	09. Porous thermophilous broadleaved litter	30. Thermophilous broadleaved forest	3112. Deciduous oak forests; 3113. Mesophilous broad-leaved forests	8.1 Downy oak forest; 8.2 Turkey oak, Hungarian oak and farnia; Cerrete, boschi di farnetto, fragno, vallonea; 8.8 Other thermophilous deciduous forests	Ostrieti, carpineti
Broadleaved Forest	10. Lettiera di caducifoglie termofile a porosità alta	01. Lettiera di caducifoglie termofile a porosità alta con sottobosco a infiammabilità bassa	1001	11. Long broadleaved litter	30. Thermophilous broadleaved forest	3114. Chestnut forests	8.7 Chestnut forest	Castagneti
Broadleaved Forest	10. Lettiera di caducifoglie termofile a porosità alta	02. Lettiera di caducifoglie termofile a porosità alta con sottobosco a infiammabilità media	1002	11. Long broadleaved litter	30. Thermophilous broadleaved forest	3114. Chestnut forests	8.7 Chestnut forest	Castagneti
Broadleaved Forest	10. Lettiera di caducifoglie termofile a porosità alta	03. Lettiera di caducifoglie termofile a porosità alta con sottobosco a infiammabilità alta	1003	11. Long broadleaved litter	30. Thermophilous broadleaved forest	3114. Chestnut forests	8.7 Chestnut forest	Castagneti
Broadleaved Forest	11. Lettiera di latifoglie sempreverdi mediterranee a porosità bassa	01. Lettiera di latifoglie sempreverdi mediterranee a porosità bassa con sottobosco a infiammabilità bassa	1101	10. Mediterranean evergreen broadleaved litter	29. Mediterranean evergreen broadleaved forest	3111. Mediterranean evergreen oak forests	9.1 Mediterranean evergreen oak forest	Leccete; Sugherete; Altre latifoglie sempreverdi
Broadleaved Forest	11. Lettiera di latifoglie sempreverdi mediterranee a porosità bassa	02. Lettiera di latifoglie sempreverdi mediterranee a porosità bassa con sottobosco a infiammabilità media	1102	10. Mediterranean evergreen broadleaved litter	29. Mediterranean evergreen broadleaved forest	3111. Mediterranean evergreen oak forests	9.1 Mediterranean evergreen oak forest	Leccete; Sugherete; Altre latifoglie sempreverdi
Broadleaved Forest	11. Lettiera di latifoglie sempreverdi mediterranee a porosità bassa	03. Lettiera di latifoglie sempreverdi mediterranee a porosità bassa con sottobosco a infiammabilità alta	1103	10. Mediterranean evergreen broadleaved litter	29. Mediterranean evergreen broadleaved forest	3111. Mediterranean evergreen oak forests	9.1 Mediterranean evergreen oak forest	Leccete; Sugherete; Altre latifoglie sempreverdi

3. National fuel database

The updated Italian national fuel database (national database) includes all the surveys in the national fuel dataset published by Ascoli et al. 2020, with the addition of 759 unpublished surveys carried out by partners during the FIREBOX project (Table 3), which covered new geographical areas (e.g., northern Apennines), new types of vegetation (e.g., subalpine shrublands), or increased the sample size in vegetation types where the Ascoli et al. (2020) database was lacking. The updated national database has more than double the number of surveys included in the Ascoli et al. 2020 publication, reaching a total of 1342 surveys, and is available as **Annex B**. The survey methodology used is the same as that adopted in Ascoli et al. (202) and is described in detail in **Annex C**.

Each fuel survey in the national fuel dataset has been assigned a class for each classification shown in Table 2, where possible.

Finally, a unique code (Univocal Code) was generated from the combination of MacroFuelType and FuelType for the classification of each fuel survey in the national fuel database.

Table 3. Update of Italian fuel database surveys and related numbers by partner.

Partner	n
Ascoli et al. 2020	583
CNR-IBE	9
UniTo	261
UniBa	304
UniMi	185
Total	1342

3.1. Changes compared to Ascoli et al. (2020)

For each survey in the updated national database, the parameters described in the publication by Ascoli et al. 2020 were evaluated, with the addition of some new parameters necessary for the harmonization of the surveys (i.e. “ShTot” = total load of the living shrub layer, in t ha^{-1}), and for the Firebox classification of fuels (i.e. to apply the criterion of belonging to a specific phytoclimatic region, each survey was assigned the value “Fitoclimatic_region”: 3 = alpine, 2 = temperate, 1 = Mediterranean).

In addition, each survey in the dataset was assigned a Fuel group, MacroFuelType, FuelType, and Univocal Code class, according to the criteria listed in paragraph 3.2.

3.2. Assignment of fuel loads to fuel type classes

The fuel loads associated with the Grass and Shrubs macrotypes were divided between the two fuel type classes (low and high flammability) using the 50th quantile of the total load (Wtot, t ha^{-1}) as the threshold, while for forest macrotypes, the loads were divided into three fuel type classes (low, medium, and high flammability) using the 33rd and 66th quantiles of the total load as thresholds (Table 4). On the other hand, agricultural macrotypes, corresponding to crop residues from different herbaceous crops, were divided according to i) the seasonality of the cultivation of the corresponding herbaceous crops and ii) the ordinary use of an irrigation system and, finally, iii) the total amount of crop residues produced.

The average total load of crop residues divided according to the seasonality of the crop and the ordinary use of irrigation was calculated as the average of the total average quantity of crop residues from crops with the same growing season and the same irrigation input. For each crop, the average total residue load was obtained by multiplying the average yield reported in the scientific literature by the ratio between the amount of crop residues and the yield (see **Annex D**).

The amount of crop residues is higher in spring-summer herbaceous crops where irrigation is provided (e.g., corn), while it is lower in crops of the same season but without water supply (e.g., soybeans, sunflowers). Finally, it appears that the total load of autumn-winter herbaceous crops (e.g., wheat, rice) is higher than that of spring-summer crops without water supply. Therefore, spring-summer crops without irrigation have been assigned a low flammability rating, autumn-winter crops a medium flammability rating, and spring-summer crops with irrigation a high flammability rating (see **Annex D**, "Agriculture burnable statistics").

For each macrotype, the fuel types form an increasing gradient of fuel bed flammability: from low (code = 01) to medium (code = 02) to high (code = 03) for forest and agricultural macrotypes, and from low (code = 01) to high (code = 02) for herbaceous and shrubby macrotypes. Special macrotypes have been assigned a unique type-macrotype correspondence (i.e., only one fuel type for each special macrotype).

In total, there are 51 fuel types, including special types.

Table 4. Total surface fuel load thresholds (Wtot, t ha^{-1}) for assigning the load to each FuelType.

NMacroFuelType	Wtot	Threshold (quantile)
01	4,4	50
02	8,0	50
03	8,8	50
04	7,9	50
05	25,3	50
06	23,8	50
07	6,9	33
07	12,2	66
08	8,1	33
08	13,8	66
09	5,7	33
09	10,6	66
10	8,0	33
10	17,9	66
11	9,1	33
11	19,2	66
12	7,4	33
12	14,2	66
13	9,1	33
13	21,0	66
14	7,3	33
14	14,0	66
15	8,4	33
15	19,2	66
16	32,6	33
16	40,6	66

3.3. National fuel dataset statistics

A total load increasing as a function of the fuel group was observed in fine dead fuels (i.e., with dimensions < 6 mm, i.e., 1 h fuels): the lowest load was found in the Grass fuel group, followed by Shrub, then Broadleaved forest, followed by Conifer forest and, finally, the Special fuel group, which includes loads detected following natural use and disturbances, showing the highest fine fuel load (Figure 3a). A similar trend was observed in larger dead fuels between 6 and 25 mm, i.e., 10 h fuels (Figure 3b), although the Broadleaved Forest and Conifer Forest fuel groups had the same load. The highest total load of the herbaceous layer was observed in the Fuel group Grass (Figure 3c), as well as in the Fuel group Shrubs, which had the highest load of the living shrub layer (Figure 3d).

In **Annex A** "Fuel Type Data Sheets," the data sheet for each fuel type was completed with descriptive statistics of the mean and variability of fuel loads, fuel bed depth, and percentage cover for each component of the surface fuel complex, for each Univocal Code.

Annex E, "Descriptive Statistics," contains a table showing descriptive statistics for each MacroFuelType and Univocal Code. The MacroFuelType with the lowest total surface fuel load is "02. Temperate grassland," with an average of 7.1±2.5 Mg ha-1, while the highest total fuel load was found in MacroFuelType "30. High-load reed bed" (80±20.7 Mg ha-1). Statistical analyses showed that the Univocal Code with the lowest average total load is 0901 (3.7±1.6 Mg ha-1), i.e., thermophilic deciduous forest with medium porosity litter and low flammability (such as English oak and lowland oak-hornbeam forests).

It can be seen that the MacroFuelTypes Grass and Shrubs, distinguished according to the phytoclimatic region to which they belong, generate a fuel load gradient, where the MacroFuelTypes present in the Alpine region represent the lowest total fuel load (herbaceous: 7.8±7.7 Mg ha-1, shrubs: 11.3±5.4 Mg ha-1), while those in the Mediterranean region represent the highest load (herbaceous: 20.3±17.7 Mg ha-1, shrubs: 27.6±10.5 Mg ha-1).
Furthermore, it can be observed that in forest MacroFuelTypes, as the flammability of surface fuel increases, so does the degree of coverage and height of live herbaceous and shrubby undergrowth, while the coverage and depth of dead fuel remain virtually unchanged (Table 5).

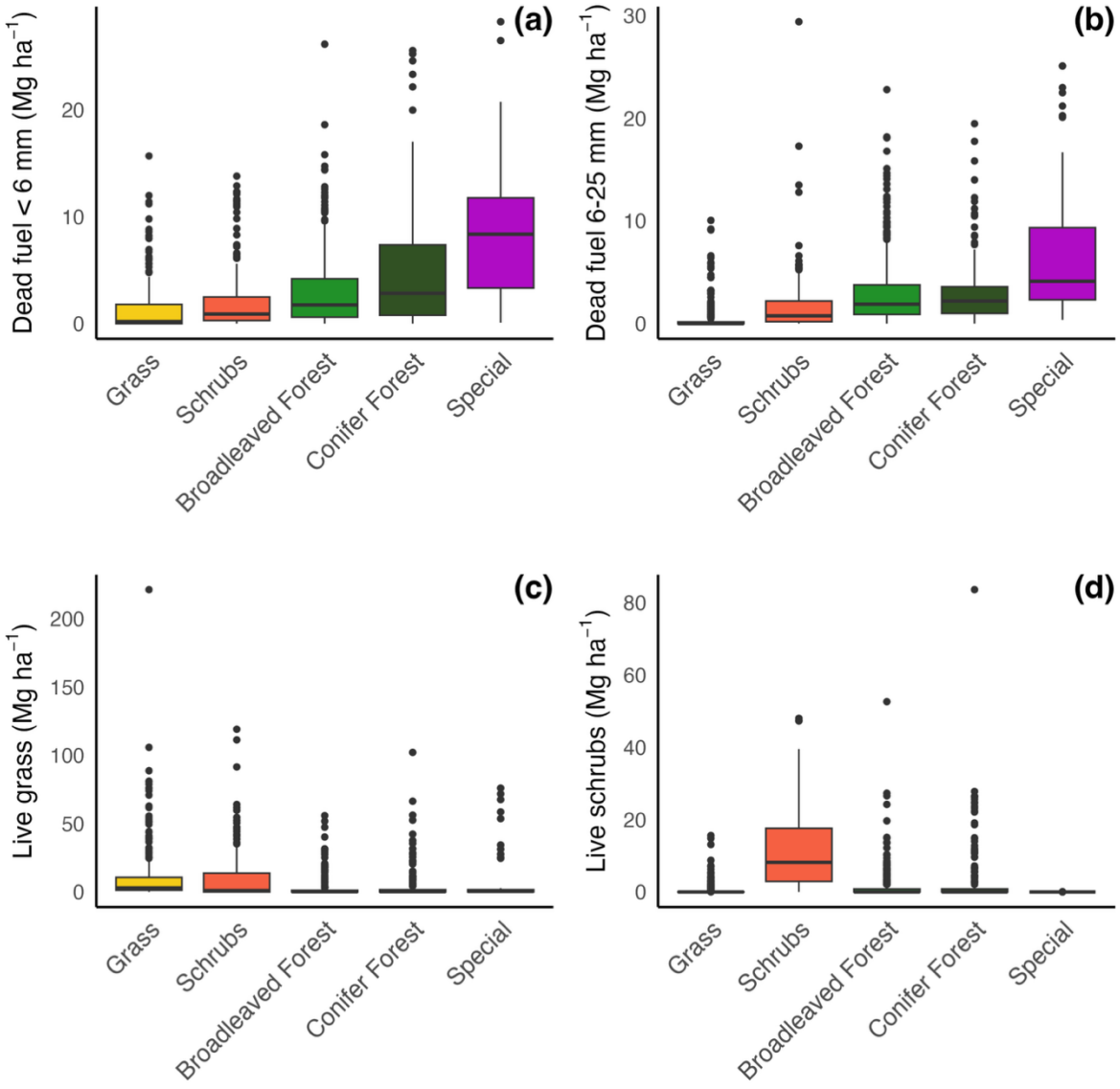

Figure 3. Fuel loads of a) fine dead fuels (diameter <6 mm), b) larger dead fuels (diameter between 6-25 mm), c) live herbaceous layer, and d) live shrub layer divided into different fuel groups.

Table 5. Mean and standard deviation of average percentage coverage (Mean_C) and average depth (mean_D) of dead fuel, including fuel classes 1h and 10h, of the living herbaceous (Gr) and shrub (Sh) layers of forest MacroFuelTypes divided into flammability classes.

Flammability		mean_Cdead	mean_CGr	mean_CSh	mean_Ddead	mean_DGr	mean_DSh
High Flammability (FuelType 03)	Mean	73,40	31,46	21,86	7,12	22,27	77,44
	±SD	26,41	18,57	15,62	5,23	20,74	95,90
Medium Flammability (FuelType 02)	Mean	75,49	27,44	17,09	6,44	16,32	61,79
	±SD	8,44	13,68	14,87	2,02	9,77	64,99
Low Flammability (FuelType 01)	Mean	68,96	29,89	14,50	6,44	21,72	56,31
	±SD	24,22	25,10	15,03	5,00	9,21	69,27

3.4. Comparison with international datasets

To verify the consistency of the load values observed in the new fuel surveys that expanded the national fuel dataset of the publication by Ascoli et al. (2020), a comparison was made between the updated Italian national dataset (excluding the values of the Fuel group Special) and the values of surface fuel complexes similar in terms of vegetation type reported in the Fuel Characteristics Classification System (FCCS, Ottmar et al., 2007) dataset (Figure 4).

The FCCS dataset stores and classifies fuel data in the United States and provides a description of fuel characteristics and properties for six horizontal layers, including: organic matter, litter, woody material, grass, and tree canopy, obtained from literature and field surveys.

Comparing the two datasets separately for the components of organic matter, fine dead fuels (fuels with a diameter < 6 mm) and larger fuels (fuels with a diameter between 6-75 mm), statistical analyses showed that the amounts of organic matter are comparable; However, when looking at the values for fine and larger dead fuel, the Italian dataset has significantly higher values than the FCCS dataset, probably due to the sampling of fuels in areas that are often more natural and characterized by the absence of silvicultural management.

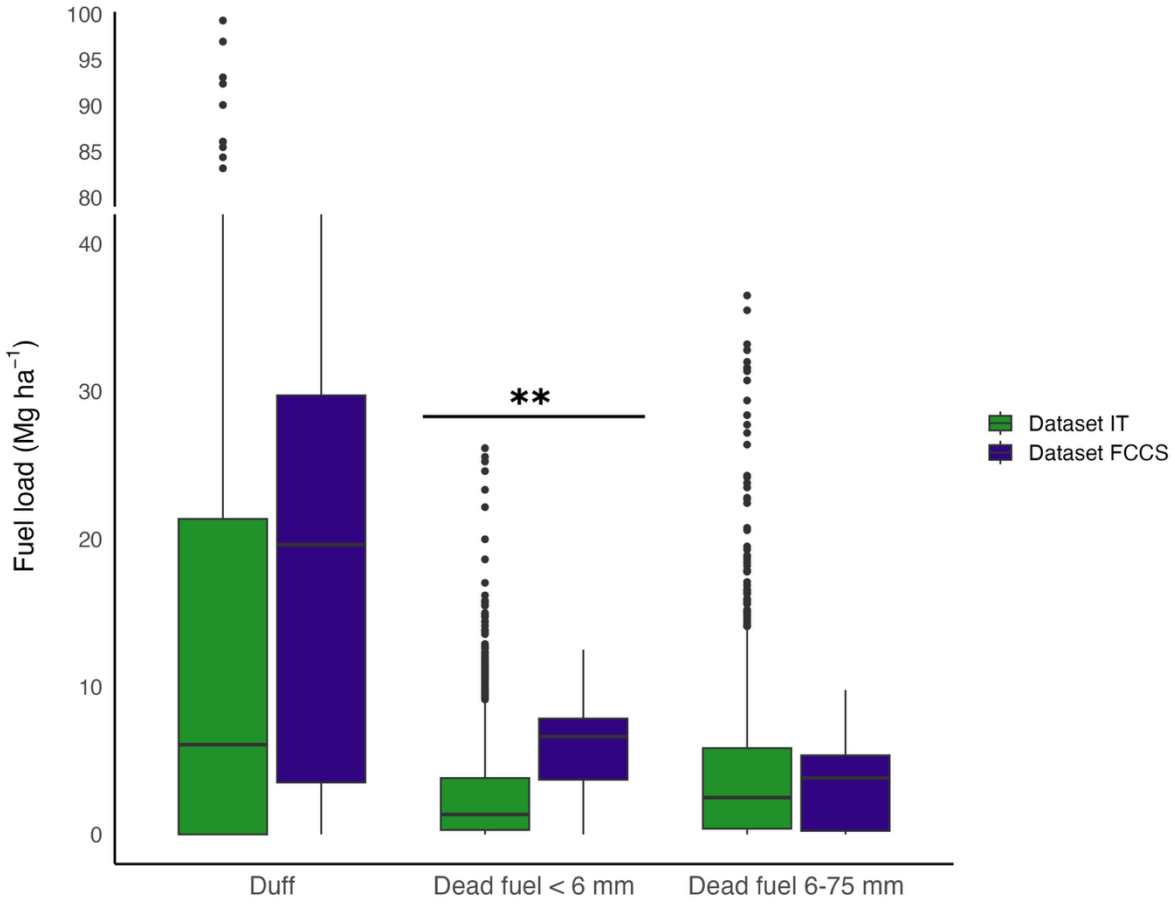

Figure 3. Comparison between the total load of organic matter (duff), fine dead fuels (fuels with a diameter < 6 mm) and larger dead fuels (fuels with a diameter between 6-75 mm) within the Italian fuel dataset (in green) and the American fuel dataset (FCCS, in blue). The asterisks indicate significance based on a t-test statistical analysis (* for $p<0.05$, ** for $p<0.01$, *** for $p<0.001$).

3.5. Multivariate relationships within the Italian national dataset

A redundancy analysis (RDA) was performed to verify the relationships between loads, coverages, and depths of different fuel types and classes and topographic factors.

The response variables used are: i) W1h: fine dead fuel with a diameter < 6 mm; ii) W10h: fine dead fuel with a diameter of 6-25 mm; iii) W100h: dead fuel with a diameter of 25-75 mm; iv) WGr: grass and live herbaceous fuel; v) WShTot: live shrub fuel; vi) Wtot: total fuel load, excluding organic matter load; vii) Ddead: depth of dead fuel; viii) DGr: depth of the herbaceous layer; ix) DSh: depth of shrub layer; x) Cdead: dead fuel cover; xi) CGr: herb layer cover; xii) CSh: shrub layer cover.

The following were used as predictors for RDA: i) CanCov: canopy cover; ii) Elev: altitude; iii) Slope: slope; iv) Southness: -cos [aspect].

The model was chosen through model preselection based on adjusted R^2, using the "ordiR2step" function of the "vegan" package for R (R Core Team 2019). The final model was checked for collinearity, ensuring that the variance inflation factors (VIF) for each predictor were <10. The significance of the model, predictors, and RDA axes was verified using an ANOVA-type permutation test with 999 iterations ($\alpha = 0.05$), and only the fourth RDA axis was found to be insignificant. The final model has an adjusted R2 of 0.13. The first four RDA axes are not very significant and explain 10%, 2%, 2%, and 0% of the model variance, respectively.

Axis 1 is strongly correlated with canopy cover, while axis 2 is explained by the combination of slope, elevation, and southern exposure predictors (Figure 5). Looking at dead fuel loads, the load of fuel class 10h responded to increases in slope and southern exposure, while the loads of classes 1h and 100h are positively correlated with elevation. The shrub load increased with decreasing altitude and canopy cover, while the live herbaceous layer load was negatively correlated with slope. Overall, the total fuel load increased with decreasing slope and southern exposure. It can be seen that the depth of the dead fuel layer and its percentage cover increased with increasing canopy cover. As with shrubs, the coverage of the herbaceous layer is negatively correlated with slope, canopy cover, and altitude, while its depth increases with southern exposure (Figure 5).

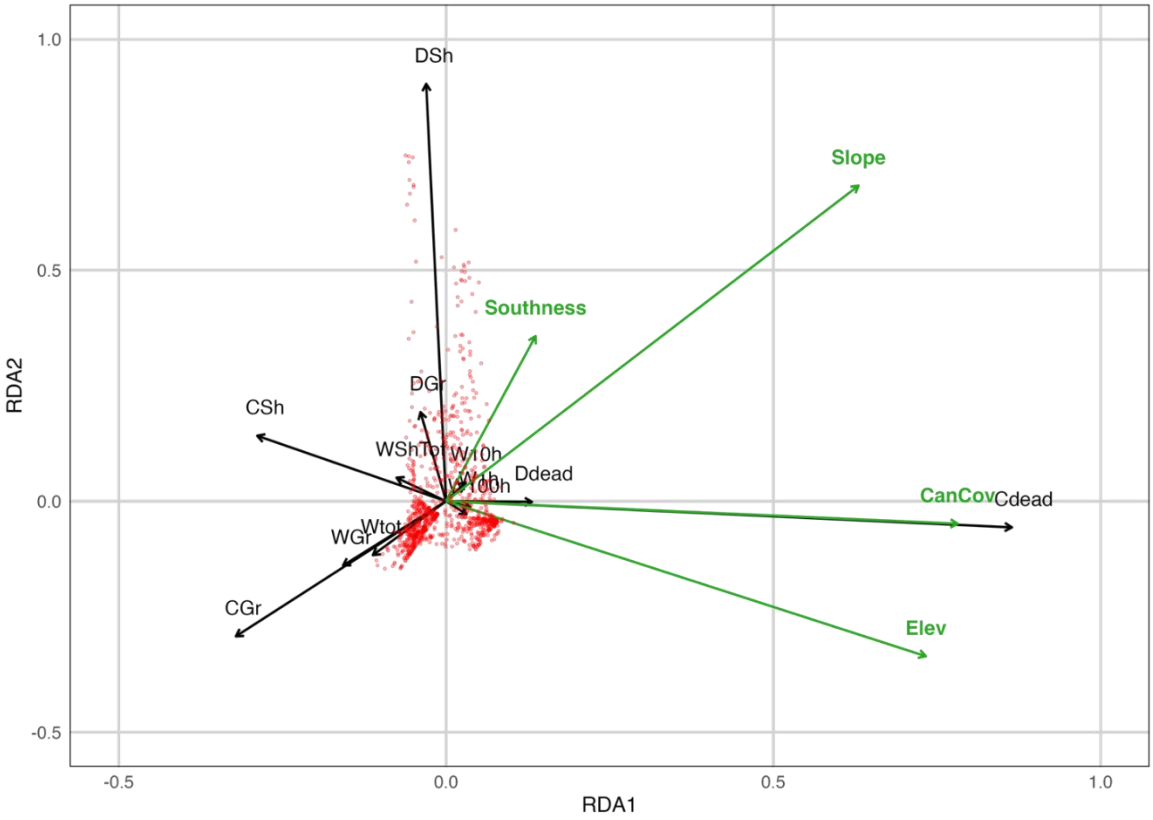

Figure 5. Biplot relationships between fuel load and site predictors. Red dots: individual sites; black arrow: response variables (W1h: fine dead fuel with diameter < 6 mm; W10h: fine dead fuel with diameter 6-25 mm; W100h: dead fuel with diameter 25-75 mm; WGr: grass and live herbaceous fuel < 6 mm in size; WShTot: live shrub fuel; Ddead: depth of dead fuel; DGr: depth of herbaceous layer; DSh: depth of shrub layer; Cdead: dead fuel cover; CGr: grass layer cover; CSh: shrub layer cover); green arrows: predictors (CanCov: canopy cover; Elev: altitude; Slope: slope: Southness: -cos[aspect]). Predictors were scaled to improve graphical representation.

4. Conclusions

This deliverable establishes the national reference framework for fuel description within the FIREBOX project by combining a harmonised fuel type classification with an expanded and standardised national fuel dataset. The classification provides a coherent system to describe Italian surface fuels across very different ecological contexts, from alpine and temperate environments to Mediterranean and agricultural systems, and organises them into three hierarchical levels: Fuel group, MacroFuelType, and FuelType. In total, the framework identifies 23 MacroFuelTypes and 51 FuelTypes, each associated with a Univocal Code to ensure consistency between classification, database attribution, and future mapping applications.

The updated national fuel database substantially improves the empirical basis available for fuel characterisation in Italy. By integrating the dataset published by Ascoli et al. (2020) with 759 new surveys collected within FIREBOX, the national database reaches 1342 surveys and increases both the geographic coverage and the representativeness of fuel conditions across vegetation types. The harmonisation of variables, the attribution of all surveys to the new classification, and the production of descriptive statistics for each fuel class make the dataset directly usable for comparative analyses and operational applications.

A further strength of D1.1 is that it creates a direct bridge between typological description and applied wildfire analysis. The classification and the associated quantitative fuel information provide the conceptual and empirical basis for the Fuel Type Map and the Fuel Model Map developed in the following deliverables of WP1, ensuring methodological continuity across the project. In this sense, D1.1 is not only a descriptive product, but a foundational step for national-scale wildfire hazard assessment, fire behaviour modelling, and planning-oriented applications.

Overall, the deliverable provides a transparent, reproducible, and updateable framework that can support future refinements as new fuel surveys become available and offers a robust basis for wildfire risk management and fuel-related decision support in Italy.

5. References

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Annexes

Annex A – Fuel Type Data Sheets

Annex B – National Fuel Database

Annex C – Surface fuel sampling protocol

Annex D – Fuel load of the Fuel group Agriculture Burnable

Annex E – Descriptive statistics of national fuel database