Fuel models for the main Portuguese vegetation types

The definition of the main structural fuel model groups is based on the ***identification of the strata most responsible for the spreading of a flame front***. Table 1 shows the structural combinations of litter and vegetation, cover and height that lead to the various fuel models: litter, mixed litter+vegetation, and vegetation, under tree cover, and shrubland or grassland, in the absence of tree cover.

Table 1 – Classification matrix for fuel model groups based structure and relative importance of litter and vegetation. C = cover, h = height. D – discontinuous fuel, F – litter (*folhada*) group; M – mixed group; V – Vegetation group.

Litter	**Vegetation: understory, shrubland, or pasture**			
	C < 1/3	1/3 < C < 2/3	C > 2/3, h < 1 m	C > 2/3, h > 1 m
C < 3/4	D	D	V	V
C > ¾, h < 2 cm	F	M	M	V
C > ¾, h > 2 cm	F	M	M	M

Fuel classification and fuel models

Quantitative parameters for the Portuguese fuel models.

	Depth (m)	Dead fuel loading ($t.ha^{-1}$)			Live fuel loading ($t.ha^{-1}$)		SVR (σ, m^{-1})			HC ($kJ.kg^{-1}$)	M_{ext} (%)
Model		1 hr	10 hr	100 hr	live shrubs	live herbaceous	1 hr	live herbaceous	live shrubs		
F-RAC	0.05	3.75	2	1	1.18	0	6500	-	4500	20500	28
F-FOL	0.15	2.67	1.27	0.69	1.16	0	4500	-	5000	20500	25
F-PIN	0.1	6.5	1.5	0	0	0	5500	-	-	20500	45
F-EUC	0.32	4.63	2.96	1.27	1.12	0	4200	-	5000	21000	26
M-CAD	0.63	4.54	1.87	0.61	9.08	0	6000	-	5000	20000	30
M-ESC	0.5	5.65	1.5	0.48	7.89	0	5000	-	5500	20500	25
M-PIN	0.5	7.21	3	0	6.89	0	5500	-	6000	21000	40
M-EUC	0.64	8.37	3.81	0	4.51	0	4700	-	5000	21000	32
M-EUCd	0.4	1.37	2.89	1.59	1.84	0	4500	-	5000	21000	26
M-H	0.1	2.71	1	0	0.1	0.66	5500	8000	4500	20500	30
M-F	0.3	4.5	1.5	0.5	0.48	2.35	6000	8000	4500	19500	35
V-MAb	0.5	6	0.5	0	7.5	0	4500	-	4500	21000	35
V-MAa	1.05	9.5	2.5	0	14.5	0	3500	-	4000	21000	35
V-MMb	0.9	4	0.5	0	7	0	3000	-	3000	20500	20
V-MMa	1.7	6	4	0	13	0	2500	-	3000	20500	25
V-MH	0.55	1	1	0	5.5	1.5	4500	8500	4000	19500	25
V-Hb	0.35	0.3	0	0	0	1.2	6000	6000	-	19000	24
V-Ha	0.6	0.65	0.15	0	0.4	2.35	4000	5500	4000	19000	24

characterization

inventorying

SVR: surface-to-volume ratio; HC: heat content; M_{ext}: moisture of extinction.

Paper P. Fern.

Pinus nigra
S. Padrela (V.P. Aguiar)

Pinus sylvestris
S. Alvão (V. Real)

Pseudotsuga menziiesii
S. Marão (V. Real)

F-RAC

(Folhada – resinosas de agulha curta)

Densely packed **litter of short needle conifers**: *Pseudotsuga*, *Cedrus*, *Cupressus*, *Chamaecyparis*, *Pinus sylvestris*, *P. nigra* stands. Mature stands of *Acacia dealbata*.

Fine fuel loading 4 – 6 t/ha.

Betula alba
S. Alvão (V. Real)

Quercus suber
Murça

Quercus rubra
S. Padrela (V.P. Aguiar)

F-FOL

(Folhada – folhosas)

Densely packed litter of evergreen and deciduous hardwoods: Oak (*Quercus*), chestnut (*Castanea*), beech (*Fagus*), and birch (*Betula*) stands. Dense stands of cork oak (*Q. suber*), holm oak (*Q. rotundifolia*), strawberry tree (*Arbutus unedo*), and acacia (except *A. dealbata*).

Fine fuel loading 2 – 5 t/ha.

Eucalyptus globulus
Amarante

F-EUC

(Folhada – eucaliptos)

Eucalypt (E. globulus) leaf litter

Fine fuel loading 4 – 6 t/ha.

Pinus pinea
Alcácer do Sal

Pinus pinaster
Murça

F-PIN

(Folhada – pinheiros)

Needle litter of pine stands with **intermediate length to long needles**: Maritime pine (*P. pinaster*), umbrela pine (*P. pinea*), Aleppo pine (*P. halepensis*), and Monterey pine (*P. radiata*).

Fine fuel loading 4 – 7 t/ha.

Quercus pyrenaica / Castanea sativa
S. Marão (V. Real)

Quercus robur / Castanea sativa
S. Açor (Arganil)

Quercus faginea
S. Sicó (Ansião)

M-CAD

(Folhada de folhosas caducifólias, com mato)

Deciduous hardwood litter with shrub understory containing abundant live fuels: Stands of oak (*Quercus*), chestnut (*Castanea*), birch (*Betula*) and beech (*Fagus*).

Fine fuel loading 8 – 17 t/ha.

Quercus suber
Murça

Quercus suber
Mirandela

Quercus rotundifolia
Portalegre

M-ESC

(Folhada de folhosas esclerófitas, com mato)

Sclerophyll hardwood litter, with shrub understory: Cork oak (*Q. suber*) and holm oak (*Q. rotundifolia*) stands.

Fine fuel loading 7 – 17 t/ha.

Pinus pinaster, Sines

P. pinaster, Ponte de Lima

Pinus pinaster, Nisa

Pinus pinaster, Mira

M-PIN

(Folhada de pinheiro de agulha média a longa, com mato).

Pine litter, average to long needles and shrub understory: stands of *P. pinaster* (maritime pine), *P. pinea* (umbrella pine), *P. halepensis* (Aleppo pine), *P. radiata* (Monterey pine).

Fine fuel loading: 8–18 (t/ha)

Eucalyptus globulus
Azambuja

Eucalyptus globulus
Vila de Rei

M-EUC

(Folhada de eucalipto, com mato)

Eucalypt litter with shrub understory. *E. globulus.*

Fine fuel loading: 9–18 (t/ha)

Eucalyptus globulus
Sever do Vouga

Eucalyptus globulus
Celorico de Basto

M-EUCd

(Folhada descontínua de eucalipto, com ou sem mato)

Eucalypt patchy litter, with or w/out shrub understory along plantation rows: young or recently *E. globulus.*

Fine fuel loading: 1–4 (t/ha)

Betula alba, Sta. Marta Penaguião

Eucalyptus globulus, V. Velha Rodão

Pinus pinea, Alcácer do Sal

M–H

(Folhada com erva, qualquer espécie arbórea)

Litter, with grass understory: forest stands, regardless of species.

Fine fuel loading: 2–5 (t/ha)

Quercus pyrenaica, Vila Real

Pinus pinaster, Vila Real

Eucalyptus globulus, Celorico de Basto

M–F

(Folhada com fetos, qualquer espécie arbórea)

Litter, with bracken fern understory: forest stands, regardless of tree species.

Fine fuel loading: 6–9 (t/ha)

Erica spp. / Pterospartium, Amarante

Erica spp. / Pterospartium, V. Real

Erica australis / Pterospartium
Vila Real

V-MAb
(Mato baixo)

Low shrubs (<1 m) with abundant dead and/or fine fuel. Heath (*Erica*), gorse (*Ulex*), prickly broom (*Chamaespartium tridentatum*), and juniper (*Juniperus*) shrublands. Also as forest understory in open or young stands, regardless of tree species.

Fine fuel loading: 7–14 (t/ha)

Ulex europaeus, Ilha da Madeira

Erica scoparia, Mafra

Ulex europaeus / P. pinaster
V. Real

V-MAa

(Mato alto)

Tall shrubs (>1 m) with abundant dead and/or fine fuel. Heath, gorse, prickly broom, and other old broom shrublands.
Also as forest understory in open or young stands, regardless of tree species. Dense natural maritime pine regeneration.

Fine fuel loading: 12–27 (t/ha)

Cytisus, Manteigas

Quercus coccifera, Porto de Mós

Cistus salvifolius, Almodovar

V-MMb

(Mato baixo, pouca biomassa morta)

Low shrubs (<1 m), with little dead fuel and/or relatively thick foliage.
Genista, Cytisus, rock rose, kermes oak, wild olive, strawberry tree, lentisk, and other mediterranean species shrublands. Blackberry thickets. Also as forest understory in open or young stands, regardless of tree species.

Fine fuel loading: 4–8 (t/ha).

Pistacia/Olea/Q. coccifera/Genista/Cistus/Lavandula, Silves

Cytisus multiflorus /Lavandula, Celorico da Beira

Q. rotundifolia/Arbutus unedo/ Er. scoparia/ Cistus/Lavandula, Fátima

Cistus ladanifer, Mirandela

V-MMa

(Mato alto, pouca biomassa morta)

Tall shrubs (>1 m), with little dead fuel and/or relatively thick foliage.
Genista, Cytisus, rock rose, kermes oak, wild olive, strawberry tree, lentisk, and other mediterranean species shrublands. Blackberry thickets. Also as forest understory in open or young stands, regardless of tree species.

Fine fuel loading: 10–19 (t/ha)

Quercus coccifera, Porto de Mós

Pterospartium, Mesão Frio

Pterospartium / Halimium / Erica
Castro Daire

V-MH

(Mato baixo e verde, com erva)

Short(<1 m), green, often patchy shrubs, with grasses.
Young shrublands, up to three years since the last fire.

Fine fuel loading: 1–5 (t/ha).

P. pinea / P. pinaster, Condeixa---a---Nova

V-Hb

(Erva baixa)

Short grass (<0,5 m).
Meadows, pastures, recent fallow lands, cereal stubble, evergreen oak woodlands.

Fine fuel loading: 1–1.5 (t/ha).

Quercus pyrenaica, Marvão.

V-Ha

(Erva alta)

Tall grass (> 0,5 m).
Meadows, pastures, recent fallow, cereal fields, reed, evergreen oak wodlands.

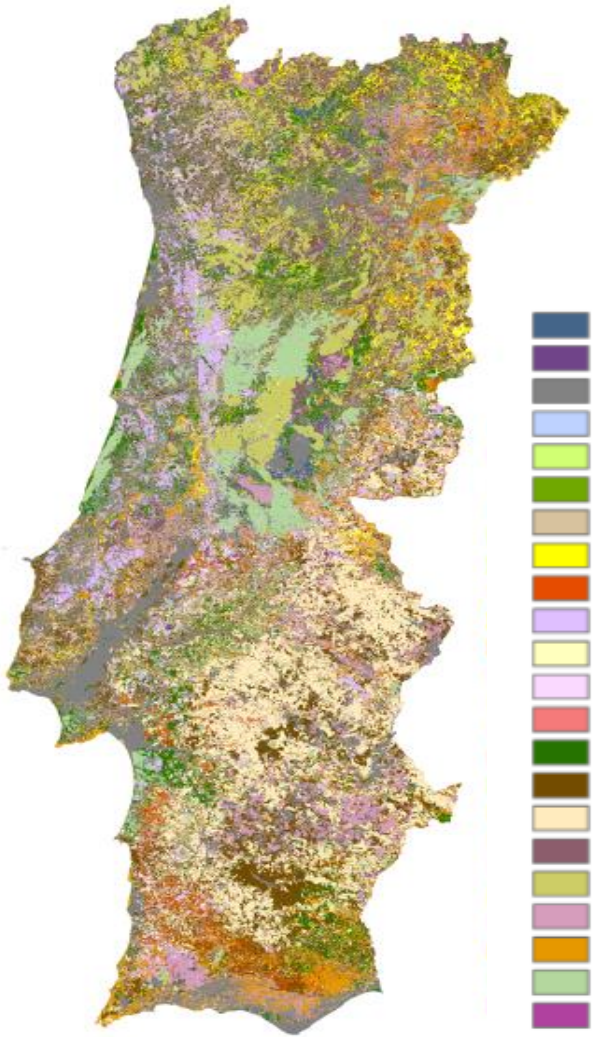
Fine fuel loading: 2–4 (t/ha).

Fuel classification and fuel models

Fuel model distribution (%) by forest type in Portugal (NFI4, 2005-06)
Dominant fuel models in each forest type in **bold**.

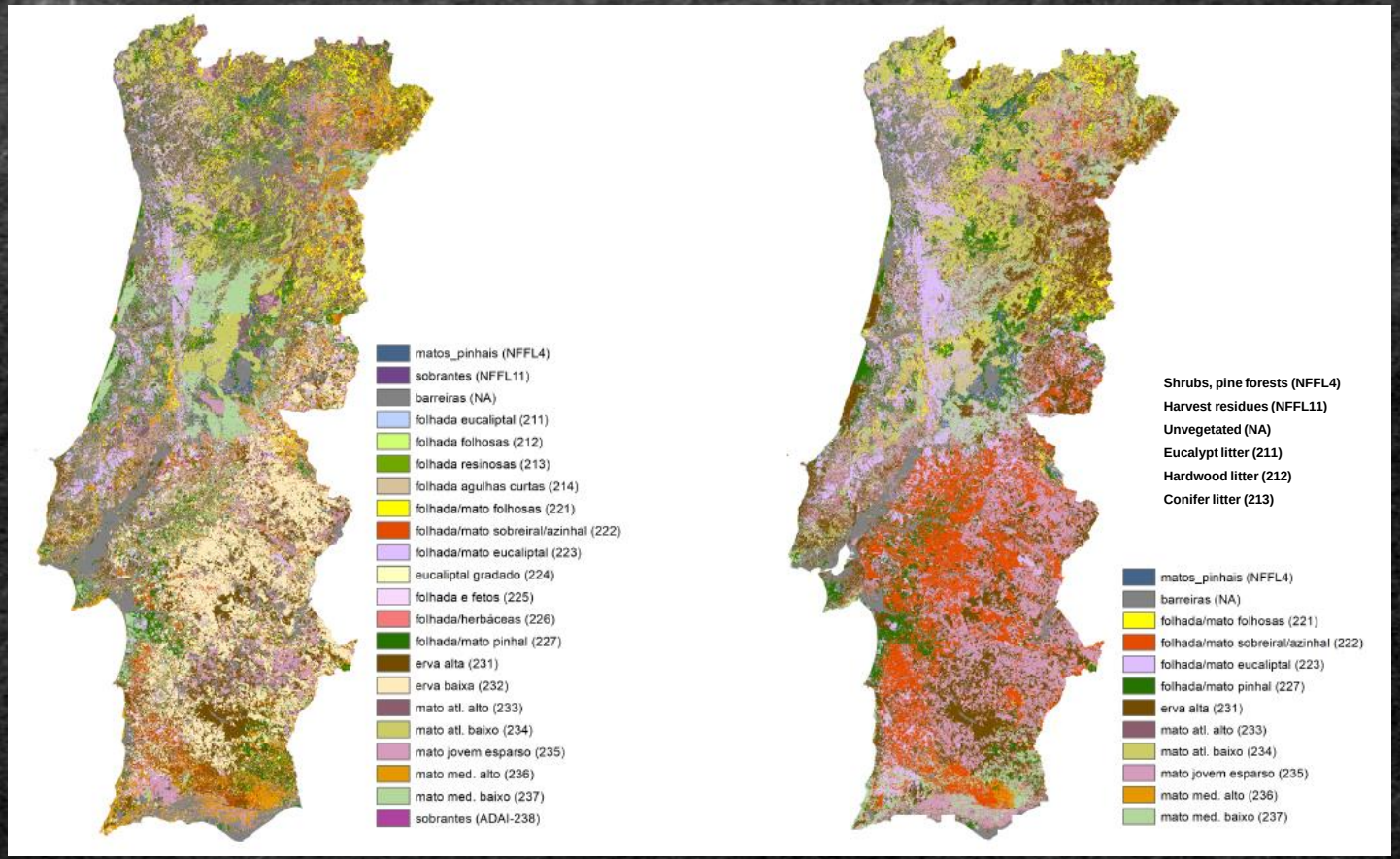
Model	Holm oak	Other oak	Eucalypt	Other hardwood	Other softwood	Maritime pine	Umbrella pine	Cork oak
F-RAC	0	0	0	0	**17.9**	0	0	0
F-FOL	1.2	**10.4**	0	8.3	0	0	0	7.6
F-PIN	0	0	0	0	3.6	**14**	9.5	0
F-EUC	0	0	6	1.9	0	0	0	0
M-CAD	0	31.1	0	**13.9**	0	0	0	0
M-ESC	2	0	0	0	0	0	0	9
M-PIN	0	0	0	0	7.1	**41**	**11.9**	0
M-EUC	0	0	**22.9**	**14.8**	0	0	0	0
M-EUCd	0	0	**36.5**	0	0	0	0	0
M-H	0.7	1.4	0.9	0.9	0	0.6	2.4	1.4
M-F	0.2	0.9	0.7	2.8	3.6	1.5	0	0.2
V-MAb	0.2	0.5	2.6	2.8	3.6	4.1	9.5	9.4
V-MAa	0	0	3	0.9	3.6	2.7	2.4	2
V-MMb	**40.4**	**18.4**	9.4	**22.2**	**28.6**	**14.6**	**26.2**	**38.3**
V-MMa	**28.7**	**33.5**	**17.3**	25	**32.1**	**19.8**	**31**	**20.6**
V-Hb	**18.6**	3.3	0.3	5.6	0	0.9	4.8	9
V-Ha	8.1	0.5	0.4	0.9	0	0.8	2.4	2.6

Fuel model map for Portugal (2018)



- Pine forest shrubs (NFFL4)
- Forest harvest residues (NFFL11)
- Unvegetated (NA)
- Eucalypt litter (211)
- Hardwood litter (212)
- Long needle conifer litter (213)
- Short needle conifer litter (214)
- Hardwood litter/shrubs (221)
- Evergreen oak litter/shrubs (222)
- Eucalypt litter/shrubs (223)
- Harrowed eucalypt stands (224)
- Litter/bracken fern (225)
- Litter/grasses (226)
- Pine litter/shrubs (227)
- Tall grass (231)
- Short grass (232)
- Tall atlantic shrubs (233)
- Short atlantic shrubs (222)
- Sparse young shrubs (235)
- Tall mediterranean shrubs (236)
- Short mediterranean shrubs (236)
- Harvest residues (ADAI238)

Fuel model maps for Portugal



Fire, decomposition and leaf traits

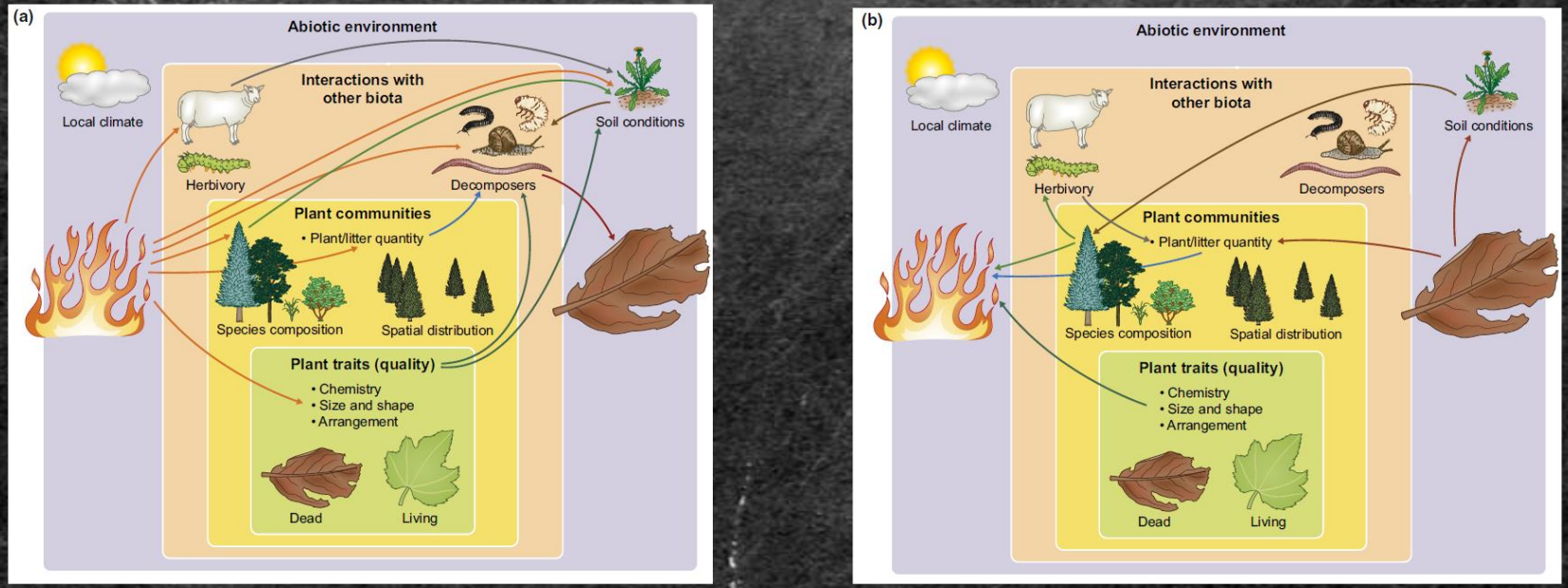


Fig. 1 Fire–decomposition feedbacks with a central role for plant traits of different species, adding concentric shells of real-world complexity through community-level interactions and other biotic and abiotic drivers. For clarity the two directions of these feedbacks are separated here: **(a) fire effects on decomposition** and **(b) decomposition effects on fire**. The **core** represents the **role of plant traits**; the **shell** around it represents **ecosystem-level factors** such as **community composition** and **species (litter) interactions**, and **amount and spatial configuration of vegetation and litter** (fuel). The next shell adds **other biotic interactions** while the outer shell represents the **(local to global) abiotic drivers** that may affect processes and connections within the inner shells.

Cornelissen, J. H., et al., (2017). Are litter decomposition and fire linked through plant species traits?. *New Phytologist*, *216*(3), 653-669.