Composition, configuration and vertical structure of Portuguese forests: implications in wildfire probability

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Abstract: Portugal with its Mediterranean climate has frequently wildfires during summertime. The knowledge of the composition and the configuration of patches that constitute the forest matrix (Godinho-Ferreira *et al*., *in press*) is important to understand the processes occurring in it, including forest wildfire probability. Forests vertical structure depicted from the third revision of the Portuguese National Forest Inventory (NFI) show different layers composed by different kinds of species occupying different percentage of cover, identifying 10 main forest types and 22 structural types (Godinho-Ferreira *et al*., 2005). A first analysis of NFI sampling plots burned between 1999 and 2005 indicates that large and very large patches of maritime pine and eucalyptus forests have the highest rates of burning areas. This presentation is part of a first and coarse approach aiming to develop more accurate methodologies within the project "PHOENIX – Forest conversion in burned areas" (POCI/AGR/58896/2004), particularly "Task 1 – What forest types are less likely to burn?".

Keywords: Forest types, forest vertical structure, forest patch configuration, wildfire probability

1. Introduction

Wildfire is characteristic of Mediterranean ecosystems and alters their structure and resource availability (Lindenmayer, D. *et al*, 2002). Natural disturbance regimes and their interactions with climate and terrain determine the size, shape, location and types of patches that provide heterogeneity in forests. Therefore wildfires can cause forest habitat loss and fragmentation of the landscape (Agee, 1999) reducing both biodiversity and quality of ecosystems (Puumalainen, 2001) shaping forests composition and structure at the tree, stand, landscape and ecosystem level (Williams *et al*, 1999). Effects of wildfire are heterogeneous depending on fire regime and landscape structure (Turner & Dale, 1990; Forman, 1997; Farina, 1998), consequently different combinations of fire regime and forest structure will cause different patterns of fire occurrence, and the configuration of burned forest patches can provide useful information on the different use of the available forest types (Moreira, F. *et al*, 2001). In fact, after the large wildfires occurred in 2003, 2004 and 2005 the Portuguese forest was severely damaged and it was necessary to assess what forest types were more affected. Moreover, in many cases forest fires promote soil hydrophobicity inducing erosion and soil loss in the following rain season (MacDonald, L.H. *et al*, 2004;Terry, J.P., 1994; Shakesby, R.A. *et al*, 1994).

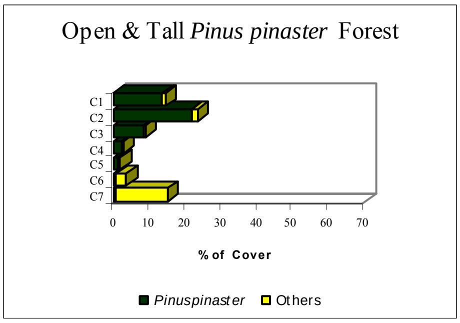
Once the data collected in the 1998 National Forest Inventory (NFI) (DGF, 2001) assembled parameters allowing the evaluation of composition, vertical structure and configuration of forest patches, it is possible to assess what kind of forest burned. Composition and vertical structure together were described by the percentage cover of forest species, or groups of species, easily identifiable on the ground, according to seven height classes which were defined from ground level to 0,5 m, from 0,5 m to 1,0 m, from 1,0 m to 2,0 m, from 2,0 m to 4,0 m, from 4,0 m to 8,0 m, from 8,0 m to 16,0 m, and over 16,0 metres (DGF, 1999). Forest types were then defined applying a *K-means* analysis to the data collected from 2258 sample plots randomly distributed through the forest area and identified by their geographical coordinates (DGF, 2001; Rego *et al.*, 2004). In a first approach there were identified ten major forest types: *Pinus pinaster* forest (PPF), *Eucalyptus* forest (ECF), *Quercus suber* forest (QSF), Diverse Other forest (OTF), *Quercus pyrenaica* forest (QPF), Other Deciduous Oaks forest (DOF), *Arbutus unedo* forest (AUF), *Cistus* shrubs (CIF), *Cytisus* shrubs (CYF), *Acacia* forest (ACF). Through further stratification twenty two forest types were obtained and classified as open and tall, open and low, close and tall or close and low, and mapped in the *Carta da Tipologia Florestal de Portugal Continental* (Godinho-Ferreira *et al*, 2005) by the Thiessen polygons method (Soares, 2000) using the ARCVIEW 3.2 (ESRI, 1999).

2. Vertical structure of the main Portuguese forest types

Among the ten major forest types, *Pinus pinaster* forest, *Eucalyptus* forest, *Quercus suber* forest and the Diverse Other forests are the most representative in Portugal mainland (Godinho-Ferreira *et al*, 2005) and show a more diverse vertical structure, as published in Rego (2004).

Pinus pinaster forest

Open and tall formations occupy 10% of the *Pinus pinaster* forest type and they are distributed in large patches mainly in the centre of Portugal from the coast to the interior. A significant large patch can be observed south of Lisboa at the Península de Setúbal. Some of these formations are mixed stands of maritime pine and eucalyptus. The understorey is mainly composed of *Erica* spp and *Ulex* spp. Open and low formations represent only 4% of this forest type. They are distributed in the interior north and centre of the country. The maritime pine overstorey sometimes contains eucalyptus and the understorey is composed mainly of *Erica* spp, *Ulex* spp, *Pterospartum tridentatum* and other plants (Figure 1).



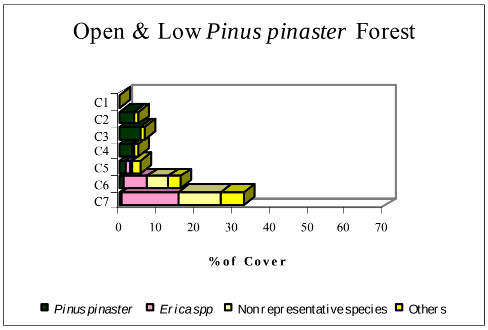


Figure 1. Vertical structure of open formations of *Pinus pinaster* forest.

Close and tall formations of *Pinus pinaster* represent 32% of this forest type, distributed mainly in north and centre, from the coast to the interior, and on the southwest coast of the country. Stands show a dense overstorey of maritime pine, sometimes mixed with eucalyptus and other oaks. *Ulex* spp, *Erica* spp, *Cytisus* spp, *Pterospartum tridentatum* and other plants compose the understorey. Close and low formations characterise 54% of this forest type, mainly distributed in the north and centre, from the coast to the interior, spreading to southern Portugal. The overstorey of these stands is composed of maritime pine sometimes mixed with eucalyptus and cork oak. The close understorey is composed of *Erica* spp, *Ulex* spp, *Pterospartum tridentatum* and other plants (Figure 2).

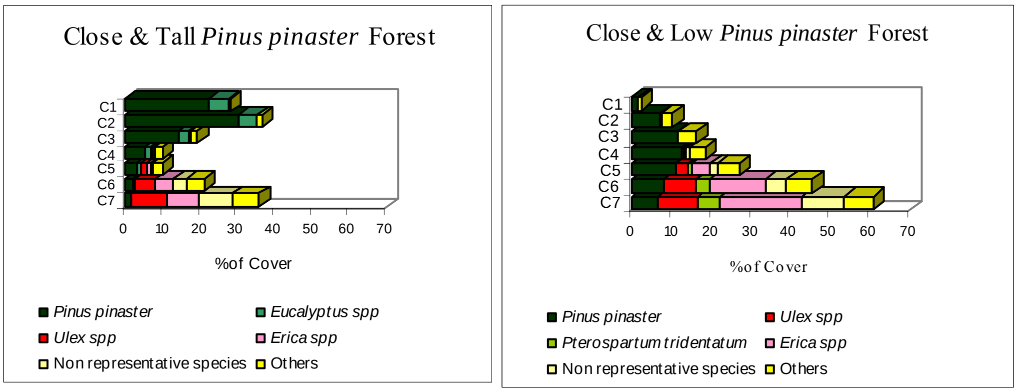


Figure 2. Vertical structure of close formations of *Pinus pinaster* forest.

Eucalyptus forest

All the *Eucalyptus* forest formations follow the same geographical distribution pattern: from north to south generally near the coast, spreading to the interior in the centre of the country. Open formations, representing 22% of this forest type, show an overstorey mainly composed of *Eucalyptus* spp and an understorey of *Erica* spp and *Ulex* spp (Figure 3).

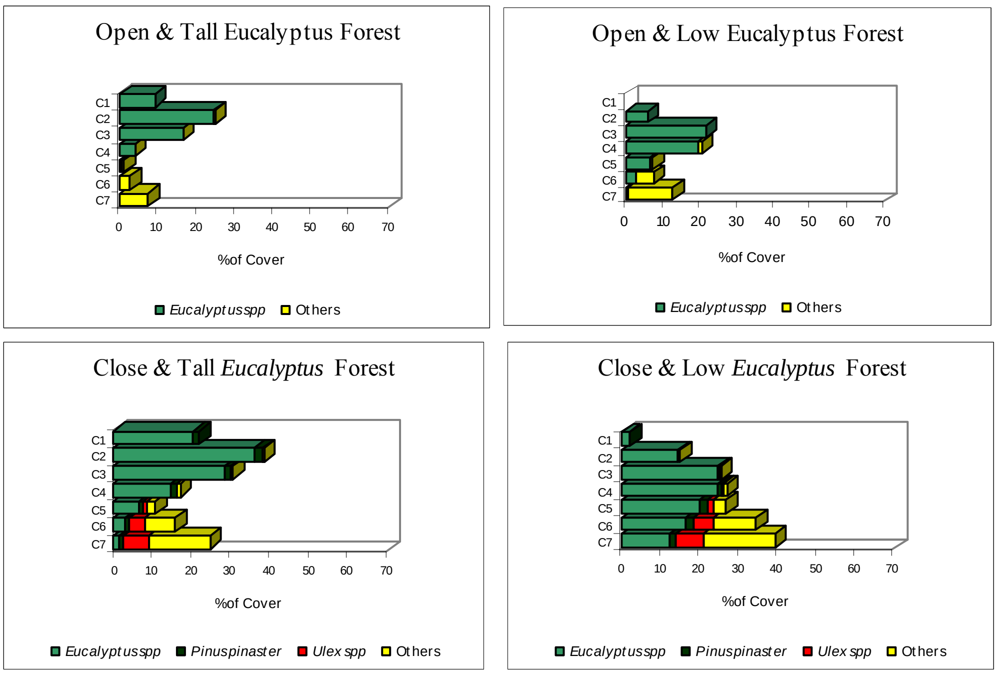


Figure 3. Vertical structure of *Eucalyptus* forest.

Close formations represent 76% of *Eucalyptus* forest. Both tall and low formations show an overstorey mainly composed of *Eucalyptus* spp, sometimes mixed with maritime pine. Tall formations understorey is composed of *Ulex* spp, *Erica* spp, *Pterospartum tridentatum* and other plants. The low formation understorey is denser and composed of *Ulex* spp, *Erica* spp, *Pterospartum tridentatum*, *Cistus ladanifer*, *Cistus salvifolius* and other plants (Figure 3).

Quercus suber forest

The *Quercus suber* forests are distributed mainly in the south of Portugal and they represent 8,5 % of the forest area. The open formations of *Quercus suber*, representing 20% of this major forest type, are "montados" where cork oaks never reach 16 metres and the sparse understorey is never higher than 1 metre, and composed of *Cistus salvifolius* and *Ulex* spp (Figure 4).

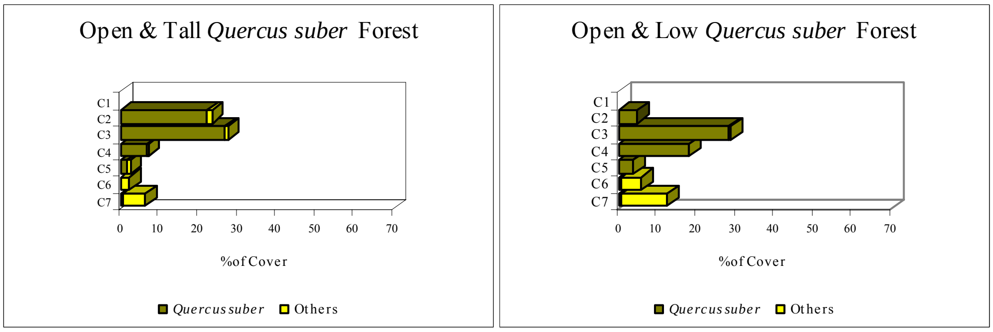


Figure 4. Vertical structure of open formations of *Quercus suber* forest.

Close formations reveal an overstorey composed of cork oak sometimes mixed with *Quercus rotundifolia* and *Pinus pinea*. Close and tall formations comprise 28% of this forest type and show an understorey composed mainly of *Cistus salvifolius*, *Ulex* spp and *Erica* spp. Close and low formations are more abundant, corresponding to 52% of the *Quercus suber* forest area; they have a denser understorey composed of *Cistus salvifolius* and *Ulex* spp *Cistus ladanifer* and *Lavandula* spp are also significant (Figure 5).

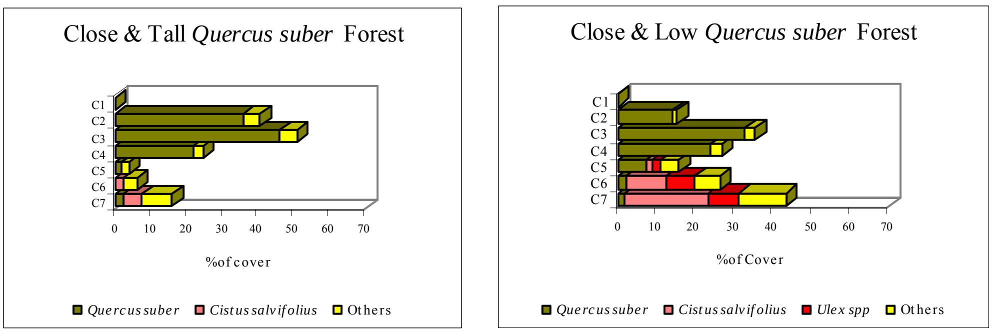


Figure 5. Vertical structure of close formations of *Quercus suber* forest.

Diverse Other forest

This main forest type covers a variety of situations representing a total of 30,7% of the Portuguese forest. Open and tall formations, representing 25% of this forest type, are open stands of *Quercus suber* and *Quercus rotundifolia*, called “montados de sobro e azinho”, sometimes mixed with eucalyptus and maritime pine, with an understorey mainly composed of *Ulex* spp. Open and low formations represent 50% of the Diverse Other forest. They are stands of *Quercus rotundifolia*, called “montados de azinho”, sometimes mixed with eucalyptus and maritime pine. The understorey is mainly composed of *Ulex* spp, *Cytisus* spp and *Cistus* spp (Figure 6). Open formations are distributed in the south of Portugal.

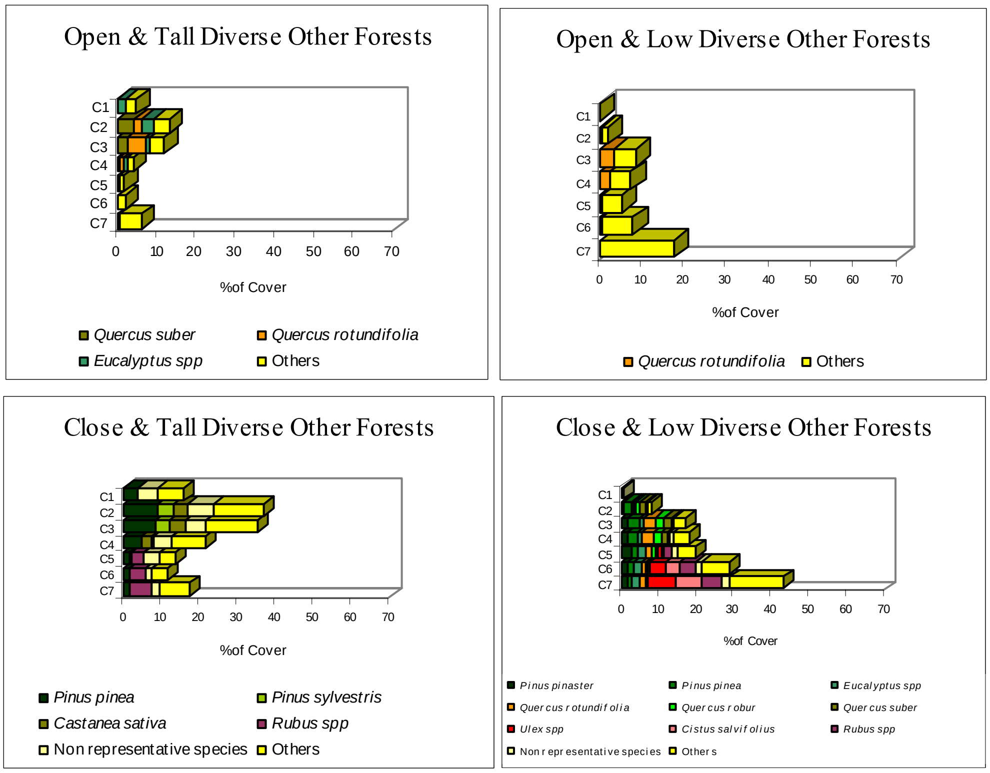


Figure 6. Vertical structure of Diverse Other forest.

Close and tall formations correspond to 4% of this forest type. They are stands of *Pinus pinea*, *Castanea sativa* and *Pinus sylvestris*, showing high diversity when mixed with maritime pine, eucalyptus and oaks. Their understorey is composed mainly of *Rubus* spp, *Ulex* spp and other plants. Close and low formations represent 21% of this forest type. They are very diverse stands with an overstorey mainly composed of maritime pine, umbrella pine, eucalyptus, cork oak, holm oak and other trees. In the dense and diverse understorey mainly composed of *Ulex* spp, *Rubus* spp, *Cistus salvifolius*, important species of *Quercus coccifera* and *Cytisus* spp can also be found (Figure 6). Close formations are distributed from north to south of the country.

3. Configurations of the main Portuguese forest types

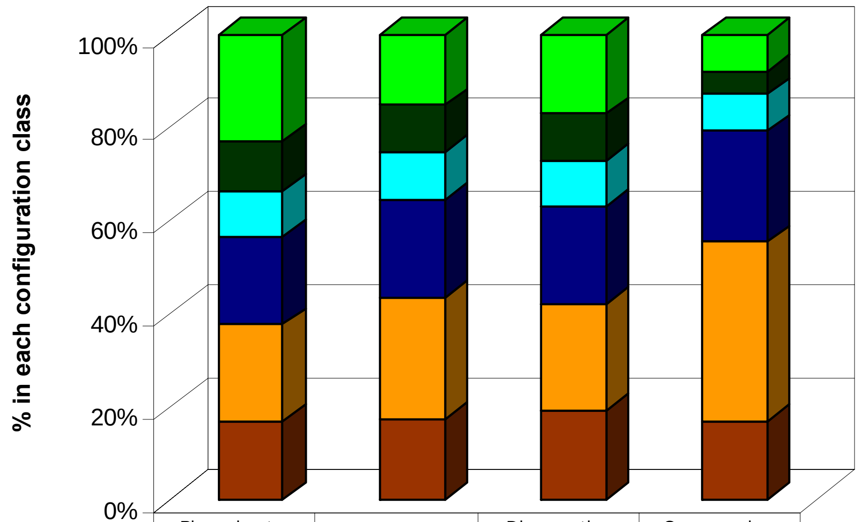
Distances measured from the centre of each survey plot to the nearest different habitat along the eight major directions, enable the assessment of forest patches configurations of 2133 survey plots from the Portuguese forest matrix. Values of area/perimeter ratio defining configurations features (Forman, R.T.T. & Godron, M., 1986;

McGarigal, K. & Marks, B.J., 1995; Godinho-Ferreira *et al*, *in press*) can be classified along a wide range of size and shape indices and sorted in six configuration classes (Table 1).

Table 1. Configuration classes according to forest patch size and shape.

Patch Size [Area (ha)]	**Patch Shape Index** [PSI=$4\pi A/P^2$]	**Configuration Class**
$0 \leq A < 20$	$< 0{,}70$	Small Irregular
$0 \leq A < 20$	$\geq 0{,}70$	Small Compact
$20 \leq A < 40$	$< 0{,}70$	Medium Irregular
$20 \leq A < 40$	$\geq 0{,}70$	Medium Compact
$40 \leq A < 70$	-	Large
$A \geq 70$	-	Very Large

As shown in Figure 7 configurations of *Pinus pinaster* stands are slightly different from both *Eucalyptus* forest and Diverse Other forest which present very similar configurations. *Pinus pinaster* forest shows less large and very large patches (38%) but significantly more small irregular patches (23%) than the other main forest types. Large patches are clearly dominant in the *Quercus suber* forest (39%) and together with very large patches reach more than half of the cork oak "montados" area (56%). They have also a large percentage of medium compact patches (24%) and a little percentage of small irregular and compact patches (13%).



	Pinus pinaster forests	Eucalyptus forests	Diverse other forests	Quercus suber forests
Small irregular	23	15	17	8
Small compact	11	10	10	5
Medium irregular	10	10	10	8
Medium compact	19	21	21	24
Large	21	26	23	39
Very large	17	17	19	17

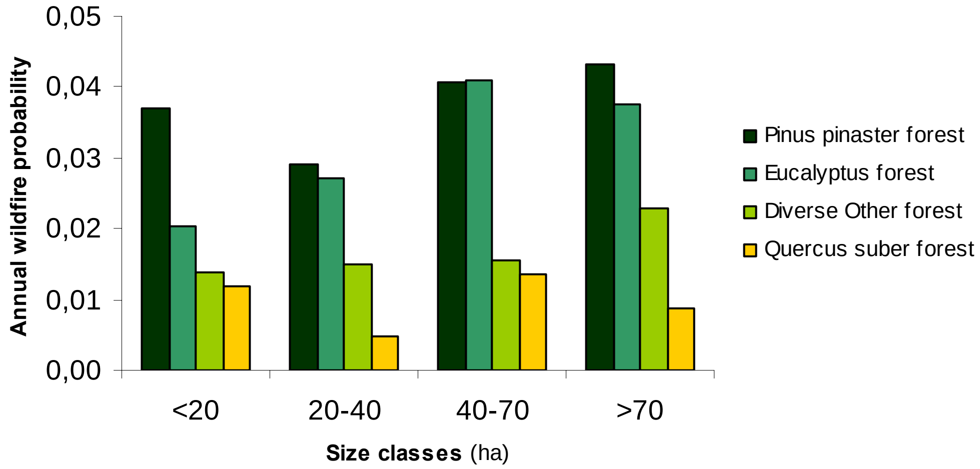
Forest Types

Figure 7. Configuration classes of the main forest types.

4. Results and final considerations

Forest types and configurations from 2133 NFI sampling plots were overlaid with burned areas surveys from 1999 to 2005 (DGRF, 2006). Assuming that the changes on the cover of the forest types were only consequence of consecutive fires, the burned area for each year was estimated excluding the ones already burned.

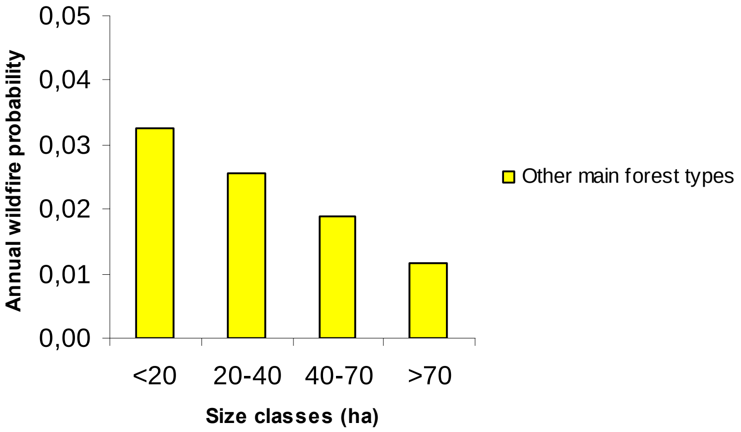
Considering the configurations of burned forest patches, size was found to be more relevant than shape. Therefore, subsequent analysis on wildfire probability is based on four size classes (A < 20 hectares; 20 ≤ A < 40 hectares; 40 ≤ A < 70 hectares; and A≥ 70 hectares).



Main Forest Types	Size classes (ha)				χ^2
	A < 20	20 ≤ **A** < 40	40 ≤ **A** < 70	**A**≥ 70	
Pinus pinaster forest (PPF)	55/213 (0,04)	37/182 (0,03)	38/133 (0,04)	33/109 (0,04)	4,53
Eucalyptus forest (ECF)	15/105 (0,02)	25/132 (0,03)	31/108 (0,04)	19/72 (0,04)	8,07
Diverse Other forest (OTF)	17/176 (0,01)	21/199 (0,02)	16/148 (0,02)	19/119 (0,02)	3,18
Quercus suber forest (QSF)	2/24 (0,01)	2/60 (0,00)	7/74 (0,01)	2/33 (0,01)	2,07
Total (PPF; ECF; OTF; QSF)	89/518 (0,02)	85/573 (0,02)	92/463 (0,03)	73/333 (0,03)	9,83

Figure 8. Graphic for the annual wildfire probability and related table of the ratio between burned NFI sampling plots from 1999 to 2005 and available plots by forest types and size classes. Chi-square values were computed for the main forest types. Annual wildfire probability in brackets.

The ratio Burned plots/Available plots/7 years can be interpreted as the annual wildfire probability, and estimated for both configuration classes and forest types. For each size class wildfire probability presents the same pattern showing *Pinus pinaster* forest the highest rates followed with similar values by *Eucalyptus* forest, while Diverse Other forest and *Quercus suber* forest are less likely to burn (Figure 8). These probability rates are in accordance with the values presented in the DGRF wildfire reports (DGRF, 2006a).



Main Forest Types	**Size classes** (ha)				χ^2
	A < 20	20 ≤ **A** < 40	40 ≤ **A** < 70	**A**≥ 70	
Other (QPF; DOF; AUF; CIF; CYF; ACF)	15/66 (0,03)	12/67 (0,03)	10/76 (0,02)	3/37 (0,01)	4,50

Figure 9. Graphic for the annual wildfire probability and related table of the ratio between burned NFI sampling plots from 1999 to 2005 and available plots by other main forest types and size classes. Chi-square value. Annual wildfire probability in brackets.

Chi-square statistic was used to test the null hypothesis that each size class for the same forest type has the same wildfire probability. Comparison of size classes for the total of the main forest types (PPF, ECF, OTF, QSF) shows that the effect of size is significant (χ^2=9,83; df=3; p<0,05) with size above 40 hectares showing higher probabilities to burn. Analysing the main forest types independently, only *Eucalyptus* forest shows a significant effect of size (χ^2=8,07; df=3; p<0,05) while the others, however statistically non-significant, follow the same general trend of wildfire probability increasing with patch size (Figure 8). In the other main forest types (QPF, DOF, AUF, CIF, CYF, ACF) wildfire probability decreases with the increasing of size class (Figure 9).

It is concluded that configuration, as assessed by patch size, has an effect on wildfire probability. For the forest types that are more likely to burn (*Pinus pinaster* forest and *Eucalyptus* forest) the tendency is that fire probability increases with patch size. For the other types (QPF, DOF, AUF, CIF, CYF, ACF) – with close and low structures – the tendency is the opposite, with wildfire probability decreasing with patch size.

This different effect of the influence of patch size could be interpreted in the basis of the different fire behaviour of the various forest types.

References

DGF,1999. Manual de Instruções para o Trabalho de Campo do Inventário Florestal Nacional. Direcção-Geral das Florestas, Lisboa, Portugal.

DGF, 2001. Inventário Florestal Nacional: Portugal Continental 3ª Revisão. Direcção-Geral das Florestas, Lisboa, Portugal.

DGRF, 2006. Cartografia de áreas ardidas. http://www.dgrf.min-agricultura.pt

DGRF, 2006a. Incêndios Florestais: Arquivo. http://www.dgrf.min-agricultura.pt

ESRI, 1999. ArcView GIS Formação ESRI Portugal – Níveis I, II e III, Sistemas de Informação Geográfica SA. Lisboa, Portugal.

Farina, A., 1998. Principles and Methods in Landscape Ecology. Chapman and Hall. London, UK.

Forman, R.T., 1997. Land Mosaics. The Ecology of Landscapes and Regions. Cambridge University Press. Cambridge, UK.

Forman, R.T.T. and Godron, M.,1986. Landscape Ecology, John Wiley and sons, New York.

Godinho-Ferreira, P., Azevedo, A., Rego, F., 2005. Carta da tipologia florestal de Portugal Continental. Silva Lusitana 13, 1-34.

Godinho-Ferreira, P., Rego, F., "in press". "Configuration of forest patches in mainland Portugal". Landscape Ecology in the Mediterranean: Inside and outside approaches. European IALE Congress 2005. Faro, Portugal.

Lindenmayer, D.B. & Franklin, J.F., 2002. Conserving Forest Biodiversity: A Comprehensive Multiscaled Approach. Island Press, Washington, Covelo, London.

MacDonald, L.H., Huffman, E.L., 2004. Post-fire Soil Water Repellency: Persistence and Soil Moisture Thresholds. Soil Science Society of America Journal, 68 (5):1729-1734.

McGarigal, K. & Marks, B. J., 1995. Fragstats: spatial pattern analysis program for quantifying landscape structure, Gen. Tech. Rep., PNW-GTR-351, Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Moreira, F.; Rego, F.; Ferreira, P.G., 2001. Temporal (1958-1995) pattern of change in a cultural landscape of northwestern Portugal: implications for fire occurences. Landscape Ecology 16 (6): 557-567, Kluwer Academic Publ., Netherlands.

Puumalainen, J., 2001. *Structural, compositional and functional aspects of forest biodiversity in Europe*, Geneva Timber and Forest Discussion Papers, ECE/TIM/DP/22, United Nations, New York and Geneva.

Rego, F., Godinho-Ferreira, P., Uva, J.S. & Cunha, J., 2004. Combination of Structural and Compositional Factors For Describing Forest Types Using National Forest Inventory Data, Marchetti M. (Ed), *Monitoring and Indicators of Forest Biodiversity in Europe – From Ideas to Operationality*. EFI Proceedings 51: 153-162.

Shakesby, R.A., Coelho, C.O.A., Ferreira, A.D., Terry, J.P., Walsh, R.P.D., 1994. Fire, post-burn land management practice and soil erosion response curves in Eucalyptus and Pine forests, North-Central Portugal. In Soil Erosion and Degradation as a Consequence of Forest Fires, pp. 111-132. M. Sala & J.L. Rubio, eds. Geoforma Ediciones, Logroño.

Terry, J.P., 1994. Soil loss from erosion plots of differing post-fire forest cover, Portugal. In Soil Erosion and Degradation as a Consequence of Forest Fires, pp. 133-148. M. Sala & J.L. Rubio, eds. Geoforma Ediciones, Logroño.

Turner, M.G. and Dale, V.H., 1990. Modeling landscape disturbances. In Quantitative Methods in Landscape Ecology. The analysis and interpretation of Landscape Heterogeneity, pp. 323-351. Edited by M.G. Turner and R.H. Gardner. Springer-Verlag. NY, USA.