Forest Fires Prevention in Portugal - Using GIS to Help Improving Early Fire Detection Effectiveness

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Abstract

Forest fires and burnt area in Portugal have been increasing in the last decades, contrarily to other southern European countries, although more resources are being allocated to prevention, detection and fire fighting. To minimize the probability of wildfires occurrence, it is crucial to assure the effectiveness of the prevention, vigilance and first attack operations. When fire prevention fails, fire fighting steps must be initiated, but this can only happen following detection. In Portugal the National Lookout Towers Network (NLTN) is the principal organized fire detection system, working together with some ground and aerial mobile units. However very few studies evaluated these systems effectiveness or contributed to know the lookout areas covered and which are the problematic areas not covered. In last years we characterized and evaluated the NLTN system in Portugal and produced several national cartography including visibility and vigilance priority maps. Using this cartography we concluded that 28% of the mainland territory is not covered by the NLTN and 31% is only observed by one lookout tower what is considered insufficient for good location purposes. We also identified the areas with high priority for fire vigilance that have simultaneously poor visibility from lookouts and high fire risk, which represents about 17% of the territory. Although there are significant differences between regions, the percentage of first detections made in Portugal by lookouts is relatively small and is apparently decreasing. In this paper we summarize these aspects related to fire detection system planning and management, and how GIS can help to improve resources optimization and early fire detection effectiveness.

Keywords: forest fires, fire detection, lookout towers network, GIS, cartography

Introduction

Forest fires and burnt area in Portugal have been increasing in the last decades, contrarily to other southern European countries (EC 2005), although more resources are being allocated to prevention, detection and fire fighting. Between 1990 and 2005, about 2.3 million hectares have burnt in Portugal (DGRF 2006), representing about 25% of the country area, and in the recent years of 2003 and 2005 the burnt area reached the highest values since 1980 (about 750,000 ha). It is generally recognized that to minimize the probability of large wildfire occurrence, it is fundamental to assure the effectiveness of the prevention, vigilance and first attack operations. When fire prevention fails, fire fighting steps must be initiated, but this can only happen following detection. Fire detection systems are considered for a long time to be crucial in order to enable the reduction of fire fighting costs and fire losses

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(Show and others 1937, Davis and others 1959, Chandler and others 1983). Besides the economic investments in human and material resources, it is very important to know the operational functioning factors and the effectiveness of the detection systems in order to optimize fire fighting. In Portugal the National Lookout Towers Network (NLTN) is the principal organized fire detection system, working in cooperation with some ground and aerial mobile units. However very few studies evaluated these systems effectiveness or contributed to know the lookout areas covered and which are the problematic areas not covered. In last years we characterized and evaluated the NLTN system in Portugal and produced several national cartography including visibility and vigilance priority maps.

Metodology

The study area is the entire Portuguese mainland, which covers about 90.000 km^2 in southern Europe *(fig. 1)*. Most part of the country is included in the Mediterranean region and the altitudes range from sea level to 2,000 m. About 27% of the country is covered by forests and 48% by agricultural areas (DGF 2001).

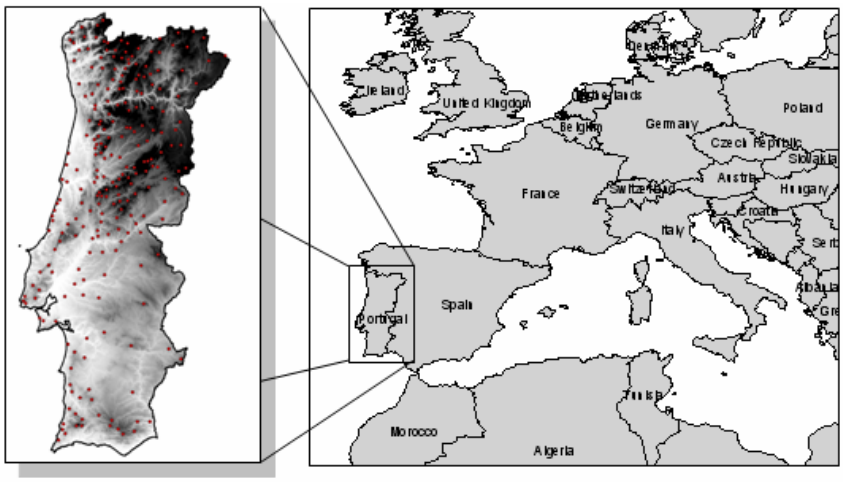

Figure 1 — General location of the Portuguese mainland, with representation of elevation and lookouts belonging to the NLTN (red points).

The methodology used resulted from an interactive process in which different approaches were evaluated. Next we synthetically describe the methodological approach used. All spatial analysis and cartographic production were made using Geographical Information Systems (GIS), using mainly *ArcInfo and ArcGis* (*ESRI*) software.

Analysis of fire detections

Since the fire season of 2001 the Forest Services established a database with records of the approximate initial geographical coordinates of each fire occurrence and the lookout tower responsible for its detection. For the analysis of fire detections and of National Lookout Towers Network efficiency we used the official Forest Services wildfires database with 75,571 occurrences detected in Portugal during the period 2001-2003, both by the NLNT and by other systems.

Lookouts visibility and fire detection probability maps

In order to determine the areas of the country where there is a higher or lower probability to detect wildfires by the NLTN system, we developed a methodology that integrates three different but complementary approaches: a) visibility analysis, b) probabilistic distance analysis, and c) probabilistic detection analysis. Based on these three complementary approaches, we also produced a synthesis map of lookouts detection probability for the entire Portuguese mainland, with 90 m spatial resolution.

Visibility and probabilistic detection analysis can only be efficiently done with a GIS, using a digital elevation map and a layer with the geographical location of the lookouts and their observation platform heights. For the cartographic production presented here we used a free digital elevation model (DEM), in raster format and with 90 m spatial resolution (NASA *and others* 2004); this map was submitted to several operations, including georrefencing and correction of negative and no data values (by interpolation methods), in order to prepare it for spatial analysis. On the other hand the inventory of all the Portuguese lookouts belonging to the NLTN system were visited (summer 2004) in order to collect their geographic coordinates with a high precision GPS (global positioning system) and to register their main characteristics (eg. in terms of observation platform height or visibility obstructions). We also had to define the detection radius to use for each lookout, because it is known that this factor varies among regions (Buck 1938; Bruce 1941; Chandler *and others* 1983; FAO 2001); for that purpose we used 6 different detection radiuses varying between 22 and 35 km, which were based in results obtained by Catry *and others* (2004) for the Portuguese lookouts. Based on this information we performed a GIS analysis to produce the national lookout network visibility map, using an automatic function to correct the refraction and terrestrial bending effects. The resulting map identifies how many lookouts can observe each location.

The probabilistic distance map was based in the concept that detection probability decreases with the distance from the observation point, already demonstrated by several authors (Chandler and others 1983, Catry and others 2004, Rego and Catry 2006); we used the official fire detection database to determine the lookout towers detection capability regarding distance, that was transformed in a detection probability function using the *Distance* program methods (Thomas and others 2002), and selected the following equation: $FD = exp\ [- y^2 / (2\ a_1^2)]\ [1 + a_2\ cos\ (2\pi y/w)] / (1 + a_2)$, where FD is the distance factor, y is the distance between the fire and the lookout (m), a_1 and a_2 are adjustment parameters (variable within lookouts), and w is the maximum detection distance (fixed in 50 km).

The probabilistic detection analysis combines in a different manner the topographic and distance factors considering some of the basic physical principles associated to the smoke column visibility. Topography was directly used to determine the smoke column height necessary to transpose the topographic obstacles between the fire and the observer (*OffsetB*), corresponding to the non visible smoke column *(fig. 2)*; distance was considered because of its influence on the minimum angle of detection (α). The function used to calculate the detectable smoke column height (H) is represented by: $H = OffsetB + 0.001454\ D$.

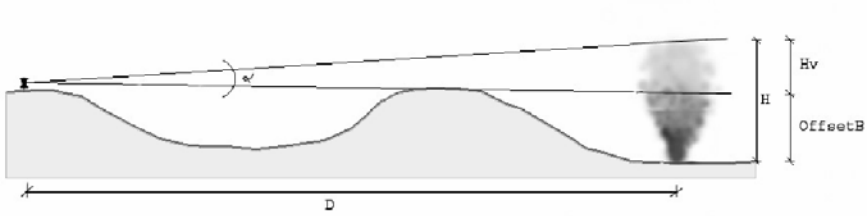

Figure 2 — Schematic representation of the detectable smoke column height concept (H).

Complementary vigilance priority map

A vigilance priority map was also produced congregating the information from the previous visibility maps, with the official Forest Services fire risk map, and with the map identifying the areas of public ecological or economic interest like natural protected areas or forested areas *(fig. 3)*. The resulting map identifies the areas where additional fire vigilance is more necessary, complementarily to the NLTN system.

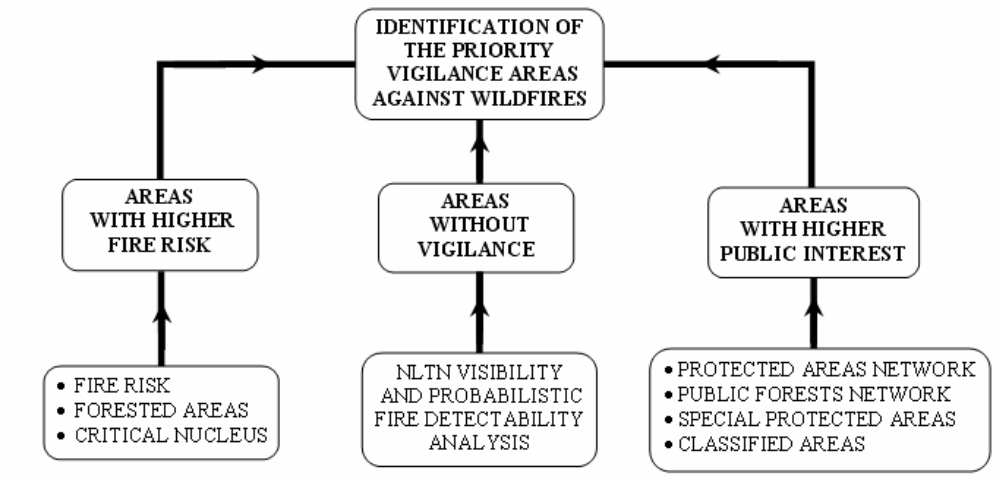

Figure 3 — Synthesis diagram of the information used to produce the vigilance priority map for continental Portugal.

For more details on methodology and concepts used see (Rego and others 2004, Catry and others 2004).

Results and discussion

Analysis of fire detections

In order to optimize the vigilance systems operating to detect forest wildfires it is crucial to know their strengths and weaknesses. Some fundamental factors in managing the fire vigilance systems are the knowledge of their detection rates, as well as the knowledge of the areas where they can effectively operate. In this study we analysed some factors related to the National Lookout Towers Network, which constitutes the principal organized fire detection system in Portugal, although there are many fires detected and reported by the population and some are also detected by ground and aerial mobile units. In Portugal the lookout towers are usually operating 24 hours per day during the "normal" fire season (from June 1 to September 30), and its operation in recent years represented an annual cost of about 2.5 million euros (Galante 2001).

Based on the analysis of the national fire detections database, we verified that the number of fires detected by the NLNT system, in relation to the total number of fire occurrences, is about 13%. At national level it seems that the NLNT efficiency is slightly decreasing, as in recent years passed from 16.5 % in 2001 to 12.4% in 2002 and to 10.9 % in 2003. Since the great majority of fires are detected by the population, this efficiency decline can probably be related with the generalization of mobile phones use in last years.

This apparently poor importance of NLNT at national level is relative, because its efficiency varies a lot among Portuguese regions. In some northern littoral areas, where population density is high the NLNT efficiency can be very low (below 5%), but in contrast there are other regions in the interior (north and centre) where the NLNT efficiency increases until 42%, and it is important to notice that the larger wildfires occur in those areas. *Figure 4* represents the percentage of fires detected by the NLNT system among the several Portuguese districts.

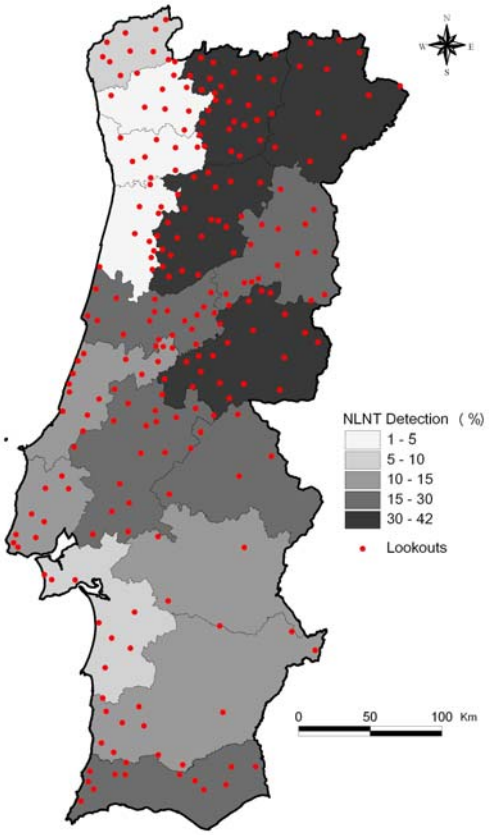

Figure 4 — NLTN fire detection efficiency (%) by district in continental Portugal; white colour represents districts with less than 5% of first detections made by the lookouts (red points).

The detection variation during the day is presented in *figure 5*, which compares the NLNT with the other detection systems. We verified that fire detection varied during the day, with a maximum during the afternoon (between 14 and 17h) and a minimum early in the morning (between 4 and 8h). During the period with more fire ignitions, the NLTN is proportionally more efficient in detection than the other systems, however during the night it seems to be less effective.

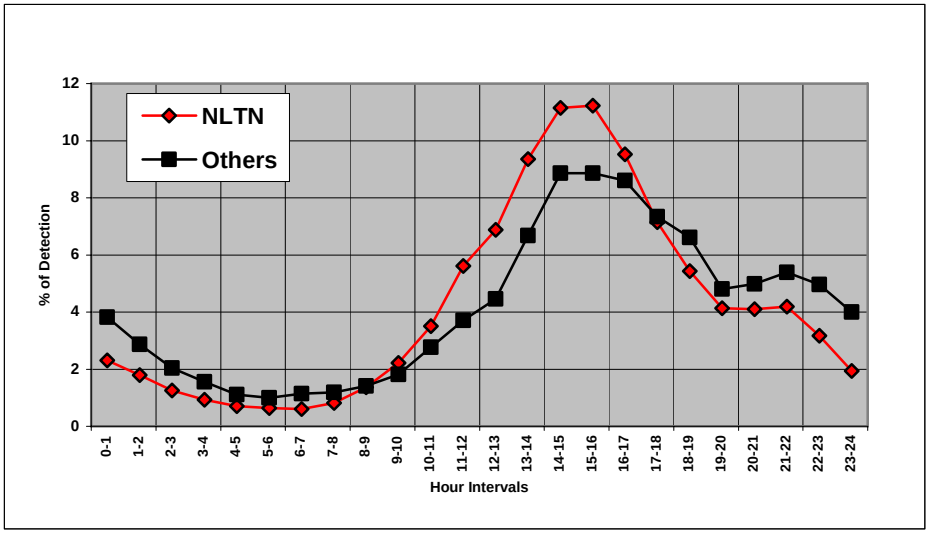

Figure 5 — Fire detections during the day; red line represents NLTN fire detections and the black represents detections by other means (based on 2001-2003 fires).

Lookouts visibility and fire detection probability maps

National results concerning 'direct' visibility from lookout network showed that about 28% of the territory is not covered by the NLTN and that 31% is only visible from one lookout tower, which is considered insufficient for a good detection location purposes. These results are consistent with those presented by Catry (Catry 2002, Catry and others 2004). About 41% of the territory is observed simultaneously by two or more lookout towers and in these areas there is a higher probability of a wildfire to be detected by the NLTN. The national visibility map obtained is presented in *figure 6*.

The synthesis map of NLTN detection probability, based on the three complementary maps obtained *(fig. 7)*, confirm this scenario by showing a very low or low detection probability in 34% of the Portuguese mainland, and a medium probability in 52% of the territory *(fig. 8)*. We analysed the relation between the estimated visibility or detection probability and the percentage of wildfires effectively detected by the NLNT system between 2001 and 2003 and verified very good adjustments ($R^2 = 0.97$ to $R^2 = 0.88$).

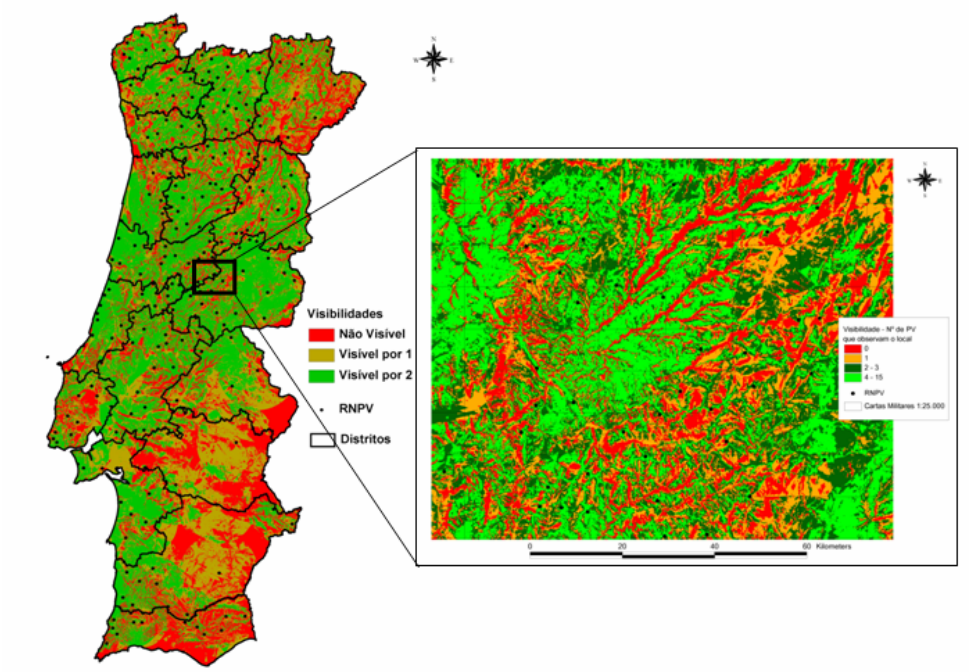

Figure 6 — Visibility map produced for continental Portugal identifying how many lookout towers observe each location (green-visible by one or more lookouts; red-not visible).

The 'visible' areas presented are related to good visibility conditions and so they are probably over-estimated; in poor visibility conditions, like the presence of haze, smog or during the night, the total area surveyed by the NLNT can be considerably lower. It is important to consider this because nocturne fires in Portugal represent about 20% of total detections.

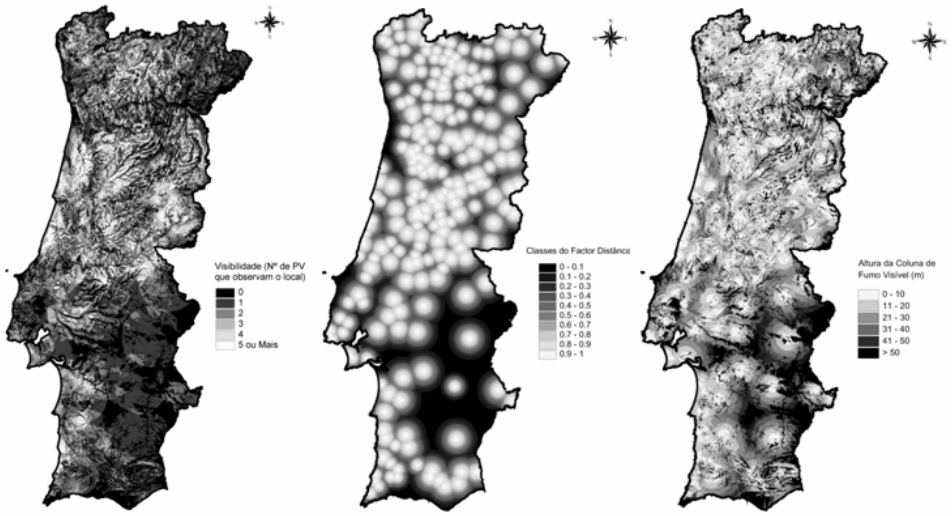

Figure 7 — Maps resulting from the three methodological approaches that originated the final synthesis NLTN detection probability map (left-visibility map; centre-probabilistic distance map; right-probabilistic detection map).

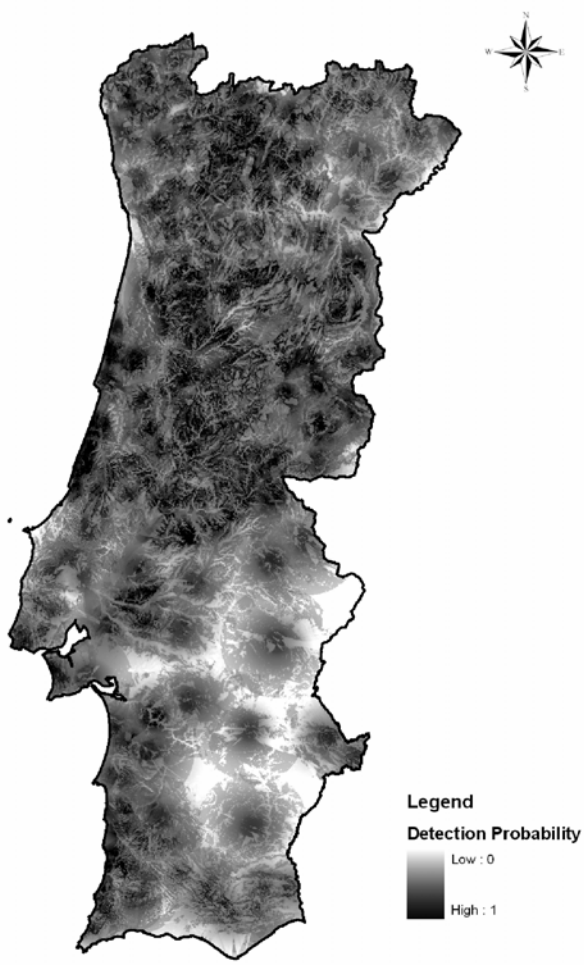

Figure 8 — Synthesis NLTN detection probability map produced for continental Portugal.

Complementary vigilance priority map

In planning and managing an operational vigilance system to prevent wildfires, and considering that available resources are limited, it is not realistic to consider that the objective is to survey all areas in the same way and so it is important to identify the areas where vigilance is most important (Davis and others 1959, ICONA 1981, Ruiz 2000, FAO 2001). By this reason we produced a national vigilance priority map considering simultaneously the information from the previous visibility maps, the official Forest Services fire risk map, and the map identifying the areas of public ecological or economic interest. The resulting map *(fig. 9)* identifies the areas where additional fire vigilance is more necessary, complementarily to the NLTN system. According to the map produced, we verified that the districts of Bragança, Guarda, Viseu, Braga, Vila Real and Castelo Branco are those who presented in average the highest complementary vigilance priority against fires. In general the territory identified with high vigilance priority (17%) corresponds to areas poorly or not covered by NLNT and having simultaneously a high fire risk, so they should be considered in the fire prevention plans, by reinforcing mobile terrestrial or aerial vigilance.

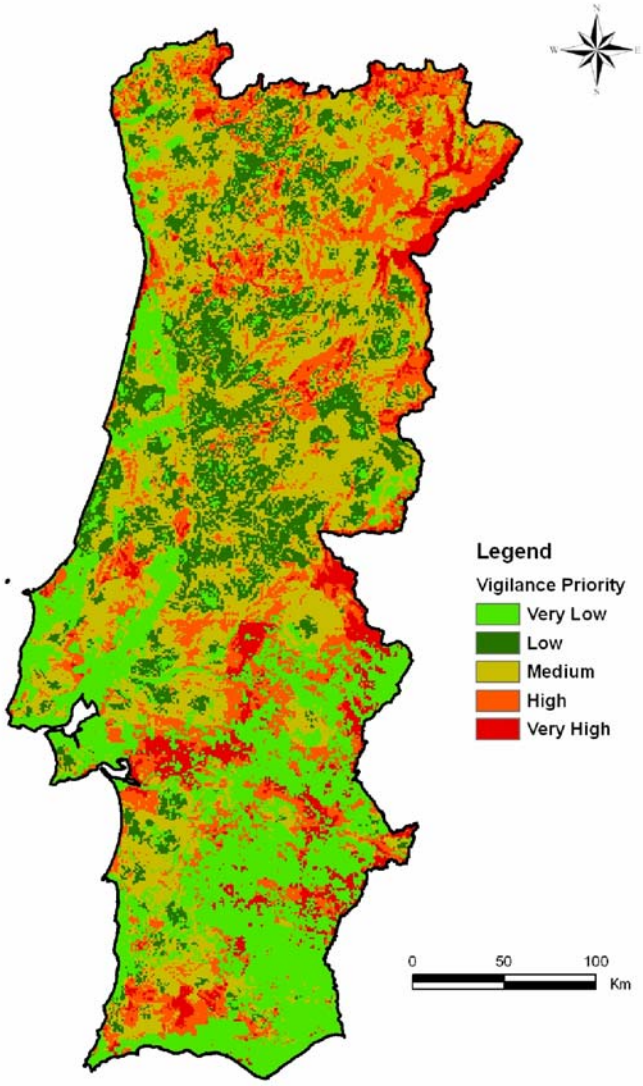

Figure 9 — Complementary vigilance priority map produced for continental Portugal.

Conclusions

We concluded that the National Lookout Towers Network is an important element in fire detection in some Portuguese regions, while in others it only detects a very low percentage of total wildfires. In general and proportionally it seems that NLNT is more efficient during the day than other detection systems, but less efficient at night. We also concluded that at least about 34% of the Portuguese mainland has a very low or low probability of a fire to be detected by lookouts, and that 17% of the territory have high priority in terms of complementary fire vigilance, due to its high fire risk and low NLNT vigilance.

Methodologies and results presented in present work can be useful and important in forest fire vigilance planning and management by helping decision making about where to improve and reorganize lookouts distribution, or to substitute

them by other systems. We also showed how GIS constitutes important tools (allowing spatial analysis that would be almost impossible or extremely time consuming some years ago), helping to improve resources optimization and early fire detection effectiveness.

Acknowledgments

Major part of this work was made in the scope of the project 'Iniciativa Incêndios Florestais' funded by COTEC Portugal. We acknowledge the Portuguese Forest Services (DGRF) for collaboration and for making available the official data concerning fire detections and NLTN. We acknowledge Inês Castro, António Gravato and Rui Almeida for their important help on data collection and organization, and Miguel Galante, Miguel Cruz, Rui Natário, Susana Dias and Miguel Bugalho for their comments. We also acknowledge the Fire Paradox project (contract no. FP6-018505), funded by EC (6th Framework Program), which allowed re-analysis and presentation of these results.

References

Buck, C.C. 1938. **Factors influencing the discovery of forest fires by lookout observers.** Journal of Agricultural Research 56(4): 259-268. Washington, DC,

Bruce, H.D. 1941. **Theoretical analysis of a smoke-column visibility.** Journal of Agricultural Research 62(3), 161-178. Washington, DC.

Catry, F. 2002. **Estudo da visibilidade em postos de vigia e da sua influência na vigilância de incêndios florestais.** Castelo Branco: Escola Superior Agrária - Instituto Politécnico de Castelo Branco; Graduation thesis.

Catry, F.X.; Almeida, R.M.; Rego, F.C. 2004. **Produção de cartografia de visibilidades para Portugal continental. A importância da sua utilização na vigilância contra incêndios florestais.** Silva Lusitana 12 (2): 227-241.

Chandler, C.; Cheney, P.; Thomas, P.; Trabaud, L.; Williams, D. 1983. **Detection.** In: Fire in Forestry - Volume II: Forest fire management and organization. pp. 69-73. John Wiley and Sons, Inc.: New York.

Davis, K.P. 1959. **Detection.** In: Forest fire. Control and use. pp. 282-303. (McGraw-Hill Book Company, Inc.: New York)

DGF 2001. **Inventário florestal nacional. Portugal continental.** 3ª Revisão, 1995-1998. Direcção Geral das Florestas, Lisboa.

DGRF 2006. **Incêndios florestais – Relatório de 2005.** Divisão de Defesa da Floresta Contra Incêndios. Direcção-Geral dos Recursos Florestais, Lisboa.

EC 2005. **Forest fires in Europe 2004.** Official Publication of the European Commission, S.P.I.05.147 EN.

Galante, L.M. 2001. **Rede Nacional de Postos de Vigia.** Direcção-Geral das Florestas, Lisboa. 79 pp.

NASA; NIMA; DLR; ASI 2004. **Digital Elevation Model.** National Aeronautics and Space Administration (NASA); National Imagery and Mapping Agency (NIMA); German space agency (DLR); Italian space agency (ASI). ftp://edcsgs9.cr.usgs.gov/pub/data/srtm/.

Rego, F.C. and Catry, F.X. (2006). **Modelling the effects of distance on the probability of fire detection from lookouts.** International Journal of Wildland Fire 15: 197-202.

Rego, F.C.; Catry, F.X.; Maia, M.J.; Santos, T.A.; Gravato, A.; Castro, I.C.; Moreira, F.O.; Pinto, P.R.; Almeida, J. 2004. **Análise da Rede Nacional de Postos de Vigia em Portugal.** Relatório Final do Projecto. ADISA/CEABN – INESC/INOVAÇÃO. Iniciativa Incêndios Florestais, COTEC Portugal.

Ruiz, E.M. 2000. **Detección.** In: Velez, R. (Coord.). La defensa contra incendios forestales. Fundamentos y experiencias. pp. 17.1-17.15. McGraw-Hill/ Interamericana de España, S.A.U.: Madrid.

Thomas, L.; Laake, J.; Strindberg, S.; Marques, F.; Buckland, S.; Borchers, D.; Anderson, D.; Burnham, K.; Hedley, S.; Pollard, J. 2002. **Distance 4.1, release 2.** Research Unit for Wildlife Population Assessment. University of St Andrews: St Andrews, UK. Available at http://www.ruwpa.st-and.ac.uk/distance.