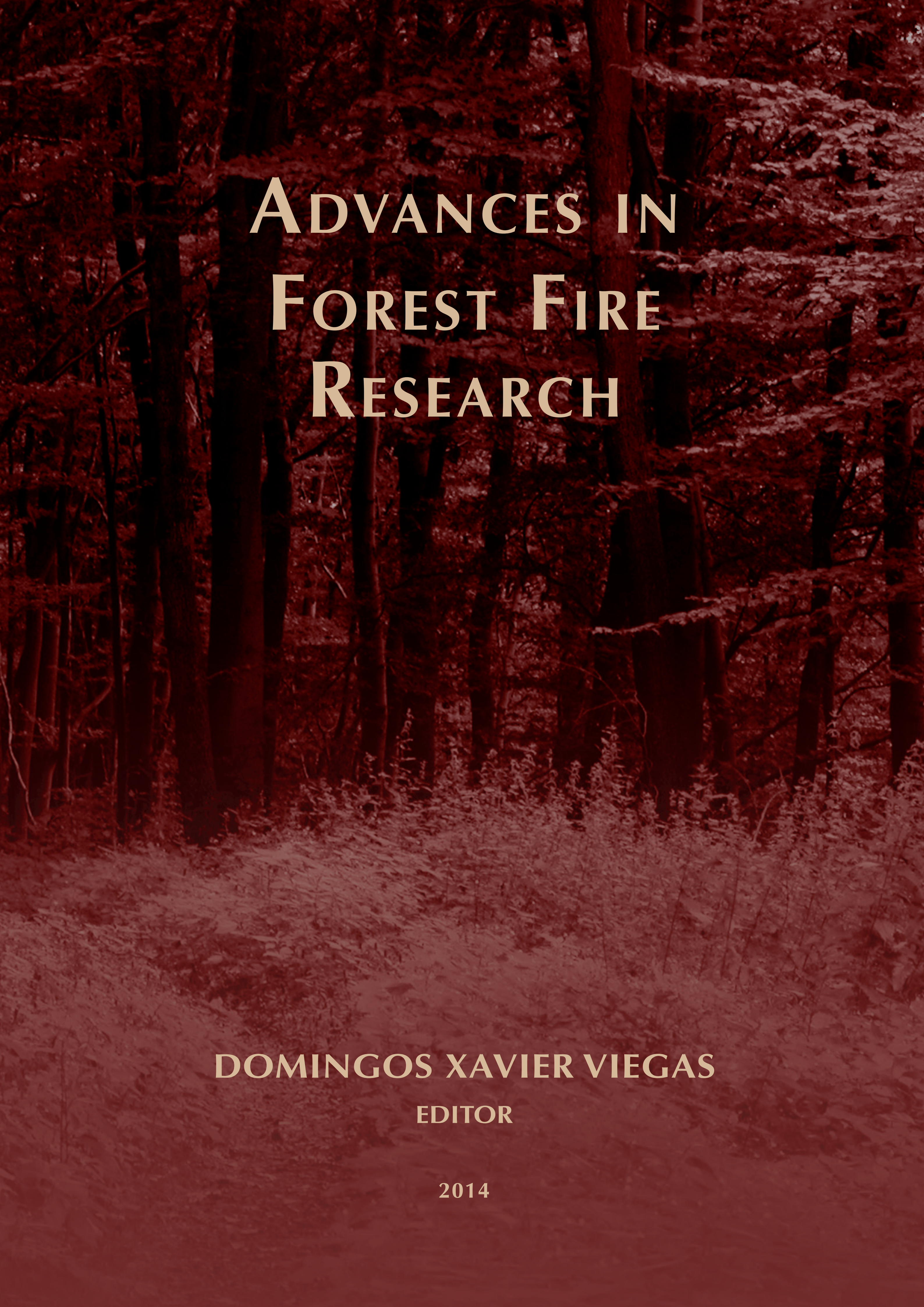

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Accuracy assessment of a mediterranean fuel-type map for wildland fire management at national scale: the cases of greece and portugal

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Abstract

Classification and mapping of wildland fuel is one of the most important factors that should be taken into consideration for wildland fire prevention and planning. In this paper we demonstrate the accuracy assessment of "ArcFUEL" project which has delivered a complete, up-to-date, methodology for Fuel Classification Mapping (FCM on a Web-Geodatabase) based on "readily available" data, harmonized, accessible & interoperable according to INSPIRE principles, for the Mediterranean Region. The fuel layer has been evaluated in terms of spatial and thematic thematic accuracy by employing an extensive field campaign in Portugal and Greece and standard photointerpretation procedures. For Greece, the overall accuracy was found to be 80.59 % , while the Kappa value was 0.74. For Portugal the overall accuracy was found to be 67% and the Kappa value was 0.63.The spatial fuel maps is an end-product essential for computing spatial fuel hazard, fire risk and simulation, fire growth and intensity and post fire effects across a landscape at national and regional scale.

Keywords: *Fuel Mapping, Fuel Management, Accuracy Assessment, Greece, Portugal, Fire Management*

1. Introduction

Increased wildland fire activity over the last 30 years has had profound effects on budgets and operational priorities of the Forest Service, Civil Protection agencies, Fire Service and local entities with wildland fire responsibilities in Mediterranean Basin. Both the number and the average size of large fires have shown an increasing trend over the last several decades causing extensive financial and ecological losses and often human casualties (Dimitrakopoulos and Mitsopoulos 2006). Mediterranean region is also considered a ''hot spot'' for fire studies, not only because of its high sensitivity to changes in recent decades such as processes of rural depopulation, land abandonment and reduction of traditional forest use but also for the reason that according to the majority of climate models the most likely evolution of this region is towards a hotter and drier climate, with a significantly higher risk of intense heat wave episodes as well as an increase in fire hazard and occurrence (Giannakopoulos *et al*. 2009; Dimitrakopoulos *et al*. 2011; Koutsias at al. 2013).

Fuel maps are an essential tool in fire management since they characterize, in a landscape level, the only factor that fire and land managers can control over many scales – fuel parameters. Coarse resolution fuel maps are useful in global and national fire and fuel hazards assessments because they help fire managers effectively plan, allocate, and mobilize suppression resources (Burgan *et al*. 1998). Regional fuel maps are useful as inputs for simulating fire behavior, fuel consumption, carbon release, smoke dispersion scenarios, as well as for describing fire hazards to support fire suppression and resources deployment (Leenhouts 1998; Leinhan *et al*. 1998). Medium and fine-resolution fuel maps are important for proposing and evaluating tactical fuel treatments, assessing fire hazard and risk, helping in environmental assessments and computing fire danger (Gonzalez *et al*. 2007). However, landscape-level fuel maps have been proved the most appropriate in fire management because they provide the required inputs for the spatially explicit fire behavior and growth models used to simulate fire propagation (Keane *et al*. 2006).

Many different approaches have been used in order to map wildland fuels (Keane at al. 2001; Arroyo *et al*. 2008). Most efforts have tried to map important fuel characteristics such as the fuel model as a function of vegetation type (Menakis *et al*. 2000) and topography (Rollins *et al*. 2004) to create spatial layers in a Geographical Information System (GIS). Some researchers have qualitatively or quantitatively related fuel information to various forms of remote sensing data at multiple scales, including digital photographs (Oswald *et al*. 1999), LANDSAT images (Wilson *et al*. 1994), ASTER images (Falkowski *et al*. 2005), AVHRR images (Burgan *et al*. 2005), Quickbird and EO-1 Hyperion (Mallinis *et al*. 2014), microwave-radar images (Arroyo *et al*. 2008), and LIDAR data (Mutlu *et al*. 2008). Other efforts have mapped fuels using statistical modeling techniques coupled with detailed field data and knowledge-based systems (De Vasconcelos *et al*. 1994). Recently, the "ArcFUEL" project delivered a complete, up-to-date, methodology for Fuel Classification Mapping (FCM on a Web-Geodatabase) based on "readily available" data, harmonized, accessible & interoperable according to INSPIRE principles, for the Mediterranean region (Bonazountas *et al*. 2012). ArcFuel utilized many and various ancillary data and delivered a consistent and systematic ex novo methodology and workflow for large scale classification and mapping of forest fuels and production of Fuel Classification Maps.

For many reasons it is difficult to map wildland fuels. The most notable factor that prevent accurate mapping is the high temporal and spatial variability of fuel parameters (Keane 2008). Fuel properties are also highly variable and vary across multiple scales; fuel strata consists of many fuel components, including litter, duff, dead twigs, shrubs, herbs and the properties of each component, such as its heat content, moisture content, and size, can be highly variable even within a single type of fuel. The variability of fuel loads within a stand, for example, can be as high as the variability across a landscape, and this variability can be different for each fuel component and property. The main objective of the current study was to assess and validate the accuracy of the Fuel Types maps developed at national scale in Greece and Portugal using the ArcFuel production chain.

2. Methods

2.1. Plots selection

In order to select the validation dataset in both countries the next steps were followed:

- Selection of LUCAS plots matching to the ArcFUEL classification: Based on SQL queries the LUCAS dataset was separated into two subsets of data, one with the LUCAS points of which the description coincided with ArcFUEL characterization and another with the LUCAS points of which it differed (FPP sample). The first subset was used as part of the ArcFUEL validation data set.
- Selection of plots visited in the field, based on the LUCAS dataset: Based on the first step, a stratified random sampling design (considering minimum representation) was applied in representative regions of the two countries and an additional subset created including a number of plots defined for field visit. This subset included conflicting with ArcFuel, LUCAS points and plots located above 1000m of altitude, which aren't considered in the LUCAS data set. Additional plots were added ad hoc during the field survey based on the fuel types occurring in each region according to the estimation of the surveyors. Field surveys have been carried out by trained personnel through the entire country in Greece and Portugal.

2.2. Field work

Field work organized for validating ArcFuel map created for the participating countries. It should be stated that ArcFuel map covering the entire country created only for Greece and Portugal. A proper field data collection protocol was defined and field campaings organized in order to create the appropriate data sets for validating the accuracy of the maps for Greece and Portugal. Although a common protocol was used the field survey implemented based on the use of different data collection technologies. A extended field campaign for collecting information necessary to validate the accuracy of the ArcFuel map was planned covering all the geographic regions of Greece. A suitable field survey daily plan was elaborated, using GPS routing optimization, for reducing travel distances, minimizing total time required for the data collection and comply with vegetation growth status in the regions visited. A commercial GPS application (Navigon) allows reaching nearby the plot, providing its coordinates. In the plot, a properly developed mobile android application installed in a tablet was used for collecting and storing in-situ the information required for the validation purpose. The information collected is based on observations referred to the description of the vegetation composition and the fuel bed horizontal and vertical structure. The ArcFuel android application provides access to a previously uploaded list of survey plots and their relevant data according to the ArcFuel map. These data are presented in a digital form, in which field data are also recorded, supporting thus a direct comparison between mapped and observed data. The field recorded data are uploaded through the web to a proper server on a daily base. Sample screens of the mobile application are shown in Figure 1. The application is available in the Google play store of android applications.

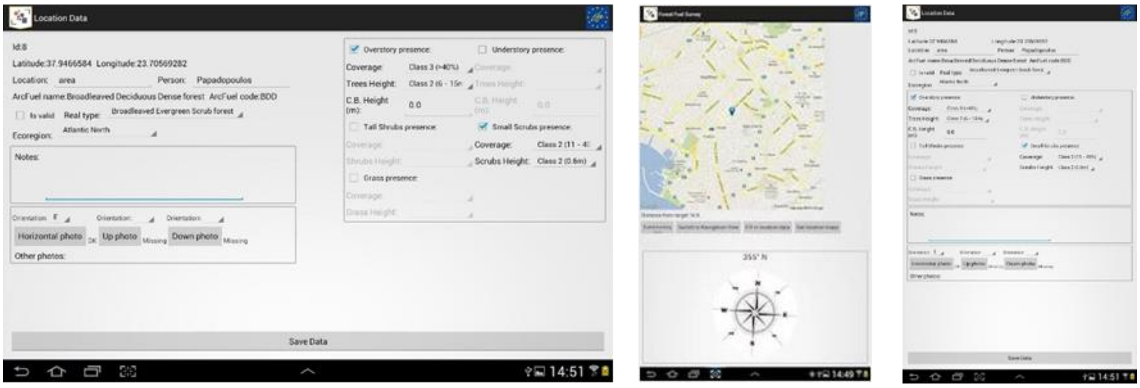

Figure 1. Fuel data collection mobile application of ArcFuel

The field data stored in the server were organized in an on-line data base (http://webservices.g-fmis.com:48080/WebArcfuel/login.jsp) with web interface. Screens of the web interface of the on-line ArcFuel data base of fuel sample plots are shown in Figure 2.

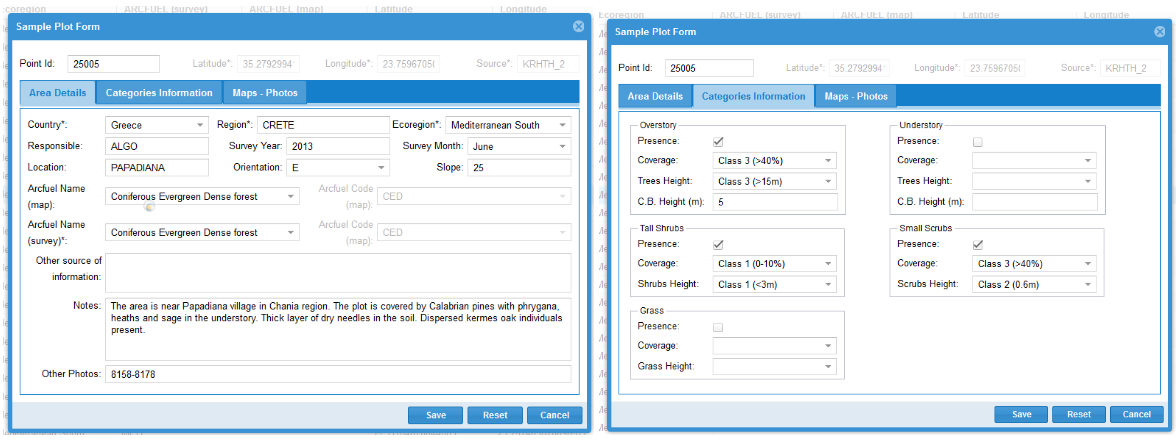

Figure 2. On-line data base of ArcFuel field plots

The data base can be extended with additional data collected in context of relevant forest fuel management campaigns. Thus map validation can be continuous and the ArcFuel mapping accuracy can be improved significantly.

2.3. Accuracy assessment

All the data from the above subsets were aggregated in order to derive the final ArcFUEL validation data set consisting of 1288 points in Greece and 275 in Portugal. In addition, information obtained through photointerpretation of large scale orthophotographs of the KTIMATOLOGIO SA for Greece (http://gis.ktimanet.gr/wms/ktbasemap/default.aspx) which are publicly available through a WMS server and VHR satellite imagery available through Google Earth, was considered along the validation process. During the photointerpretation process, an area equal to 0.25 ha corresponding to the ArcFUEL pixel size, around each point was inspected. To estimate the accuracy of the ArcFUEL map an error matrix was derived. The Kappa coefficient of agreement was also calculated (Fleiss *et al*. 2003). A slightly different methodology was applied in Portugal, deriving the accuracy matrices independently for LUCAS and the remaining field points. Furthermore, three classes that identified “deciduous conifers” during the methodology application were removed from the final analysis as they were considered erroneous a priori. There are no deciduous conifers in Portugal, at least not at a scale that would allow its identification using ArcFUEL methodology.

3. Results and discussion

For Greece, the overall accuracy was found to be 80.59 % (Figure 3), while the Kappa value was 0.74. For Portugal the overall accuracy was found to be 67% (Figure 4), the Kappa value was 0.63.

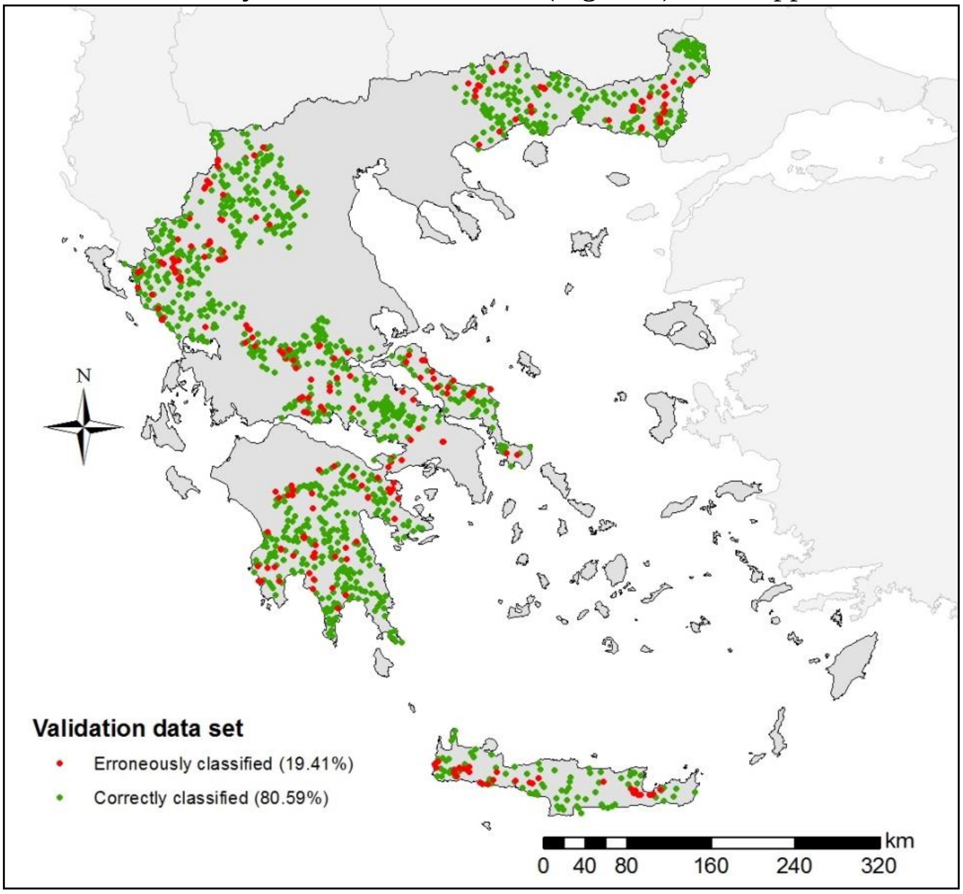

Figure 3. Validation findings based the 1288 point dataset in Greece

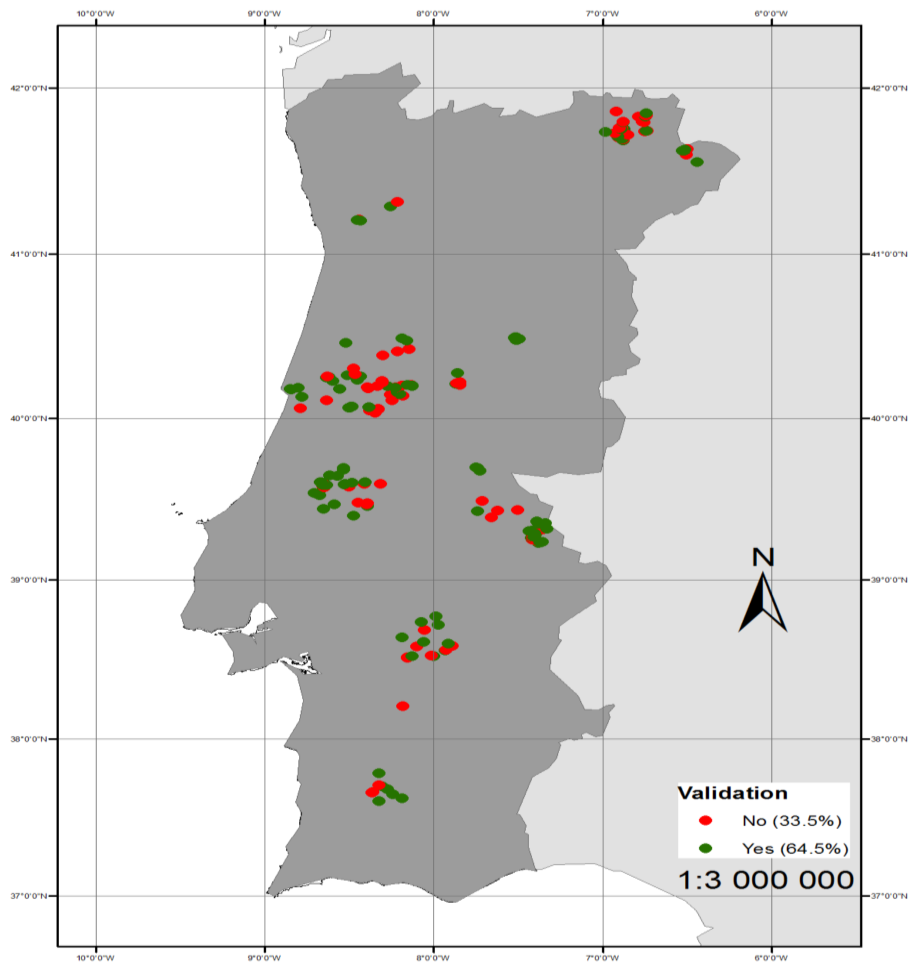

Figure 4. Validation findings based the 1288 point dataset in Greece

Two main efforts have been conducted in Europe for generating fuel maps at large scale. The European Fuel Map developed by Joint Research Center (JRC) (Sebastián López *et al*. 2002), where 44 fuel types were classified by using two databases: the CORINE Land Cover (CLC) and the Map of Natural Vegetation of Europe (MNVE). The CLC classes were stratified into sub-regions according to phyto-sociological criteria, which accounted for the floristic composition and other factors governing the distribution of the vegetation. These sub-regions were then linked to the National Fire-Danger Rating System (NFDRS) Fuel Model map in order to assign a fuel type to each of the sub-regions. The NFDRS fuel load corresponding to each of the fuel model classes was then assigned to each of the fuel models. However, the fairly poor spatial resolution of the datasets prevents the use of the data set for fine scale fire behavior and effects modeling. In 1999, the Prometheus project a new fuel type classification system was developed to better represent the fuel characteristic of the European Mediterranean ecosystems (Lasaponara and Lanorte 2006). However, this classification is principally based on the height and density of fuel, which directly influences the intensity of a wildfire and does not take into consideration the fuel physical and chemical properties which are required for simulating fire behavior and growth. In the USA, the recent LANDFIRE project feature 30-m raster grids of fuel models at national scale by integrating many geospatial technologies including biophysical gradient analyses, remote sensing, vegetation modeling, ecological simulation, landscape disturbance and successional modeling (Rollins 2009).

In United States the most commonly used fuel classifications are the 13 models of Anderson (1982) and the 40 models of Scott and Burgan (2005), all of which are used as inputs in the BEHAVE, FARSITE and FLAMMAP fire prediction systems, and the 26 fire danger models of Deeming *et al*.

(1977) that are used in the US National Fire Danger Rating System. Several surface fuel models are currently used by fire and forest management agencies in the United States, Europe, Canada and Australia, and most of these systems have the same categories, components and description variables (Sandberg 2001). In Mediterranean Basin, Mallinis *et al*. (2008) created a set of custom fuel models that were mapped across a large landscape using Quickbird imagery for input to the FARSITE model. In Italy, Santoni *et al*. (2011) developed two fuel models in order to simulate fire behaviour for various shrubland ecosystems and Bacciu *et al*. (2009) used field loading data to create fuel models for Mediterranean vegetation types for FARSITE simulations. To evaluate fire hazard in Portugal, Fernandes (2009) created a set of 19 fuel models based on the dominant vegetation types in Portuguese forests. Despite of fire behavior studies, fuel classification systems have been used as primary inputs for estimating fuel consumption and smoke emissions models (Reinhardt *et al* 2001), fire danger models (Deeming *et al*. 1977) and fire risk studies (Thompson *et al*. 2011).
Quantitative accuracy assessments are essential for evaluating map quality and fire simulation outputs. Fire growth predictions should, for example, identify those fuel types that generate high fire intensities but are mapped with poor accuracy. Furthermore, accuracy assessments should indicate if additional fuel sampling is needed for the fuel models mapped with a low level of reliability. Accuracy assessments are critical in fuel mapping because most fuel classifications efforts use indirect techniques where the vegetation types are the main mapped entity and not the fuel beds. For that reason, accuracy assessments should be explicitly built into any standardized fuel mapping approach. Moreover, low accuracies could also be a result of inherent sampling and analysis errors such as scale differences in field data and mapped elements, improper use of vegetation as fuels classifications and differences fuel spatial variation.

4. **Conclusions**

This study performed an extensive accuracy assessment of the ArcFUEL fuel types based on a field campaign and standard photointerpretation procedures The resulted fuel type maps accompanied by accurate measurements of fuel physical and chemical properties (fuel load, bulk density, surface area to volume ratio, moisture of extinction, heat content) would provide high resolution raster files of fuels which are the required inputs in most fire simulation systems, such as FARSITE and FlamMap. Further validation of the data set by sampling a larger number of field plots would substantially improve the ArcFUEL spatial data set.
Maps depicting fuel types are essential to fire and land management at many scales because they can be used to compute fire hazard, risk, behavior, and effects for planning and real time wildfire applications. Future efforts for classifying and mapping fuels need to incorporate measurements of canopy fuels (e.g., Mediterranean conifer forests), as well as, the quantification of fuel spatial variability in order to play an important role in revising and refining the resulted fuels maps. Since no other spatial fuel data sets exist with capabilities in wildfire behavior and effects, the proposed fuel classification scheme could be applied for supporting fire management activities on interim basis.

5. **Acknowledgements**

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