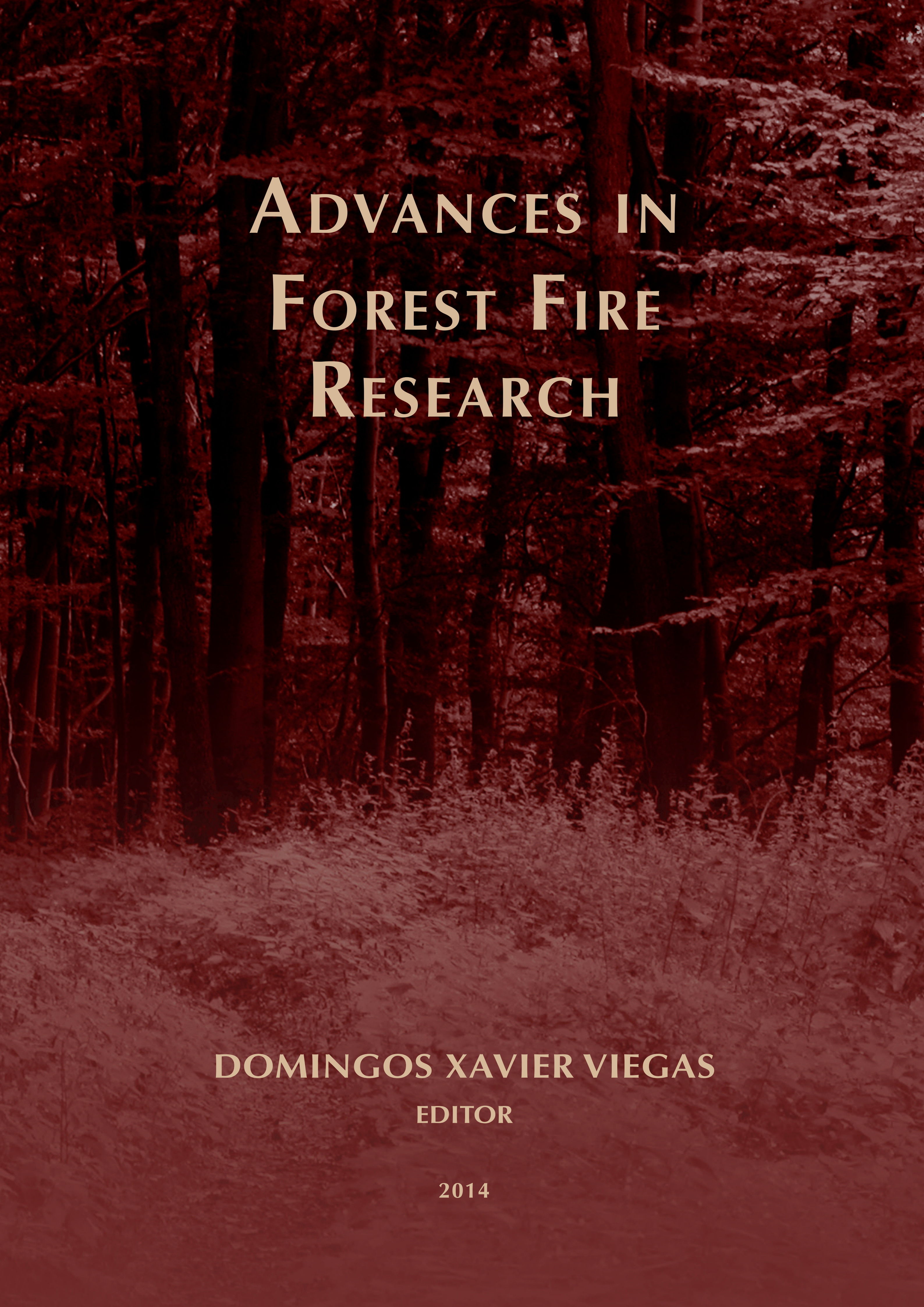

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LIFE ArcFUEL: Mediterranean fuel-type maps geodatabase for wildland & forest fire safety

M. Bonazountas[a], A. Astyakopoulos[a],G. Martirano[b], A. Sebastian[c], D. De la Fuente[c], L.M. Ribeiro[d], D.X. Viegas[d], G. Eftychidis[e], I. Gitas[f], P. Toukiloglou[f]

[a] *Epsilon International SA, Monemvasias 27 Marousi-Greece,* bonazountas@epsilon.gr
[b] *Epsilon Italia srl, Via Pasquali 79 Mendicino-Italy,* g.martirano@epsilon-italia.it
[c] *GMV Aerospace & Defence SA, Juan de Herrera Boecillo Valladolid-Spain,* asebastian@gmv.com
[d] *ADAI, Coimbra, Rua Pedro Hispano 289 Coimbra-Portugal.* luis.mario@adai.pt, xavier.viegas@dem.uc.pt
[e] *Algosystems SA, Syggrou 206 Athens-Greece,* geftihid@algosystems.gr
[f] *AUTH, Aristotle University of Thessaloniki P.O. Box 248-Thessaloniki Greece,* igitas@for.auth.gr

Abstract

ArcFUEL [1] is a LIFE+ Project that involves six European Partners with the objective of producing updated fuel maps to be used in forest fire management operations and geoplatforms. The ArcFUEL project delivers a complete, up-to-date, methodology for Fuel Classification Mapping (FCM on a Web-Geodatabase) based on "readily available" data, harmonized, accessible and interoperable according to INSPIRE principles, for the Mediterranean Region. This paper outlines the: (i) history of the Fuel Classification Maps (FCMs), (ii) the problem targeted in fuel mapping, (iv) the significance of FCMs for Forest Fire (FF) Management, (v) the ex-novo ArcFUEL methodology developed within the project, (vi) two case studies applied in Spain and Portugal, (vii) the field validation process and (viii) the final results derived from the project.

Keywords*: wildland, forest fire management, fuel maps, fuel types, LIFE, ArcFUEL, ESRI ArcGIS, QRASS GIS*

1. History

Fuel Classification Maps (FCMs) production started in the 90's when experts used the reclassification vegetation type's method to produce Fuel Maps from Forest & National Maps based on assumptions [2]. In the last decade established forest fuel catalogues (NFFL, Scott & Burgan, and PROMETHEUS) were used in several FCM projects in combination with Remote Sensing Techniques [3] [4] [5] [6] [7] [8]. A number of projects on fuel mapping for operational purposes have been accomplished in several European countries [9]. However, with some exception [10], these efforts concentrated at local or regional scale, and no maps at national scale are produced. Fuel type mapping was also approached at a pan-European within the FUELMAP Project [11]. This project derived a novel fuel classification adapted to European environments that enables a high level harmonization of the different fuel mapping initiatives. Yet, the JRC's fuel map was not meant for local scale applications.

ArcFUEL compiles information from past FCM efforts, utilizes ancillary data, and delivers a new era of FCMs, an ex-novo methodology and workflow.

2. The problem targeted

Effective Forest Fire (FF) Management requires knowledge of Fuel Classification Maps (FCMs) that are poorly available in Mediterranean countries since they are produced only at local or regional scale, without any regular updates and/or using standardized methodologies. Therefore available FCMs cannot support the systematic use of FF modelling at operational levels (prevention, suppression planning) of FF management.

3. Why FCMs for FF Management?

Forest vegetation is considered as a "fuel" and its structure and status govern the dynamics of a fire. This is the reason why Fuel Models and their spatial patterns (i.e. FCMs) are significant for FF Management Actions during all four phases of the FF lifecycle: 1 (Awareness phase - prior to the fire), 2 (Emergency phase - during the fire), 3 (Impacts phase - after the fire), 4 (Dissemination phase - lesson learnt). Moreover, fuel models are dynamic; either due to natural or anthropic causes (mostly because of the latter), the composition and loading of forest fuel changes and hence the need for up-to-date forest fuel information.

4. The ArcFUEL methodology

The ArcFUEL methodology consists of cascaded steps based on the use of multi-temporal LANDSAT [12] Thematic Mapper (TM) images for the distinction of fuel classes with different seasonal characteristics and further refinement based on ancillary data, such us burned areas, and canopy cover density data [13] derived from satellite observations. In more details, the ArcFUEL methodology is accomplished in 2 major blocks: (i) pre-processing of Landsat satellite imagery and (ii) forest fuel classes mapping.

The pre-processing of Landsat scenes involved:

1. Searching, selecting, ordering / downloading Landsat scenes (5TM or 7 ETM+ SLC-) of interest via the official sources (USGS' Landsat archive, GloVis and EarthExplorer web-services). The selection criteria are strict in the sense to get as much as possible cloud free acquisitions which, in addition, were timely as close as possible. All Landsat scenes in a geospatial database
2. Trimming scene border fringes
3. Converting Digital Numbers (DNs) to Top-of-Atmosphere Reflectances (ToAR) by normalizing either a statistical approach for most cloud-free scenes, or the 6S algorithm for scenes that were significantly cloud-contaminated (as per the cloud cover percentage estimation given in the metadata, as well as after visual control).
4. Detecting clouds and cloud shadows
5. Topographically correcting Imagery by using the Minnaert method (insert reference?) based on the ASTER GDEM2 dataset.
6. Relatively normalizing images (separate handling for each spectral band and season) to balance up seasonal radiometric variations based on the Histogram Matching technique.
7. Creating a large surface reflectance mosaic (for each band) for the whole study area.

The forest fuel classes map production comprised the following steps:

1. Extracting major vegetation classes from existing land data bases, i.e. (i) forested areas (Broadleaved, Coniferous and Mixed) from JRC's Forest Type Map (2006), (ii) surface fuels from JRC's Forest Fuel Type Map (2006), (iii) ground and azonic fuels (and non-fuels) as the remaining areas from the Corine Land Cover 2000/6.
2. Separating deciduous and evergreen vegetation (and, similarly, grasses and shrubs) is done via a bi-temporal classification approach, i.e. clustering and classifying the seasonal vegetation index difference inside the two main vegetation categories (forest and surface fuels) [14] [15]. Clustering is performed by implementing a modification of the K-Means algorithm.
3. Sub-classifying the above vegetation classes based on forest density criteria [16]. This is done by using JRC's up-to-date Tree Cover Map.
4. Filtering spatially and temporally relevant burned areas extracted from JRC's [17] Burnt Area Perimeters data base [18].

5. Additionally, sub-classifying the fuel type classes can be achieved by incorporating JRC's Environmental Zones [19] (Eco-Regions) classification.

Figure 1 below presents the whole ArcFUEL methodology.

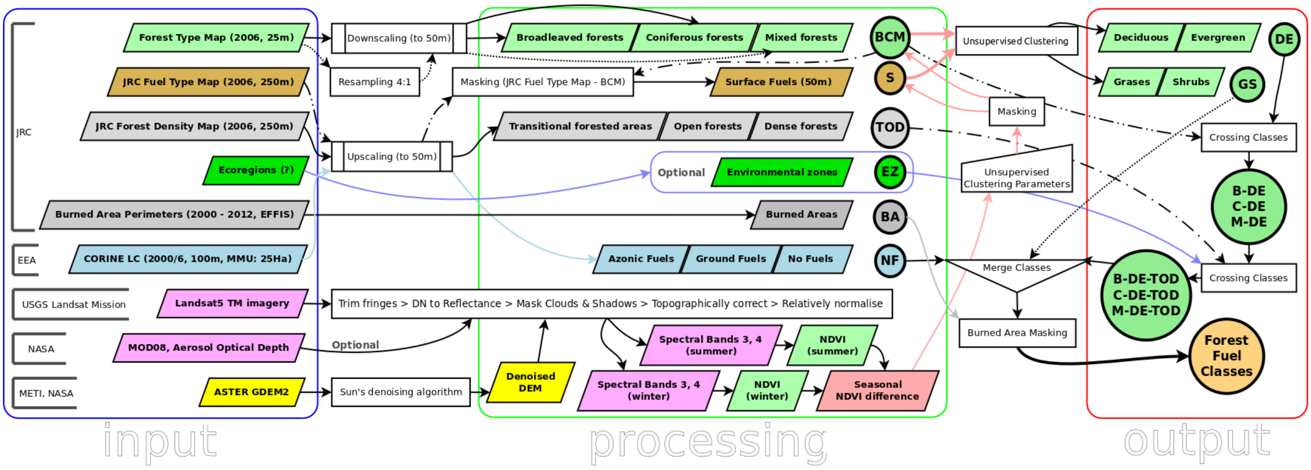

Figure 1. ArcFUEL methodology

5. Case Study

Two case studies are presented, one in Portugal and the second in Spain. In both cases the study consisted on two phases, a prior testing of the methodology in a smaller pilot area, and the implementation of the refined methodology over a larger area of interest.

Phase I: The pilot area chosen was located in Central Portugal in the area of the Lousã Mountains, part of the NATURA 2000 Network (Figure 2). The most representative species of forest stands and shrublands for Portugal occur in this region. It is an area of 10000 ha delimited by the coordinates 40º7'N – 40º13'N and 8º15'W – 8º7'W, and with altitudes ranging 80-700m. The region, falls inside the "Lusitanian" Ecorregion.

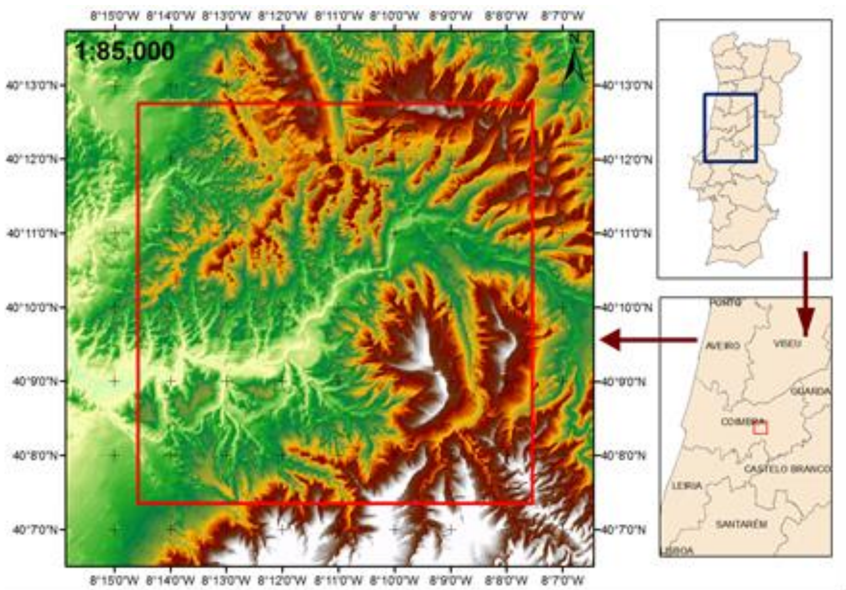

Figure 2. Portuguese pilot area (red box) (Phase I)

The application of the methodology in this first phase produced the map shown inFigure 3. It was proven to be an easy to use procedure although some fine tunings had to be done, particularly regarding the definition of the density parameter. A couple of methodologies were tested and it was finally decided to use the density cover map produced by JRC [20] and freely available.

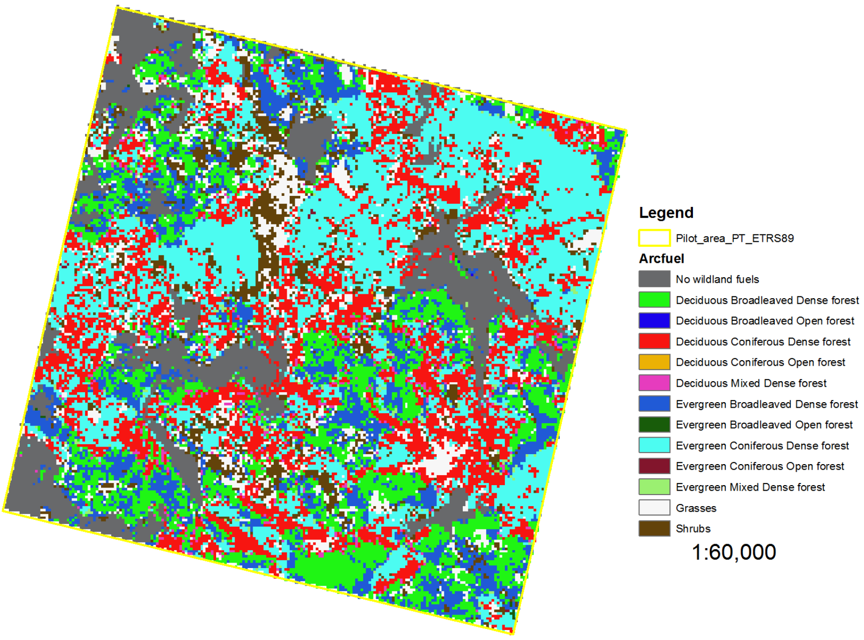

Figure 3. Phase I PT Pilot Area fuel map (reprojected to ETRS 89))

Phase II: After tuning the methodology the ArcFUEL fuelmap was produced for the entire Portuguese (islands excluded). The work was performed with the GIS tools ArcMap 10.1 [21] and Grass GIS 7.0 [22]. The workflow consisted of the following general steps of the production chain:

- Mapping of the main ArcFUEL vegetation classes
- Multi-temporal analysis
- Refinement of the produced fuel classes based on density cover
- Merge of all the produced map layers in a single one
- Combination of the fuel classes with Ecoregions data

A crucial part of the methodology application was the selection of good clear Landsat images. For Portugal we had to go back to 2007 and use Landsat 5 images as they were the only acceptable ones covering the entire country. The new Landsat 8 should provide new up to date images that will allow us to update the maps. All areas burned in 2007 were masked from the final map (Figure 4).

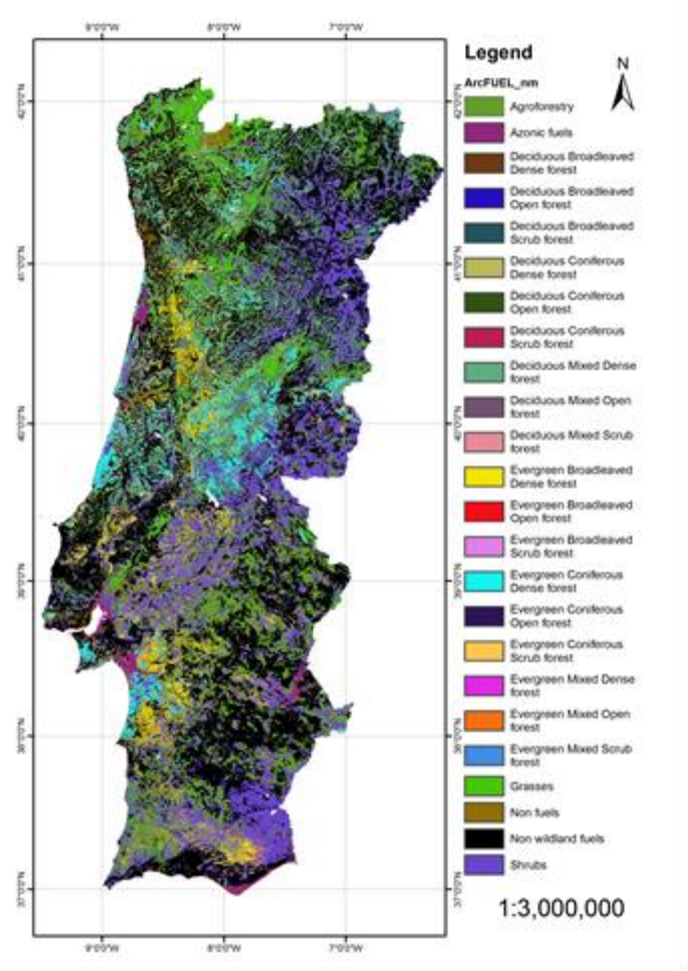

Figure 4. Final ArcFUEL map for Portugal mainland

The accuracy assessment of the produced map is currently being performed. A predefined number of control points is being directly checked in the field in order to check for the map consistency and reliability. At the moment, and after slightly more than 2/3 of the field campaign finished, the matching between the produced map and the reality can be considered visually satisfactory. Further statistical analysis will allow us to define a more reliable accuracy percentage.

5.1. **Case study in Spain**

The pilot area chose for Phase I was the Sierra de Las Nieves Natural Park, located west of Málaga province (Andalucía region), inside a Biosphere Reserve of the same name, showing very high terrestrial biodiversity. The area covers 20.163 ha and shows a high elevation gradient, raging in few km, from near the sea level to circa 2000 m (highest elevation peak at 1.919 m).

The area of interest (AOI) selected for Phase II in Spain was made up by the provinces of Málaga and Córdoba (north of Málaga), both in Andalucía region.

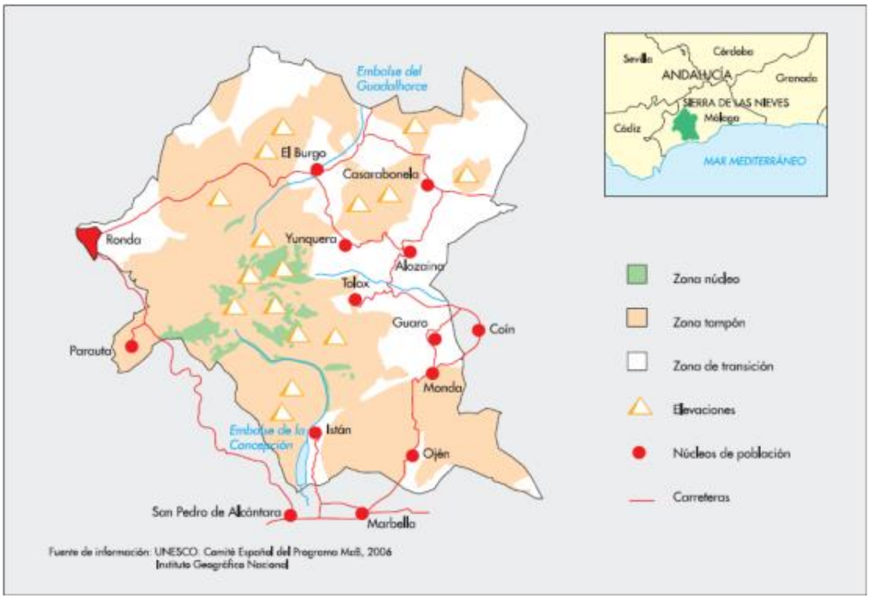

Figure 5. Biosphere Reserve of Sierra de las Nieves (Phase I)

Six Landsat 5TM images were used to cover the entire area in spring-summer, and another six to cover it in winter. Images date from year 2009, 2010 and 2011.

Erro! A origem da referência não foi encontrada. below shows the ArcFUEL fuel types derived over the entire area of study in Spain. The map shows a clear predominance of a few classes: Broadleaved Evergreen Scrub (18%), Broadleaved Evergreen Dense (32%), Coniferous Evergreen Dense (21%) and above all, Shrubs (42%). The non-wildland fuels represent a 17% of the study area. To assess these results a two-step validation was performed:

Validation step 1 (over pilot area)**:** focused on the discrimination between deciduous and evergreen species. This was done using the National Forest Inventory (NFI3) field plots, distributed in a regular 1-km grid.

Crossing the ground- truth with the classification values at each of the 163 IFN3 plots falling within the “Deciduous”/ ”Evergreen” classes of the pilot area yielded very satisfactory results (95,6% overall accuracy), particularely in what concerns Evergreen forests. Conversely the discrimination of Decidous trees in the classification was not always correct (33% commission error). The impact of this is not relevant since the percentage of the area covered by Deciduos vegetation was less than1,6%. A similar procedure was followed to assess the discrimination of Shrubs and Grasses, and comparable results were obtained: (86,7% overall accuracy).

Validation step 2 (over Málaga and Córdoba): focused on the discrimination of vegetation assemblages, a concept closer to the term “fuel type” (e.g.: dense pine plantation with high shrubs, or abandoned olive trees plantation with grasses and dispersed shrubs).

For this purpose two ancillary sources having information on vegetation assemblages were used as ground truth:

I. The LUCAS (Land Use / Cover Area Frame Statistical Survey) multipurpose (agriculture, environment) field survey, with more than 250.000 sample points throughout the EU. LUCAS 2009 campaign was downloaded from EUROSTAT Web site [23] (free access).

II. The Integrated product “SIOSE” [24] plus “Vegetation map of Andalucía” (scale 1:10.000), property of the Andalusian Government (free access).

By crossing the classification values with the validation sources (LUCAS and SIOSE) at the 171 valid LUCAS plots falling within the AOI, we deduced that 136 of them were correctly classified (80%) while 35 were not (20% error).

The analysis per fuel type class showed again particularly good results for the Shrubs (90%) and Coniferous Evergreen classes (96%). Whereas the plots falling in the Broadleaves Evergreen Dense, and specifically those in deciduous classes (incorrectly classified) were not enough in number to draw any conclusion.

It must be noted that several inconsistencies were observed between LUCAS and the Andalusian Land Use/Vegetation Map, on the one hand, and the EU layers defining the first levels of ArcFUEL classification on the other (CLC [25], the Forest Types Map). Nonetheless results yielded (80% of correctly classified plots) evidence a satisfactory performance.

Overall this work has been a rather intense exercise of assessment, as the classification was crossed with field data and local scale maps with information on vegetation assemblages in a significant number of points. Moreover, this exercise was difficult since the intervening ancillary datasets have different reference date (2005 and 2009), level of detail and legends. It is concluded that the difference in dates (Landsat scenes leading to the classification map dated 2009-2011) might be behind the poor results shown by the most dynamic classes: Grasses, on the one hand, and Deciduous species, on the other.

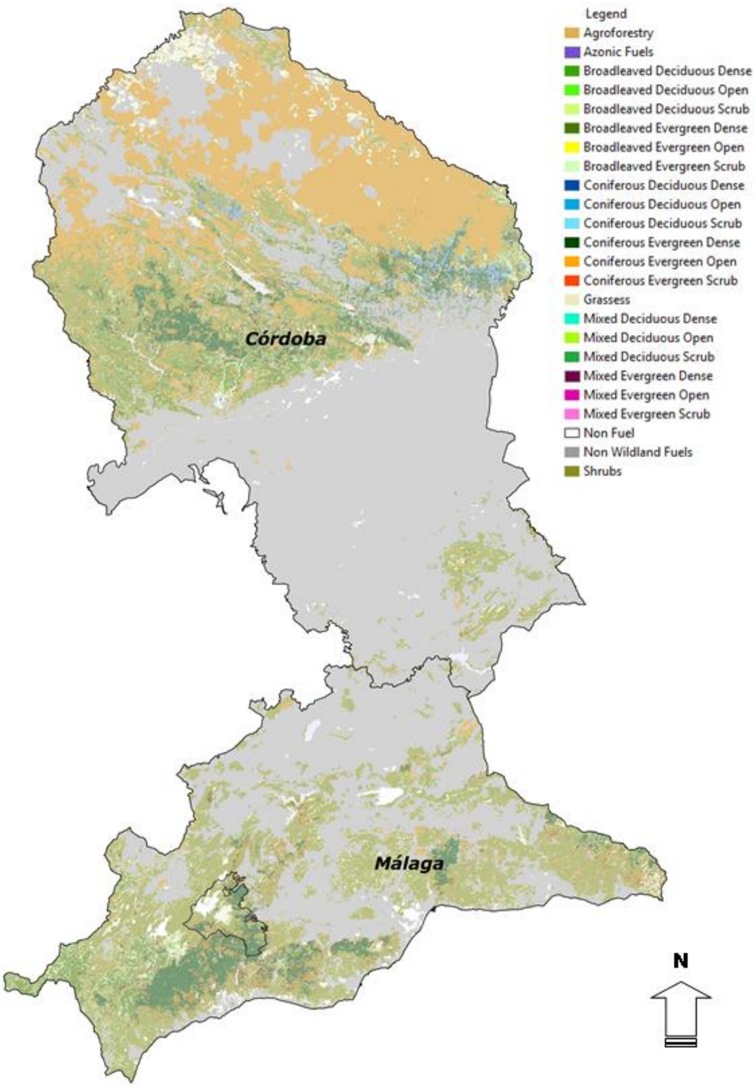

Figure 6. ArcFUEL fuel types over the study area in Spain (21.077 km2) and Pilot area (202 km2).

6. Field Validation

Purpose of the field validation is to create a dataset of point values for validating the ArcFUEL map. This comprises of the following steps:

1. We overlay LUCAS points to the ArcFUEL map and we separate LUCAS in two subsets of data, one with the LUCAS points which description coincide with ArcFUEL characterization and another with the LUCAS points which description differs from ArcFUEL. We keep the first subset as part of the ArcFUEL validation data set.
2. We use the second subset of point 1 and apply the following methodology per region:
    a. We select in each region randomly LUCAS points from the second subset and create the second part of ArcFUEL data set.
    b. We define a number of sampling points per region depending on its extent.
    c. We take care including all ArcFUEL types (AFT) in the data set derived.
    d. Sample points are located in a distance <300m from road and in slope <40%.
3. We randomly select 5% of the number of points defined in 2.b in elevation >1000m (LUCAS points are up to 1000m) taking into account the coverage of the ArcFUEL types.
4. During the field work:
    a. We fill the form with the data that we have defined (we have developed an android application for collecting these data).
    b. We allow taking as sample point a point close to the LUCAS point but representing better the forest fuel type in the specific location.
    c. We take additional sample points of representative fuel types along the way moving from one point to another.

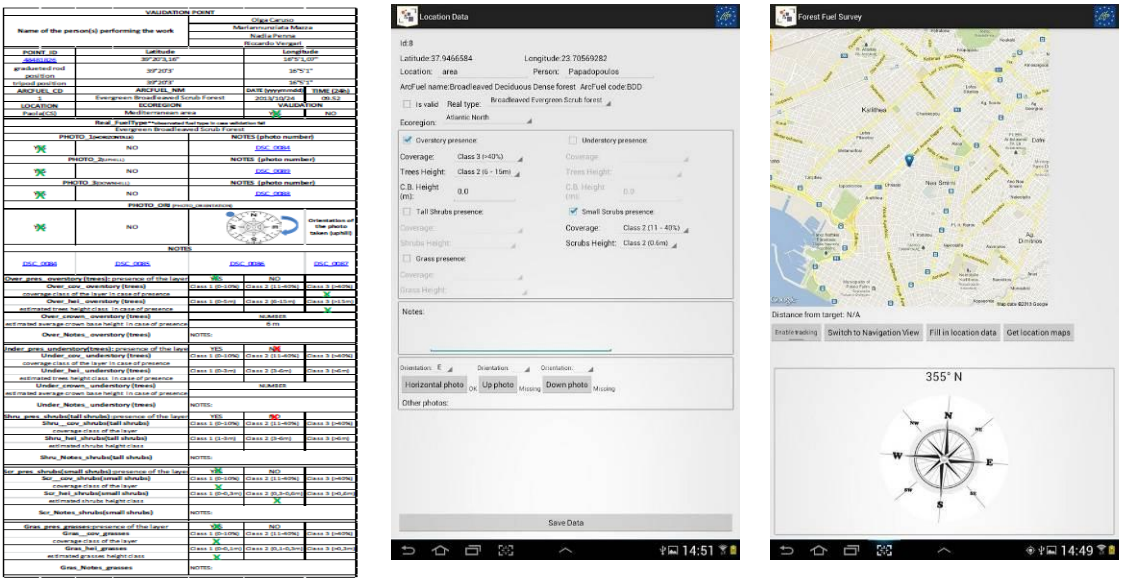

Figure 7. Field validation application, location data

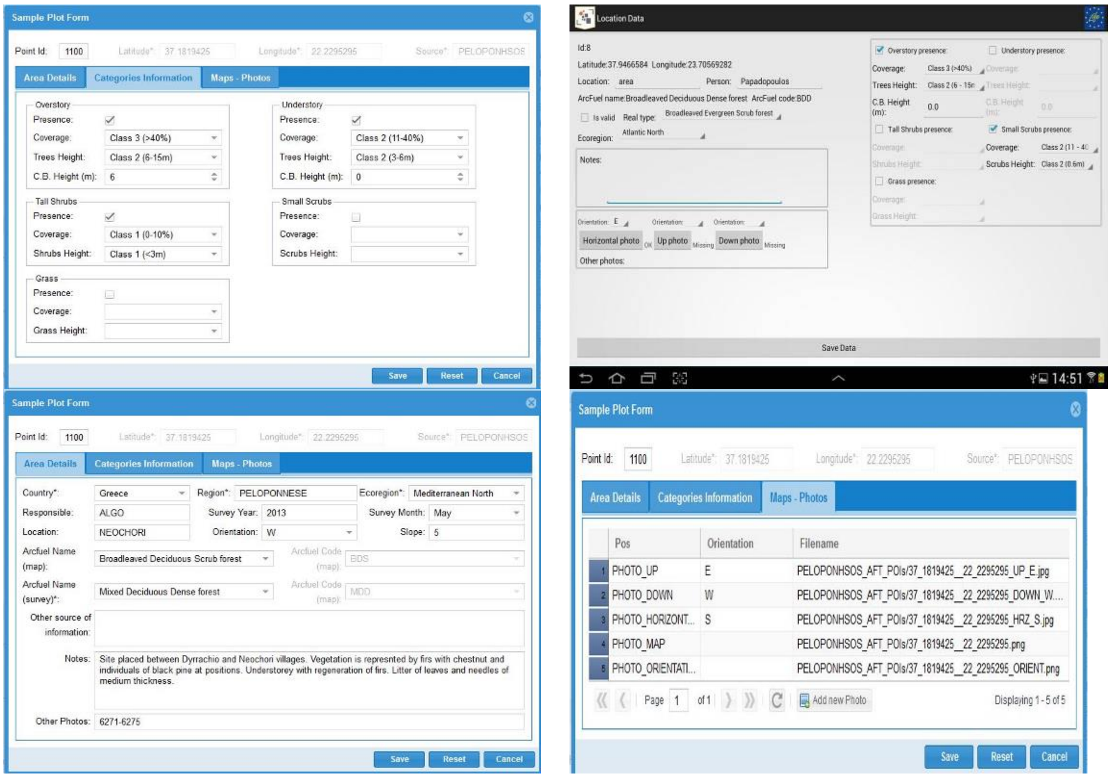

Figure 8. Field validation application, sample plots

5. We aggregate all data from the subsets mentioned above in point 2 (LUCAS=AFT), 3 (LUCAS≠AFT), 4 (>1000m) and 5 (additional AFT based points) for deriving the ArcFUEL validation data set.
6. In defining the above methodology we consider:
   a. We wanted to create a data set of point information for validating the accuracy and quality of the ArcFUEL map. Thus the main purpose was to create such a data set with distributed points, covering the area of interest and including all the fuel types present in each of the areas.
   b. We used LUCAS points in order to have information for a number of these points without new ArcFUEL survey but based on the new LUCAS survey data.
   c. We had to check deviation from LUCAS characterization in the field to see if and what the problem is.
   d. We had to enrich the ArcFUEL data set with additional points e.g. points at elevation greater than 1000m or points of representative fuel types.
   e. We considered 250 sample points to be distributed all over Greece and Portugal for the ArcFUEL map validation data set after the end of the field survey.

7. Fuel maps.

The LUCAS point dataset description was checked again to the ArcFUEL classification map to isolate points correctly classified. In addition to this overlay approach visual inspection using large scale orthophotographs of KTIMATOLOGIO SA [26] and Google Maps [27] was performed in order to identify any inconsistencies. A selective sample of these points is presented especially for randomly selected NATURA sites around project’s areas.

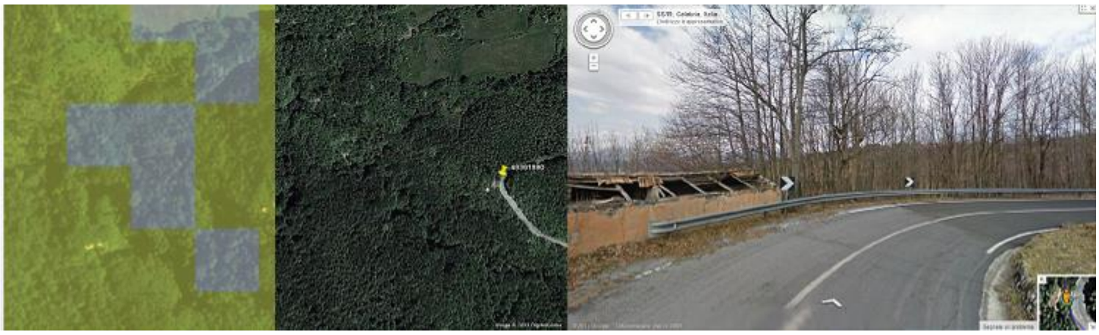

Figure 9. Visual inspection to identify inconsistencies

8. Conclusions

The ArcFUEL methodology was tested and demonstrated producing forest fuel maps for Greece and Portugal at national scale and Italy and Spain at regional scale. The quality of the mapping was validated against field data.

During the field survey the ArcFUEL Consortium visited a total of 670 points in 4 countries, namely Greece, Portugal, Italy and Spain. The accuracy of the ArcFUEL methodology proved quite good, as it reached 73,2%. In detail, number of points visited during the field survey and accuracy of the ArcFUEL methodology in each country was:

- Greece: 298 points (81%)
- Portugal: 275 points (67%)
- Italy: 41 points (76%)
- Spain: 56 points (60%)

ArcFUEL delivered forest fuel maps with spatial resolution of 50x50m for Greece and Portugal at the country level and fuel maps of selected regions in Italy (Calabria and Sardinia) and Spain (Malaga, Cordoba).

ArcFUEL methodology proved to be a comprehensive method for rapid classification of forest vegetation into fuel types, delivering relevant input layers for fire modeling at an appropriate spatial resolution, using freely available data. Any future update of the input maps used in the ArcFUEL project will strongly improve the accuracy of the forest fuel maps. Synchronizing further the time reference of the input layers in the FCM production shall greatly improve the quality and accuracy of the ArcFUEL products.

The final fuel maps for Greece, Portugal, Italy and Spain are presented below:

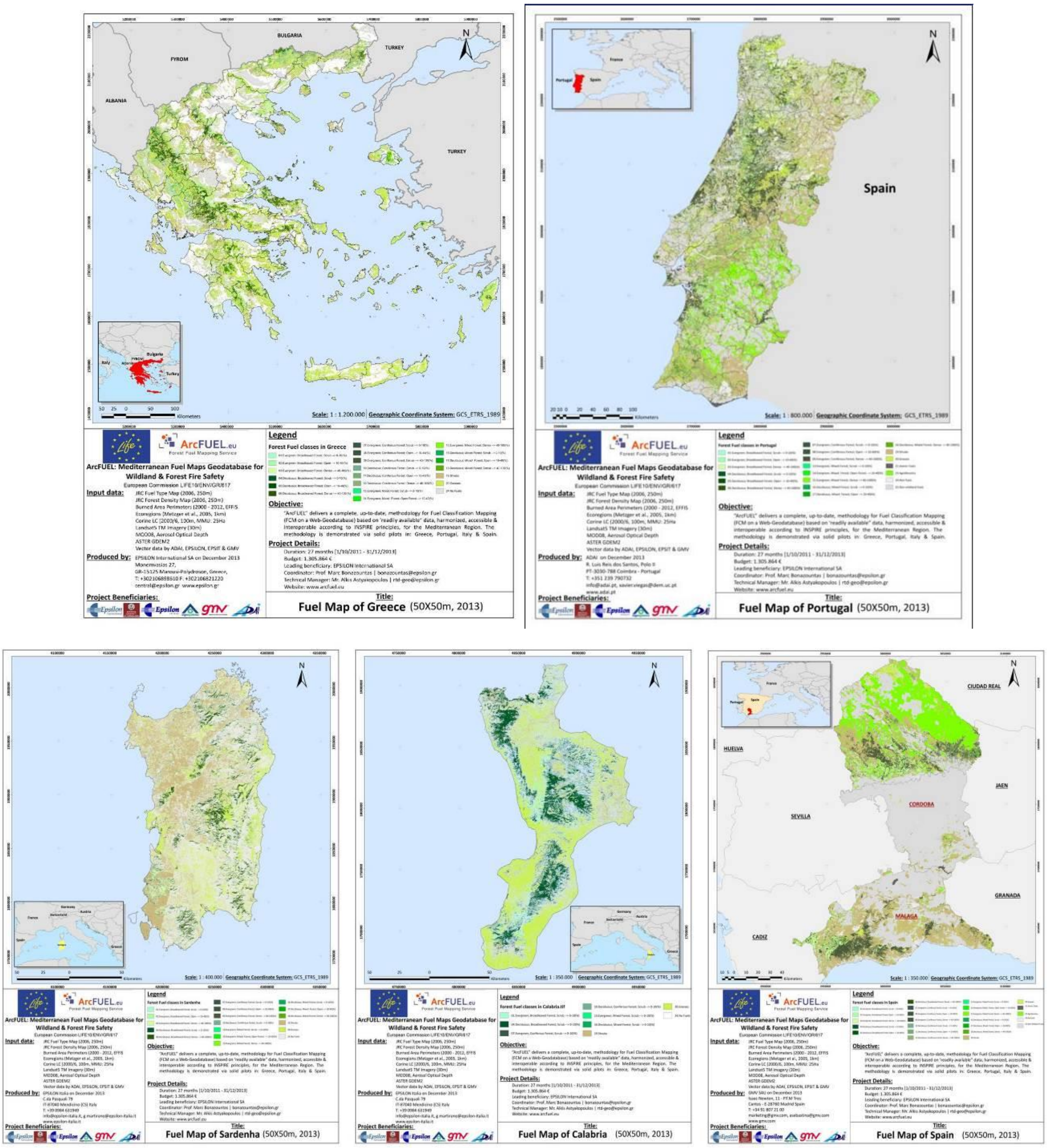

Figure 10. ArcFUEL final fuel maps

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