3D GEO-VISUALIZATION OF MEDITERRANEAN SHRUBS IN DIFFERENT SPATIAL SCALES FOR LANDSCAPE FIRE MANAGEMENT

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ABSTRACT

Surface fire fuels are the primary source of combustion in most wildland ecosystems. Mediterranean shrubs constitute important understory surface fuels, as they are mainly dry and flammable during the summer fire season. Critical forest fuel properties for fire prevention and control are species composition, density, structure, and vertical and horizontal continuity. This paper refers on a three-dimensional visualization system of shrub fuels in different spatial scales that was developed using high-resolution QuickBird satellite imagery and *in-situ* data of shrublands measured in field surveys at Kratigos National Forest, Lesvos Island, Greece. The main objective was to provide a methodology for the integration of *in-situ* shrub data (detailed spatial information) and a 3D Graphics Software (Visual 3D Nature) via Geographic Information Systems (GIS) to develop a useful tool for construction of multi-scale 3D landscape models for fire management. Selection of utilized optical variables and explicit processes were analyzed and presented for the visual optimization of shrub fields in different spatial scales. Emphasis was given not only on the suitability of optical variables regarding visualization, but also on the sources, demands and limitations that were applied in each case. The results showed that the proposed 3D visualization plays a key role in understanding the structure and spatial distribution of surface shrub fuels in different scales for end-users involved into forest fire ecology and management.

Keywords: Mediterranean Ecosystems, Wildfire Fuels, Spatial Scale, 3D Visualization, High-Resolution Remote Sensing, GIS

1. INTRODUCTION

Fire is a dominant disturbance in many wildland ecosystems worldwide (Mooney *et al*., 1981; Pyne *et al*., 1996; Morgan *et al*., 2001). The Mediterranean region is particularly susceptible to wildfires. The Mediterranean ecosystem comprises a heterogeneous and highly fragmented mosaic of grass, shrub, wood and forest lands that form a complex and highly variable vegetation cover within an equally complex and highly variable land use and terrain setting.

Fire occurrence and propagation are strongly correlated with the morphology (height, density), chemistry (flammability), status (moisture content) and quantity of vegetation that are grouped into fuel models. Forest fuel is one of the most important factors that influence wildfire behavior (Rothermel, 1972) and knowledge of fuel distribution is an invaluable tool for forest and fire-fighting services (Banninger *et al*., 2002). In Mediterranean-type ecosystems, fire propagates mainly through a fuel bed of shrubs that exist both as open shrublands and as forest understory during the summer fire season, when shrubs are mainly dry and flammable. Critical forest fuel properties for fire prevention and control are species composition, density, structure, and vertical and horizontal continuity.

Fuel maps are essential for computing spatial fire hazard and risk, and simulating fire growth and intensity across the landscape. Comprehensive and accurate fuel mapping integrates extensive field sampling, GIS data sources and high resolution satellite imagery (Keane *et al*., 2001). Satellite remote sensing data are able to provide fast and efficient analysis and interpretation of site features and conditions and, because of their digital format, are compatible with geographical information and visualization systems (Banninger *et al*., 2002).

Geographic visualization has an important role in geographic research as it provides a meaningful tool for geographical data representation. The increasing power of information technology permits to create more accurate 3D geovisualizations in different scales. The aim of this paper is to present the methodology followed for the creation of the 3D landscape fuel models of Kratigos area in Lesvos Island based on data derived from high-resolution QuickBird satellite imagery and *in-situ* data measured in field surveys in different spatial scales. In this paper will discus scale issues in 3D fuel model visualization in different scales and issues related to selection of the appropriate optical variables for different vegetations species.

Visualization is a useful tool for representing projections of vegetation structure, species composition and landscape conditions. Modeling and rendering of forest scenes based on field data from GIS is an important and challenging problem in forestry applications (Yu *et al*., 2004). The basis of the 3D visualization of the study area is the development of a complete 3D landscape model generated from remote sensing data as well as additional geo-information (Almer *et al*., 2002). By the 1980's, computer storage and display were replacing the need from hand-drafted paper maps for the representation of geographic information (Monmonier, 1985).The growth of computer technology has allowed some degree of automation in the modern production of three-dimensional landscape renderings. Computer software is being designed specifically to display three-dimensional datasets, removing some of the abstraction present in two-dimensional maps (Almer *et al.*, 2002*)*. The three-dimensional presentation of geo-information is important for scientists, but also for decision makers in forest and fire-fighting management both for the planning of precautionary measures and in general decision making procedures (Stelzi *et al.*, 2004).

The objective of this research has been to provide a methodology for the integration of detailed spatial information (*in-situ* shrub data) and 3D Graphics Software (3D Visual Nature Studio) via Geographic Information Systems for the development of multi-scale 3D landscape models for fire management. High-resolution Quick-Bird satellite imagery and a Digital Elevation Model were used for the development of 3D visualization, along *in-situ* data of shrublands measured in field surveys at Kratigos National Forest, Lesvos Island, Greece.

Moreover, visualization results from the view of used data will be examined in this paper. That means relationships and differences between in-situ data visualizations and imagery derived data visualizations visual results will be discussed in order to resolve the "Exist data problem" in the way of choosing, merging and treating Geodata for Geovisualizations. "Exist data problem" is the creation of a big variety and multipurpose visualizations by using existing or the first available geographical data from a very wide number of sources in order to create digital representations (of any size). "Exist data problem" has to do with data that don't have the appropriate spatial characteristics to give the correct result according to the objective of geovisualization but the demands and limitations that apply in each case as well.

2. STUDY AREA

The island of Lesvos covers an area of 1672 km^2 with a variety of geographical formations, climate conditions and vegetation types (i.e. forests, shrub fields, grasslands and agricultural lands). The *Kratigos National Forest* (KNF) test site is located in the southeastern peninsula of Lesvos Island, around 15 km south of the city of Mytilene, covers an area of 648 ha and encompasses a diversity and mixture of grassland, shrubland and pine forests. KNF is extended from S-SE to N-NW and is characterized by coastal areas and low elevation ranges. The terrain is rather hilly with its highest peak at 547 m altitude.

The research was conducted on the top of the "Kourteri" peak in KNF. The study site covers an area of 60 ha and the vegetation is characterized by phryganic formations (*Cistus spp., Sarcopoterium spinosum),* maquis-type shrubs (*Pistasia lentiscus, Quercus infectoria)* and pines (*Pinus brutia*) (Figure 1).

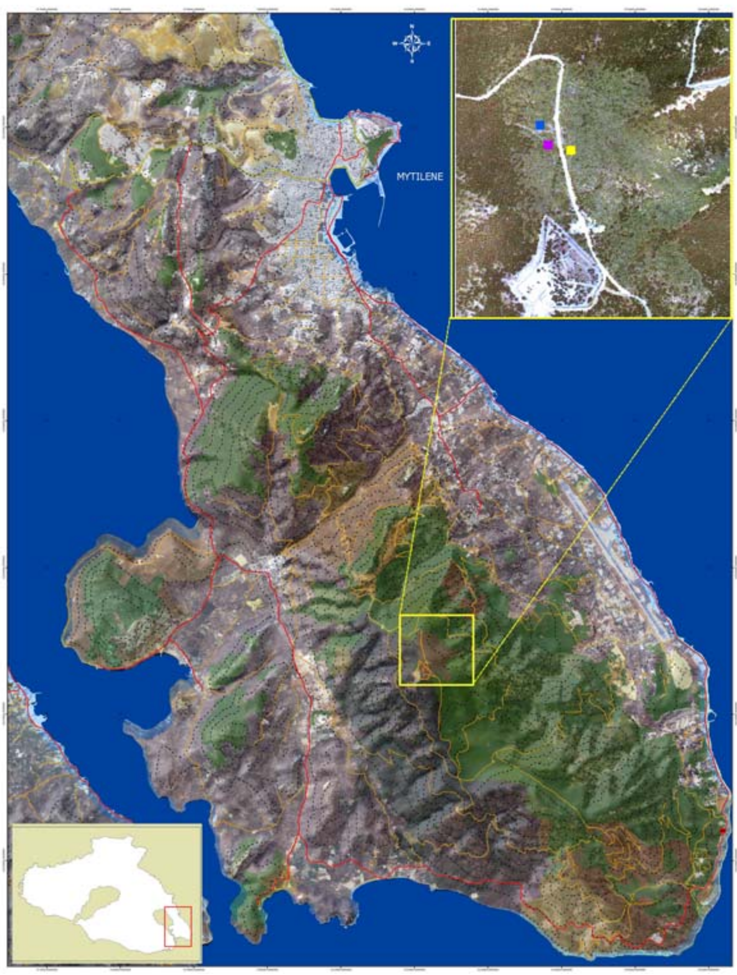

Figure 1: Map of Study Site, Kratigos National Forest, Lesvos Island, Greece

3. DATA AND METHODOLOGY

Surface shrub fuels can appear in different spatial and vertical structural arrangements, varying from a continuous dense shrub cover to sparsely distributed patches over herbaceous layer. In order to assess the frequency, composition and structure of plant communities, field measurements were taken in line transects as sampling units, a method called “line intersect sampling” (Gore and Paranjpe, 2001). Furthermore, a geo-database was developed to unify *in-situ* data in groups with common visual attribute and spatial reference. The developed database was used as input to mapping purposes and three-dimensional visualization.

3.1 Data pre-processing (in-situ data)

Fuel sampling was carried out in a shrubland in Kratigos National Forest during the summer of 2003. In particular, three shrub sampling plots (20x20 m) were established in the study area, including phygana (*Cistus spp.*, *Sarcopoterium spinosum)* and mixed evergreen sclerophylous shrubs (*Quercus coccifera*). Sampling plots were selected in homogeneous stratification to be representative of the study site. The plots were delineated and the coordinates of their corners were measured with GPS. Moreover, all these plots were photographed and the vegetation in them was characterized and measured thoroughly. In shrub plots, vegetation cover and height were determined by systematic measurements along four parallel transects in each plot. Field-derived data regarding types and characteristics of vegetation in the three shrub plots of the study site are showed in Table 2.

In each transect the following measurements were taken:

(a) starting and ending point of each shrub

(b) maximum height of each shrub on the transect line, and

(c) the perpendicular width of shrubs intersected. This was an optional measurement and needed to estimate the plant density of the plot (Figure 2).

In each of the twelve transects, all shrubs were recorded individually, grouped and processed. In order for each shrub to obtain a spatial reference, each shrub should be marked as a point (Figure 2).

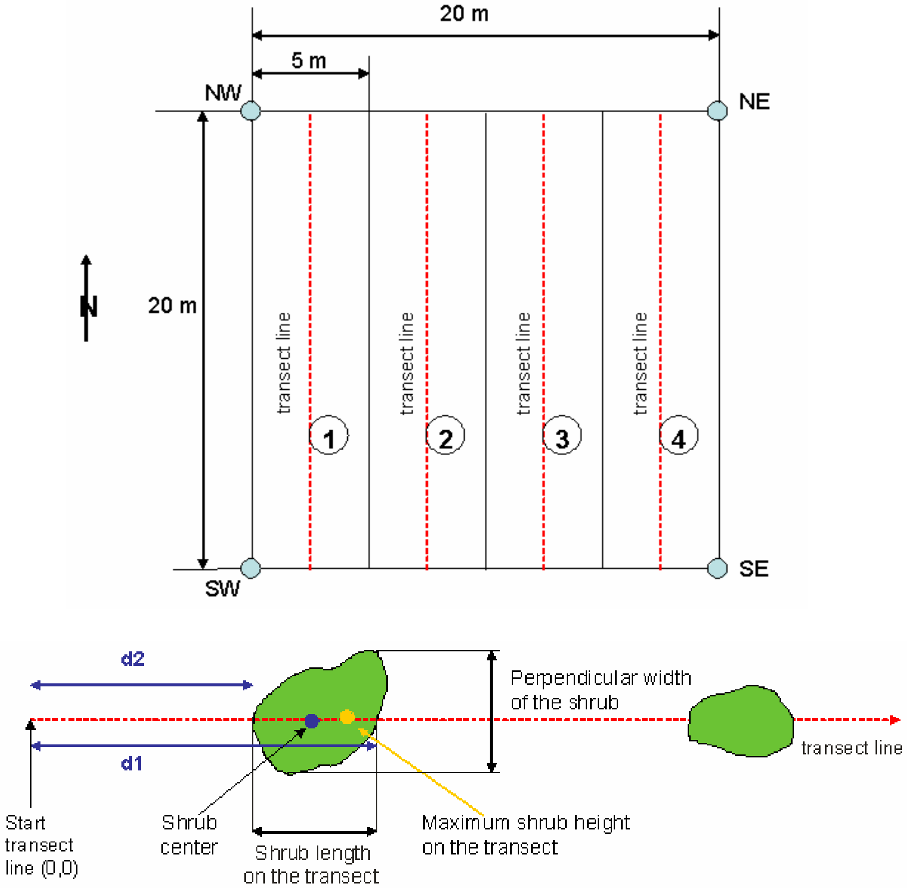

Figure 2: Sampling design for each shrub plot (20x20m)

On the recognition that the center of shrub length on the transect will be a point that characterizes each shrub, the center of each shrub length was measured from the beginning of each transect, following the equation:

$$C_i = \left[\frac{(d_1 - d_2)}{2} + d_2 \right]$$

where, Ci is the center of each shrub (i refers to the shrub number), d_1 is the distance from the beginning of the transect to the end of each shrub, and d_2 is the distance from the beginning of the transect to the start of each shrub on the transect. This procedure has as a result for each shrub to obtain attributes of geographical reference, height, length, width and species.

Plot No.	Species	Mean Shrub Height (cm)				
		T1	T2	T3	T4	Average
1	*Cistus Spp*	51.00	46.00	47.00	58.00	50.50
	Quercus infectoria	69.00	42.00	75.00	80.00	66.50
	Sarcopoterium spinosum	30.00	30.00	30.00	33.00	30.75
	Phillyrea media	160.00				160.00
2	*Cistus Spp*	54.00	52.00	54.00	68.00	57.00
	Quercus infectoria	75.00	69.00	93.00	96.00	83.25
	Sarcopoterium spinosum		35.00		34.00	34.50
	Phillyrea media		75.00	110.00		92.50
	Pinus brutia		105.00			105.00
3	*Cistus Spp*	55.00	61.00	49.00	51.00	54.00
	Quercus infectoria	62.00	64.00	71.00	68.00	66.25
Plot No	**Species**	**Shrub Cover (%)**				
		T1	**T2**	**T3**	**T4**	**Average**
1	*Cistus Spp*	41.30	28.00	37.35	33.90	35.14
	Quercus infectoria	18.70	20.35	15.75	33.50	22.08
	Sarcopoterium spinosum	6.50	9.00	7.75	8.25	7.88
	Phillyrea media	5.00	0.00	0.00	0.00	1.25
2	*Cistus Spp*	16.00	8.55	7.45	9.75	10.44
	Quercus infectoria	52.50	61.20	72.55	81.00	66.81
	Sarcopoterium spinosum	0.00	4.25	0.00	1.55	1.45
	Phillyrea media	0.00	3.50	3.50	0.00	1.75
	Pinus butia	0.00	7.25	0.00	0.00	1.81
3	*Cistus Spp*	31.75	17.25	9.00	27.75	21.44
	Quercus infectoria	53.00	73.60	48.00	54.30	57.23

Plot No	Mean Shrub Height (cm)	Shrub Cover (%)	Shrub Density (shrubs/m2)
1	57.77	66.34	2.43
2	70.77	82.26	1.08
3	60.13	78.66	1.40

Table 2: Biometric measurements from three shrub plots within the study site (KNF)

Moreover, the panchromatic Quick-Bird image (0.6 m resolution – acquired in 2004) is fused with the multi-spectral image (2.8 m resolution – acquired in 2002) leading to a pan-sharpened QuickBird imagery of resolution 0.6 m. The produced pan-sharpened Quick-Bird satellite image (0.6 m resolution) for the study site in KNF was used to extract useful geographical information to study landscape wildfires (e.g. fuel models, road network, land-use boundaries etc.). The classification of the surface fuel models is based on image interpretation.

Finally, a Digital Elevation Model produced from map sheets of scale 1:50000 has a resolution of 20 meters between data points and has been the most complete and highest resolution dataset available for Lesvos Island. At the end of process all vector data were unified into a geodatabase to create 3D models of the study site with the use of the 3D Visual Nature Studio software, not only for the study area but for each shrub plot as well.

3.2 Three-dimensional visualization procedure

The software 3D Visual Nature Studio 2.53 has been chosen for the present research.3D Visual Nature Studio (VNS) is software that brings geovisualizations to real life. VNS imports any GIS or geospatial data and makes all of the numbers and obscure information into a photorealistic image or animation that anyone can easily understand. VNS provides tools to control visualization directly from GIS data, simplifying and automating the process. VNS gives extensive support of readily available terrain, 3D object, vector, point, image, image sequence and GIS data formats (Visual Nature Studio, 2007).

More specifically, a three-dimensional visualization of shrub fuels was developed in two different spatial scales: a) study site (60 ha) and b) plot (20x20m). At study site scale, a geo-database was developed that included the digital elevation model (DEM), vector data of the classified information (e.g. fuel models, road network, land-use boundaries) for the study site and the pan-sharpened Quick-Bird satellite image (resolution 0.6m). At plot spatial scale, a geo-database was developed that included the digital elevation model (DEM), the pan-sharpened Quick-Bird satellite image and vector data produced by *in-situ* data of shrubs. Vectors indicating the position of shrubs were generated in the CAD program and imported into the 3D Visual Nature Studio software. The methodology used is presented graphically in Figure 5.

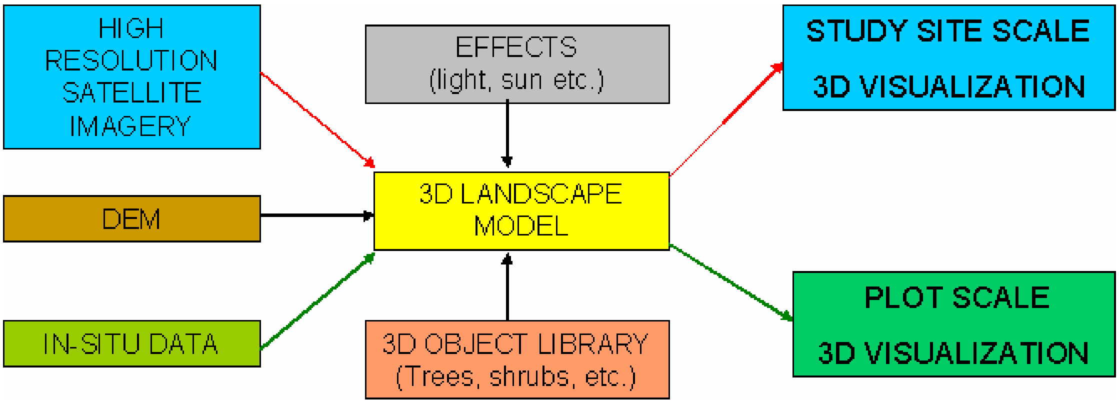

Figure 5: Methodology flow chart

Visual Nature Studio provides an important tool that detects the projection and file format of the DEM and projects it to VNS's internal format. Regarding the process, firstly, a project file for the study area is created, and then, the digital elevation model (DEM) and land cover data were loaded. The next step was to set the variables that were directly measured in the field (in-situ data), including camera information and sun position. Within VNS, a view camera was established to mimic an eye view of a person walking in the study area and its positioning was set, including latitude, longitude, elevation, roll, pitch and bearing. The sun position was set to correlate with the date and time the measurements were taken. Visual Nature Studio provides a tool that calculates the correct sun position in the sky based on this time information. Setting the sun position adjusted, the lighting of the rendered image was created to closely imitate this of the *in-situ* data.

An object library was developed containing all necessary forms of vegetation like trees and shrub species in order to visualise the study area as realistically as possible. Objects for artificial ecosystems such as pines, shrub and grass forms were found from the libraries of VNS and were categorized to approach the study area land use.

4. EVALUATION

In each scale, all available data are needed to be modified so as to be suitable for visualization, regarding the software's requirements. Particularly, the digitization of data collected in field survey was needed in the plot scale, while classification of the stands in the satellite imagery was required in the study site scale. More specifically *in-situ* data were categorized and preprocessed in a way of giving the correct correlations with the visual attributes that should have. For the 3D visualization, emphasis was given not only on the suitability of optical variables regarding visualization, but also on the sources, demands and limitations that were applied in each case.

5. RESULTS – DISCUSSION

The biggest problem facing forest and fire-fighting services in fuel management for fire prevention and control is the high diversity and fragmentation of the Mediterranean plant community and the great variability shown by it over short distances (Banninger *et al*., 2002). The use of geo-informatics procedures and geovisualization contributed to better understanding and explanation of landscape wildfire and vegetation dynamics.

Wildland fuels are critical elements in many landscape fire planning and management activities, as is one of the most important factors that should be taken into consideration for computing spatial fire hazard and risk and simulating fire growth and intensity across a landscape. Fire managers need to spatially describe fuel characteristics across many spatial scales to aid in fire management decision-making (Keane *et al*., 2001).

The goal of visualization of the Kratigos NF *in-situ* data was to turn the vast quantities of geographic data currently available into a three-dimensional virtual representation that can be used to visualize and explore data in a way that is both useful and easy to understand. The presented work was composed from two major parts. The first was the visualization of the fuel models classification that extracted from a high resolution satellite image (Figure 6). The second part was to find a way to transform collected *in-situ* data of each transect (being in an .xls format) into a digital data format easy to import and visualize with VNS (Figure 7).

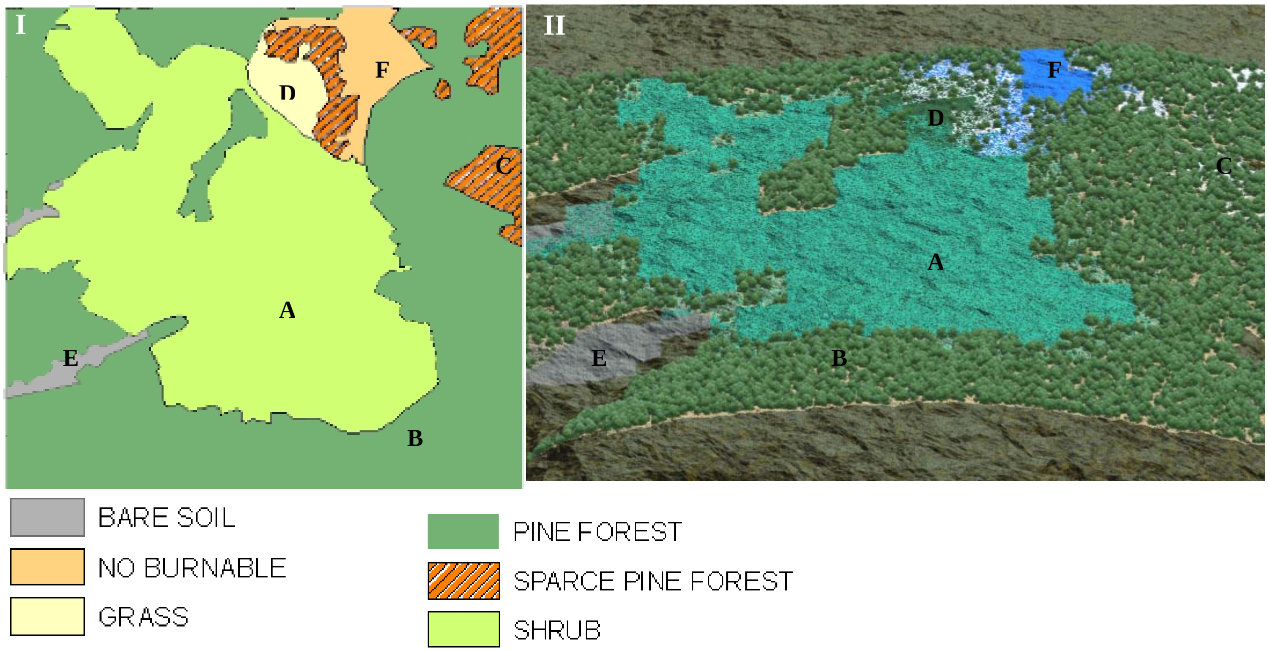

Figure 6: Visualization of KNF study site: (I) GIS map of land covers; (II) 3D visualization with VNS.

Species	From	To	Sh_cnt	Height	Width	Length
Quercus infectoria	0,00	0,75	0,375	69	230	75
Cistus Spp	0,80	1,40	1,1	0,56	74	60
Cistus Spp	3,25	3,80	3,525	40	60	55
Cistus Spp	4,20	4,90	4,55	92	135	70
Quercus infectoria	4,90	5,70	5,3	85	118	80
Quercus infectoria	5,70	8,50	7,1	140	300	280
Quercus infectoria	8,70	9,20	8,95	48	40	50
Cistus Spp	9,20	9,95	9,575	38	70	75
Quercus infectoria	10,00	10,80	10,4	55	165	80
Quercus infectoria	11,35	11,50	11,43	25	35	15
Cistus Spp	11,50	12,10	11,8	45	65	60
Quercus infectoria	12,60	17,30	14,95	105	600	470
Sarcopoterium spinosum	0,60	1,20	0,9	35	50	60
Quercus infectoria	1,20	2,60	1,9	75	60	140
Philerea media	2,80	3,50	3,15	75	90	70
Sarcopoterium spinosum	3,90	4,15	4,025	35	35	25
Cistus Spp	4,50	4,80	4,65	50	75	30
Quercus infectoria	6,70	7,35	7,025	60	86	65
Cistus Spp	7,35	7,65	7,5	58	40	30

Figure 7: 3D visualization of four transects of plot

For the presentation of the classification results, 3D visualization plays a crucial role because classification results that may be raster or vector maps using specific colors for different classes are not easy to understand for all users involved into fire prevention (Stelzl *et al.*, 2004). The classification results of the study site (KNF, Lesvos Island, Greece) were visualized by generating artificial ecosystems. Virtual 3-D landscape was build up that give the user a photorealistic impression of the terrain and its cover.

At plot spatial scale, the 3D geo-visualization aid to simulation of plant distribution for converting inventory data into individual plant level information. Figure 7 illustrates at plot scale the accurate static fuel properties, such as fuel arrangement, species composition, structure, loading and continuity of vegetation complex. The produced image is too close to reality. Accurate information on fuel complexes is the key element for reliable assessment of potential fire behavior and effective proactive fire prevention and control measures.

Every change in the attribute data (fuel models, height, width, length and species) leads to an automatic change in the 3D model of study site. So, the described visualization techniques make possible the automatic 3D visualization of vegetation analysis and change simulation, thereby giving decision-makers an additional innovative tool for planning purposes.

Scale is a key issue for developing forest visualizations. At broader spatial scales, less explicit information is conveyed to the user/readers in the 3D visualization and less information is needed to create the visualization. Data for stand scale visualizations must be explicit with accurate input data (height, width, length, density and species composition. Stand scale visualization usually focuses on vertical structure and dynamics of the stand, while landscape scale visualization focuses on horizontal variations, spatial patterns or landscape transformations.

Computer software, such as 3D VNS, is being designed specifically to display three-dimensional datasets, removing some of the abstraction present in two-dimensional maps. Such a tool would provide a way to turn the huge amounts of geospatial data presently available into understandable information that can be used, explored, and learned from. By creating three-dimensional landscape visualizations that look as realistic as current technology allows, it becomes possible to see, explore, and spatially understand parts of the Earth as if everyone was actually there. These visualizations remove all data abstraction by putting the user in a map, making it much easier to interpret the existing information.

6. CONCLUSION

Each year several researches and surveys are carried out on forest fire management in Mediterranean-type ecosystems. So, various geo-referenced field data are recorded providing important and useful information for forest management. Even though the collection of field data is the most critical task in the mapping of fuels and it is often the most costly and time-consuming part of any mapping effort (Wilson *et al*., 1994; de Vasconcelos *et al*.1998; Keane *et al*. 1998b), these data are not widely used.

Three-dimensional visualization of forest landscapes could be actively used in planning processes as means of communication between planners and the public, in particular for discussion of visual impacts of proposed changes in the landscape. Actually, the 3D Visual Nature Studio software can be used to simulate the changes of forest landscapes that occur as a result of natural processes or man-made disturbances such as planting, thinning and harvesting.

Through visualization results it was concluded that no ideal resolution exists, but rather a range of suitable resolutions. One should at least try to avoid using resolutions that do not comply with the effective scale or inherent properties of the input dataset (Hengl, 2006) and the output visual size. Before make a Geovisualisation we should consider how we can select the most appropriate scale and optical variable to represent vegetation and land use to a 3d representation according to: a) the objective of geovisualization, b) the available data and c) scaling that applies in each case. A tool for correct data selection should be create in order to help scientists find the suitable Geodata for scale transitions and make their visualization more effective based on the aim of Geovisualization. Thus will help inexperienced users select a suitable data resolution and suitable optical variables without doing extensive data preprocessing in order to have the best result.

Research needs to continue to aid in the development of methods and procedures to enable the creation of 3D visualization tools that promote the use and understanding of complex geographic datasets. At plot spatial scale, continuous research is needed so as to complete the gaps between transects (by using several techniques such as interpolation) to reveal more knowledge of hidden information. Finally, the 3D visualization of the whole fuel model can be improved by representing time dependent dynamic fuel properties (i.e. distribution of fuel moisture, proportion of dead-live material) by using further *in-situ* data.

7. ACKNOWLEDGEMENTS

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