Forest Fire Fuels Mapping by Geoinformatics for Fire Behavior Modeling

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Abstract

This research study aimed at quantifying and mapping key characteristics of forest structure through field inventories and sampling, statistics and GIS to create a fire behavior modeling data set for Lesvos Island, Greece. Field sampling was based on the FIREMON protocol, measuring the necessary vegetation attributes in over one hundred 405-m^2 plots with a stratified random sampling design. Most of these plots were located inside conifer forest stands, while a few were taken inside olive groves, oak forests and chestnut trees. An allometric equation was created to predict height from DBH for *Pinus brutia* trees, while published equations were used to calculate the branch and foliage weight of the tree canopy. After data processing, the derived stand characteristics were used to construct regression models using Ordinary Least Squares (OLS) and General Additive Models (GAM). Several combinations of explanatory variables were tested to find the best fit for each of the four depended variables (i.e. Stand Height, Canopy Cover, Crown Base Height and Crown Bulk Density). Mapping of vegetation properties was accomplished with a 2007 Landsat 5 TM satellite image and other derived explanatory variables that have ecological significance in forest growth and biomass. The adjusted R^2 of the dependant variables ranged between 0.79 (Stand Height) and 0.46 (Crown Base Height). Fuel models were mapped by Thiessen polygons around plots that defined the area closest to each plot. The forest characteristic layers were then imported into the FARSITE fire behavior and growth simulator to create a ready-to-launch application that will be tested for its prediction accuracy with data from the 2010 fire season.

Keywords: Fire Simulation; Fire Management; Geostatistics; Fuel Mapping; GAM; Lesvos Island

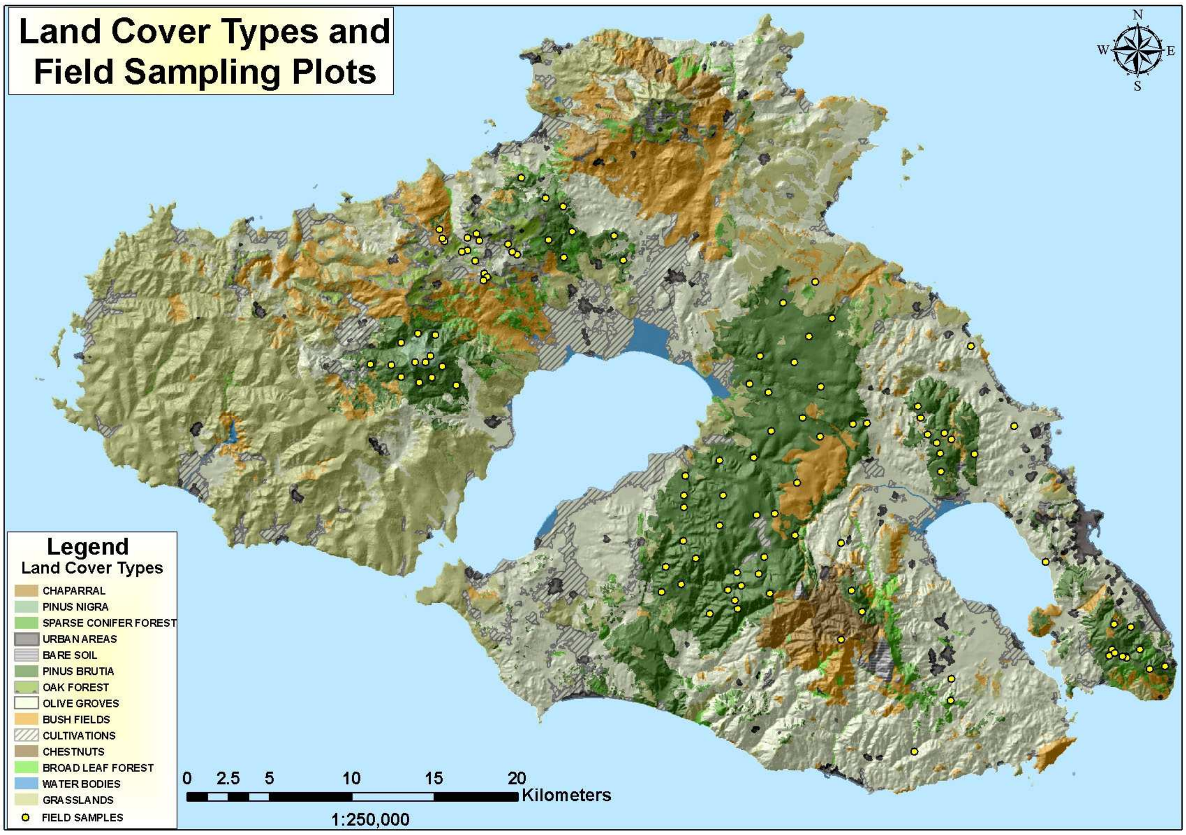
1. Scope of the Research

Fire behavior models need a variety of vegetation and fuel characteristics maps to produce precise spatiotemporal predictions. These maps may be accurately created either by modern remote sensing techniques (e.g. Lidar) or by combining collected field data with derived variables from satellite images and other environmental gradients through regression models and Geographic Information Systems (GIS).

The main goal of this research study was to identify the capabilities of regression methods, in conjunction with field data and widely available medium-resolution satellite images, to map accurately the necessary forest canopy layers needed for precise fire behavior modeling. Most of the current fuel models maps are based on the CORINE 2000 vegetation classifications, linking the vegetation cover types with fuel models in a coarse manner with misclassification errors; geoinformatics techniques may provide promising tools to overcome these shortcomings.

2. Study Area

Lesvos Island in NE Aegean, Greece, covers an area of 1632 km^2 and extends from 38° 57΄ N to 39° 23΄ N latitude, and from 25° 49΄ E to 26° 36΄ E longitude (Map 1). Its coastline forms two bays in the south--the Gera and Kalloni Gulfs--and many bights and promontories. The most important mountain peaks are Olympus (967 m), Lepetimnos (968 m) and Prophet Elias (800 m). The eastern and central part of the island is occupied by olive groves, pines, chestnuts, beeches and plane trees. Generally, the flora and fauna of the island are extremely rich. The climate of Lesvos is mild Mediterranean-type with moderately cold and moist winters, and warm and dry summers.



MAP 1

3. Sampling Strategies and Data Collection

Field sampling was based on the FIREMON protocol (http://frames.nbii.gov/firemon), measuring the necessary vegetation attributes in over one hundred 405-m2 plots with a stratified random sampling design (Map 1). *Pinus brutia* plots were the majority (80) of them, followed by *Quercus spp.* plots (15), *Olea europea* plots (6), *Pinus nigra* plots (4) and *Castanea spp.* plots (1). More specifically, we recorded the diameter at breast height (DBH) for every tree or snag larger than 10 cm; and the height, crown base height (CBH) and major and minor crown diameters for 8 trees per plot. Two fuel model types (one for the normal and another one for the extreme fuel conditions) were assigned at every plot. The canopy cover was quantified with a spherical densitometer, while the ground fuel loading was assessed using the planar intersect technique.

4. Sampling Data Analysis

Data were analyzed to create forest descriptive variables. These were crown length, basal area, quadratic mean diameter, Lorey's height, trees per hectare, and fuel weight per size class. An allometric relation to predict tree height from DBH was created using a power regression (i.e. $Y = 1.563 + X^{0.548}$) for *Pinus brutia* trees with 300 tree samples (Figure 1); results revealed significantly strong relationship ($R^2 = 0.75$; $p<0.001$). A published equation that predicted the 1-hr TL crown fuel for *Pinus brutia* trees in Lesvos was used to calculate the crown bulk density (CBD) for every plot (Ziannis et al., 2010); the equation was in the form $\ln Y = 4.12 + 1.825 \ln DBH$ ($R^2 = 0.98$). CBD estimation was achieved by using data derived from the above equations and by creating vertical canopy fuel profiles (per 1 m) smoothed with a 3-m running mean (FFE-FVS: http://www.fs.fed.us/fmsc/fvs/description/ffe-fvs.shtml).

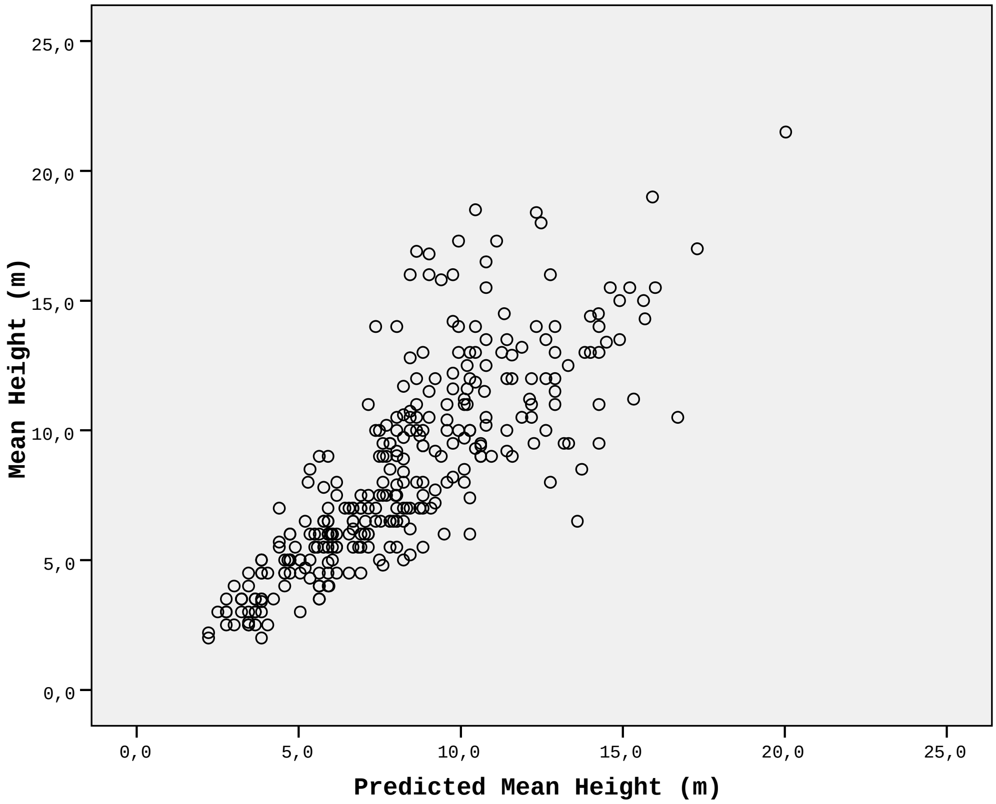


Figure 1: Observed vs. predicted values of the *Pinus brutia* tree height allometric equation

5. Explanatory Variables

It is critical to choose the appropriate explanatory variables, so that they can have an actual ecological link with the response variables. The choice of appropriate explanatory variables for spatially predicting vegetation conditions is a compromise between those variables that have ecological significance and those that are available as spatially explicit layers in GIS format (Zerger et al., 2009). Three categories of variables (i.e. topographic, weather and remote sensing products) were used to choose the most appropriate among the available ones. The topographic variables were elevation, slope and TRASP (the circular aspect variable is transformed into a radiation index, i.e. TRASP). The weather variables were wind (modeled with the Wind Atlas Analysis and Application Program; Palaiologou et al., 2010) and solar radiation (modeled with ArcGIS 9.3). The remote sensing products were the vegetation indices of NDVI and GRVI; the Principal Components 1, 2 and 3; and the Tasseled Cap Analysis results, i.e. Greenness, Wetness and Brightness. A 2007 Landsat 5 TM image was geometrically and radio-metrically corrected and used to produce the above variables.

The variables produced were tested for large correlation coefficients (r>0.75) and a decision was made on which to exclude from every response variable's model. Correlations were noticed only among the remote sensing variables (Table 1).

	NDVI	GRVI	PCA1	PCA2	WETNESS	BRIGHTNESS	GREENESS
NDVI	1	0.84			0.83		0.97
GRVI	0.84	1	0.91		0.88	0.89	
PCA1		0.91	1		0.95	0.99	
PCA2				1			0.78
WETNESS	0.83	0.88	0.95		1	0.9	0.78
BRIGHTNESS		0.89	0.99		0.9	1	0.99
GREENESS	0.97			0.78	0.78		1

Table 1: Large correlation coefficients (r>0.75) among the explanatory variables

6. Statistical Analysis and Results

General Additive Models (GAM) were used to identify the relationship of the four response variables with the independent variables. Results were compared with those produced by the standard Ordinary Least Squares (OLS) method (Table 2). With GIS, we produced the final maps and converted them into a FARSITE readable format. All statistical analyses were made with the R software. GAM fitting was made with the MGCV package of R (Wood, 2006), using the penalized thin plate regression spline "shrinkage" method.

Initially, all the uncorrelated explanatory variables were inserted in every model to identify the overall model performance. Then, the general backward selection method was applied, removing each explanatory variable at a time. If the GCV score for the model was reduced, or if the effective degrees of freedom (e.d.f.) were close to zero (meaning that the variable has been "zeroed out" and the partial plot showed a horizontal line at the x axis), then the variable was removed. OLS method was used for comparisons with GAM results.

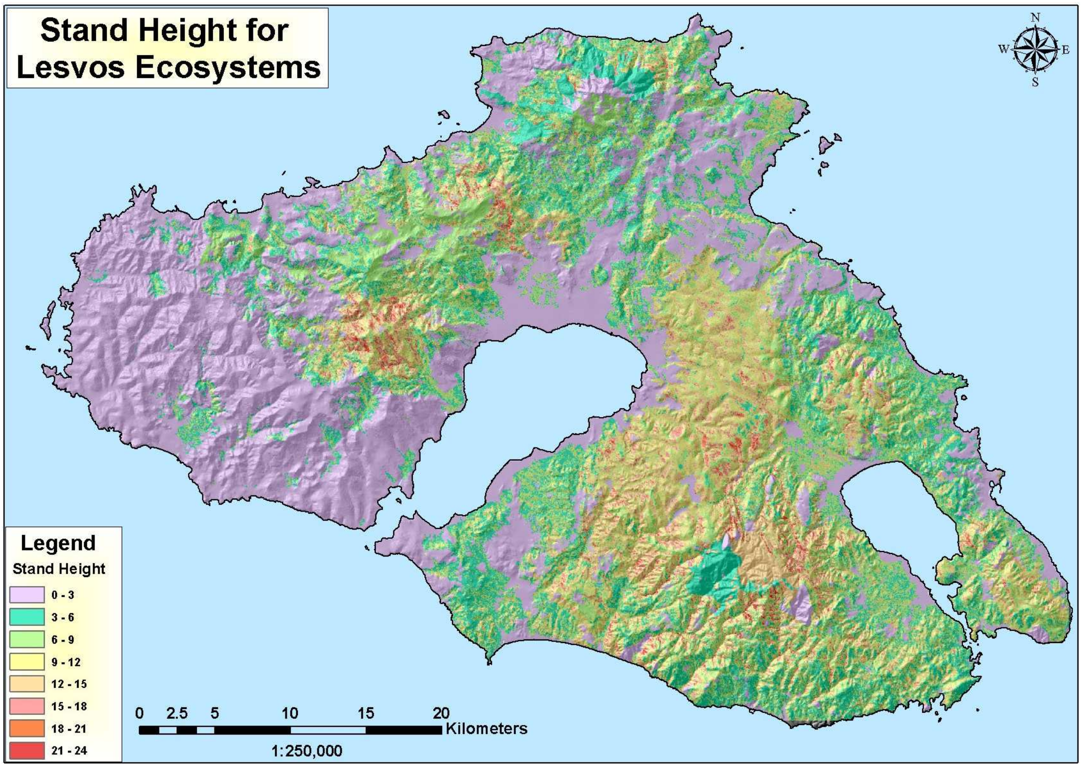
	n	GAM R^2 (adj.)	OLS R^2 (adj.)	Deviance (%)	GCV score	Family	Link function
Canopy Cover	100	0.75	0.55	77.8	105.51	Gaussian	Identity
formula	intercept***	greenness***	pca3***				
Stand Height	96	0.79	0.57	85.4	4.5691	Gaussian	Log
formula	intercept***	pca1***	pca2***	wind***	solar***	pca3***	trasp***
CBD	99	0.71	0.41	79	0.0066768	Gaussian	Inverse
formula	intercept*	pca1^{NS}	pca2**	pca3^{NS}	dem***	trasp^{NS}	

CBH	96	0.469	0.41	50.7	2.5854	Gaussian	Identity
formula	intercept***	greenness*	grvi*	solar*			
Statistical Significance: $p<0.001$ ***; $p<0.01$ **; $p<0.05$ *; $p>0.05$ ^{NS}							

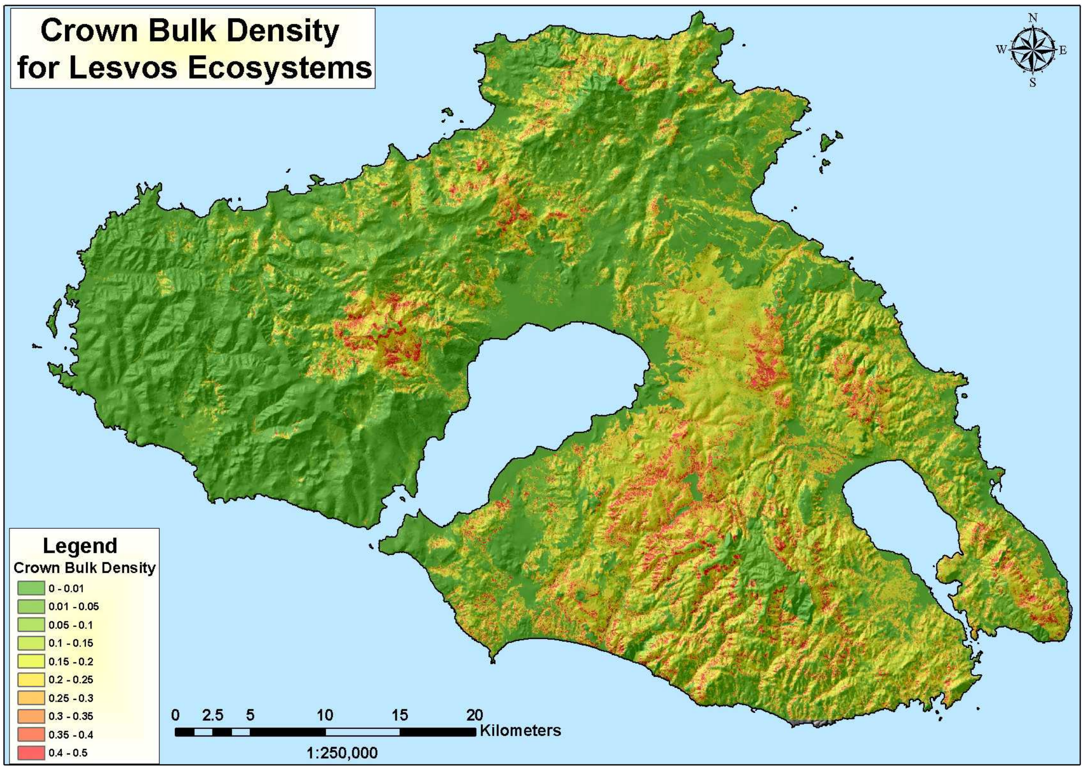
Table 2: Statistical analyses and results

7. Mapping of Vegetation Characteristics

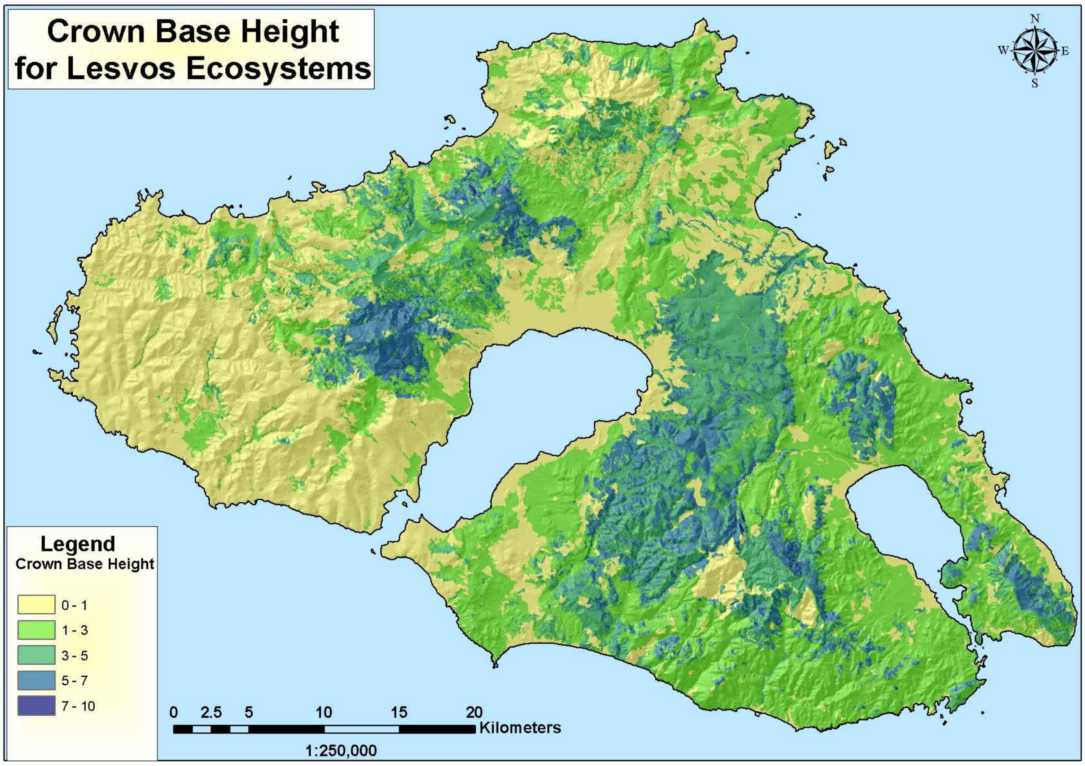
A land cover map produced by a Quickbird 2003 image mosaic of the island (supervised classification with field data) was the main mapping layer for analysis and reference (Map 1). The mapping procedures were accomplished with Marine Geospatial Ecology Tools and ArcGIS 9.3 Spatial Analyst Tools. Then, the resulting map for every variable was further analyzed. Areas with no tree cover (e.g. grasslands, shrubs) were zeroed, while areas with high standard errors (tree cover types that were insufficiently sampled), were substituted by a constant value derived from the available references or other studies on the island (e.g. *Castanea spp.* stands = 15 m height). The resulting layers for stand height, CBD, CBH and canopy cover are depicted in Map 2 through Map 5, respectively. To create the Fuel Model map (Map 6), the Thiessen polygons method was used to identify the area closest to every sample plot, assigning afterwards the appropriate fuel model to each of these polygons. Finally, the maps were clipped and assembled into a FARSITE project file.



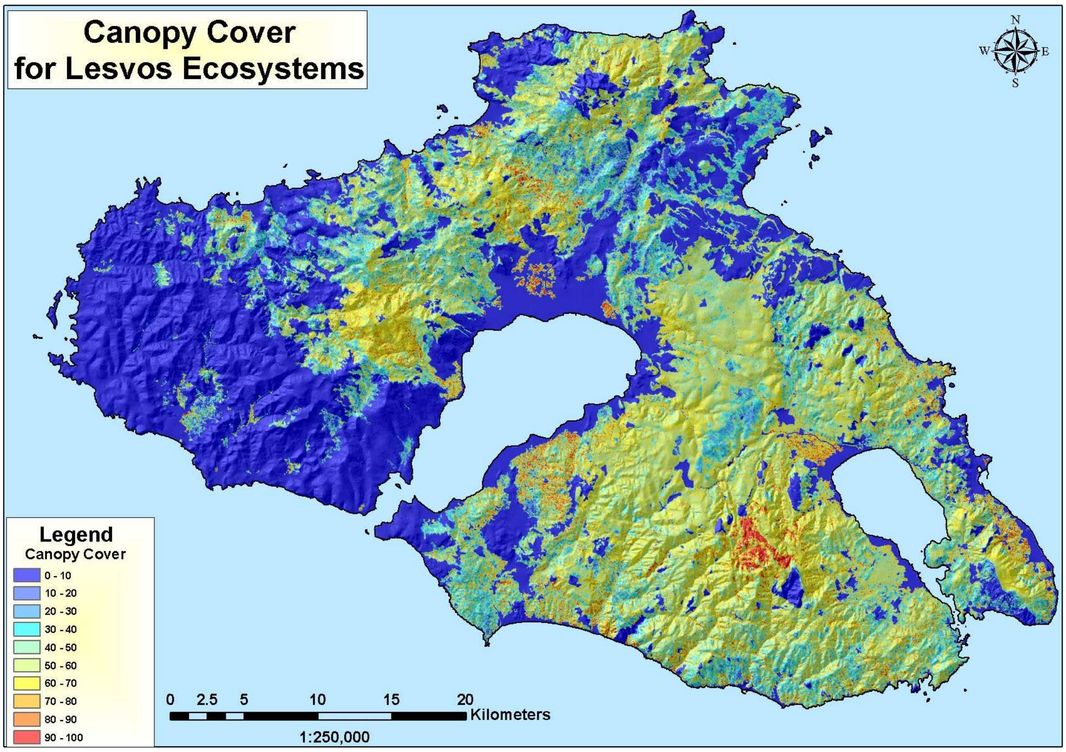
MAP 2


Crown Bulk Density
for Lesvos Ecosystems
N
W
E
S
Legend
Crown Bulk Density
0 - 0.01
0.01 - 0.05
0.05 - 0.1
0.1 - 0.15
0.15 - 0.2
0.2 - 0.25
0.25 - 0.3
0.3 - 0.35
0.35 - 0.4
0.4 - 0.5
0 2.5 5 10 15 20
Kilometers
1:250,000

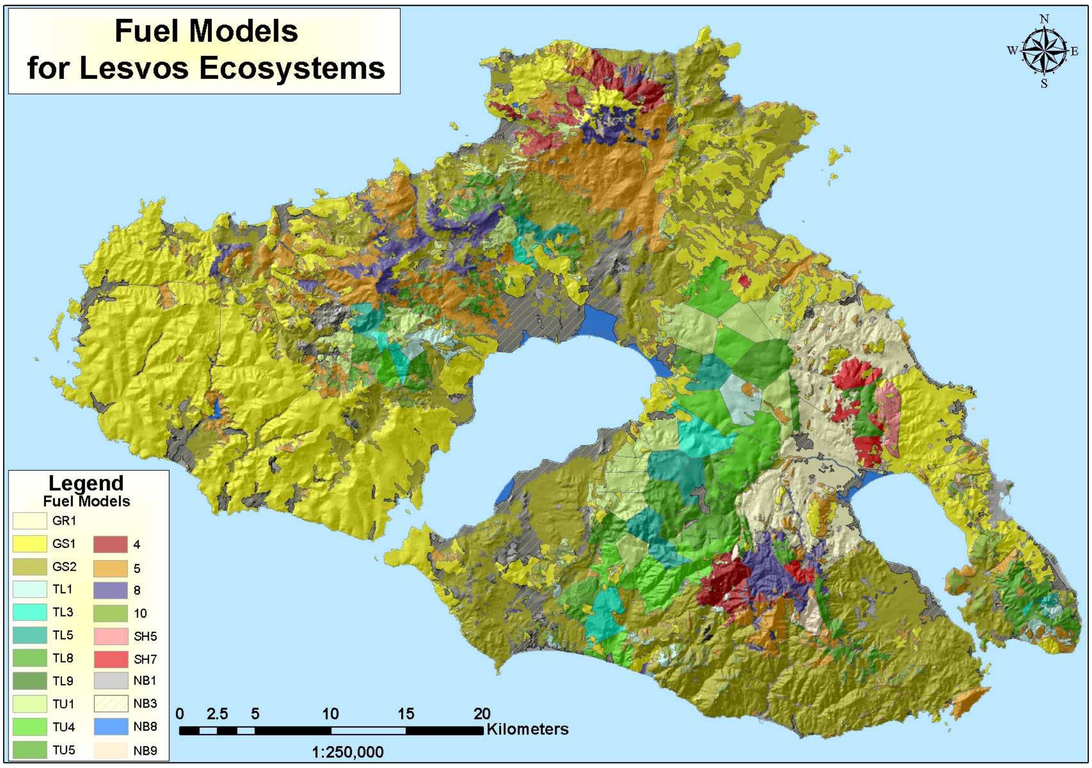
MAP 3


Crown Base Height
for Lesvos Ecosystems
N
W
E
S
Legend
Crown Base Height
0 - 1
1 - 3
3 - 5
5 - 7
7 - 10
0 2.5 5 10 15 20
Kilometers
1:250,000

MAP 4


Canopy Cover
for Lesvos Ecosystems
N
W
E
S
Legend
Canopy Cover
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
0 2.5 5 10 15 20
Kilometers
1:250,000

MAP 5


Fuel Models
for Lesvos Ecosystems
N
W
E
S
Legend
Fuel Models
GR1
GS1
GS2
TL1
TL3
TL5
TL8
TL9
TU1
TU4
TU5
4
5
8
10
SH5
SH7
NB1
NB3
NB8
NB9
0 2.5 5 10 15 20
Kilometers
1:250,000

MAP 6

8. Conclusions

Mapping canopy structure elements using ecologically significant variables, in conjunction with field data for Lesvos Island, revealed strong relations among them; while the derived maps are ready to be used in FARSITE and FlamMap simulations. Landsat 5 images and its analysis products (indices, single bands and principal components) were important variables in any response testing procedure and in the final GAM formulas, too. It is important to test model prediction accuracy with independent datasets; thus, additional field samplings are planned for summer and autumn 2010. The OLS method gave lower modeling accuracy but not as low as expected, considering that the method lacks any smoothing or non-linear fitting capabilities. Additional environmental variables (such as seasonal temperature, accumulated rainfall, fire number per pixel) that cannot be substituted by other variables will probably modify the results, but these data have not been available yet. Future analysis will involve the use of other satellite products (e.g. an Aster satellite image) and fire behavior accuracy tests with FARSITE on past fire events.

9. Acknowledgements

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10. References

1. Palaiologou P., Kalabokidis K., Haralambopoulos D., Feidas H., Polatidis H. (2010). Wind characteristics and mapping for power production in the island of Lesvos, Greece. Computers and Geosciences (in press).
2. Wood, S. N. (2006). Generalized Additive Models: An Introduction with R. Chapman & Hall/CRC. ISBN 9781584884743.
3. Zerger, A., Gibbons, P., Seddon, J., Briggs, S., Freudenberger, D. (2009). A method for predicting native vegetation condition at regional scales. Landscape and Urban Planning 91, 65–77.
4. Zianis, D., Xanthopoulos, G., Kalabokidis, K., Kazakis, G., Ghosn, D., Roussou, O. (2010). Allometric equations for aboveground biomass estimation by size class for *Pinus brutia* Ten. trees growing in North and South Aegean islands, Greece. European Journal of Forest Research (in press).