Forest road network planning for biomass exploitation and fire preventions: a least cost path analysis

Sarantis-Angelos Georgios Liampas*, Christos Constantinos Stamatiou, Vasileios Constantinos Drosos

(*Department of Forestry and Management of the Environment and Natural Resources, Democritus University of Thrace, 68200, N. Orestiada, Greece*)

Abstract: The projects related to forest opening up constitute fundamental infrastructure projects for the development of our mountainous and semi-mountainous national economy. In the beginning, timber transportation and connection between forest settlements served as the sole purpose of forest opening up. However, nowadays, the perspective of forest opening up as being an important preventive measure of forest protection, which is a basic pillar of a multipurpose forestry system of the Greek Mediterranean mountains, is gaining ground. The application of modern tools in the opening up is now imperative for choosing the most economical and efficient forestry route. The paper presents a new method of forest opening up based at the least cost path analysis (LCPA) and Multi-Criteria Analysis (MCA) using a Geographical Information Systems (GIS) environment.

Keywords: least cost path analysis, multi-criteria analysis, forest opening up, analytic hierarchy process, GIS, Greece

Citation: Liampas, S. A. G., C. C. Stamatiou, and V. C. Drosos. 2019. Forest road network planning for biomass exploitation and fire preventions: a least cost path analysis. Agricultural Engineering International: CIGR Journal, 21(4): 33–42.

1 Introduction

Undoubtedly, forests are included among the most important ecosystems of the Mediterranean Sea. The ecosystems constitute valuable productive resources for our country, as they are very rich in biodiversity and they also provide an array of environmental services. The productive forest ecosystems of Greece lie primarily on semi-mountainous, mountainous and rugged areas which exhibit, intense relief with adverse terrestrial and climate conditions as well as uneven distribution of vegetation, thus rendering the planning of the forest net, which will be used as a guarantee for the development of the mountainous regions, difficult. The fundamental principle, which consists the basis of the forest policy in our country, is the eternal operation of our forest ecosystems rendering as necessary, the policymaking regarding the Worth - living Completed Development of forest areas, that is the simultaneous economic, social, technical and technological, political as well as cultural harmony, which will be executed dialectically, accompanied with respect towards the Human and the environment. One of the most important human interventions in a forest ecosystem is its opening up with the means of the planning and the construction of a transport premises' network (forest roads, tractor roads, displacement's by –roads), which definitely contributes to the displacement and transfer of forest products as well as to its tourist development and most importantly to its protection (Sedlak, 1993). Besides the above positive effects, the opening up takes its toll on the environment and causes damages to the landscape, which partially can be covered, but most of the times, it is impossible to be restored. However, it is considered as essential and inevitable for the rational operation and protection of the forestry ecosystem (Heinimann, 1994; Drosos et al., 2008; Liampas et al., 2014).

Received date: 2018-08-10 **Accepted date:** 2018-12-04

*** Corresponding author:** Liampas Sarantis-Angelos, Phd, Department of Forestry and Management of the Environment and Natural Resources, Democritus University of Thrace, Tel: 306974827300, Email: angel40das@yahoo.gr

Under the term of forest opening up, one can define the combination of natural and artificial facilities and projects which aim at:

• The access in isolated forest surfaces

• The transport of the staff, the means, the materials and the machines, which regard the exploitation, the cultivation and the protection of the forest and

• The transport of wood, displacement and transfer from the logging positions to the consumption and the processing places.

What is not included under the term of 'opening-up', is the use of opening up project (forest roads), which usually aim at the exploitation of forest as well as the wider area for recreational purposes.

The notion of recreation inside the forest constitutes a continuously increasing human activity over the past years. The opening up of forests depends on the type, the terrestrial distribution, the density and the combination of any opening up means. This could lead to the conclusion that the opening up can be accomplished using various means.

As excellent opening up, one could define the opening up which creates beneficial conditions, that the forest exploitation can accomplish within predefined time periods (capital recouping time) the highest network revenues, that is the most beneficial cost- benefit association The construction of forest roads, which aim at the accommodation of forest purposes, made its main advent, when the forest exploitation started to take place with the purpose of financial incentives, that is the profit. Since then the systematic forest opening up started to take place as well as the construction of forest roads, which would meet the demands of economical transfer of wood and the forest projects that take place in the forest. The necessity of rational forest opening up and the appropriate as well as systematic distribution of forest roads into the forest (place distribution) led to the profound study of the factors and conditions, which affect the construction of the forest road net. (Stergiadis, 1985; Karagiannis, 1999).

The opening up of a forest region is completed within four stages, which are the following:

1. The general planning of the opening up with the purpose of finding the perfect solution among multifarious opening up plans.

2. The execution of the study with the purpose of the detailed processing of the perfect solution from a technical, ecological, and economical point of view, so that its execution could be regarded as easy in practice.

3. The construction of opening up projects and

4. The maintenance of opening up works.

The forest roads constitute the framework of the opening up of forests and they serve to the transfer of forest products, the material, the machines, the forest staff's transportation, the rational exploitation and the protection of the forest, the development of mountainous regions and generally the accommodation of the population in forest and mountainous areas, which aim at:

• Accommodating the excellent opening up of the forest region, the easy circulation of forest products, material and forest staff, the rational exploitation and protection of the forest, the expansion of mountainous tourism and forest recreation.

• Reducing the cost of displacement as well as the transfer of the main forest product that is, wood (Karagiannis, 1991).

Following the main factors which affect the planning of the forest roads' network: a) The managing form of the forest, b) the topographical conformation of the forest region, the density and the distribution of vegetation, c) the quality and the quantity of wood capital and utilizing the new tools which are provided in the Geographical information system, the opening up of forests is changing.

The implementation of analysis path with least cost (Acar, 2016; Acar et al., 2017) to the opening up of Greek forests will contribute to the optimal utilization of the very little resources which are available at the Forest Service during the times of economic crisis. The Geographical Information Systems (GIS) let the planer to easily spot, with the aid of least cost path, the 'cheapest 'path from one place to another. The surface cost is represented with the means of a raster map, in which each cell is assigned with some cost, which defines how expensive it will be, if it is to cross that point (Gulci and Akay, 2015). This process is automatically executed with the means of an algorithm which seeks the lowest price (Douglas, 1994; Lee and Stucky, 1998).

The analysis path method of least cost has been applied to a lot of disciplines which are associated with space and its operation. In Greece, it has been used in historical studies for the specification of transfer paths of the population in the regions of Thesprotia (Liakos and Vasileiadis, 2009). In the urban environment, the application of the cost path, was implemented in the municipality of Zografou, for the creation of suggested green nets (Antoniou et al., 2015), whereas in the mountainous space the opening up of new roads was studied, so as to reduce the time and distance between the settlements of Zakliveri, Livadi and Petrokerasa in the prefecture of Thessaloniki (Stamatiou and Liampas, 2014).

2 Materials and methods

The forest of Echinos (Figure 1) was chosen as a research area, which lies in the Northern- Northern Eastern edge of the prefecture of Xanthi among the degrees of 24 54′4″ to 25 3′21″ eastern longitude from the meridian and 41 15′25″ to 41 21′50″ northern latitude. The Echino's forest cluster lies on the southern hillside of the Northern Eastern part of the mountainous area in Rodopi. It extends attitudinally from the coastal altitude of 250 m to 1167 m. The area exhibits intense terrestrial relief, which combined with the equally intense corrugation of the ground, they create a continuous interchange with regards to the bevel and the exposure. The prevailing bevels are severe from 40% to 80%. Generally, the orientation of the forest is Southern-Southwest. The forest of Echinos is run across from all directions from a number of small or big streams due to the intense relief of the ground. The central stream of the area is the "little river' which crosses from NW to SE the forest of Echinos and it receive the smallest streams which channel the forest. The total area is 7.852,25 ha, following the calculation of the ArcGIS, from which the 88% are covered or partially covered from forest areas.

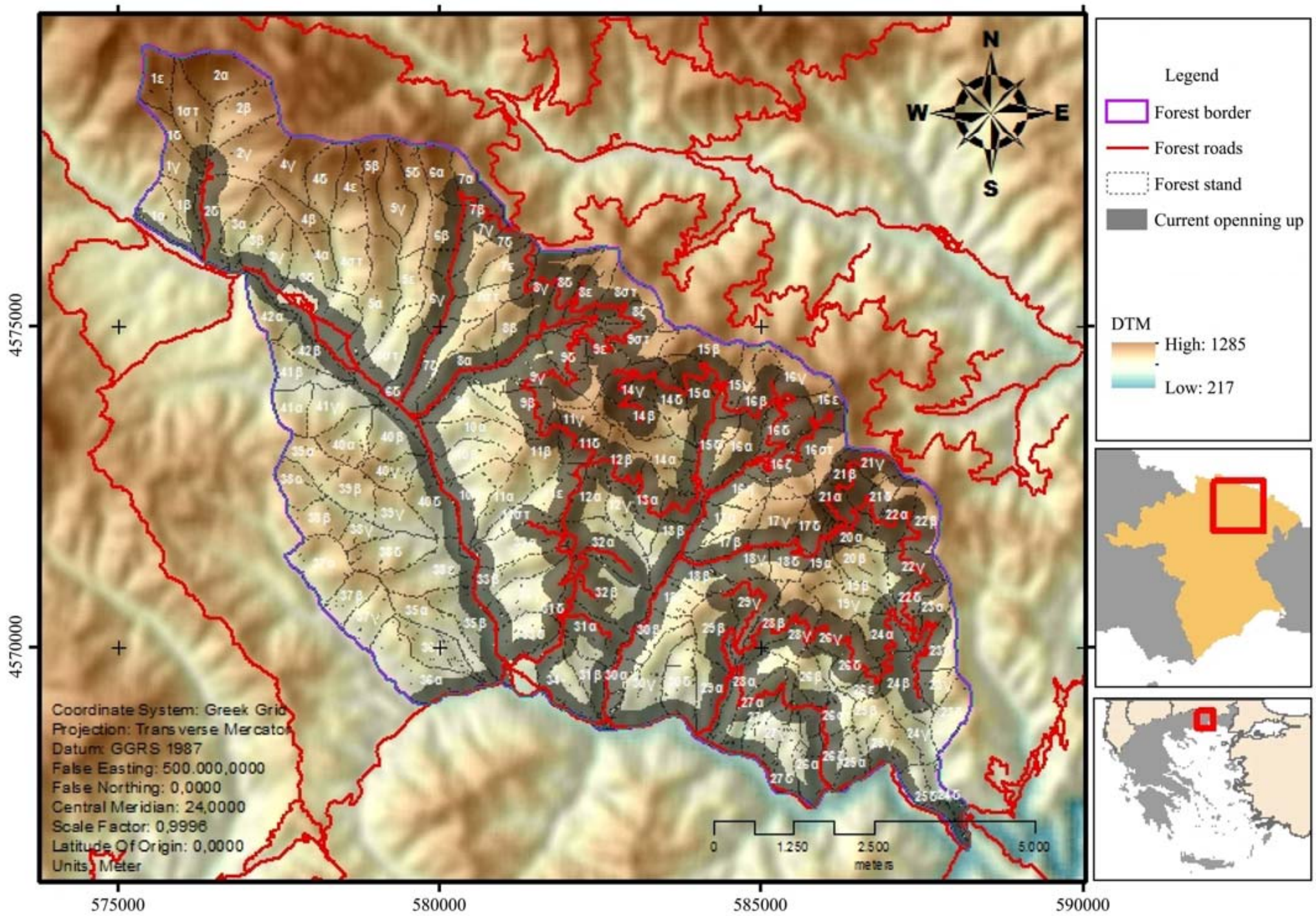

Figure 1 Research area: forest complex Echinos

The project and the least cost path analysis, implemented with the ArcGIS 10.0 application with the use of the tools that are available in the extension of spatial analyst. (Acar, 2016). With regards to the selection of the most affordable and the most effective opening up of the forest, the process of decision - making was used, based on the multi-criteria analysis. This method is known for the international bibliography such as MCDA (Multi Criteria Decision Making), however the term multi- criteria analysis Multi-Criteria Analysis (MCA) is used more often. The analysis of multiple criteria or the multi – criteria analysis constitutes a tool which facilitates the decision-making, which has been developed for composed problems of multiple criteria, which include qualitative or/and quantitative aspects of a problem during the process of decision - making (Abdi et al., 2009).

The criteria and indicators which were used are shown in Table 1 (each criterion was divided to several sub-factors with several values, as they have presented by Xu et al. (2005), properly modified. In the current paper, the weights have been modified to Greek conditions. The Analytic Hierarchy Process (AHP) is a theory based on approach to compute the weights representing the relative importance of criteria (Setiawan et al., 2004). The AHP uses a pairwise criteria comparison to arrive at a scale of preferences among sets of alternatives (Saaty, 1980; Saaty, 1996; Saaty and Vargas, 1991). The pair-wise comparisons are made on a scale of relative importance where the decision maker has the option to express the preferences between two factors on a ratio scale.

The criteria which were employed are six and they include 29 indicators. The first criterion is the ground's slant, which was produced via the digital terrain model (DTM) which was created by digitizing the even elevated curved lines in the maps 1:50000 of the H.A.G.S. (Hellenic Army Geographic Service) in the area of Echinos and Medousa. The criterion of slant consists of seven indicators which are the slant's categories of the ground which the forest ecology uses (Ntafis, 1986). The second criterion is the use of the ground on land (Figure 2) and it consists of 10 indicators. The uses of terrestrial areas in the research area were digitized via the vegetation map of the operational study in the forest of Echinos. The third criterion concerns the categorization of the clusters based on their productivity (GEOTEE, 2009), and in this, there are three indicators (Figure 3) poor clusters, average clusters and rich clusters. The fourth criterion is the annual increment per hectare of each cluster and it consists of three indicators. The fifth criterion is the timber production per hectare (Figure 4), and it consists of three indicators. The sixth criterion is the ground's erosion (Figure 5), and it consists of three indicators. The source of the criteria's data three, four, and five were the description sheets of the operational study and the data of the erosion were based on the Joint Research Centre of the European Union (Panagos et al., 2015).

Table 1 Indicators of opening up criteria

Variable	Weight variable	Indicators	Weight indicator	Total Weight
Slope	0.352	<10%	0.028	0.010
		10%-20%	0.055	0.019
		20%-35%	0.083	0.029
		35%-50%	0.112	0.039
		50%-75%	0.194	0.068
		75%-100%	0.250	0.088
		>100%	0.278	0.098
Vegetation	0.327	Barren land	0.021	0.007
		Agricultural land	0.085	0.028
		Without vegetation	0.021	0.007
		Broadleaved	0.064	0.021
		Querqus	0.149	0.049
		Broadleaved partially	0.085	0.028
		Querqus partially	0.106	0.035
		Fagus partially	0.128	0.042
		Fagus	0.170	0.056
		Pinus	0.170	0.056
Growing stock (m^3 ha^{-1})	0.124	<100 m^3 ha^{-1}	0.450	0.025
		100-300 m^3 ha^{-1}	0.350	0.043
		>300 m^3 ha^{-1}	0.200	0.056
Annual Increment (m^3 ha^{-1})	0.081	<3 m^3 ha^{-1}	0.450	0.016
		3-6 m^3 ha^{-1}	0.350	0.028
		>6 m^3 ha^{-1}	0.200	0.036
Timber production (m^3 ha^{-1})	0.054	<10 m^3 ha^{-1}	0.450	0.0108
		10-25 m^3 ha^{-1}	0.350	0.0189
		> 25 m^3 ha^{-1}	0.200	0.0243
Erosion (tn ha^{-1})	0.062	< 1tn ha^{-1}	0,52	0.032
		1-5 tn ha^{-1}	0,37	0.023
		> 5 tn ha^{-1}	0,11	0.007

The table above (Table 1) in the first column contains the criteria which were used. The second column represents the weight coefficient of each criterion which emerged from them between correlation. The third column contains the indicators of each criterion and the fourth one shows the weight coefficient of each indicator within the criterion. The fifth column represents the total weight of each coefficient that is the product of the criterion's weight (column 2) along with the indicator's weight in each criterion (column 4).

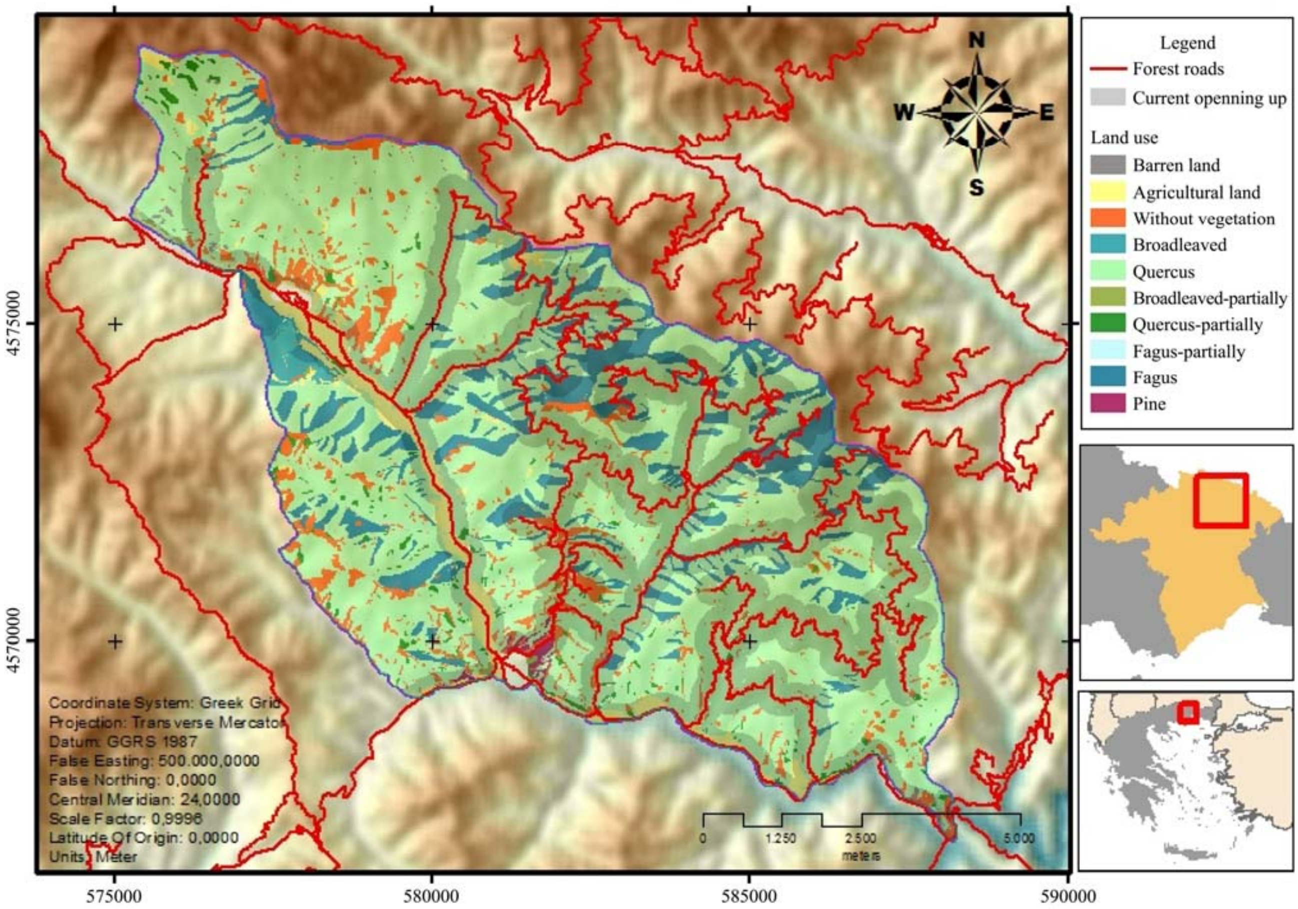

Figure 2 Land use map

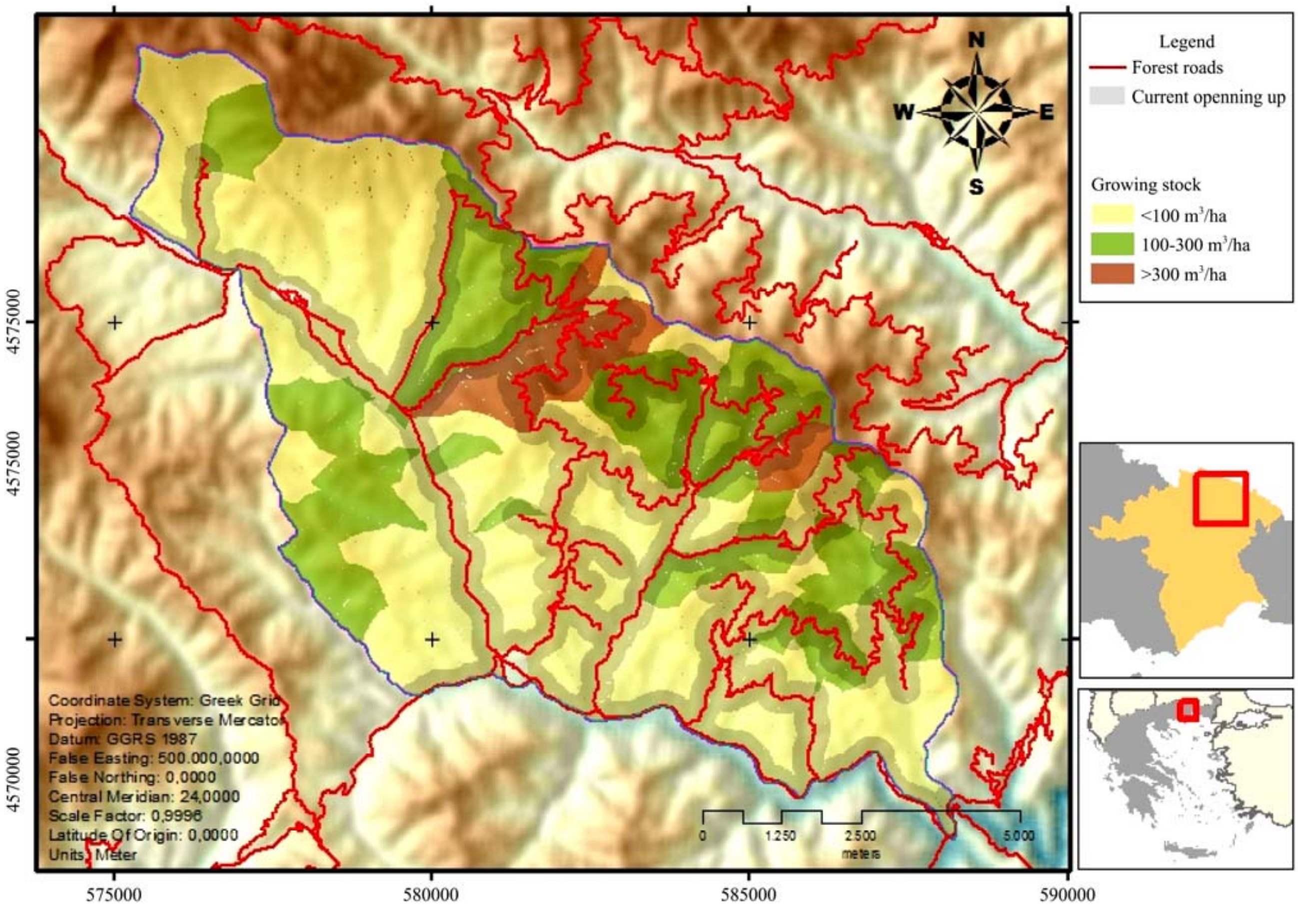

Figure 3 Map of the growing stock m^3 ha^{-1}

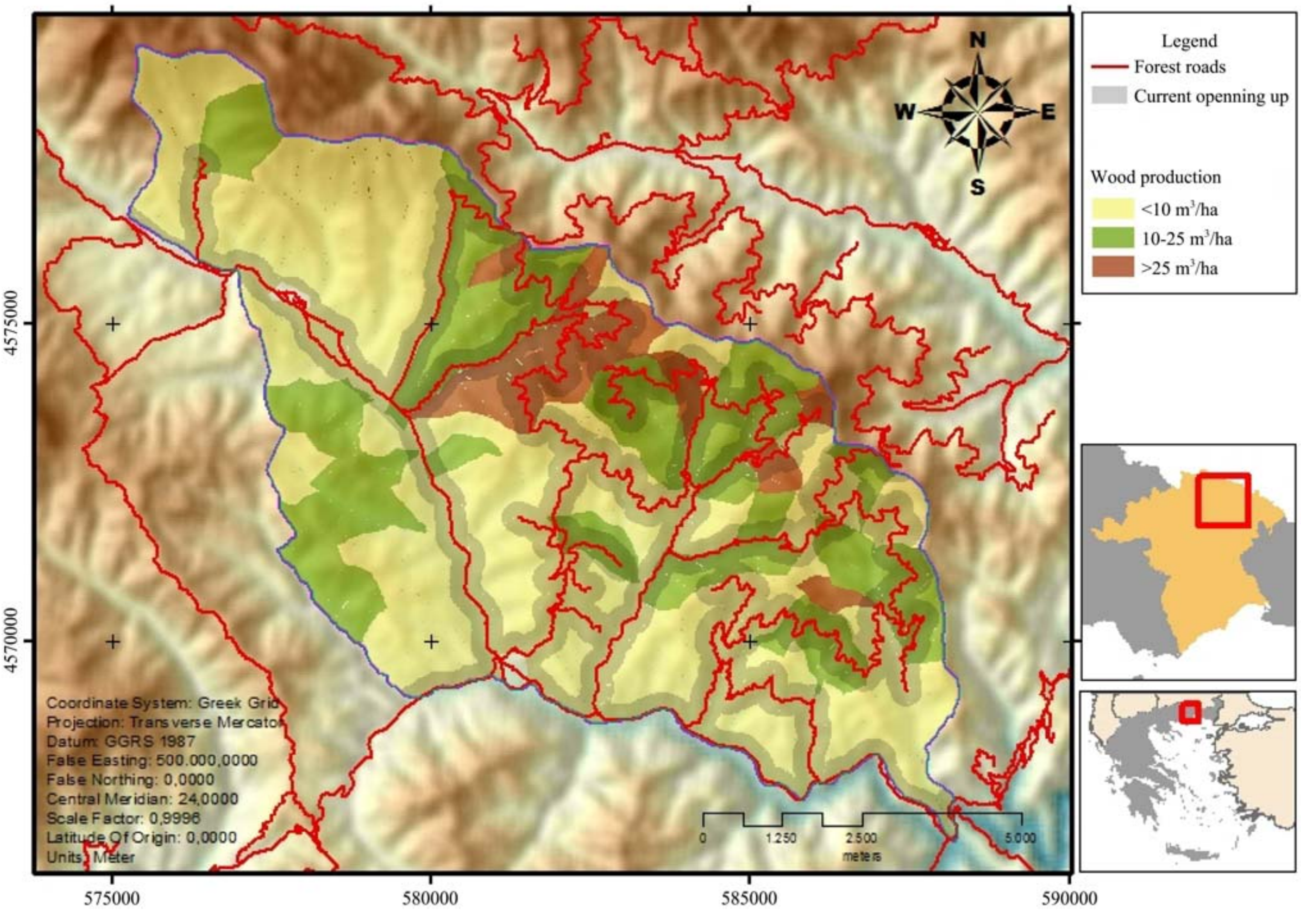

Figure 4 Map of the timber production m^3 ha^{-1}

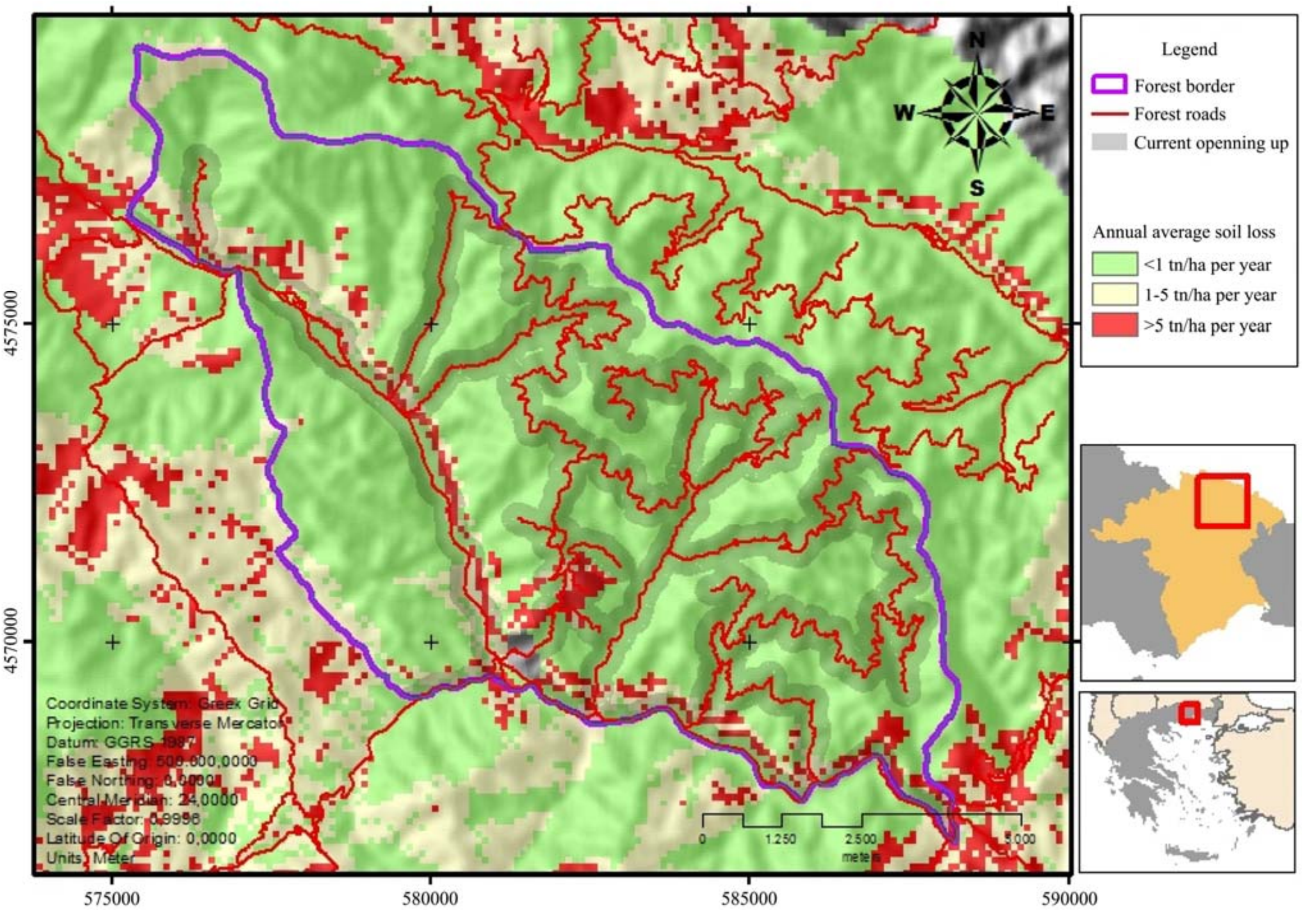

Figure 5 Erosion map

With regards to the implementation of least cost path analysis, all of the crossed data were converted to mosaics with the size of each alveolus reaching 5 meters. During the creation of five mosaic archives there is the respective rate of the total weight of the criterion's indicator in each alveolus of the mosaic archive. In addition, the rates of the fifth column are multiplied by 1000 so that the mosaic archives could have integral numbers.

3 Results

For the implementation of the least cost path analysis, five mosaic archives were added using the raster calculator, in order to create the mosaic archive of cost. The existing road network is considered to be denser on the southern and eastern part of the forest of Echinos (Figure 1), whereas the northern and western part of it has almost no roads, meaning that the forest opening up will focus on the clusters which face access and harvest problems.

The suggested roads are five, three on the northern part of the forest and two on the eastern. All suggested roads have as a starting place the existing road network and finally existing or suggested roads (Figure 6). The length of the existing roads is 110346.07 meters, so the road density is 14.05 meters per hectare, following the opening up of the five roads with the length of 16715.84 meters, the road density will be 16.18 meters per hectare.

A crucial factor for the forest opening up is the opening up zone that is the area from the road to the forest, which could easily become harvest projects. The opening up zone in the present paper is bilateral and its width from the road network is 250 meters, consequently 500 meters in total (Erdas, 1997; Liampas, 2015). With the aid of ArcGIS and the buffer tool, the opening up zone was calculated for the existing road network as well as the opening up zone's area by subtracting the areas' cover (Figure 7).

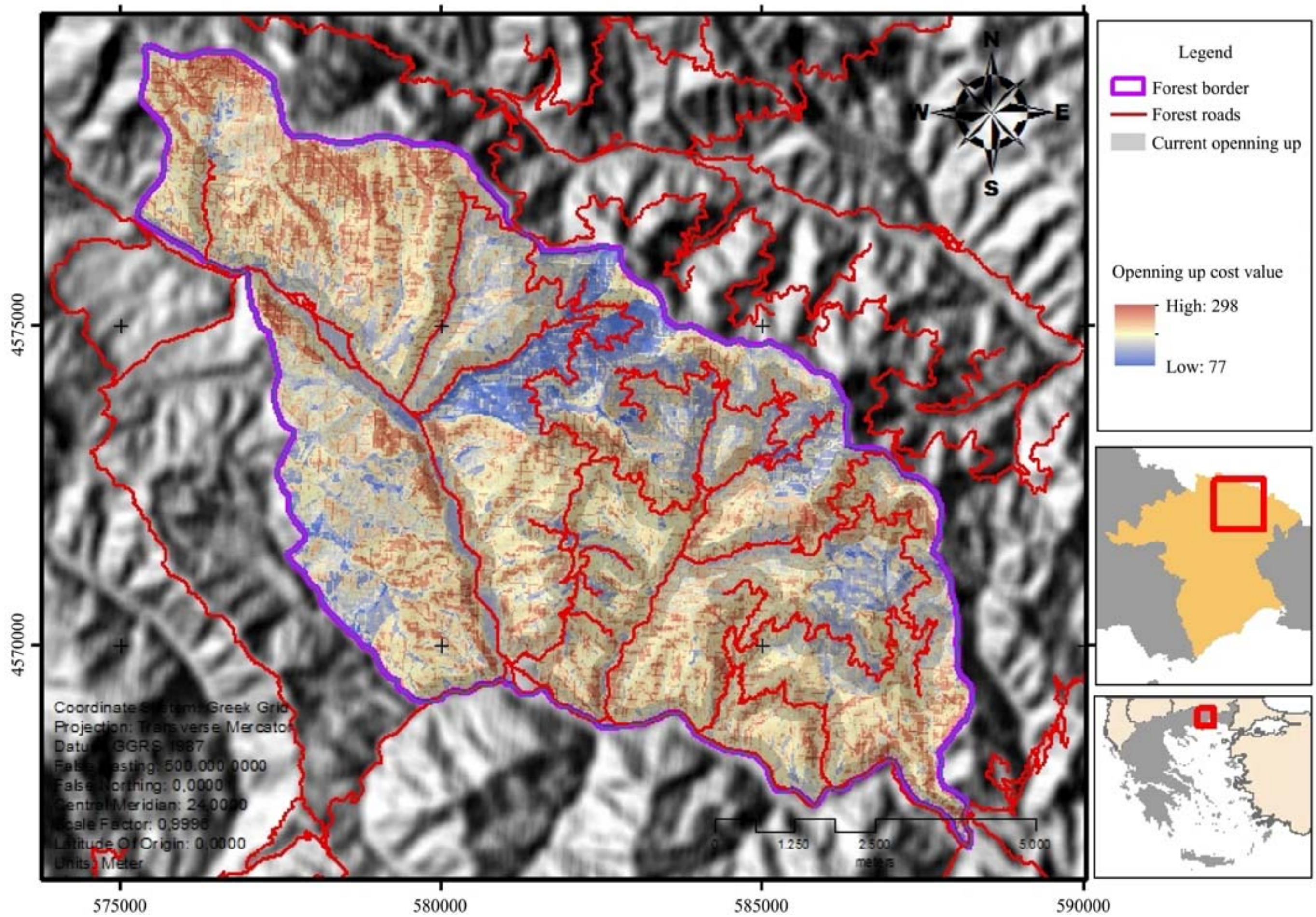

Figure 6 Map with opening up cost and the proposed roads

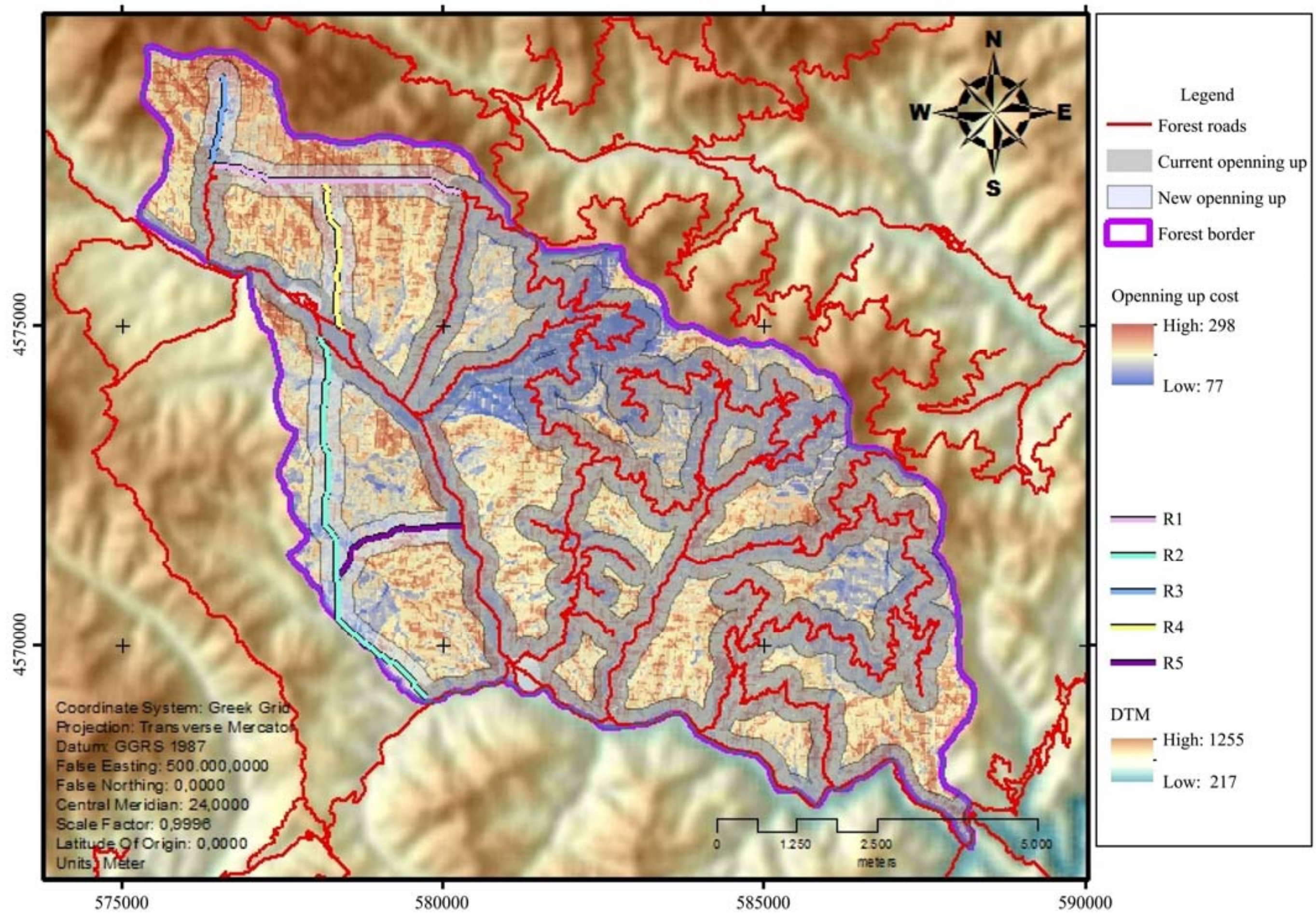

Figure 7 Map with the 5 proposed roads and the final opening zone

The following Table 2 contains the results of the opening up in the area of Echino's forest. The first column of the table contains the forest's land, the second one contains the length of the suggested roads. In the third column there is the total length of road network and in the fourth one, the opening up zone's land, at first without the suggested roads but with their addition afterwards. In the fifth column someone may see the percentage of forest land which lies inside the opening up zone and finally in the last column there is a presentation of the percentage's variation each time a new road is added.

Table 2 Results of proposed roads and opening up

Forest area (ha)	Proposed roads (m)	Length roads (m)	Opening up area (ha)	Opening up zone (%)	Openig up variation (%)
7852,25		110346.07	3760.89	47.89%	
	R1=4008.03	114354.10	3978.15	50.66%	+2.77%
	R2=6503.75	120857.85	4234.14	53.29%	+5.40%
	R3=1428.70	122286.55	4301.66	54,78%	+6.89%
	R4=2426.93	124713.48	4389.38	55.89%	+8.00%
	R5=2348.43	127061.91	4471.74	56.94%	+9.05%

Taking the results of Table 2 into consideration, it can be seen that the opening up of these suggested five roads of total length of 16715.84 mwill increase forest opening's up percentage per 9.05% and the total opening up zone's area will reach 56.94% of the forest comparing to 47.89%, which is the percentage with the existing road network. A very important piece of information, which affected the suggested roads' planning, is the number of clusters, whose part lies within the opening up zone. With already existing road network, the opening up zone affects 144 clusters out of the 168 in Echino's forest. One of the goals of the suggested opening up was the increase of clusters' numbers, which are affected by the opening up zone per 9.05%. The clusters which are affected are 165 out of 168. The ones that are not affected are the forest stands: 1e, 5e and 23d.However, the not affected forest stands lie very close to an opening up zone.

4 Conclusion

The paper presents a road opening up method in the forest with the use of Geographical Information Systems and its multi- criteria analysis. The process of the opening up of new roads with the aid of GIS, contributes to a more affordable and efficient forest opening up. The least cost path analysis is considered to be appropriate for the procedure of opening up forest's planning and it is more efficient as the distance increases between two points we want to connect. The multi – criteria analysis can contribute to the addition of more opening up criteria, apart from the two most used which regard slant and the exploitation of land. The goal is considered to be the most effective planning of the opening up for the accomplishment of the goals regarding the management study, the implementation of more criteria such as in the present project of timber's reserve, increment and of the waste which provides the opening's up researcher with a better insight of the forest and his productive capability.

The use of GIS and the implementation of least cost path analysis can reduce the time which is required for the planning of new road and it also offers the opportunity for a lot of opening up options to be processed and for areas to be spotted, which are in need of becoming opening up works. The main goal of the forest opening up planning should be the access of all the forest clusters via the opening up zone in the road network. The distance of 250m from the road network contributes to a better utilization of the products found in the forest, its protection, as well as its cultivation and upgrading.

References

Abdi, E., B. Majnounian, A. Darvishsefat, Z. Mashayekhi, and J. Session. 2009. A GIS-MCE based model for forest road planning. *Journal of Forest Science*, 55(4): 171–176.

Acar, H. H. 2016 Environmental sensitive road planning and transportation techniques in forest engineering. *Journal of The Faculty of Forestry-Istanbul University*, 66(2): 710–726.

Acar, H. H., E. Dursun, S. Gulci, and S. Gumus. 2017. Assessment of road network planning by using Gis-based multi-criteria evaluation for conversion of coppice forest to high forest. *Fresenius Environmental Bulletin,* 26(3): 2380–2388.

Antoniou, I., D. Kaluvas, and P. Nektarios. 2015. Creation of proposed green grids with the help of cost path of GIS in the Municipality of Zografou. In *Conference Geographical Information System Spatial Analysis in Agriculture and the Environment*, page 28-29. Athens, Greece., 28-29 May. ISBN: 978-960-6806-15-5.

Douglas, D. H. 1994. Least cost path in GIS using an accumulated cost surface and slope lines. *Cartographica*, 31(3): 37–51.

Drosos, V. C., V. J. Giannoulas, R. Ath. Giovannopoulos, D. Eur. Farmakis, and S. A. G. Liampas. 2008. The applicability of different g.p.s - types with the survey of forest road networks and paths in Greece. In *International Conference Studying, Modeling & Sense Making of Planet Earth*. Mytilini, 1-6 June.

Erdas, O. 1997. *Forest Roads I-II.* Trabzon, Turkey: Karadeniz Technical University, Forestry Faculty Publication.

GEOTEE. 2009. *Standard Technical Specifications for The Development of Management Plans for Forest Ecosystems*. Thessaloniki, Greece.

Gulci, S., and A. E. Akay. 2015. Assessment of ecological passages along road networks within the Mediterranean forest using GIS-based multi criteria evaluation approach. *Environmental Monitoring and Assessment*, 187(12): 779.

Heinimann, H. 1994. Umweltverträglichkeit forstlicher Erschließungen - Konzept für die Abwicklung, die Analyse und die Bewertung. *Schweiz. Z. Forstwegs*, 145(2): 139–157.

Karagiannis, E. 1991. Estimation of the degree of forest opening up in the mountainous regions of Greece. Ph.D. diss., Aristotle University of Thessaloniki, Greece.

Karagiannis, E. 1999. *Notes on Forest Opening Up and Wood Transportation.* Thessaloniki: AUTH.

Lee, J., and D. Stucky. 1998. On applying viewshed analysis for determining least-cost paths on digital elevation models. *International Journal of Geographical Information Science*, 12(8): 891–905.

Liampas, G. S. A. 2015. Forest opening up for timber transportation and protection. Ph.D. diss., Department of Forestry and Management of the Environment and Natural Resources, Democritus University of Thrace, Greece.

Liakos, L., and S. Vasileiadis. 2008. Determination of the exploitation area and the migration routes of the ancient settlements of the sprotia and Southern Albania using surface cost analysis and Model Xtent. In *10th National Cartography Conference: "Cartography of the Continental Region Boundaries - Axes - Standards - Quality*". Cartographic Scientific Society of Greece, Ioannina., 12-14 November.

Liampas, G. S. A., C. V. Drosos, G. A. K. Doucas, and J. V. Giannoulas. 2014. Forest opening up in mountainous Greek conditions. In *Forestsat 2014: A Bridge Between Forest Sciences, Remote Sensing and Geo-Spatial Applications*. Riva del Garda, Italy., 04-07 November.

Ntafis S. 1986. *Forest Ecology*. Thessaloniki, Greece: Giaxoudi-Giapouli.

Panagos, P., P. Borrelli, J. Poesen, C. Ballabio, E. Lugato, K. Meusburger, and C. Alewell. 2015. The new assessment of soil loss by water erosion in Europe. *Environmental Science and Policy* 54, 438–447.

Saaty, T. L. 1980. *The Analytic Hierarchy Process, Planning, Priority Setting, Resource Allocation*. New York: Mc Graw Hill.

Saaty, T. L. 1996. *The Analytic Hierarchy Process.* Pittsburgh: RWS Publications.

Saaty, T. L., and L. G. Vargas. 1991. *Prediction, Projection and Forecasting*. Dordrecht: Kluwer Academic Publishers.

Sedlak, O. 1993. Walderschliessung und Naturschutz. Allgemeine Forstzeitung. *Wien*, 7(2): 8–11.

Setiawan, I., A. Mahmud, S. Mansor, S. A. R. Mohamad, and A. A. Nuruddin. 2004. GIS-grid-based and multi-criteria analysis for identifying and mapping peat swamp forest fire hazard in Pahang, Malaysia. *Disaster Prevention and Management*, 13(5): 379–386.

Stamatiou, C., and S. A. Liampas. 2014. Upgrading of road's network by using least-cost path analysis in a typical Greek forest. In *International Symposium "Forest and Sustainable Development"*, 348–355. Brașov, Romania., 24-25 October.

Stergiadis, G. 1985. *Forest Roads Network and Timber Transportation*. Thessaloniki, Greece: Giaxoudi-Giapouli.

Xu, D., L. Dai, G. Shao, L. Tang, and H. Wang. 2005. Forest fire risk zone mapping from satellite images and GIS for Baihe Forestry Bureau, Jilin, China. *Journal of Forestry Research*, 16(3): 169–174.