Forest Transportation Planning by using GIS-based Decision Support System

Abdullah E. Akay*, Aso Azad Haji Kakol

Kahramanmaras Sutcu Imam University, Faculty of Forestry, Department of Forest Engineering, 46100 Kahramanmaras, Turkey. Tel: +90(344)2801713 Fax: +90(344)2801712
akay@ksu.edu.tr*; eng_asoazad@yahoo.com

Summary

Transportation of forest products is a complex engineering problem that requires evaluation of many alternative routes. This indicates the necessity of using computer-assisted methods in planning transportation of forest products and systematically searching for the optimum route. In this study, an application of GIS based decision support system was presented to determine the optimum route that minimized the total cost of transporting forest products. The network analysis method under "Network Analyst" extension of ArcGIS 10 program was applied. The road network data of Kahramanmaras (Central) Forest Enterprise Directorate at Kahramanmaras Forest Regional Directorate were considered in execution of the system. The optimum route with minimum unit cost in transportation of forest products was investigated by evaluating 10 harvesting units and two forest depots (Tekerek and Sucati). The results indicated that using GIS decision support system was able to reduce total transportation cost by 28.29% by considering both forest depots in the study area.

Key words: Forest transportation, forest products, network analysis, GIS, decision support systems

Introduction

Transportation planning is an important part of producing forest products in forest industry. If transportation of forest products is not planned adequately, forest managers may encounter organizational problems and high amount of transportation cost. Thus, planning of forest transportation activities is very crucial in order to minimize organizational risks and to lower down transportation cost (Akay and Erdaş, 2007).

To develop an adequate transportation planning, many alternative transportation plans should be evaluated so that an optimum plan with minimum cost can be selected. Conventional transportation planning methods, which usually depend on the experiences of a planner, are not capable of searching alternative transportation plans. There are number of studies where computer-based methods, using computer technology and optimization techniques, have been employed to assist planners in evaluating high number of alternative transportation plans (Ichihara et al., 1996; Akay and Sessions, 2005; Aruga et al., 2005; Akay et al., 2012a).

Solving transportation problems such as shortest path, maximum flow, and optimum task allocation, computer-based network analysis method provides accurate and quick solutions (Akay et al., 2012b). In the solution process of network method, various parameters such as cost, travel time, and length are assigned to the network links and then the shortest or optimal path is selected by searching the alternatives (Zhan, 1997; Chung and Sessions, 2002).

Geographical Information System (GIS) technology has been increasingly used in many forestry applications such as forest operations, forest transportation, forest management, forest fires, etc. (Sivrikaya et al. 2007; Yuksel et al., 2008; Akay et al., 2008;

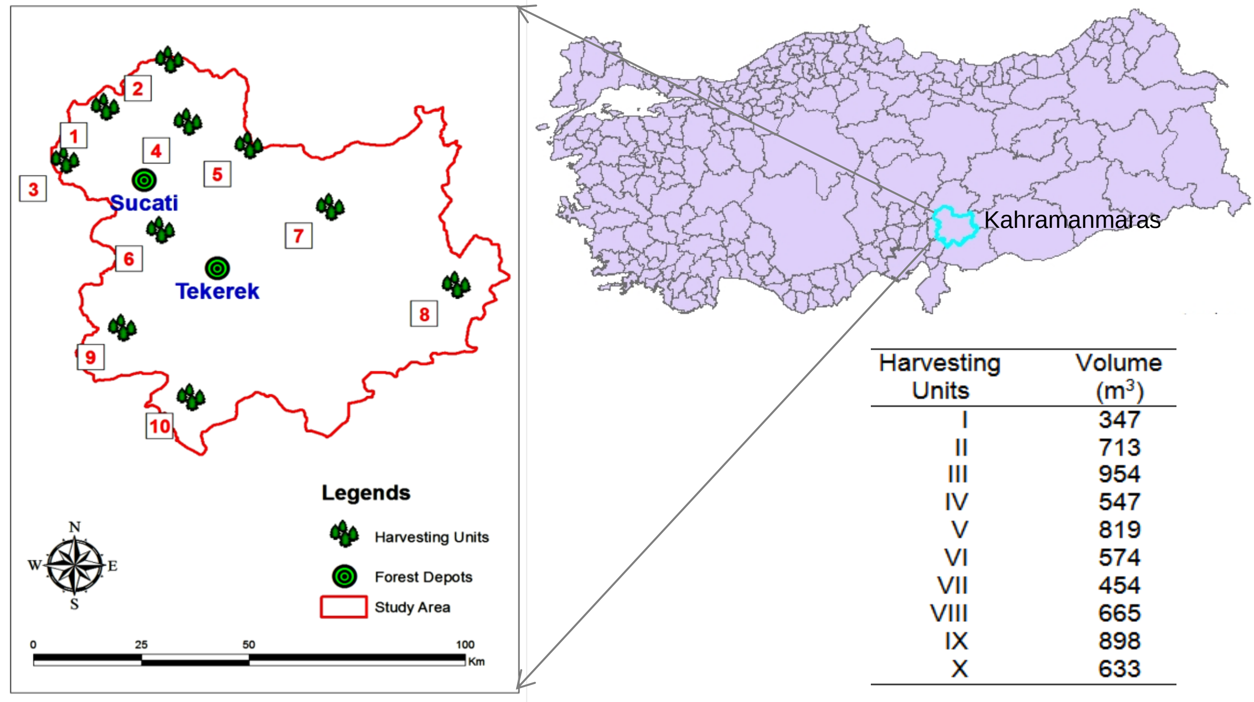
Gumusay and Sahin, 2009; Wing et al., 2010). A modern GIS facilitates four basic components including hardware, software, data, and people (Davis 1996). With the advanced tools and improved capabilities of GIS, it is possible to efficiently integrate forest transportation planning techniques into GIS. Alternative routes can be evaluated quickly and accurately by using GIS techniques. Especially, network analysis-based modules of GIS such as Network Analyst can be efficiently used for solving transportation problems (Akay et al., 2012b).

Improperly planned forest transportation can be significant proportion of overall costs of timber production (Acar and Eroğlu, 2001). Thus, a better planning of forest transportation is necessary for optimal connection of the forest resources with processing facilities. In this study, a GIS based decision support system was implemented on minimizing the cost of forest transportation activities taken place in a Mediterranean city of Kahramanmaraş in Turkey.

Material and Methods

Study Area

Kahramanmaras (Central) Forest Enterprise Directorate within the border of Kahramanmaras Forest Regional Directorate was selected as study area. The study area is located within 38.05°-37.17° North and 36.45°-37.60° East coordinates. The area covers about 615247.65 ha land where the average elevation and ground slope is about 1066.27m and 15.63%, respectively. The main tree species in the area include *Pinus brutia* (Brutian Pine), *Pinus nigra* (Black Pine), *Cedrus libani* (Cedar), and *Querqus* (Oak). In the study, the optimum routes were investigated for 10 different harvesting units, considering two different forest depots including Tekerek and Sucati (Figure 1).



Harvesting Units	Volume (m^3)
I	347
II	713
III	954
IV	547
V	819
VI	574
VII	454
VIII	665
IX	898
X	633

Figure 1. Harvesting units and forest depots in the study area

Road Network

The road types map was generated based on topographical map (1/25000) of the study area. In order to develop network database, transportation cost of logging truck on each road section was computed based on five parameters road length, road type, road condition, average vehicle speed and travel time. Thus, "Attribute Table" of the road map included fields for these parameters.

The road length was calculated by "Calculate Geometry" tool in "Attribute Table". The road types in the study area were divided into three classes including access roads, main forest roads, and secondary forest roads. The road conditions (good, average, poor) were determined based on information obtained from Forest Enterprise Directorate. Then, the average vehicle speed was estimated based on road types and road conditions (Table 1).

Table 1. The vehicle speed as a function of road types and road conditions (km/hr)

Road Types	Road Conditions		
	Good	Average	Poor
Access Road	60	50	40
Main Forest Road	50	40	30
Secondary Forest Road	30	25	20

Finally, travel time of the logging truck for each road section was computed based on Equation 1 by using "Field Calculator" tool in "Attribute Table":

$$t_i = \frac{l_i}{v_i} 60 \qquad (1)$$

t_i : travel time on road section *i* (minutes)
l_i : length of road section *i* (km)
v_i: vehicle speed on section *i* (km/hr)
60: coefficient to convert time from hours to minutes

After computing travel time for each road section, transportation cost (Euro/m^3) was computed based on machine rate (Euro/hr), truck road capacity (m^3), and travel time (hr):

$$C_i = \frac{MR}{\left(\frac{load}{t_i}\right)*60} \qquad (2)$$

C_i: trasportaion cost (Euro/m^3)
load: load capacity (m^3)
MR: machine rate (Euro/hr)

Network Analysis

Network Analyst extension in ArcGIS software works based on the methodology of network analysis. It provides network-based spatial analysis including routing, service area, closest facility, travel directions, and new location-allocation analysis (Figure 2). Using a sophisticated network model, users can easily build networks based on GIS database. Network Analyst also enables users to dynamically model realistic network conditions such as turn restrictions, speed limits, and height restrictions, and traffic conditions.

In order to run methods of Network Analyst extension, firstly, a Personal Geodatabase under ArcCatalog module was generated, and then, network dataset was produced based on road types map containing transportation cost information for each road section in the study area. Finally, links (*ND_Edges*) and nodes (*ND_Junctions*) data layers were generated by using network database. After having network database, the new closest facility method under Network Analyst extension was used to find the optimum routes with minimum transportation costs from 10 harvesting units to two forest depots in the study area.

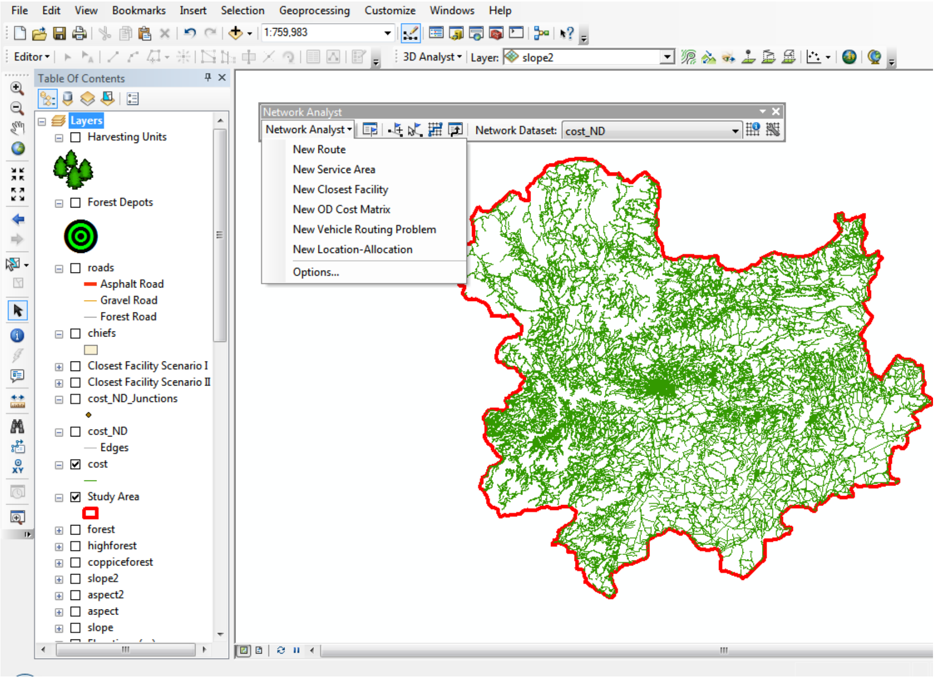


Figure 2. Network Analyst extension in ArcGIS 10

In the application, the network analysis was performed on two scenarios:

- *Scenario I:* The optimum routes in transportation of forest products from 10 different harvesting units were investigated by considering only main forest depot of Tekerek.
- *Scenario II:* The optimum routes in transportation of forest products from 10 different harvesting units were investigated by considering both Tekerek and Sucati depots.

Results and Discussion

Road Network

The results indicated that total length of the road network in the study area was computed as 14451.63 km. Most of the road types were secondary forest roads (48.04%), and followed by main forest roads (44.73%) and access roads (7.23%). Total number of road sections was 2077. By considering road conditions in the study area, it was found that 59.88% of the road network was in good condition, while 31.21% and 8.91% of the roads were in average and poor conditions, respectively (Table 2). All of the access roads in the study area were classified as good condition. The most of the main forest roads were also in good conditions (63.76%), and followed by average (18.42%) and poor roads (17.82%). On the other hand, half of the secondary forest roads were in good conditions (50.23%), while 47.82% and 1.94% of the roads were in average and poor conditions, respectively. Figure 3 indicates road types map in the study area.

Table 2. The length information about road types in the study

Road type	Total Length (km)	Road Conditions (km)		
		Good	Average	Poor
Access Road	8653.67	1044.92	--	--
Main Forest Road	4510.96	4121.33	1190.86	1152.02
Secondary Forest Road	1287.01	3487.42	3320.1	134.99
Total	14451.64	8653.67	4510.96	1287.01

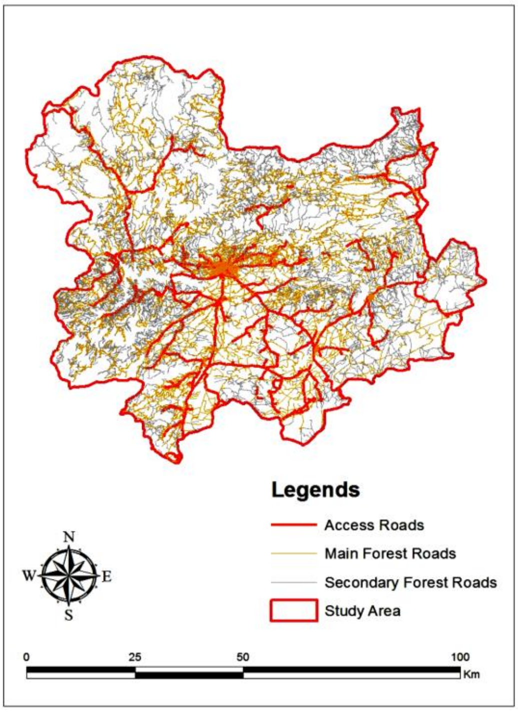


Figure 3. Road types map

Network Analysis

Network analysis was performed by using Network Analyst extension based on two main data layers including links and nodes data layers. The links layer contained road sections with transportation cost information, while nodes layer was indicating connection points of neighboring links.

In the first scenario, the optimum routes in transportation of forest products from harvesting units were investigated by considering only main forest depot of Tekerek in Kahramanmaras. The total cost of transportation was found to be 12833 Euro. The results indicated that the travel time is effected by road length and road types (Table 3). It was also found that the minimum unit cost of transportation was at the route from harvesting unit VI, followed by VII and X (Figure 4).

Table 3. The transportation cost summary for each harvesting units

Harvesting Units	Timber Volume (m^3)	Unit Cost of Transportation (Euro/m^3)	Total Cost of Transportation (Euro)
I	347	1.93	669.71
II	713	2.73	1946.49
III	954	2.22	2117.88
IV	547	1.96	1073.94
V	819	2.34	1919.19
VI	574	0.74	426.67
VII	454	1.50	679.49
VIII	665	2.25	1496.25
IX	898	1.79	1604.43
X	633	1.42	898.86

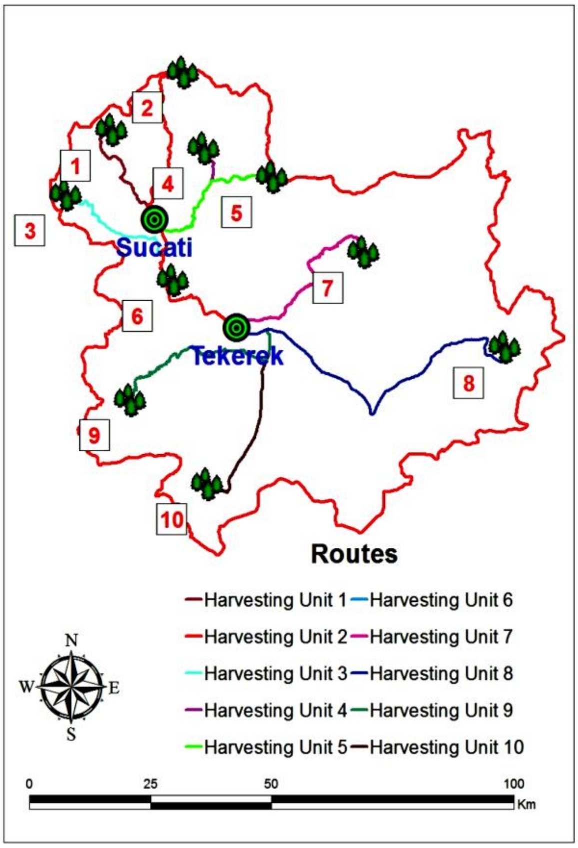


Figure 4. Optimum routes from harvesting units to Tekerek Depot

In the second scenario, the optimum routes in transportation of forest products from 10 different harvesting units were investigated by considering both Tekerek and Sucati depots. The total cost of transportation was found to be 9202 Euro. The results indicated that in the second scenario lowered down the total cost by 28.29%.

It was found that the minimum unit cost of transportation was at the route from harvesting unit VI, followed by I and IV (Table 4). The forest products extracted from harvesting units I to VI was hauled to Sucati Depot, while forest products extracted from rest of the harvesting unit was hauled to Tekerek Depot. Figure 5 indicates the optimum routes from the harvesting units to the forest depots.

Table 4. The transportation cost summary for each harvesting units

Harvesting Units	Forest Depot	Timber Volume (m^3)	Unit Cost of Transportation (Euro/m^3)	Total Cost of Transportation (Euro)
I	Sucati	347	0.83	289.17
II	Sucati	713	1.63	1162.19
III	Sucati	954	1.15	1093.92
IV	Sucati	547	0.98	537.88
V	Sucati	819	1.36	1116.57
VI	Sucati	574	0.56	323.35
VII	Tekerek	454	1.50	679.49
VIII	Tekerek	665	2.25	1496.25
IX	Tekerek	898	1.79	1604.43
X	Tekerek	633	1.42	898.86

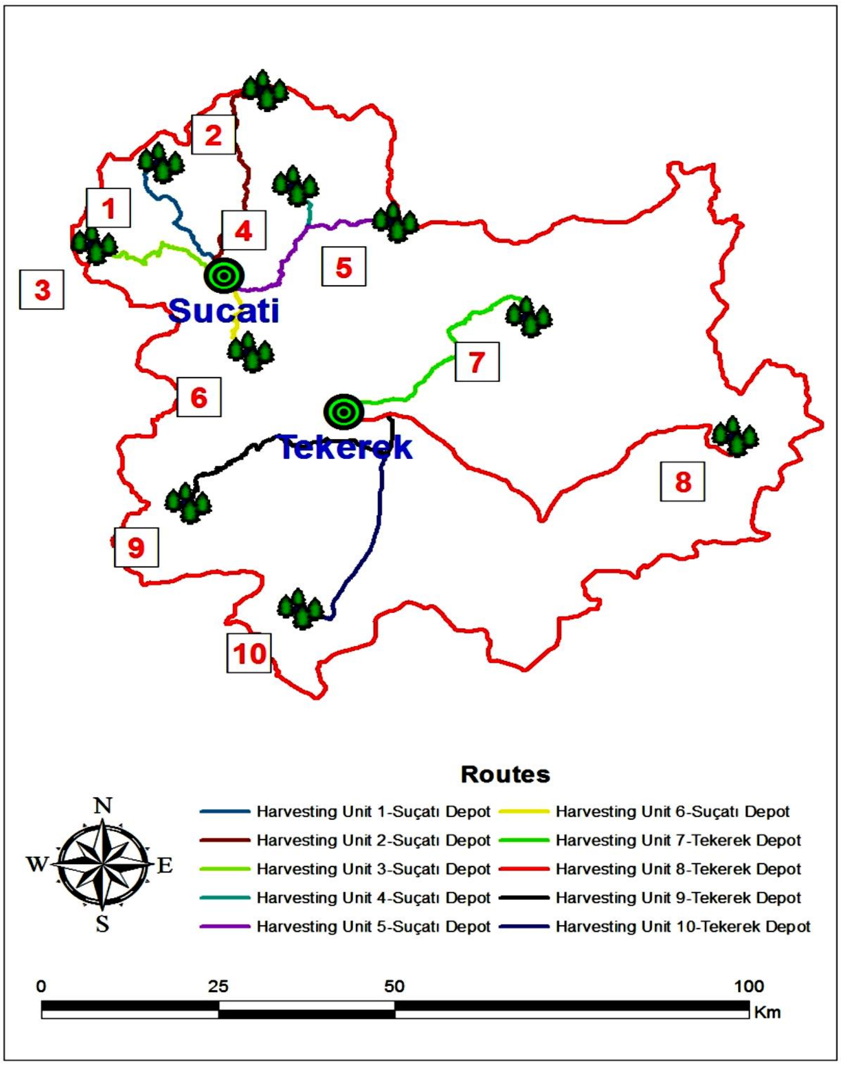


Figure 5. Optimum routes from harvesting units to forest depots

Conclusions

An application of GIS based decision support system was implemented to determine the optimum route that minimized the total cost of transporting forest products. The network analyst method under "Network Analyst" extension of ArcGIS 10 platform was used to systematically search for optimum routes. In the study, 10 different harvesting units and two forest depots (Sucati and Tekerek) located in Kahramanmaras (Central) Forest Enterprise Directorate at Kahramanmaras Forest Regional Directorate were considered in execution of the system.

The optimum routes with minimum transportation cost were determined for two different scenarios. In the first scenario, the optimum routes in transportation of forest products from 10 different harvesting units were investigated by considering only Tekerek forest depot. The results indicated that total cost of transportation was 12833 Euro in the first scenario. In the second scenario, the optimum routes from harvesting units were investigated by considering both Tekerek and Sucati forest depots. The total cost of transportation reduced to 9202 Euro. This suggested that evaluating two alternative depots caused a reduction of 28.29% in total transportation cost.

The results suggested that road types and road conditions affect vehicle speed which reflects transportation time and then operator costs. Besides, longer haul distance increase transportation time and fuel costs. The longer the distance a truck must travel, the higher the variable costs in labor, fuel, and maintenance, which leads to reduction in the overall productivity of forest transportation.

REFERENCES

Acar, H.H., Eroğlu, H., 2001. The Planning of Wood Transport on the Forest Roads. Kafkas University, Artvin Faculty of Forestry Journal. 1(2001): 61-66.

Akay, A.E., Erdaş. O., 2007.Network Model Approach in Transportation Planning of Forest Products.İstanbul University, Faculty of Forestry Journal, A-Series. 57(2):1-20.

Akay, A. E., Erdas, O., Reis, M., Yuksel, A., 2008. Estimating Sediment Yield From a Forest Road Network by Using a Sediment Prediction Model and GIS Techniques. Building and Environment, 43(5): 687–695.

Akay A.E., Doucas K., Erdaş O., Oğuz H., Sivrikaya F., 2012a. Using GIS Techniques to Determine Fire Protection Zones Considering Forest Road Network. Forest Engineering: Concern, Knowledge and Accountability in Today's Environment Hotel Croatia, October 8 - 12. Dubrovnik (Cavtat), Croatia.

Akay, A.E., Wing, G.M., Sivrikaya, F., Sakar, D. 2012b. A GIS-Based Decision Support System for Determining the Shortest and Safest Route To Forest Fires: A Case Study in Mediterranean Region of Turkey. Environmental Monitoring and Assessment. 184(3):1391-1407.

Aruga, K., Sessions, J., Akay, A.E., 2005. Heuristic Techniques Applied to Forest Road Profile. The Japanese Forest Society, J. For. Res. 10(2):83-92.

Chung, W., Sessions, J. 2002.Optimization of Cable Logging Layout Using a Heuristic Algorithm for Network Programming. Proceedings of the Council of Forest Engineering, 16-20 June 2002, Auburn, AL. 104 p.

Davis, B. 1996.GIS – A Visual Approach, Onword Press, Santa Fe, NM.

Gumusay, M.U., Sahin, K., 2009. Visualization of Forest Fires Interactively on the Internet. Scientific Research and Essay, 4(11):1163–1174.

Ichihara, K., Tanaka, T., Sawaguchi, I., Umeda, S., Toyokawa, K., 1996. The Method for Designing the Profile of Forest Roads Supported by Genetic Algorithm. The Japanese Forestry Society, Journal of Forestry Research. 1:45-49.

Sivrikaya, F., Keles, S., Cakir, G., 2007. Spatial Distribution and Temporal Change of Carbon Storage in Timber Biomass of two Different Forest Management Units. Environmental Monitoring and Assessment, 132:429-438.

Yuksel, A., Akay, A. E., Gundogan, R., 2008. Using ASTER Imagery in Land Use/Cover Classification of Eastern Mediterranean Landscapes According to CORINE Land Cover Project. Sensors, 2008(8), 1237-1251.

Wing, M.G., Eklund, A., Sessions, J., 2010.Applying Lidar Technology for Tree Measurements in Burned Landscapes. International Journal of Wildland Fire, 19:104–114.

Zhan, F.B., 1997. Three Fastest Shortest Path Algorithms on Real Road Networks: Data structures and Procedures. Journal of Geographic Information and Decision Analysis. 1:70–82.