Environmental effects of forest operations on a suburban forest landscape – a forest engineering approach

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Summary: Non-timber forest products and resources are highly valued by society. Operating technologies that reduce damage to residual vegetation, decrease soil disturbance, and improve timber recovery will benefit timber management while at the same time increasing substantially the value of the non-timber goods and services provided by forests. Forest operations alter the environment. Some of these effects are intended; others are undesirable consequences. Most impacts are associated with driving equipment and moving material in the forest. Soil, water, and residual vegetation can be affected. Effects must be considered in terms of their quantity, severity, persistence and location within the landscape. Some impacts are short-lived, while others may affect the long-term productivity of the forest. Impacts that are concentrated may be significant, while the same impacts spread across a stand may not be ecologically important. Harvesting and other forest operations are tools for managing the forest landscape. Aim of this paper is to investigate the effects of both harvest planning and forest earthworks or road net on a suburban forest landscape. Harvest planning involves the gathering and analysis of information to decide on the best way to harvest an area. Key factors in decision-making are safety, protection of environmental values, the road infrastructure and productivity. Roads, landings and logging earthworks are potentially the greatest source of sediment into waterways and hence strict guidelines are adhered to in order to minimize any adverse effects on the environment.

Keywords: landscape; decision-making; harvest planning; forest earthworks

1. Introduction

In most industrialized countries, the use of draught animals in forest operations represents a curiosity, rather than a technical necessity. The rapid mechanization of all rural activities has brought animal power to the brink of extinction, despite the staunch resistance of its few loyal supporters (Magagnotti, Spinelli 2011).

The broad area of Forest Operations comprises the analysis and design of systems and processes for the sustainable management and utilization of forests and landscape. Topics of particular interest include: Forest Technology and Harvesting, Bioenergy and Renewable Bio- Resources, Forest Engineering, Transport systems and Logistics, Environmental impact analysis and Technical impact assessment. Also the aspects and needs of human labor involved in these systems and processes should be taken into consideration.

Forest operations consist of all technical and administrative processes required to develop technical structures and facilities, to harvest timber, to prepare sites for regeneration, to maintain and improve quality of stands and habitats, etc. (Sessions and Garland 1999).

In simple words the methods, materials, and systems used to transform the forest are the technology of forest operations. Forest operations include active and passive site preparation, thinning, cutting, timber harvesting, prescribed fire and construction and maintaining roads.

In some cases, logging of forest stands creates conditions beneficial for seedling establishment by disturbing soil surfaces. This effect is considered a type of passive site preparation. Active site preparation may be needed to kill unwanted vegetation, alter soil properties, or reduce logging debris. Active site preparation can be accomplished by prescribed burning, or by mechanical or chemical methods (herbicides). In many cases, mechanical, chemical or prescribed burning methods have similar effects.

In many cases, mechanical, chemical, or prescribed burning methods have similar effects. Mechanical methods requiring large machinery often prove impractical on slopes exceeding 25 to 35 percent, and may not produce the desired effects on rocky surfaces or frozen and snow-covered soils. Chemical treatments may prove ecologically unacceptable in sensitive areas or adjacent to ponds, lakes and streams. Prescribed burning must be avoided where there is high risk of escape, and where smoke may create health, safety, and visibility problems. The heat may also kill residual trees a landowner wants to preserve, and a burn may only temporarily affect the targeted vegetation (Nyland 1996).

Generally speaking, site preparation also should be avoided where managers want to safeguard ground conditions to inhibit some unwanted species, or to prevent surface erosion.

Thinning are intermediate cuttings made in immature stands to control stand density and redirect resources (light, water, and nutrients) to residual trees (Beck 1986).

Therefore, knowing the various biotic and abiotic factors such as site quality, stocking density, crown position, fire history, climatic stresses (drought, frost, ice), and insect and disease conditions are related on tree growth will help to understand how the thinning affects tree growth and stand volume production.

Cutting (Improvement, Sanitation, and Salvage) tends to focus on the poor-quality trees for removal, whereas thinning tends to focus on the residual stand or crop trees (Hicks 1998). Cuttings serve primarily to reduce financial losses from a recognizable injurious agent such as remove dead or dying trees from forest stands. With cuttings upgrading the condition and quality of the growing stock, these measures may reduce sources of pests and diseases and manipulate stands so that they are less susceptible to destructive agents (Nyland 1996).

Harvesting timber is a complex process of interconnected activities. Harvesting and other forest operations are tools for managing the forest landscape. Timber harvesting provides goods and income from the forest, and it can improve the condition of the residual forest.

Greece presents unique challenges to cost-effective and ecologically-sensitive harvesting. The forester must select a system that provides the greatest benefits at the least cost. Animal logging was replaced by tractor logging in the 1950’s to reduce costs. Yet, 64 years later, animal logging systems are still found in Greek forests. Various surveys indicate a public perception that animal logging is ecologically and visually preferred over more mechanized systems. The low production rate and minimal move-in costs make animal logging operations most competitive on small harvest units or on sensitive areas such as parks, suburban forests etc. The primary advantages of animal logging are minimal soil disturbance and residual tree damage, suitability to small tracts and selective cutting, and minimal noise and pollution. Balancing these advantages, however, are the low overall production rate, a significant reduction in productivity with small diameter pieces, stand disturbance associated with loading and woods roads, and the need to minimize skidding distance.

Steep terrain and poor access increase extraction and transportation costs and require specially adapted equipment but till today the lumberjacks used to do the logging of wood in mountainous productive (logs) forests by tractor that pull logs uphill from tractor roads or traditional by skidding logs with draught animals in a distance of more than 200 m and in non-productive forests (firewood) the logging is done by loaded (carrier) animals in downhill direction in a distance of more than 500 m (Figure 1) (Drosos et al. 2013).

The size of slope also is a key factor that indicates the need to minimize soil disturbance and implement effective management practices in order to avoid water quality impacts. Three basic types of harvesting systems are used today in whole over the world: ground-based, cable logging, and aerial systems. In Greece the first one is a widespread method, the second one is in pilot implementation stage and as for the third one is not be used and is not going to be used due to high costs and scarce and scattered growing stock.

According to Leibundgut (1961), forestry followed everywhere the road construction and a forest is economic and exploitable only by a good road network.

The most important forest technical infrastructures to prevent fire are:
a forest roads network (opening up) for fire protection
b spatial distribution (Buffer Zones)

(a) (b)

Figure 1. Draught animals in productive forest (logs) (a) and Carrier (loaded) animals in nonproductive forest (firewood) (b).

Direct fire suppression requires access on forest roads in the outbreak of fire and appropriate equipment of fire fighting vehicles with special hoses (Oguz et al. 2012).

The increasing density of road networks in and adjacent to many forest, shrub, and grassland areas has been an important factor in changing patterns of disturbance by fire on the landscape. Roads provide access that has increased the scale and efficiency of fire suppression, and roads have created linear firebreaks that affect fire spread (Salazar and Gonzalez-Caban 1987). These factors can be useful in both fire suppression and prescribed fire operations. In addition, road access has undoubtedly contributed to increased frequency of human-caused ignitions in some areas (Conard and Weise 1998, Xanthopoulos and Varela 1999).

Least but not last is the planning, construction and maintaining of forest roads. Roads and access to an area impose a major constraint to development. They are a necessary evil in that you need to provide access to residential areas, parks, etc., but they divide the land and increase costs of development. Roads also create an impervious surface, increasing runoff, and resulting in impacts in adjacent areas. But they have undoubtedly contributed to increase the income of the local population and to put an end in the isolation of the forest mountainous areas especially in Para Mediterranean basin (Doucas and Drosos 2013).

Forest Engineering encompasses both harvest planning and forest earthworks or road net. Harvest planning involves the gathering and analysis of information to decide on the best way to harvest an area. Earthworks involve the construction and maintenance of roads, landings (roadside), stream crossings, firebreaks and land preparation operations.

Aim of this paper is to investigate the effects of both harvest planning and forest earthworks or road net on a suburban forest landscape taking into consideration the protective and hydrologic role of the suburban forest.

2. Materials and Methods

2.1. Study area

The prefecture of Xanthi with the prefectures of Drama, Kavala, Rodopi and Evros is the region of Eastern Macedonia and Thrace, which is in the north-eastern part of Greece. Its capital is the city of Xanthis. The flora and fauna of Xanthi are characterized by high biodiversity. It is among the 5-6 most important prefectures of the country from wooded view. In 2006 an area of 2,336.14 Ha was declared as a number of forests in Greece and categorized as environmentally protected one. The protective suburban forest is located between the 4553800 – 4558500 N and 571000 – 581500 E coordinates of the Hellenic Geodetic Reference System 87 (HGRS ’87). The role of suburban forest is multiple. It has beneficial effects on the social, economic and especially environmental field. It is an oasis of rest and inspirational for the people of the region who has been sensitized enough, especially in recent years, showing in practice their friendly feelings about the forest (Figure 2).

The suburban forest was established by artificial reforestation in the past and is on the one hand the green lung of Xanthi, while on the other hand a place of recreation of the townspeople who often visit it, combining visits to the three monasteries that exist in this (religious tourism). The suburban forest of Xanthi, concerning the management form, characterized as high, even-age in areas coniferous forest. The species used in artificial reforestation are the Calabrian pine (*Pinus brutia, Thassos origin*), maritime pine (*Pinus maritima*), the Scone Pine (*Pinus pinea*) and Cypress (*Cupressus sempervirens*), with an understory consisting of native broadleaved species (oak, beech, elm, maple, hornbeam etc.).

Figure 2. View of the suburban forest of Xanthi.

2.2. Methodology

Descriptive data in this paper were generally obtained through standard literature review methods and from the forest management plan of the suburban forest. The evaluation of harvest planning and forest earthworks or road net on a suburban forest landscape, however, involved some additional data analysis.

For the research in the area of suburban forest of Xanthi and in order to achieve the research goals that have been set in the frame of this paper were used AutoCAD Civil 3D 2009 and Raster Design on Autodesk Map 3D 2009 and the subroutine of Autodesk Map 3D for Geospatial 2009.

Digital orthophotos were the primary source of spatial data required for this study. Additionally carried out the vectorization (convert to vector) from TIFF format analog topographical maps of Xanthi in scale 1:50000 and the corresponding analog topographical diagrams in scale 1:5000 (3536_1, 3536_3, 3536_4, 3536_5, 3536_6, 3537_3, 3537_4, 3537_5, 3537_6) of topographic military service.

The list below summarizes the conversion of hard-copy maps and diagrams to CAD ones, using the raster to vector converter software Raster Design on Autodesk Map 3D 2009:

1. Create a raster file by scanning a hard-copy drawing with a scanner.
2. Use Raster Design on Autodesk Map 3D 2009 to convert the raster file to the vector format.
3. Import the vector file to CAD application.
4. Edit the maps and diagrams in CAD application.

- Interior orientation (georeferenced) was performed in order the coordinates of the digital maps to meet the real coordinates system Hellenic Geodetic Reference System 1987 (HGRS '87) of the survey area.
- Then digitized the contours (contour lines every 20 m and 100 m) and the corresponding regions.
- With the help of the software AutoCAD Civil 3D 2009 created by the contours the Digital Terrain Model from the electronic data processing of which resulted the digital maps of slopes and aspects.
- The forest road network and the land uses of the study areas were also mapped in vector format (polylines).
- All the spatial analysis was performed in AutoCAD Civil 3D 2009.
- Road density and skidding distance were the first parameters which were measured in an effective way.
- Opening up zones (buffers) were placed according to the existing skidding method which is drought animals (300 m downhill). In this procedure we took into consideration the topographical relief using breaklines to represent streams and ridge lines.

The skidding means used in the study area is only the animals. The opening up percentage was calculated by creating the digital map and uphill of existing roads area (buffer) width equal to the mean skidding distance.

For the study of the transportation network were compared the existed road network with the theoretical and the economic model. In order to calculate the optimum road density either the existing one D_{ex} or the optimum theoretical D_{th} and optimum economic Dec one has been used the Kroth method (Kroth 1973, Trzesniowski 1993). This method refers to the economic result of the investments which are available for the construction of forest roads. For this purpose the following parameters have been determined in relation to the road density and after the investigation of the local data: the land revenue (K_B), the annual annuity per cubic meter of wood which is produced in the suburban forest of Xanthi (K_R), the maintenance cost of the road network, (K_{SU}), the skidding cost of wood, (K_r), the total cost (K_S). Also were calculated the coefficient of road network correction, the coefficient of mean skidding distance correction, the years of amortization and the interest rate.

The determination of the average vertical skidding distance and the coefficient of road network correction achieved using GIS and taking into consideration the skidding means (for animals: one-sided skidding of the uphill to downhill direction).

Step out the study area, and sighting from its highest points and the use of all recorded geographical and geodetic information led us how it would be preferable and more ergonomic to be installed and used the existing and proposed infrastructure forest constructions for better fire protection of the forest and the possible suppression of forest fire.

3. Results

Data of suburban forest of Xanthi are the following:

1. Harvesting: 1.13 m^3/year/hectare.
2. Road construction cost: 20.00 €/m.
3. Road maintenance cost: 0.28 €/m.
4. Fix skidding cost (C_F): 5.82 €/m^3.
5. Variable skidding cost (C_V): 0.0181 €/m.
6. Years of amortization: 30 years
7. Interest rate: 3%.
8. Coefficient of road network correction (W): 1.82
9. Coefficient of mean skidding distance correction (F): 1.84
10. Land revenue (K_B): 0.00018 €/m^2.

According to the above mentioned data the economical and the theoretical optimum road density are D_{ec} = 18.90 m/ha and D_{th} = 16.23 m/ha, respectively.

In figure 3 is shown the silviculture map of the suburban forest with all the proposed works on it in order to improve or minimize the environmental effects on the suburban forest landscape.

4. Discussion and Conclusions

4.1. Conclusions

The existing road density is D_{ex} = 13.40 m/ha, less than the optimum economical and the theoretical road density so must be constructed new forest roads and they are presented on figure 3.

Thus the specifications of managing forests are separated from the old ones, whose aim was the harvesting of wood in the productive forests. Concerning the design of forest roads the definitions of optimal road density and spacing is totally altered from the traditional meaning of the productive forests.

The forest roads should be designed with the minimum geometric characteristics in order to minimize their impact to the environment. But some of the protected forests are at the same time characterized as high risk to fires by legislation. This results in a conflict between the fire services and the environmental ones.

The suburban forest of Xanthi is one of these cases. The environmental history of one region describes the interactions between the landscape and the people that inhabit it. The mountains have also shaped the people and culture of the region and continue to do so today. An environmental history of Greece allows us not only to see the full impact of human settlement on the mountain and semi mountain landscape, but also to document the role of environmental forces in shaping human actions. Xanthi residents took of the suburban forest woods for heating and now they have been given up this habit and the suburban forest has developed an understory capable for fires (Figure 4). The suburban forest of Xanthi is a typical example of a multifunctional Green Infrastructure (GI) area that is capable of combining farming, forestry, housing, as well as tourism and recreational activities in the same space whilst at the same time keeping freshwater systems clean, air healthy and wildlife safe.

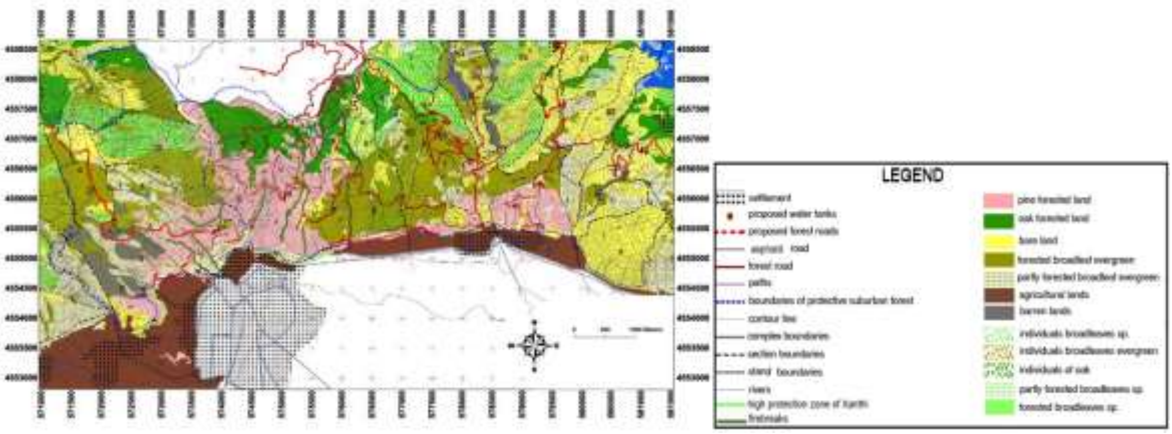

Figure 3. Silviculture map of the suburban forest of Xanthi.

Figure 4. Understory of suburban forest of Xanthi with accumulation of fuel.

In order to improve this Green Infrastructure, we must be able to maintain healthy ecosystems by using nature-based solutions such as biological control of insects and diseases affected pine and reconnect fragmented natural and semi-natural areas in the area of the suburban forest and restore damaged habitats, so they can provide us with more and better goods and services. For these reasons are proposed only 12,873 m forest roads in the whole area in order to prevent forest fires. Also a number of firebreaks must be done for the same reason as shown in figure 3.

The suburban forest region consists of physical, biological, and human landscapes.

The physical landscape can be described by its climate, geology, topography, soils, and drainage.

Forest operations do not affect the climate, geology and topography but they have minimal impact on soils and drainage.

Generally the climate of the region is classified as sub-humid Mediterranean with a tendency towards dry Mediterranean. The soil in zone of the marbles is generally shallow and skeletonize. It is considered suitable only for growing indigenous vegetation, which consists mostly of various deciduous and evergreen broadleaves. In the zone of gneiss - granite, in areas of high forest cover the soil is deep and has a high water capacity.

The biological landscape is defined by the biomes or biological communities found in the region.

Increasing of animal capacity of forest ecosystem is a necessary prerequisite for conservation and increasing the populations of various species. This increase is possible by creating within the recovery-cultivation of forest, the appropriate stages of forest development (structures) and alternation of ecosystems (agro-forest) while creating habitats. Doing so will create appropriate environments for feeding, nesting and “coverage” of many kinds. The reduction of grazing pressure will act beneficially to the improvement of feeding conditions of herbivore species.

Also, it should be noted that a special protection area in the under study suburban forest called: “PANAGIA - KALAMOUS – TAXIARCHON” characterized as wildlife refuge with an area of 1,590 Ha.

The physical and biological landscapes have also been modified by the people who have lived there and defined the cultural landscape.

Harvesting and other forest operations are tools for managing the forest landscape. Especially harvesting has evolved into a vegetation management tool. Harvesting systems, for example, may be used to alter species composition, promote natural regeneration, create habitat, or modify fuel loading.

Ecological requirements for natural regeneration in particular forest species in the suburban area needs regeneration felling that may include certain light levels, soil conditions, and seed-source spacing. While other stands of different kinds of broadleaves must be opened up to a certain density; stems must be selectively removed based on size, species, and spacing; and the soil litter layer should be disturbed for seed catch, but not compacted.

The harvesting comes from the thinning of pine forests in order to establish the broadleaves species, i.e. the Oak is the predominant species of native vegetation. Beech is occupied mainly north aspects. Other types of natural vegetation of the area are the Hornbeam (*Caprinus betulus*), Hop - hornbeam (*Ostya carpinifolia*) and the Holly Oak (*Quercus coccifera*).

The forest stands of Pine can be replaced by broadleaves; due these species is the climax vegetation for the area. So conversion measures of vegetation composition, in order to long-term, from conifer forest, turn into broadleaves forest. The latter measure is considered necessary because of the greater resistance of broadleaved species in fires over the pine, which is classified as flammable item.

Proposed forest roads, firebreaks and other logging earthworks are potentially the greatest source of sediment into waterways and hence strict guidelines are adhered to in order to minimize any adverse effects on the environment.

Till today the lumberjacks used to do the logging of wood by draught animals in a distance of more than 200 m in the suburban forest. New skidding and transportation systems work at longer extraction distances, can operate effectively on smaller diameter trees, and traverse the land more gently. A forest operation planning model for the suburban forest shows in figure 5 a specific skidding system that can be used based on its technical capabilities and determines where that system should work to reduce operational costs and increase the value of wood.

The fundamental question facing the forester is whether the prescribed operation is both technically - economically feasible and environmentally sound.

The forest roads network and skid trails on the forested landscape resulted in part from limitations on extraction distance and terrain. Stand composition of regenerated acres reflects the past site preparation and stand establishment techniques. Similarly, future landscapes of forests will be an expression of the capabilities and limitations of today’s technology. Understanding the role of technology in shaping forest conditions will help predict the future of the forest resources (aesthetic forest resource is the landscape).

Figure 5. Proposed harvest plan.

Growing demands for forest products and services, accentuated by political goals of increased utilization of renewable resources imply that pressure on suburban forests is likely to intensify considerably in the future. This increased demand will be met by human innovation and intervention. Key factors in decision-making are safety, protection of environmental values, the road infrastructure and productivity. Above all, offers us a smart, integrated way of managing our natural capital.

4.2. Suggestions

In order to maximize the positive environmental effects on the landscape of this suburban forest and of course as an extension to others with similar conditions with it can be done:

1. Add new kinds of vegetation to control erosion
2. Alter the habitat for potentially damaging agents, including harmful insects, diseases, and animals
3. Enhance conditions for wildlife, and improved forage,
4. Reduce fuels that potentially increase the risks of damage from future wildfire,
5. Improving access for secondary operations such as recreation, walking etc.

Due to:

- the development of ecological issues such as water-quality concerns,
- the development of guidelines for minimizing visual impacts and the better and wider definition of aesthetic values,
- the highlight of the protection and healthy role of the forests and
- the growing understanding of nutrient recycling and global carbon sequestration

is leading to new technologies and opportunities in forests, especially the suburban forests.

Decision Support System (DSS) models for semi mountainous areas and especially for suburban forests, where forest management is concerned with wood production, hydraulic and soil protection, biodiversity conservation, and tourism, require complex analysis. For example, the density and size of remaining standing trees have a high influence on skidding operations. In addition, planning models must consider not only environmental and stand factors but also the prevention of soil compaction damage and wildfire.

The combination between Geographic Information Systems (GIS) and Geographic Positioning Systems (GPS) will allow the implementation of more complex treatment plans that are better adapted to site-specific ecological features with the development and design prescriptions that better address the variation of conditions across the landscape, due to better presentation, manipulation, and transfer and storage of map-type data.

The use state-of-the-art systems and high-tech machinery in order to meet the mechanical and engineering challenges of every forest operation in a safe and environmentally responsible manner is the tomorrow challenge.

4.3. Final conclusion

Forest operations provide the link between the growing forest and both material and immaterial forest products we use every day especially by the suburban forests. Forest operations are the physical actions which change the forest, altering structure, composition, condition, or value in order to meet society’s needs for clean air and water, forest products, wildlife, recreation, and other benefits and finally they are the source of both the benefits of management and the negative impacts and leave an imprint on the landscape.

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