Proceedings of the Biennial International Symposium "Forest and Sustainable Development"
8th Edition, 25th-27th of October 2018, Brașov, Romania

PROPOSAL OF A THREE-STEP WATER MANAGEMENT PARADIGM FOR MULTI-PURPOSE FORESTRY: THE CASE OF MOUNTAINOUS HALKIDIKI - GREECE

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Abstract: *This paper presents the results of canopy reduction contribution, due to tree harvest, to water yield and soil. It focuses on the relationships and interactions between the ecosystems integrated parts water-soil-trees, as a result of different silvicultural treatments. In addition, it gives a combined solution regarding the water shortage problems during the dry summer seasons. The interactions and relationships as well as sustainability are of major importance in forest ecosystems, which are governed by the law of the unified field. The suggested solution is comprised of the common by the Forest Service thinning treatments (10-15% of total basal area) and the creation of small and large scale multi-purpose water collectors.*

Key words: *water management, silvicultural treatments, oak ecosystems.*

1. Introduction

In nature, the law of the unified filed is predominant. According to this law, everything is interconnected and the slightest change to one part of nature, can influence the whole. Ecosystems are not the sum of their parts but more than this and are functioning united.

Oak ecosystems can play a significant role in a multi-purpose forestry, as they comprise the largest part of the forested area in Greece. The optimization and management of water resources in the region has become a more challenging task in recent years. Future implications on fresh water availability, will have a profound impact on Mediterranean countries like Greece. In these areas, important economic sectors such as agriculture and tourism, are strongly dependent on water. Proper management in order to increase the available water becomes a priority, taking into consideration that half of the country's forested area is covered by oak ecosystems. These also comprise the most important water producing areas [18]. In Mediterranean areas facing severe time and space problems of water deficit,

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whilst having dense forest cover (e.x. Halkidiki, North Greece), it is possible to increase water yield, benefiting both the ecosystems and humans. This can be achieved through rational and controlled reduction of tree canopy.

2. Materials and Methods

The experimental plots are located in the Taxiarhis University Forest (TUF) (40°N, 23°E) which is managed by the Aristotle University of Thessaloniki in Greece for educational, research and demonstration purposes (Figure 1). TUF has an area 3,895 ha, is located in central Halkidiki and is dominated by hardwoods. The dominating tree species is *Quercus frainetto (confertta)*.

Long-term mean annual precipitation is 756 mm, which mainly falls from October to March. The climatic data were collected at the TUF weather station (altitude 860m), that was 150m from the first study plot (exposure SE).

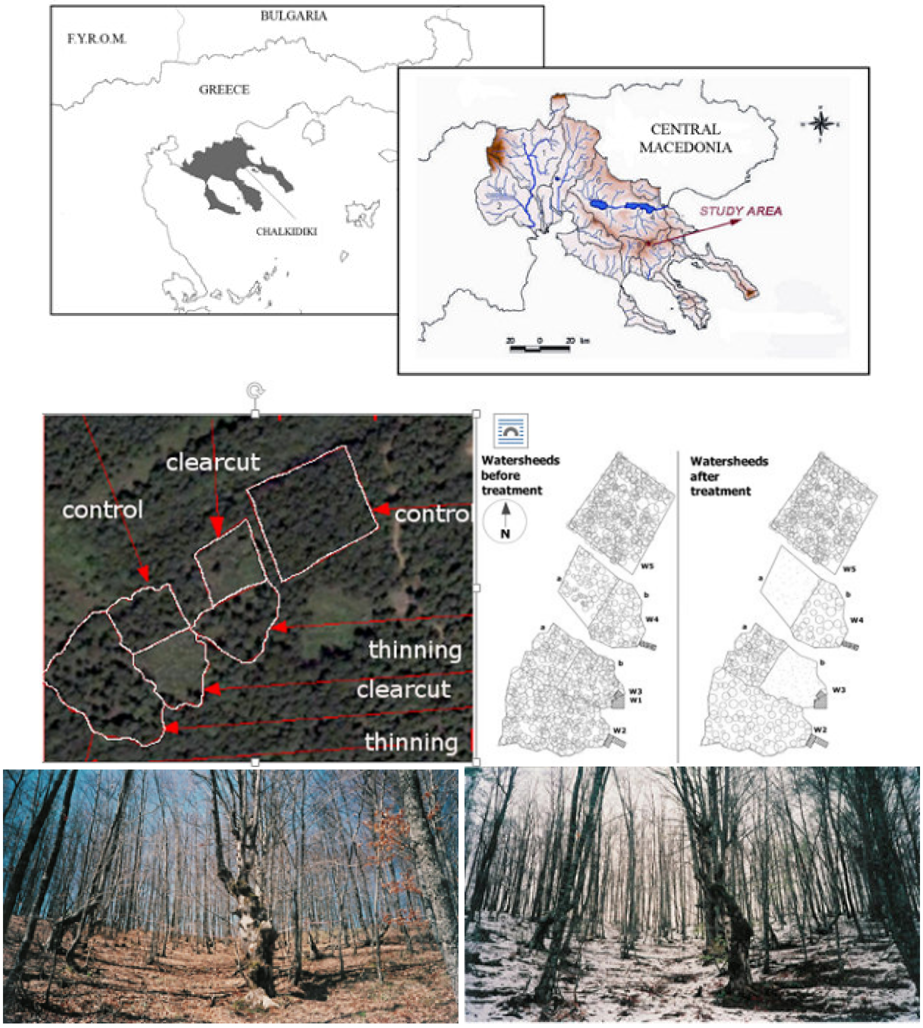

Fig. 1. The study area

Canopy closure is 100% in the summer. Soil is covered by forest floor with average depth of 2-3cm, which increases infiltration and decreases overland flow and erosion. The decomposition rate is high due to favourable temperature and moisture conditions [1]. Today the soils at TUF are well protected by the existing vegetation and forest floor and they are fertile with limited surface erosion. Soil depth is fairly deep (53cm) in the upper part of the study plots and deep (110cm) at their lower part.

Experimental watersheds have been established for the study of the impacts of thinning and clear cutting on water yield and soil. Watersheds were used as control, while others were under thinning (removal 50% of basal area) and clear cutting treatments [8].

The first and the last one (W1 and W5) were the controls with no vegetation removed. In W2 the basal area was decreased by 50%. In the upper part of W3 (W3a) no treatment was applied, whereas its lower half (W3b) was clear cut. The upper half of W4 (plot W4a) was clear cut and in its lower half (W4b) 50% of the standing trees were removed during the period from September - October 2001. The experimental design and data about each watershed can be viewed in Figure1.

All harvesting works in the TUF are conducted according to the harvesting schedule, which is included in the management plan (Figure 2). Forest operations are practiced by the forest workers' cooperative of the adjacent community of Taxiarhis under the supervision of the Greek Forest Service. According to the management plan, thinning operations aim at the conversion of the existing coppice forest into high quality forest [11].

Fig. 2. The three study treatments: a) control; b) thinning 50%; and c) clearcut [8-9]

Through fall at the study watersheds was measured for a continuous period of 24 months, starting from November 1st 2001 until October 31st 2003. Three fixed and three roving collectors (Figure 3c) were used for each treatment.

Surface flow was measured with the help of four water collectors, located at the lower limit of W1, W2, W3, W4 with a depth of 1m and an area of 40 m^2, 42 m^2, 30 m^2 and 50 m^2 respectively (Figures 3a, 3b, 4 and 6). No ditch was dug for W5 because of its zero slope. All ditches were carefully coated with plastic material in order to inhibit water infiltration and provide more accurate measurements. Otherwise, plastic cover is of no use because the main purpose of constructing ditches in a large scale is to minimize surface runoff and maximize infiltration. The amount of water gathered in the ditches was measured once per week, from November 1st 2001 until October 31st 2003, as well as after each occurrence of heavy rain events during the entire study period. The collected water was pumped into two plastic barrels (120 lt and 80 lt respectively) with the help of an oil pump.

Fig. 3. Construction of the ditches, the pumping of surface runoff from the collectors and a collector of through fall (c, left) [8]

Fig. 4. Watershed collectors: a) thinned-W2 (left); b) clearcut-W3 (lower part); c) thinned- W4 (lower part) [8]

The birth place of water production is the mountainous forests that also play an important regulatory role. Due to the bedrock type of the study area, within an area of thousands of hectares, only few springs (five in total as far as we know-one located in the selected area) flow throughout the year (Figures 5a and 5b). Natural water reservoirs are missing from the area. Therefore, the study suggests a simple but effective system of constructing ditches, to increase infiltration rates. Similar ditches were used in our study as surface runoff collectors and made its measurement easy and simple.

Approximately 2 Km far from the study watersheds, on behalf of and in collaboration with the Forest Service Department, Ganatsios with the support of Professor Pavlidis, planed, designed, studied (2011) [11] and supervised (2013, 2014) the construction of four multi-purpose (hydrological, aesthetic, recreational, ecological) dams. At the selected location, runoff (both surface and subsurface) appeared periodically, and was minimized or eliminated during the dry season. The water shortages on mountain Holomondas were a major motivation to create these dams for aesthetic, recreational, ecological and fire protection reasons. Above all, it is an effort to create a water storage input, both at surface and subsurface level, to enrich the underground horizons and hopefully re-initiate springs that once used to flow. It is important to balance inputs with outputs. Four dams were constructed at the lower end of the basin of the local torrent (the origins of Olynthios torrent.), as part of integral water management plan which is comprised of 3 parts: a) silvicultural treatments to increase through fall (precipitation inputs), b) small scale water collectors, c) bigger water reservoirs.

Fig. 5. Two of the few springs of Holomontas Mt.

3. Results

3.1. Impacts of Treatments on Soil

In control plots, the rhythm of accumulation of organic matter and the amount and weight of forest litter, were found high. The volume of the Ao horizon was much higher than Aoo horizon, which is an indication of relatively good decomposition conditions of organic matter. Decomposition in thinned plots was found much higher in comparison to the clear cut plots. There was significant reduction of organic matter at Ao horizon in clearcut and thinning plots. This reduction is attributed to the lower production of organic matter (falling leaves etc) which is enriching the soil. Although, theoretically, the logging creates better decomposition conditions, data showed that clear decomposition in plots under treatment (very high thinning degree and clear cutting) has been reduced, mainly due to the drier conditions compared to the control plots [8].

3.2. Impacts of Treatments on Water Yield

Canopy annual interception amounted for 9.0%, 6.7% and 1.8% of the total precipitation in the untreated, thinned and clear cut plots respectively. Surface flow was found very low even during large rainfall events. On 21.09.2001 (before any treatments took place) a rainfall event of 49.4 mm in three hours was recorded. Such a large amount of water was not expected for this specific time of the year. Based on the water balance method [14], no water surplus was expected, still in the collector there was 0.4 m^3 of water.

Table 1

Major precipitation incidents during 2 years period and measured surface runoff in the collectors (direct rainfall excluded)

Major precipitation incidents during 2 years period				Measured surface runoff in collectors excluding direct rainfall				
Percipitation Incidents	Percipitation [mm]	Duration [hours/day]	Months Total [mm]		Watershed			
				Pumped cubic meters [pcm]	Control (W1)	thinned (W2)	control+ clearcut (W3)	clearcut + thinned (W4)
				Water shed area [ha]	0,193	0,195	0,1633	0,156
				Ditch area [m^2]	0,04	0,042	0,03	0,05
21/9/2001	49,4	3h	49,8	pumped [m^3]	0,5	0,5	0,4	0,4
September 2001				**Calibration before treatments September 2001**	**0,5**	**0,5**	**0,4**	**0,4**
9-12/3/2002	44,1	4 days					0,2	0,2
22-24/3/02	30	3 days						
March 2002			**87,5**	**March 2002**	**0**	**0**	**0,2**	**0,2**
1/12/02	70	13h				0,1	1,5	1,5
7/12/02	50,1	24h						
1-9/12/02	192,7	9 days			0,1	1,0	4,7	2,4
13-19/12/02	53,7	6 days				0	0,4	0,3
December 2002			**259,7**	**December 2002**	**0,1**	**1,1**	**6,6**	**4,2**
January 2003			**91,3**	**January 2003**	**0**	**0**	**0,1**	**0,1**
Total collected surface runoff in ditches [m^3]					**0,1**	**1,1**	**6,9***	**4,5***
Total potentially collected surface runoff in ditches [m^3/ha]						**5,6**	**42,2**	**28,8**
Total potentially collected surface runoff in ditches [m^3/Km^2]						**560**	**4200**	**2880**
Total potentially collected surface runoff in ditches m^3/5.4Km^2						**3.024**	**22.680**	**15.552**

***** In W3 collector, surface runoff appeared higher than that in W2, because clear cut treatment applied in the lower part of W3. In the field water collector only 0.4 m^3 of water was observed (Table 1).

According to the results presented in Table 1, the observed surface runoff comprises a small portion of the expected total surplus including surface and subsurface runoff and infiltration. (On December 1st and 7th 2002) after two rainfall events of 70 mm (duration 14 hours) and 50 mm (duration 24 hours) no surface flow was measured in the control plot compared to 6.2 m^3/ha and 39.0 m^3/ha measured for the thinned and the clear cut plots, respectively. Only for March 2002, December 2002 and January 2003 when 87.5 mm, 259.7 mm and 91.3 mm of total precipitation have been recorded, respectively, there was water from runoff measured in the ditches. Mean average interception loss was reduced by 107 mm and 209 mm for the thinned and clearcut plots respectively.

Table 2

Expected total runoff and observed surface flow for the study watersheds for the peak period of March 2002, December 2002, January 2003. The expected amount of runoff was based on the water balance method, while the observed was from field water collectors [8]

Watershed	Expected total runoff (surplus) [m^3/(m^3/ha)]	Expected total water surplus [(m^3/5.4 Km^2]	Observed surface flow [m^3/ (m^3/ha)]
W1 (0,1932 ha)	415 / 2.148	1.159.920	0 /0
W2 (0.1950 ha)	465 / 2.385	1.287.900	1.1 /5.6
W3 (0.1633 ha)	413 / 2.529	1.365.660	6.9 /42.2
W4 (0.1560 ha)	384 / 2.461	1.328.940	4.5 /28.8

Sustainable management of forests through thinning operations, has increased water yield and gave an additional 13,2 mm/year (1mm of rain in a watershed of 1Km^2 is equivalent of 1000m^3 of water, 13.200 m^3/year/Km^2). Clearcutting increased the available amount of water by a mean annual average of 42.8 mm (and decreased water surplus for both treatments by 4.6% and 14.7% respectively). This decreased interception (from 185.8mm/2-year study period in control plots to 137.1mm/2years in thinned plots) represented a gain of 24.3mm/year, compared to the control watersheds. The total water surplus represented 29.5%, 30.9% and 33.9% of the average annual precipitation for the control, thinned and clearcut plots, respectively. This increase of 1.4% of total water surplus in thinned plots (compared to control plots), equals to 13.2mm/year (total water surplus).

Thinning at the a rate of 50% of basal area provides 127.980$m^3$of total water surplus during the peak months of March 2002, December 2002 and January 2003 in a watershed of 5.4 Km^2, similar to those where the dams were constructed. A water quantity of a quarter of this amount, approximately 30.000m^3/year, is the estimated total water surplus, and gained by the common thinning practice (10-15% of the basal area). A portion of this winter surplus can be stored in water reservoirs for multi-purpose services (Figures 6 and 7).

The height of the main dam at the crest level is 10.5m, the lake area is 4.170 m^2 and its volume is 13.430 m^3. Under flood conditions this volume can be raised up to 17.859 m^3. The height of the three smaller dams varies between 2,2 to 3m at the crest level. Since 2014, the dams are fully functional.

Fig. 6 . Smaller and bigger scale water management in Mountainous Halkidiki

4. Discussion

Vegetation cover has an important influence on the hydrological cycle. A proportion of rainfall in forest ecosystems is intercepted, collected and stored by the plant foliage while some of it is subsequently lost by evaporation, resulting sometimes in intensified loss of water affecting the hydrological balance. Understanding the relationships between canopy characteristics and interception is thus essential for quantitative prediction on the effects of deforestation [10] and changes in land use and vegetation [3] on water yield.

Forest treatments can increase water yield while reforestation can decrease it. Studies have shown a definite response of water yield to cover alteration [4]. The hydrological cycle of watersheds is affected by canopy interception, which in some cases amounts 10-30% of the rainfall, and can even amount to 50% of the rainfall in some areas [5-6]. Interception varies greatly among species, as a result of differences in leaf area and shape, forest density and structure, and climatic conditions [6]. The investigation of various forest harvesting treatments on the hydrology cycle has been conducted with the help of paired watershed studies in many parts of the world [19].

The results regarding interception agree with previous studies that found interception reduction was not proportional to the amount of biomass removed. In our case, removal of 50% of basal area led to an annual average decline of interception by 34.3% (reduced from 9% to 6.7% of the total precipitation). In other studies with other species 50% removal of basal area led to 18.5% [18], 30.2% [2] and 41.6% [7] decline of interception loss.

Fig. 7. The 4 multipurpose dams (Ganatsios 2014-2017)

The observed surface flow represents a small part of the total runoff. This could be attributed to various soil factors that increases the subsurface flow and the water holding capacity. Springs are areas of discharging this subsurface and infiltrate flow. Silvicultural treatments can play an important role in modifying the hydrological cycle of forested areas for the benefit of human needs. Thinning treatments could increase the available water especially in areas with low precipitation, given the fact that many areas already face water problems in Greece. Serengil et al. (2007a, 2007b) suggest that any thinning over 11% could be described as baseline for water yield increase in a deciduous ecosystem. According to Brown et al. (2005), changes in water yield can be detected after thinning intensities of more than 20%.

However, management priorities should be clearly defined taking into consideration the complexity of environmental factors of the respective area. The role of soil in ecosystems is of primary importance as a life-supporting system. It is a source of: a) nutrients, b) water supply, c) tree support and growth. Soil also determines the infiltration rates and the water yield. The limiting factor of forest growth in these soils is their depth and the seasonal change of soil moisture. It is of primal importance, to maintain forest litter, which regulates temperature and moisture conditions and feeds the precious soil. Wood harvest affects its properties therefore the improvement of these properties is the best investment for a prosperous future. Thinning treatments, can be used to improve soil characteristics e.g. the decomposition rate. Nevertheless, there is a limit over which the deterioration is taking place. So, despite the increased water yield through intense thinning (50% of basal area) [8-9], less thinning and no clear cutting are suggested.

Thinning should be much less for soil protection and creation purposes, which is in common practice of the Forest Service (thinning rate of 10% up to 15%, with upper level implemented in limited cases). Even with this thinning degree, the estimated gain of 5mm/year (5.000m^3/year/Km^2), is very important. The measurement of this gain is a project under study as a means to contribute to the need for further investigation of the hydrological processes in this mountainous area. In order to optimize the thinning degree, we have to keep balance between the needs of increasing water yield and improving the soil's characteristics while also increasing its depth. Although clear cut treatments increased water yield significantly (42,8mm/year, 42.800 m^3/year/Km^2), they still should be avoided at all cost (flood risk, valuable soil loss). Regarding this statement, some recent, extensive unsustainable forest management practices in Romania and elsewhere, reminded us of the value of sustainability.

5. Conclusions

Holistic knowledge of forest ecosystem services, provided by sustainably managed areas, could facilitate the increase of awareness on the importance of these ecosystems and on their interactions and interconnections with human life. This paper aspires to contribute to our knowledge on the effects of different silvicultural treatments in oak forests related to water yield. Areas like Halkidiki have to cope with heavy pressure on water resources, especially during the summer months, as they represent major touristic attractions for the inhabitants of Greece and the neighbouring countries. Reserving a small portion of annual precipitation, like 5mm/year- winters surplus in particular- is considerable to the benefit of ecosystems and humans.

The plan suggested for integral water management, also aiming at the improvement of soil properties, is comprised of three parts (two of these already applied-a & c): a) silvicultural treatments(thinning-10-15% of basal area) used to change the structure, the composition and the density of forest stands and in this manner increase through fall (precipitation inputs) and water yield, b) small-scale water collectors, c) bigger water reservoirs.

Acknowledgements

For the support and collaboration many thanks to Forest Service Department, especially to Foresters, Panourgias George and Papadopoulos Stavros and all colleagues contributed to the culmination of works. Warm thanks to Professor Pavlidis Theofanis for his inspiration, guidance and support. Thanks to Genarakis Manousos and Fran with his team for their cooperation and for constructing the dams.

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