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• Name, address, telephone (including the mobile phone number) and fax numbers, and email address of the corresponding author,
• Acknowledgment of the individuals who contributed to the preparation of the manuscript but who do not fulfil the authorship criteria.

Abstract: An English and a Turkish abstract should be submitted with all submissions. Submitting a Turkish abstract is not compulsory for international authors. Abstract section of all types of articles should be unstructured. Please check Table 1 below for word count specifications.

The style of abstract must be concise and must not contain references. The abstract should be prepared to summarize the following parts in an unstructured way:

• Aim of study: Set the goal or directly the specific objectives and, describe the relevance of the study;

• Study area: Specify the geographic area in which the study has been made;
• Material and methods: Describe briefly materials and methods, crops or organisms involved must be identified, as well as soil type, chemicals, or other details which can be important for the interpretation of the results;
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Keywords: Each submission must be accompanied by a minimum of four to a maximum of six keywords for subject indexing. The keywords should be listed in full without abbreviations. Keywords should be written both in Turkish and English at the end of the related abstract. The authors should not use the same words as the manuscript title.

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Statistical analysis to support conclusions is usually necessary. Statistical analyses must be conducted in accordance with international statistical reporting standards. Information on statistical analyses should be provided with a separate subheading under the Materials and Methods section and the statistical software that was used during the process must be specified.

Units should be prepared in accordance with the International System of Units (SI).

Review Articles: Reviews prepared by authors who have extensive knowledge on a particular field and whose scientific background has been translated into a high volume of publi-

cations with a high citation potential are welcomed. These authors may even be invited by the journal. Reviews should describe, discuss, and evaluate the current level of knowledge of a topic in the field and should guide future studies. The main text of review articles should be begun with an Introduction section and finalized with a Conclusion section. The remaining parts can be named relevantly to the essence of the research. Please check Table 1 for the limitations for Review Articles.

Short Note: This type of manuscript present significant findings from tangential investigations that are offshoots from larger studies or from early results that will have to be confirmed through further study. The main text should be structured with Introduction, Materials and Methods, Results and Discussion, and Conclusion subheadings. Please check Table 1 for the limitations for Short Note.

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All acronyms and abbreviations used in the manuscript should be defined at first use, both in the abstract and in the main text. The abbreviation should be provided in parentheses following the definition.

Scientific plant and animal names should be written in italics in the main text.

When a product, hardware, or software program is mentioned within the main text, product information, including the name of the product, the producer of the product, and city and the country of the company (including the state if in USA), should be provided in parentheses in the following format: "EC meter (Orion Star A212, Thermo Scientific, MA, USA)

All references, tables, and figures should be referred to within the main text, and they should be numbered consecutively in the order they are referred to within the main text.

Limitations, drawbacks, and the shortcomings of original articles should be mentioned in the Discussion section before the conclusion paragraph.

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For single authored reference: (Clausen, 1992)

For double authored reference: (Kelso and Smith, 1998)

Reference with multiple authors: (Medvec et al., 1999)

For multiple references, in order of year: (Lebow, 2000; Imamura, 2001; Cooper and Taylor, 2005)

For references with the same author and year: (Hill, 2000a; Hill, 2000b)

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Table 1. Limitations for each manuscript type

Type of manuscript	Word limit	Abstract word limit	Reference limit	Table limit	Figure limit
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Review Article	8000	250	60	8	10 or total of 20 images
Short Note	4000	200	20	8	10 or total of 20 images

The reference styles for different types of publications are presented in the following examples:

Journal Article: Heede, B.H., 1991. Response of a stream in disequilibrium to timber harvest. *Environmental Management* 15 (2): 251-255.

Books with a Single Author: Birkeland, P. W., 1984. Soils and Geomorphology. Oxford University Pres, New York.

Editor(s) as Author: Brilon, W. (Ed.), 1988. Intersections Without Traffic Signals, Proceedings of an International Workshop. Springer-Verlag, Berlin.

Book Section: Fischer, G.W., Nagin, D., 1981. Random versus coefficient quantal choice models. In: Manski, C.F., McFadden, D. (Eds.), Structural Analysis of Discrete Data with Econometric Applications, MIT Press, Cambridge, MA, pp. 273-304.

Symposium, Conference and Workshop Papers: Dahlgren, R. A., 1988. Effects of forest harvest on stream-water quality and nitrogen cycling in the Casper creek watershed. In: Proceedings of The Conference on Coastal Watersheds: The Casper Creek Story. May 6, Ukiah, California.

Daganzo, C., 1996. Two paradoxes of traffic flow on networks with physical queues. II.Symposium Ingenieria de los Transportes, Madrid, 22-24 May 1996, pp. 55-62.

Online Document (Web) Reference: FAO. 2006. Rural radio transmissions and rural youth in Mali. http://www.fao.org/sd/dim_kn1/kn1_060202_en.htm (Accessed: 27 February 2006).

Article by DOI: Asakawa, S., Yoshida, K., Yabe, K., 2004. Perceptions of urban stream corridors within the greenway system of Sapporo, Japan. *Landscape and Urban Planning*, in press doi:10.1016/S0169-2046(03)00158-0.

Thesis: Güner, H.T., 2016. The Miocene flores and vegetation of the Yatağan Basin, Western Anatolia. Unpublished Ph.D. Thesis, İstanbul University, Institute of Sciences, p. 185., İstanbul, Turkey.

REVISIONS

When submitting a revised version of a paper, the author must submit a detailed "Response to the reviewers" that states point by point how each issue raised by the reviewers has been covered and where it can be found (each reviewer's comment, followed by the author's reply and line numbers where the changes have been made) as well as an annotated copy of the main document. Revised manuscripts must be submitted within 30 days from the date of the decision letter. If the revised version of the manuscript is not submitted within the allocated time, the revision option may be cancelled. If the submitting author(s) believe that additional time is required, they should request this extension before the initial 30-day period is over.

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CONTENTS

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Mechanical recovery of a native forest with shrubs of the Espinal Ecoregion (Argentina)

Espinal Ekolojik Bölgesindeki bir ormanda mekanik müdahele ile çalılar üzerinde sağlanan iyileşme (Arjantin)

Rafael Alberto Sabattini ⓘD, Julián Alberto Sabattini ⓘD, Juan Carlos Cian ⓘD, Mauro Lindt ⓘD

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ABSTRACT

The invasion of woody plants in various parts of the world has been a longstanding concern in livestock production due to the expected negative impact on secondary production. Native forests cover 30% of the earth's land surface. A great part of the livestock production of Entre Ríos is developed in these ecosystems, which have been highly degraded due to inadequate cattle management, and the invasion of shrub species. The aim of this study was to evaluate the natural pasture recovery in a degraded native forest, subjected to a mechanical intervention with a frontal roller-chopping, in order to increase the grazing area and improve secondary productivity. The study was carried out in Paraná Department (Entre Ríos, Argentina). On 15/12/2014 a mechanical intervention was carried out with a frontal roller-chopping designed by the Chair Ecology of Agricultural Systems. To evaluate the dynamics of the recovery of the natural grassland of the native forest, seven measurements were made on the following dates: 15/05, 12/06, 28/07, 11/09, 27/10 and 21/12/2015, and 22/02/2016. The vegetation cover was measured with the line intercept method and phytomass production. In each of the evaluations, forage species cover was higher in the mechanically intervened area, presenting significant differences with respect to the control and registering an average relative increase of 47% at the end of the trial. In the section where mechanical intervention had been made, the coverage of *Baccharis punctulata* showed a marked decrease during all the measurements with respect to the control, obtaining an average decrease of 91.8% at the end of the sampling. Mechanical intervention enables the cover of shrubs that compete with natural grassland in a degraded native forest to be reduced, while also recovering forage vegetable species and thus improving primary production, due to a raise in the forage availability because of increased grazing area.

Keywords: Roller-chopping, *Baccharis spp.*, shrub control, shrublands, secondary productivity

ÖZ

Dünyanın çeşitli yerlerinde odunsu bitkilerin işgali, ikincil üretim üzerinde beklenen olumsuz etki nedeniyle canlı hayvan üretiminde uzun zamandır devam eden bir endişe kaynağı olmaktadır. Yerli ormanlar dünyanın toprak yüzeyinin %30'unu kaplamaktadır. Entre Ríos'un hayvancılık üretiminin büyük bir kısmı, yetersiz sığır yönetimine ve çalı türlerinin istilasına bağlı olarak büyük ölçüde bozulmuş olan bu ekosistemlerde geliştirilmiştir. Bu çalışmanın amacı, otlatma alanını arttırmak ve ikincil verimi artırmak amacıyla, önden silindirli doğrama ile mekanik müdahaleye maruz kalan, bozulmuş bir ormandaki doğal mera geri kazanımını değerlendirmektir. Çalışma Paraná Bölgesi'nde (Entre Ríos, Arjantin) gerçekleştirilmiştir. 15/12/2014 tarihinde, Ziraat Sistemleri Kürsüsü Ekolojisi tarafından tasarlanan bir önden silindirli doğrama makinesi ile mekanik bir müdahale gerçekleştirilmiştir. Doğal ormanın doğal otlaklarının toparlanma dinamiklerini değerlendirmek için, aşağıdaki tarihlerde yedi ölçüm yapılmıştır: 15/05, 12/06, 28/07, 11/09, 27/10 ve 21/12/2015 ve 22/02/2016. Bitki örtüsünün örtü hattı kesilme yöntemi ve fitoma üretimi ile ölçülmüştür. Değerlendirmelerin her birinde, yem türlerinin örtüleri mekanik olarak müdahale edilen alanda daha yüksek bulunmuş olup, kontrol açısından önemli farklılıklar göstermiştir. Deneme çalışması sonunda ortalama %47'lik bir nispi artış kaydedilmiştir. Mekanik müdahalenin yapıldığı bölgede, Baccharis punctulata'nın kapsamı, tüm ölçümler sırasında kontrol açısından belirgin bir düşüş göstermiştir ve örneklemenin sonunda %91,8'lik bir ortalama düşüş elde edilmiştir. Mekanik müdahale ile bozulmuş otlak alanlardaki doğal otlakla rekabet eden çalı örtüsü azaltılmış, aynı zamanda otları bitki türlerini geri kazanarak, otlatma alanlarındaki yem artışı nedeniyle birincil üretimi iyileştirmektedir.

Anahtar Kelimeler: Silindirli-doğrama, Baccharis spp., çalı kontrolü, fundalık, ikincil verimlilik

INTRODUCTION

Grasslands, shrublands, and savannas, collectively termed 'rangelands', contribute to around 50% of the Earth's land surface (Bailey and Ropes 1998). These areas provide about 30-35% of net terrestrial primary productivity, they contain >30% of the world's human population, and support the majority of the world's livestock production (Safriel and Adeelm 2005, Reynolds et al. 2007). Furthermore, these biomes provide a variety of other ecosystem services, such as carbon sequestration, maintenance and conservation of genetic diversity, among others (Anadona et al. 2014).

The surface occupied by native forests represents 30% of Earth's land surface (FAO 2007). Recent studies by Hansen et al. (2013) quantified that the loss of native forests was 2.3 million km^2 over the period 2000-2012. In such a world context, South America suffered the greatest net forest loss estimated as 0.04 million km^2 (FAO 2007). Argentina is not excluded from this global phenomenon, having an estimated loss of two thirds of its forest patrimony due to agricultural expansion (Cozzo 1979, FAO 2009). In Entre Ríos, at the beginning of the 20th century, the surface occupied by native forests was 2.5 million hectares, and in 2008, in seven departments, Sabattini et al. (2015) determined it to be 1.56 million hectares.

These ecosystems, where a great part of the livestock production of Entre Ríos is developed, have been highly degraded due to inadequate cattle management. The invasion of shrub species because of sub-grazing, soil erosion, and the presence of bare soil by overgrazing has occurred in these ecosystems (Casermeiro et al. 2001, Sabattini et al. 2002). In certain parts of the world the invasion of woody plants has been a long-standing concern in livestock production due to the expected negative impact on secondary production (Scholes and Archer 1997), and control techniques in both private and public areas have been used (Anadona et al. 2014). At present, more than 70% of the Argentine territory has been invaded by woody and semi-woody species, which are characterized by having a great power of adaptation to the environment, as well as great persistence due to the selective effect exercised by animals in grazing. These weeds compete with species of the herbaceous stratum for light, water and nutrients, causing a rapid invasion within a pasture and preventing the management of livestock (Böker et al. 1989).

The invasion of herbaceous and shrub species which are not consumed by cattle in the province of Entre Rios has been verified with the presence of *Baccharis* spp. L., *Eupatorium* spp. L., *Aloysia gratissima* (Gillies and Hook.) Tronc. *Eryngium horridum* Malme, and *Melica macra* Nees. These plant communities cause areas for animal foraging to be restricted since they prevent access. This triggers a vicious circle that brings the development of weed species into that area (Sione et al. 2006). Sabattini et al. (2015) reported that 66.35% of the native forests of the Villaguay Department show a high degree of invasion of shrub species, as well as 50.28% in the Federal Department, 56% in La Paz De-

partment and 18.7% in the Feliciano Department, the most important shrub species being *Baccharis punctulata* L., *Aloysia gratissima*, *Baccharis coridifolia* DC., *Eupatorium bunifolium* RMKing and H.Rob., *Trithrinax campestris* Drude and Griseb., *Baccharis notosergilla* L., *Senecio grisebachii* Baker, and *Opuntia ficus indicus* (L.) Mill. In addition, there are other herbaceous weed species that compete with natural grassland growth such as *Eryngium horridum* and *Melica macra*.

The frequency of closed native forests being overtaken by shrubs or semi-woody plants is considerably higher than in open native forest areas (Sabattini et al. 2015), and the incorporation of mechanical control and management techniques would enhance the secondary production of these environments. A great ecological advantage of these weeds is their great ability to regrow and reseed, thus invading the area easily. In this sense, research in these environments has demonstrated the effectiveness of these practices, revealing a greater coverage of palatable plant species and, thus a favorable trend of natural pasture quality and an increase of 15-20% in the grazing surface (Sabattini et al. 2002).

Techniques for the control of invasive shrub species are very diverse: mechanical (shredder for open field, bulldozers, chains, roller-chopping, chainsaws and line trimmer), biological (grazing of bovine, ovine, equine and caprine), physical (fire-fighting) and chemical (selective herbicides). Mechanical control causes an instantaneous reduction of the vegetal cover of shrubs with high efficiency but presents low efficiency in the months after the intervention due to the seasonal regrowth of vegetation.

In Argentina, roller-chopping is a type of mechanical control used to eliminate the shrub. The technique consists in the passage of a tractor that drags a roller-chopper above the shrub mass, causing the folding of the vegetation and its subsequent cutting. The principle of the operation is based on the kinetic energy of rotation that occurs when the roller is set in motion and, with the presence of blades, the cutting of young trees, shrubs and herbaceous vegetation is generated (Mora and Mercado 2014).

The aim of this work was to evaluate the natural pasture recovery in a degraded native forest, which had been subjected to a mechanical intervention with frontal roller-chopping, to increase the grazing area and improve secondary productivity of a livestock company.

MATERIALS AND METHODS

Work Area

The study was carried out in 'Establecimiento San Germán', located on Provincial Route No. 32, 3.5 km from Hasenkamp in the Paraná Department (Entre Ríos, Argentina). A section of land with native forest was selected, and a mechanical intervention with roller chopping was carried out on a sector of the same to assess the response of the natural pasture (Figure 1).

The study area has a mild humid plain climate (Plan Mapa de Suelos [Soil Mapping Plan], 1986). Mean annual rainfall during
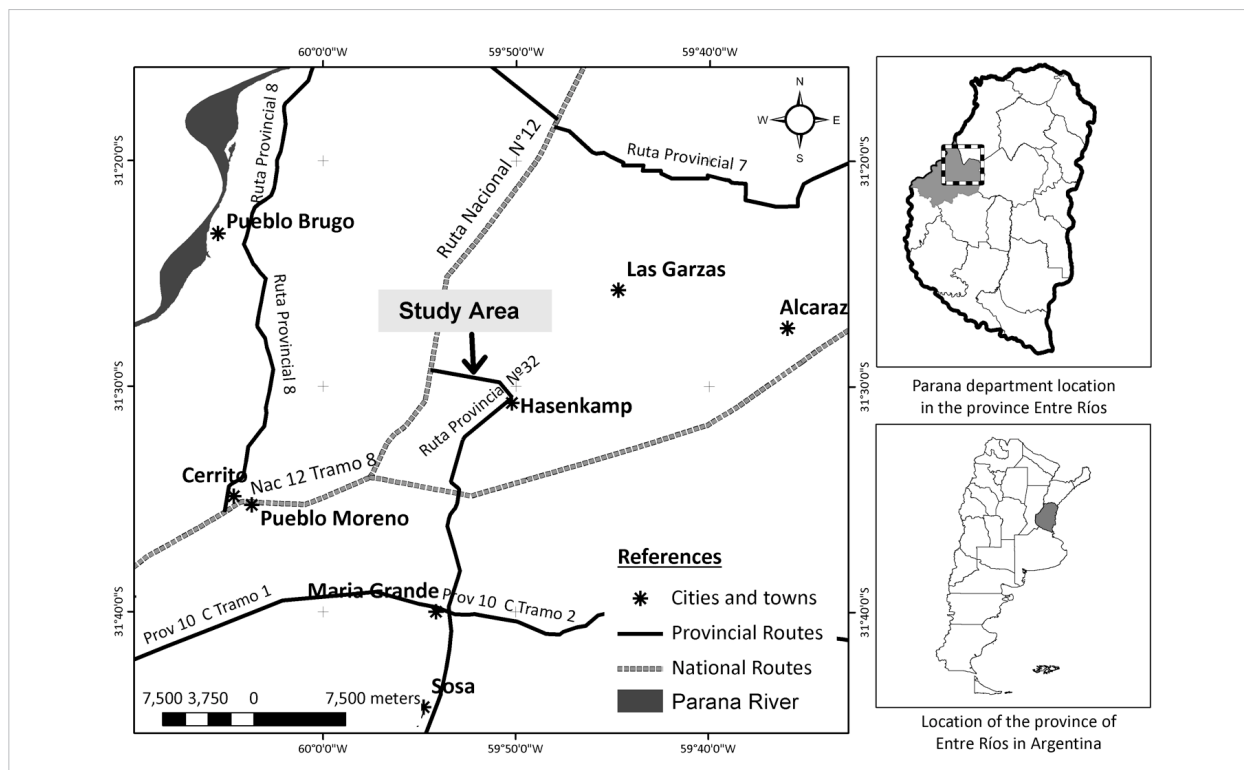
Figure 1. Location of study area
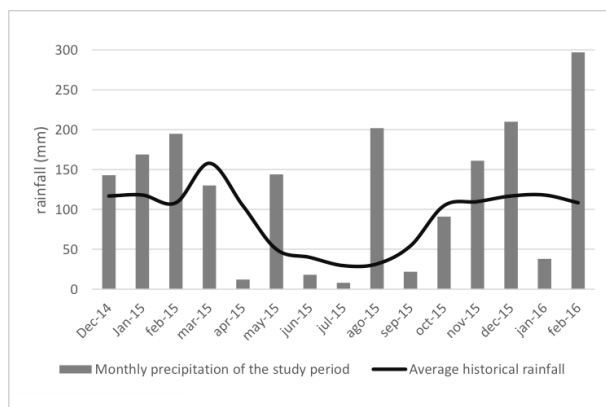
Figure 2. Monthly precipitation of the study period (records of the meteorological station to Bolsa de Cereales de Entre Ríos) and average historical rainfall for the 1934-2010 period (INTA Paraná)

the period of 1934-2010 was 1,025 mm, concentrated between the months October and April. By contrast, in the summer months a situation of water deficit in the soils of the region is expected (Rojas and Saluso 1987). In 2015 annual precipitation in the locality of Hasenkamp was 1586 mm, 54.7% higher than the annual average (Figure 2).

The soil corresponds to 'Las Avispas Consociation', formed by 'Las Avispas' (Peluderte argiacuólico) and 'El Pingo' (Ocracualfe vértico) series, located topographically on a very gently rolling peninsula with gentle slopes. Both soils present physical and chemical limitation of the subsurface horizon owing to their mineralogical composition (Plan Mapa de Suelos [Soil Mapping Plan] 1998).

The native forests represent the characteristics of the Ñandubay District of the Espinal Ecoregion, which extends from central-south of Corrientes Province and central-north of Entre Ríos Province, encompassing the Departments of La Paz, Federal, Feliciano, Villaguay, Tala and Paraná (Cabrera 1976, Brown and Pacheco 2006). The native forest has the characteristics of high and closed native forest (Sabattini et al. 1999, Sabattini 2015, Sabattini et al. 2015) due to the presence of shrubs such as *Baccharis* spp., *Eupatorium* spp. and *Aloysia gratissima*, as well as other non-forage herbaceous species such as *Melica macra*, *Eryngium horridum*, and numerous young individuals of *Vachelia caven*. This vegetation structure is typical of the Espinal Ecoregion in Argentina, characterized by the invasion of woody and semi-woody species that are adapted to the environment and that compete with the herbaceous species for light, water and nutrients because of bovine overgrazing. The livestock in natural ecosystems has intensified in the last 200 years. During this period, the livestock population rapidly increased exceeding the carrying capacity of natural pastures (Archer 1995). This process was characterized by an intense and continuous grazing that produced changes in the floristic composition of the natural pastures, including the increase in the abundance of undesirable woody species (Walker et al.1981, Cingolani et al. 2005).

Figure 3. Roller-chopping designed by the Chair Ecology of Agricultural Systems (FCA-UNER)

Mechanical Intervention and Sampling Design

On 15/12/2014 a mechanical intervention was carried out with frontal roller-chopping designed by the Chair Ecology of Agricultural Systems (INNOVAR, 2016), on a surface of 250 m². The implement developed is a hollow metal cylinder of 2.25 m in width by 0.98 m in diameter that weighs 1,900 kg without water inside and has 19 parallel cutting blades. The roller-chopper is coupled in front of a tractor by means of two hydraulic arms, and in this way, it crushes the plants allowing the tires to advance on clean ground. To attach the hydraulic arms, a 110 HP Massey Ferguson 292 RA double drive tractor was used (Figure 3). The implementation is done by pushing the tractor forwards or backwards in a linear way, supporting the roller-chopper on the ground surface. When changing the working direction, the roller-chopper is lifted with the hydraulic arms and is positioned in a new direction. In addition, it has a particular design in the hydraulic pistons because of irregularities of the ground, while in working position, the transverse movement of the roller-chopper should not be transmitted towards the tractor, thus avoiding possible risks of overturning.

To evaluate the dynamics of the recovery of the natural grassland of the native forest, seven measurements were made on the following dates: 15/05, 12/06, 28/07, 11/09, 27/10 and 21/12/2015, and 22/02/2016. These dates correspond to 151, 179, 225, 270, 316, 371 and 434 days after the mechanical intervention (DMI), respectively.

The line intercept method (Canfield 1941, Kent and Coker 1992) in which the transect line is thought of as a vertical plane that is perpendicular to the ground- was used and modified according to Sione et al. (2006) to quantify the percentage of vegetation cover considering the fraction of herbaceous forage species (monocotyledonous, dicotyledonous and palatable sedges), chaff (senescent plant material), bare soil (without vegetation,

with exposed soil), other non-forage herbaceous species, *Baccharis punctulata*, *Aloysia gratissima*, and young individuals of *Vachellia caven*. For the measurements, ten transects of 10 meters length were used at random (five in the mechanical intervened sector and five in the control site). Each transect was divided into ten parts and the coverage of each fraction of both right and left sides was evaluated, obtaining a total of 60 records in the mechanical intervened sector and control site.

The phytomass production was assessed at random in the 10 replicates of each treatment (control and mechanical intervened) by cutting herbaceous forage species, at a height of 5 cm from the ground in an area of 0.25 m². The plants were weighed with a portable scale of one decimal precision and then oven drying was performed at 80℃ for 48 hours. The dry matter was then weighed to estimate dry matter percentage (%DM) and biomass production in terms of kg DM.ha⁻¹. The availability of forage for bovine consumption was estimated based on the accessibility to the forage by the cover of the shrubs according to the following formula:

Availability forage= (kg DM.ha⁻¹)	Phytomass production of herbaceous forage species x (kg DM.ha⁻¹)	Accessibility to grazing (100 - % cover of the shrubs) (%)

A controlled and intensive grazing was carried out with breeding cows on 19/09/2015 and 13/01/2016 with high instantaneous animal load according to the forage supply. The lot typically had a rotary type grazing with low stocking in time, because the annual primary productivity of grassland was very low compared to pastoral systems in the region.

Data was then analyzed statistically and the normality of the information was analyzed using the Shapiro-Wilk test. Significant differences between control and mechanical intervention were determined using nonparametric analysis of variance was performed with the Kruskal-Wallis'test for vegetation cover and biomass using InfoStat® software version 2012 (Di Rienzo et al. 2012).

RESULTS

Forage species cover was higher in the mechanically intervened area in each of the evaluations, presenting significant differences ($\alpha=0.05$) with respect to the control, registering an average of 47% at the end of the trial. The recorded chaff coverage was significantly lower in the native forest which had been mechanically intervened with respect to the control during the fall (15/05/15 and 12/06/15) and spring (27/10/15 and 21/12/15). In the winter-spring period the results were different, and the chaff coverage was significantly higher in the intervened area compared to the control in July and September ($p<0.0001$ and $p<0.0019$, respectively). Bare soil did not show significant differences ($\alpha=0.05$) being up to 371 DMI. However, the last sampling performed in February 2016
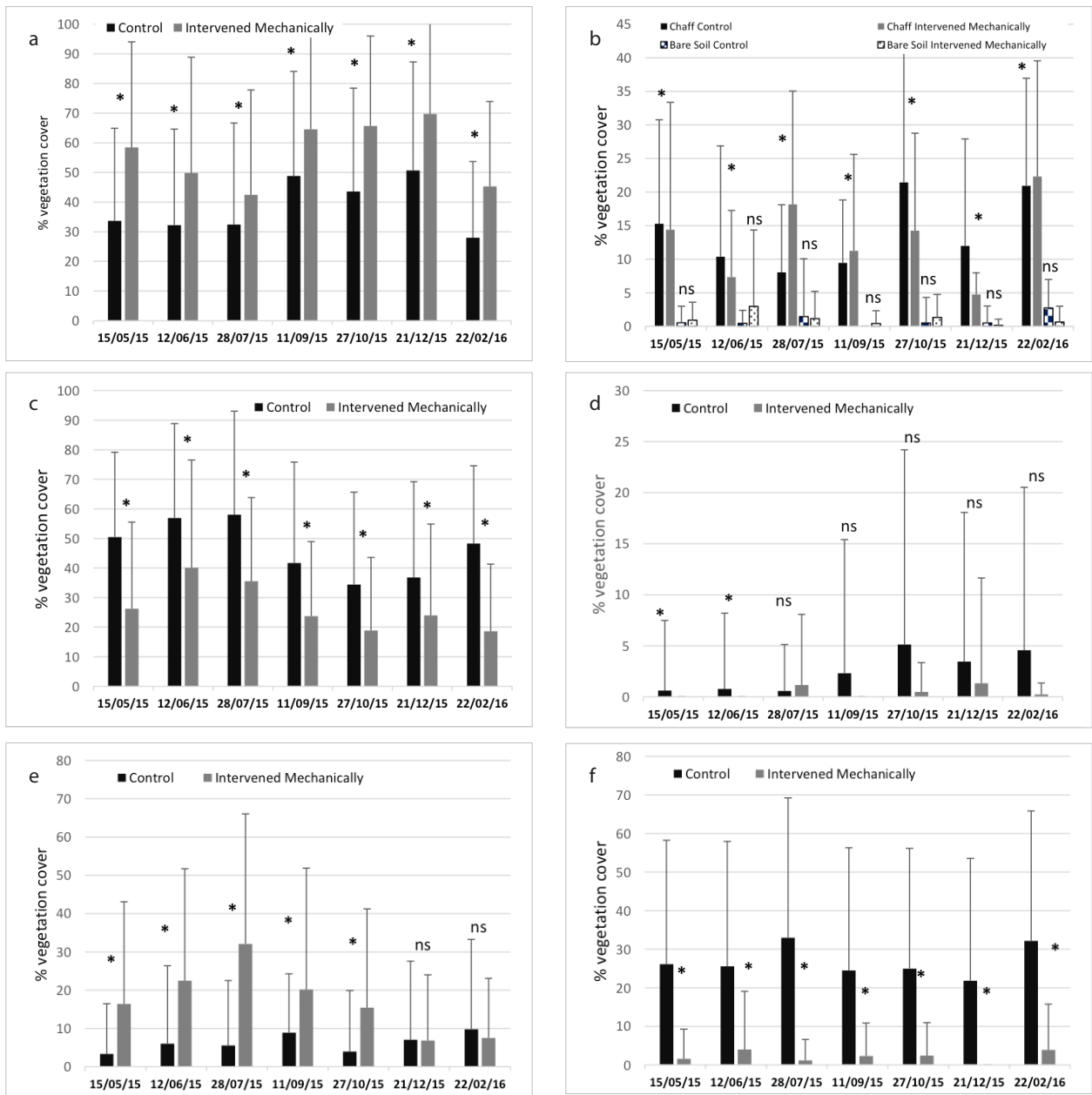
Figure 4. a-f. Dynamics of the coverage of fractions in control and mechanically intervened sectors: (a) herbaceous forage species, (b) chaff and bare soil, (c) other non-forage species, (d) young individuals of *V. caven*, (e) *A. gratissima*, (f) *B. punctulata*. Test Kruskal-Wallis, * means are significantly different (p>0.05) and ns- are not significant

showed significant differences in favor of the control because of adverse weather conditions (Figure 4).

Compared with the control, the coverage of *Baccharis punctulata* showed a marked decrease during all the measurements in the section which had been intervened mechanically, obtaining an average decrease of 91.8% at the end of the sampling. Moreover, *Aloysia gratissima* coverage increased significantly in the mechanically intervened area compared to the control until 15/10, whereas on 16/02/2016 no significant differences were found between the treatments. The average increase in the coverage

of this section was 170% in the intervened sector with respect to the control. Juvenile individuals of *Vachellia caven* presented an average vegetation cover of less than 5%, and a significant decrease in coverage was observed on 15/05 and 12/06/15. Subsequently, no significant differences were observed between the mechanically intervened area and the control site.

The mechanically intervened native forest showed a significantly decreased coverage of the other non-forage herbaceous species for cattle, and on all the evaluation dates a decreased average of 42.6% was observed with respect to the control.
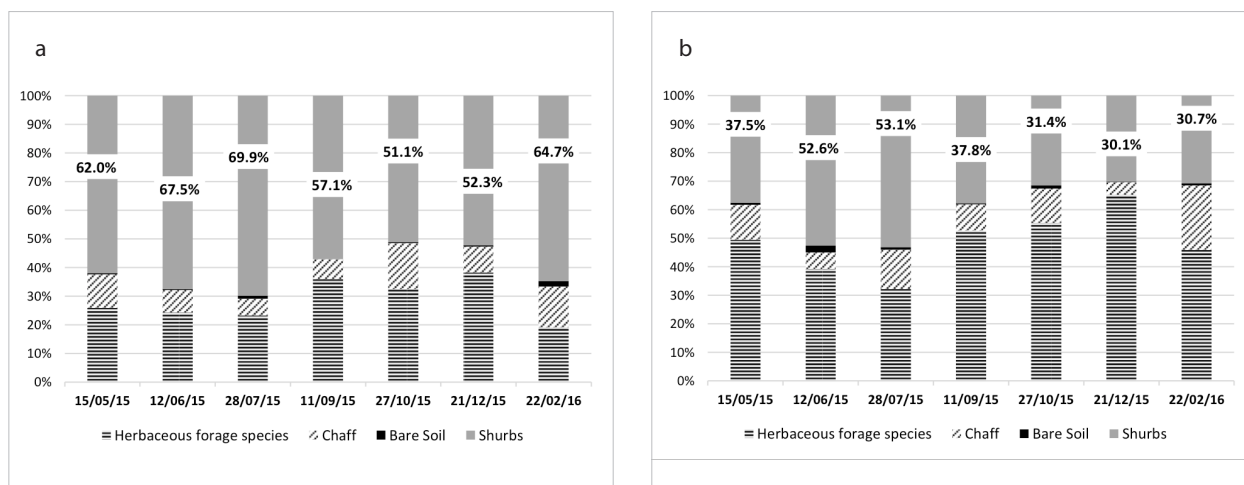
Figure 5. a, b. Relative coverage in the control area (a) intervened mechanically (b) sectors of the fractions: herbaceous forage species, chaff, bare soil and shrub (*Baccharis punctulata + Aloysia grattisima*)

Table 1. Values of phytomass production of herbaceous forage species values r (Kg DM.ha^{-1}), cattle accessibility to grazing (%) and forage availability (Kg DM.ha^{-1}) in the control area and section which had been intervened mechanically. Kruskal-Wallis test means between treatments with a common letter are not significantly different (p>0.05)

		Control			Intervened mechanically		
Date	DMI	Phytomass production of herbaceous forage kg DM.ha^{-1}	Accessibility to grazing %	Forage availability kg DM.ha^{-1}	Phytomass production of herbaceous forage kg DM.ha^{-1}	Accessibility to grazing %	Forage availability kg DM.ha^{-1}
15/05/2015	151	675.3±165.9[a]	38.0	256.6±63.0[a]	760.1±137.9[a]	62.5	475.0±86.2[b]
12/06/2015	179	667.4±152.2[a]	32.5	216.9±49.5[a]	781.6±239.4[a]	46.4	362.7±111.1[b]
28/07/2015	225	749.0±438.9[a]	30.1	225.4±132.1[a]	739.6±167.4[a]	46.9	346.9±78.5[b]
11/09/2015	270	1030.2±174.3[a]	42.9	441.9±74.8[a]	958.4±380.8[a]	62.2	596.1±236.8[b]
27/10/2015	316	405.2±185.2[a]	48.9	198.1±90.6[a]	448.0±176.7[a]	68.6	307.3±121.2[b]
21/12/2015	371	1838.8±548.3[a]	47.7	877.1±261.5[a]	1490.0±361.1[b]	69.9	1041.5±252.4[a]
22/02/2016	434	164.4±48.2[a]	35.3	58±17.0[a]	224.0±108.9[a]	69.3	155.3±74.9[b]

DMI: days after the mechanical intervention

Table 2. Evolution of the percentage of dry matter (% DM) in the mechanically intervened and control sectors. Kruskal-Wallis test, means with a common letter are not significantly different (p>0.05)

Date	DMI	Control	Intervened mechanically	H	p
15/05/2015	151	43.8±5.3[a]	47.3±5.7[a]	3.58	0.0585
12/06/2015	179	44.2±3.6[a]	43.5±2.4[a]	0.38	0.5379
28/07/2015	225	52.8±7.6[a]	51.2±4.4[a]	0.56	0.4545
11/09/2015	270	66.7±10.8[a]	78.9±9.0[b]	8.69	0.0032
27/10/2015	316	29.6±4.8[a]	34.5±3.9[b]	6.74	0.0094
21/12/2015	371	59.4±16.3[a]	60.0±5.1[a]	0.63	0.4284
22/02/2016	434	39.6±8.9[a]	28.2±6.9[b]	8.43	0.0037

DMI: days after the mechanical intervention

In general, there was an increase in herbaceous forage species coverage due to a significant reduction of shrubs in the intervened mechanically sector compared to the control in all evaluations (Figure 5a, b). These results would indicate an increase in forage accessibility, thus improving efficiency in grazing. Moreover, an increase in the percentage of chaff in the intervened mechanically sectors was observed due to senescent plant material generated after the intervention.

A greater phytomass production of herbaceous forage species was observed in the mechanically intervened sector compared with the control, but from a statistical point of view the differences are not significant except for the sampling taken on 12/21/2015 (Table 1). In terms of forage availability, significant differences were obtained on all the evaluated dates, except for 12/21/2015. Total forage availability increased to 89.6%, reaching 2200.6 kg DM.ha^{-1} in the mechanically intervened sector and 1160.6 kg MS.ha^{-1} in the control at 434 DMI.

DISCUSSION

The control of shrubs induces a secondary succession of the natural grassland, improving its ability to compete against weeds due to the cover and production of phytomass herbaceous forage. The mechanical intervention with frontal roller-chopping enables a high control of the aerial biomass of the shrubs in this type of native forest and little plant death. For this reason, it would not affect the biodiversity of the intervened systems. These initial results would indicate that the treatment is maintained over time, taking into account observations of other mechanical interventions carried out in the region since 2004 (Sabattini RA, personal communication).

Ecologically, mechanical intervention is an ecosystem disturbance that is applied for agronomic or forestry purposes. It is considered a discrete event given that it occurs in a period of time, is located in space, and modifies ecosystems, communities or populations because it changes the availability of resources and substrates, as well as the physical environment (Kunst et al. 2008). Anthropic disturbances are phenomena that alter the structure of ecosystems and the physical factors, lead to the change of one serial community for another (White and Pickett 1985), and whose magnitude depends directly on spatial size and its temporality (Chapin et al. 2002).

The response in herbaceous forage species coverage in the mechanically intervened sector compared to the control was similar to other research conducted in Argentina, where the researchers presented an increase of 66.8% and a decrease of 38% in shrub cover (Mora and Mercado 2014). This increase generates better conditions for the use of water and soil nutrients by forage species (Adema et al. 2004), caused by the increase in the average percentage of chaff (Figure 4). This condition would allow the soil to be covered with senescent plant material and the infiltration rate to be improved, reducing surface runoff and increasing the organic carbon content in the superficial horizon of soil by reactivating decomposition mechanisms (Adema et al. 2004, Martín et al. 2008). Studies carried out in La Pampa, Argentina, indicate that the total density of grasses in the rolled sectors was higher than in the control, and were directly affected by water stress conditions, indicating a significant loss of plants (Adema et al. 2004). Apart from this, in Entre Ríos, there was a similar response in the increase of natural pasture cover in the sector intervened with a mechanic cut using a motorbike and retouching with a machete (Cottani and Sabattini 2006, Sabattini et al. 2014).

The average coverage of shrubs in the control area of the native forest was higher than 60%, which would represent a high ratio of native shrubland-grassland, equivalent to 2.3: 1. These results provide assurance that the 'arbustization' process generates an imbalance in the natural proportion of shrubs and pastures, provoking a strong competition for ecological resources such as water at the soil surface as indicated by Kröpfl et al. (2002). Semi-woody species such as *Baccharis spp, Aloysia spp* and *Vachellia caven* capture an important solar interception with

negative consequences for forage species for grazing. Therefore, their management is central not only to increasing the primary productivity of grasslands, but also to changing the botanical composition of the herbaceous community (Adema et al. 2004). Subsequent to the treatment, a high reduction of the percentage of shrubs was observed (Figure 3), improving the natural shrub-grassland ratio (0.9: 1).

The plant cover of *Baccharis* spp. was significantly reduced by mechanical intervention, being less than 5% in all evaluations. Nonetheless, *Aloysia gratissima* showed a steady increase until the middle of winter 2015, and thereafter it decreased towards the middle of summer 2016. This behavior is attributable to its ecological requirements, since it is a highly invasive species, and its frequency, vegetative cover and the size of the individuals are favored in conditions of high luminosity (Perreta and Vegetti 2004). Due to the reduction of the vegetation cover of *Baccharis punctulata* - a species whose height reaches 2.5 m - light is increased, representing a favorable environment conducive for the development of *Aloysia gratissima* (Burkart 1969). This behavior was observed in the northern region of Entre Ríos (Argentina) in a study of natural pasture recovery through chemical dewatering, where control of *Baccharis punctulata* favored the development of other non-forage species (Sabattini R, com. pers.). The size of *Aloysia gratissima* in an adult state is similar to a woody species, the stem / leaf ratio being very high. After growing, the regrowth is expressed with larger leaf architecture, more coriaceous and with a lower stalk / leaf ratio. These changes cause the shrub to occupy more space in the plant community, exerting greater competitive effect in the natural grassland.

It is important to mention that these shrub species have a very high resilience capacity depending on different environments (Kimmins 2003), allowing them to adapt to periodic disturbance events, regenerating asexually through basal regrowths or seeds (Morello et al. 2012). Several studies on the mechanical control of the shrub stratum argue that, given the rapid recovery of these weeds, another deforestation must be considered whose frequency will depend on the type of invasive species, ecological conditions and livestock management. In this regard, Brassiolo et al. (2008) concluded that, in order to maintain the productivity of the semi-arid Chaco pasture, it is necessary to carry out a cycle of deforestation every five years. Marchesini (2003), on the other hand, emphasizes that the mechanical control of *Baccharis punctulata* is immediate, and that treatment repetition must be performed before the year as these weeds rapidly re-grow using their reserves.

Other non-forage herbaceous species decreased their coverage significantly by mechanical intervention (Figure 4), with an emerging outbreak of *Melica macra, Eryngium horridum, Sida rhombifolia, Senecio grisebachi* and *Baccharis ulicina*. Similar studies have demonstrated the impact of *Melica macra* on the biomass and cover of this weed by frequent cuts (Rupp 1994). However, by reducing *Eryngium horridum* plant cover using a combination of mechanical cutting and the application of specific herbicides it might be possible to improve the natural

grassland, but logistically and economically it would not be a feasible option for livestock production (Lallana et al. 2004).

The reduction of the competition of the shrub species did not result in an increase in the production of vegetal biomass in the sector which had been intervened mechanically with respect to the control, but in terms of forage availability the reduction in shrub cover would allow greater accessibility for cattle to graze (Figure 5). These results were similar to those obtained in other regions of Argentina by Adema et al. (2004) and Mora and Mercado (2014), as well as in the northern center of Entre Ríos (Cottani and Sabattini 2006, Sabattini and Sabattini 2012).

The percentage of dry matter in both sectors did not show a significant variation until the 225 DDR; in contrast a linear increase of the DM% was observed until the 270 DMI, due to the closure to the bovine grazing until 19/09/2015. Subsequently, a significant increase of 34.5% DM in the rolling area compared to 29.6% DM in the control (Table 2) was recorded on 10/27/2015 attributable to changes in the plant cycle due to grazing, which causes a rejuvenation of the plant tissues.

CONCLUSION

Mechanical intervention permits the reduction of the cover of shrubs that compete with the natural grassland in a degraded native forest, and this recovers forage vegetable species, which in turn improves primary production due to an increase in the forage availability of the grazing area. This is directly translated into the secondary productivity of a livestock agroecosystem. These studies should be continued in other productive cycles from an ecological approach and as agronomic studies in order to check if mechanical intervention persists over time.

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Original Article

Determination of carbon concentration of tree components for Scotch pine forests in Türkmen Mountain (Eskişehir, Kütahya) Region

Türkmen Dağı (Eskişehir, Kütahya) sarıçam ormanlarında ağaç bileşenlerine ait karbon yoğunluklarının belirlenmesi

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ABSTRACT

The purpose of this study was to investigate the relationship between carbon concentration of different tree components and some ecological factors for Scotch pine (*Pinus sylvestris* L. subsp. *hamata* (Steven) Fomin.) in Türkmen Mountain Region. Data were collected from 58 ecologically different sample plots and were evaluated using ANOVA and correlation analysis. Carbon concentration varied significantly within five tree components (p<0.001), with the values ranging from 50.94% for root to 54.75% for bark. We also calculated the weighted carbon concentration as 52.37% for Scotch pine forests. Some significant relationships were found between the carbon concentration of tree components and some ecological factors and stand parameters. Site index and elevation negatively correlated with tree component carbon concentration. However, elevation strongly correlated with 1- and 2-year-old needle carbon concentration (p<0.01). We also found that slope position positively correlated with 2- and 3-year-old needles but negatively correlated with bark in terms of carbon concentration. The carbon concentrations that we calculated in this study can be used for calculating the carbon content of either whole tree or any tree component in Scotch pine forests.

Keywords: Scotch pine, tree components, carbon concentration

ÖZ

Bu çalışmanın amacı, Türkmen Dağı (Eskişehir, Kütahya) Bölgesi sarıçam (*Pinus sylvestris* L. subsp. *hamata* (Steven) Fomin.) ormanlarında ağaç bileşenlerine ait karbon yoğunlukları ile bazı meşcere ve yetişme ortamı özellikleri arasındaki ilişkileri belirlemektir. Örneklemeler farklı yetişme ortamı özelliklerine sahip 58 alanda yapılmıştır. Elde edilen veriler varyans ve korelasyon analizleri ile değerlendirilmiştir. Altı ağaç bileşeninin karbon yoğunlukları arasında istatistik bakımdan önemli farklılıklar bulunmuştur (p<0,001). Karbon yoğunluğu en düşük kökte (%50,94), en yüksek ise kabukta (%54,75) bulunmuştur. Sarıçam ormanları için ağırlıklı karbon oranı %52,37 olarak hesaplanmıştır. Ağaç bileşenlerine ait karbon yoğunlukları ile bazı meşcere ve yetişme ortamı özellikleri arasında önemli ilişkiler tespit edilmiştir. Bonitet endeksi ve yükselti ile ağaç bileşenleri karbon oranları arasında negatif ilişki bulunmuştur. Ancak yükselti ile bir ve iki yaşlı ibre karbon oranları arasındaki ilişki daha güçlü (p<0,01) ortaya çıkmıştır. Ayrıca yamaç konumu iki ve üç yaşlı ibre karbon oranı ile pozitif ilişki gösterirken kabuk karbon oranı ile negatif ilişki göstermiştir. Elde edilen karbon oranları, sarıçam ormanlarında gerek ağaçlarda gerekse ağaçların farklı bileşenlerinde depolanan karbon stoğunun hesaplanmasında kullanılabilir.

Anahtar Kelimeler: Sarıçam, ağaç bileşenleri, karbon oranı

INTRODUCTION

Atmospheric CO_2, which has been continuously rising in the last century, is one of factors that contribute to global warming. There are mainly two strategies for combatting global warming: decreasing the emission and/or increasing the fixation of CO_2. Forests constituting the most important carbon sink in terms of carbon sequestration are good tools available to be used for mitigating carbon content in atmosphere. Therefore, an accurate carbon inventory in forests is essential as a starting point (Asan, 1995; Lamlom and Savidge, 2003; Malmsheimer et al., 2011).

International agreement was reached to decrease the anthropogenic atmospheric gases to avoid climate change (IPCC, 2001). More than 160 countries signed the Kyoto Protocol, which required countries to reduce anthropogenic atmospheric gas emissions during the period from 2008 to 2012 by an average of 5.2% below the levels in 1990 (Colombo et al., 2005). In this context, countries were requested to report the carbon sink change at national level. Moreover, carbon sink change calculations in forestland were expected to be based on AFOLU Guideline (IPCC Guidelines for National Greenhouse Gas Inventories for Agriculture, Forestry and Other Land Use) (IPCC, 2006).

This guideline suggested that the annual carbon stock changes should be estimated as the sum of changes in all land-use categories. For land-use category "forest land remaining forest land", changes in ecosystem carbon stocks consist of: 1) living above-ground and below-ground biomass, 2) dead organic matter (i.e., dead wood and litter), and 3) soil organic matter. It is important to estimate carbon content and total biomass of aboveground carbon stocks for the estimation of total carbon stocks in forest ecosystems. The guideline provides some empirical values based on forest type, climate zones and tree species. But it recommends that specific values obtained through research conducted for tree species at local level should be used for a reliable estimation (IPCC, 2003; IPCC, 2006). Because studies show that carbon concentration varies depending on tree species, tree components and other environmental factors (Laiho and Laine, 1997; Lamlom and Savidge, 2003; Bert and Danjon, 2006; Thomas and Malczewski, 2006; Çömez, 2012; Karatepe, 2014; Güner and Makineci, 2017). Therefore, studies on carbon concentration of tree species based on forest types (high forest or coppice, natural or plantation), tree components (root, stem, branch, bark and leaves) and ecological conditions (geographical region, climate type, altitude, slope, and site quality) are essential for accurate carbon reporting.

Scotch pine (*Pinus sylvestris*) is one of the important species in terms of carbon stock change calculations, while it is distributed on an area of 1 518 000 ha (6.8% of total forested area) in Turkey (OGM, 2015) and covers 24% of forested area (about 75 000 000 km²) in Europe (Janssens et al., 1999). Carbon concentration of Scotch pine in different tree components considering different ecological, geographical region and sites will provide more accurate estimation for reliable national reporting on carbon budget. Therefore, there are various research findings that show carbon concentration changes depending on tree components (Tolunay, 2009; Çömez, 2012; Thomas and Martin, 2012; Güner and Çömez, 2017), geographical regions (Çömez, 2012; Durkaya et al., 2015), formation time of wood (early or late wood) (Lamlom and Savidge, 2003) and even dimension of roots (Akburak et al., 2013). But this study differs from the other research in that we found out the relationships between carbon concentration of tree fractions and some stand parameters and environmental factors.

In this study, we aimed at investigating carbon concentration changes depending on different tree components (root, stem, bark and leaves), some stand parameters (age, Dbh and site index) and physiographical factors (altitude, inclination, slope position and aspect) for Scotch pine in Türkmen Mountain Region. Additionally, we calculated the weighted tree carbon concentration taking account of the biomass ratios of different tree components.

MATERIALS AND METHODS

Study Area
The research was conducted in Türkmen Mountain location situated between 39°16'-39°38 'north latitudes and 30°06'-30°36' east longitudes (Figure 1).

According to the geographical map of Turkey, parent materials in the research area include rhyolite and dacite together with basalt, claystone and limestone (MTA, 2015). The main soil type is grey brown and podsolic grey brown forest soils (Güner, 2006). The climate type of the study area varies from semi-humid to humid in Thornthwaite water balance system. Eskişehir, Kütahya and Afyonkarahisar meteorological stations, which are the closest three data sources, recorded the average annual temperature ranging from 10.6°C to 11.1°C, and annual precipitation from 374 mm to 562 mm.

Scots pine is the dominant species in the study area. Some of the other common plant species in the area include Anatolian black pine (*Pinus nigra* Arnold. subsp. *pallasiana* Lamb. (Holmboe), trembling poplar (*Populus tremula* L.) and oriental beech (*Fagus orientalis* Lipsky.). Main understory species are laurel leaved cistus (*Cistus laurifolius* L.), tinctory oak (*Quercus infectoria* Oliv.), downy oak (*Quercus pubescens* Willd.), Turkish oak (*Quercus cerris* L.), common oak (*Quercus robur* L.), prickly juniper (*Juniperus oxycedrus* L.), wild service (*Sorbus torminalis* (L.) Crantz.), dog rose (*Rosa canina* L.), and hawthorn (*Crataegus pentagyna* Willd.) (Güner, 2006). Some site properties of the study area are presented in Table 1 (Güner et al., 2012).

Sampling Method and Laboratory Analyses
Data were collected from 58 sample plots identified in the study area at different elevations, inclinations and slop positions. In each plot, one sample tree with a dominant position in the stand was cut for analysis. Diameter at breast height and height of tree were measured in cm for accuracy; one-, two- and three-year-old needles were sampled from top shoots. Age was determined at tree stamp cut in October and root samples were extracted from soil by digging with pickaxe. Wood and bark samples were taken from stem at the breast height of the sample tree.

All samples (58 plots×6 components=348 samples) were dried at 65±2°C until constant weight and ground for carbon analysis. Carbon concentration of the samples were analysed using LECO CN TruSpec 2000 elementary analysis device (Leco, 2000).

Site index (SI$_{100}$) of the sample plots was determined using the site index table prepared by Alemdağ (1967) for natural Scotch pine stands. Slope position (SP) was calculated as percentage in relation to the length of the whole slope. Aspect was recorded
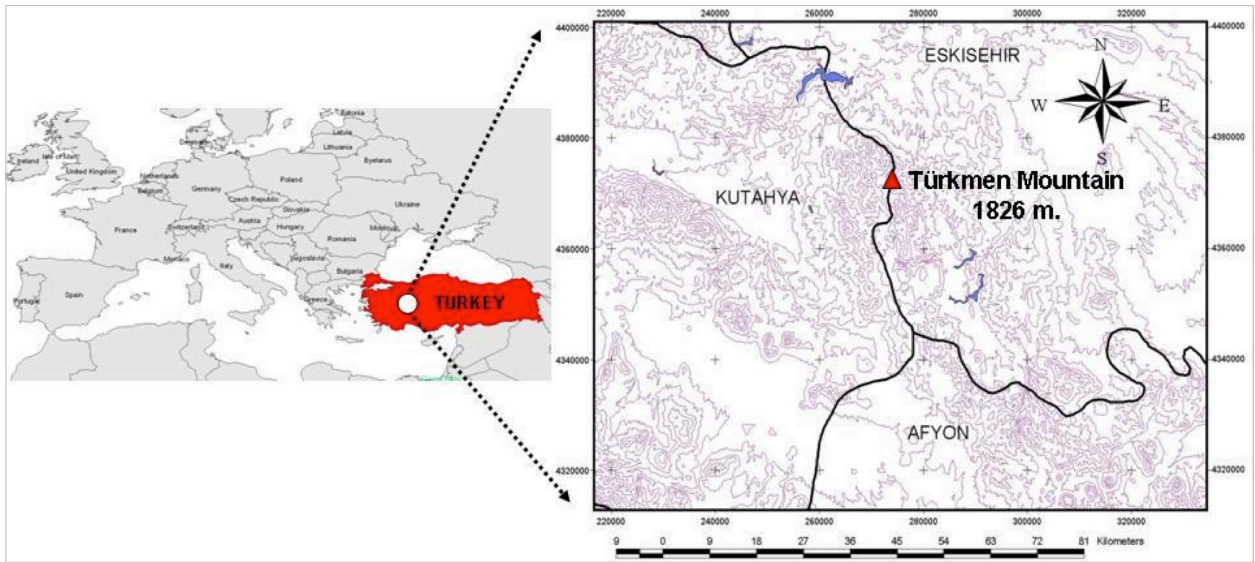
Figure 1. Location of the study area

Table 1. Some site and stand characteristics of sample plots (Güner et al., 2012)

	Mean	Minimum	Maximum
Stand properties			
Stand volume (m3 ha-1)	411.3	218.7	683.2
Stand density (tree ha-1)	1035	500	2000
Stand age (Year)	87	67	108
Diameter at breast height (cm)	23.2	16.8	31.1
Height (m)	17.9	10.3	26.8
Physiographic factors			
Elevation (m)	1492	1222	1708
Inclination (%)	20	3	40
Slope position (%)	51	13	83
Radiation index (dimensionless)	0.516	0.004	0.983
Climatic properties			
Mean annual temperature (℃)	7.8	6.3	8.9
Annual rainfall (mm)	727	609	854
Actual evapotranspiration (mm)	412	399	425
Water deficit (mm)	157	119	183
Water surplus (mm)	286	206	394
Rainfall of the most drought month (mm)	17	13	22
Rainfall from June to September (mm)	145	119	167

as azimuth (Q) measured from true north, and converted to a radiation index using the following Formula: 1

$$RI = \left[1 - \cos((\pi/180)(Q - 30))\right]/2 \qquad (1)$$

Where; RI is radiation index (dimentionless); Q is azimuth (degree).

This assigns a value of zero to a land that orients in north-north-east direction (typically the coolest and wettest orientation) and a value of 1 to the hotter, drier south-southwest facing slopes (Moisen and Frescino, 2002; Aertsen et al., 2010).

The weighted carbon concentration of an individual tree was calculated based on component biomass ratios using Formula 2.

$$wcc = \sum (ccc_i * cb_i)/100 \qquad (2)$$

where; wcc is weighted carbon concentration of total biomass (%); ccc_i is carbon concentration of ith tree component (%); cb_i is biomass ratio of ith tree component in total tree biomass (%).

To calculate the weighted carbon concentration, we used the biomass distribution ratios to the tree components prepared by Çömez (2012) for Scotch pine. These ratios were 0.735, 0.046, 0.048, and 0.171 as average of all stand types for stem including branches, bark, needles and cones including root, respectively. We used an average C ratio of one- two- and three-year-old needles to calculate the weighted C ratio of a needle. Therefore, the biomass ratio of a needle was calculated as one value without considering the needle age.

 Statistical Analysis
The differences in carbon concentration between the tree components were analysed using ANOVA. Duncan test was applied to get homogeneous groups for the datasets that revealed statistically significant differences (at p<0.05 level) after ANOVA. The relationship between the carbon concentration of tree components and some of the tree sizes and physiological fac-

tors were tested using correlation analysis. All statistical analyses were performed with Statistical Package for the Social Sciences statistical software (SPSS version 22.0®, 2015).

RESULTS AND DISCUSSION

Carbon Concentration of Tree Components

The variation in the carbon concentration across six tree components was highly statistically significant (F=187.695; p<0.001) with the value ranging from 50.94% for root to 54.75% for bark (Table 2). The variation across the samples was not so high with an average standard deviation of 1.39%. Higher carbon concentration of bark may be due to its higher lignin and extractive content (Güner and Çömez, 2017).

Table 2. Duncan test results and some statistics for carbon concentration (%) in tree components (n=58)

Tree component	Mean*	Minimum	Maximum	Std. Dev.
Root	50.94[a]	49.09	54.60	1.04
One-year-old needle	51.83[b]	50.83	53.08	0.46
Wood	52.55[c]	51.07	54.82	0.74
Two-year-old needle	52.60[c]	51.29	54.14	0.62
Three-year-old needle	53.33[d]	51.53	55.16	0.67
Bark	54.75[e]	52.81	56.39	0.69
Weighted mean	52.37			

*: Letters shows the significantly different carbon concentration values based on ANOVA (p<0.001)
Std. Dev.: standard deviation

Another clear result that we observed was an increase in carbon concentration in consecutive years depending on the age of needles. The average carbon concentrations of one-, two- and three-year-old needles were found to be 51.83, 52.60 and 53.33%, respectively. These results suggested that the carbon concentration was related to the age of needles. However, Bert and Danjon (2006) did not find a significant difference across the ages of needles for carbon concentration in *Pinus pinaster* in France whereas Tolunay (2009) found a significant difference only in three-year-old leaves of one-, two- and three-year-old for Scotch pine trees in Bolu-Aladağ forests. But, when the age of leaves is not considered, i.e. for mixed leaves, we calculated the carbon concentration for Türkmen Mountain as 52.58%, which was slightly lower than the values calculated as 53.02%, 53.8% and 53.19%, respectively, for the same species by Tolunay (2009) for Aladağ Region, by Laiho and Laine (1997) for Finland and by Çömez (2012) for Sündiken Mountains. However, Janssens et al. (1999) calculated the carbon concentration of needles as 48.2% for Scotch pine in Belgium, which was quite lower than the values reported by the other studies. This wide variation in the same species implies the geographical effect on needle carbon concentration.

We calculated the carbon concentration of stem wood, which is the most important carbon sink among the tree components, as 52.55%. For the same species, Laiho and Laine (1997), Janssens et al. (1999), Tolunay (2009) and Çömez (2012) calculated this concentration as 51.80%, 48.90%, 51.20 and 52.31%, respectively.

Bark was found to have the highest average carbon concentration with 54.75% in tree component while the lowest as 50.94%

Table 3. Correlation (Pearson) matrix for relationship between some tree sizes, ecological conditions and tree component carbon concentrations (n=58)[a]

Tree comp.	Factors	Age	Dbh	SI	Incl	Elev	SP	RI
Coynd	Correlation	-0.209	-0.322*	-0.233	0.027	-0.418**	0.274	-0.029
	Sig.	0.116	0.014	0.078	0.838	0.001	0.060	0.845
Ctwynd	Correlation	-0.051	-0.299*	-0.310	0.030	-0.458**	0.354*	0.003
	Sig.	0.706	0.023	0.018	0.826	0.000	0.014	0.985
Ctynd	Correlation	0.040	-0.282*	-0.325*	0.055	-0.314*	0.292*	0.067
	Sig.	0.768	0.032	0.013	0.681	0.016	0.044	0.652
Cwood	Correlation	-0.140	0.279*	0.270*	0.202	-0.031	0.157	-0.014
	Sig.	0.293	0.034	0.040	0.129	0.816	0.287	0.926
Cbark	Correlation	-0.006	0.145	-0.121	-0.261*	0.094	-0.312*	0.277
	Sig.	0.964	0.277	0.364	0.048	0.483	0.031	0.056
Croot	Correlation	0.180	-0.061	-0.117	-0.035	-0.810	-0.024	-0.005
	Sig.	0.176	0.647	0.381	0.793	0.547	0.869	0.974

**Correlation is significant at 0.01 (2-tailed); * Correlation is significant at 0.01 (2-tailed); [a] Coynd: Carbon concentration of one-year-old needles (%); Ctwynd: Carbon concentration of two-year-old needle (%); Ctynd: Carbon concentration of three-year-old needles (%); Cwood: Carbon concentration of wood (%); Cbark: Carbon concentration of bark (%); Croot: Carbon concentration of root (%); Age: tree age (year); Dbh: Diameter at breast height (cm); SI: Site index(m. at T=100); Incl: Inclination of sample plot (%); Elev: Elevation of sample plot (m); SP: Slope position (%); RI: Radiation index (dimensionless)

of average carbon concentration was calculated for root. Laiho and Laine (1997), Tolunay (2009) and Çömez (2012) calculated bark carbon concentration as 53.20%, 53.46% and 53.78%, respectively, which were slightly lower than that we found for Scotch pine. Durkaya et al. (2015) calculated bark carbon concentration relatively low as 51.2 % for *Pinus sylvestris*. For Scotch pine, Janssens et al. (1999) and Çömez (2012) calculated root carbon concentration as 49.4 and 51.27%, respectively.

Weighted Carbon Concentration

We calculated the weighted carbon concentration as 52.37% (Table 2), using formula 1. Çömez (2012) calculated the weighted carbon concentration of Scotch pine in Sündiken Mountain (Eskişehir) Region as 52.47%, which was quite similar to our findings. This maybe because of the similarity between the two regions, which are geographically close to one another. Tolunay (2009) and Alakangas (2005) calculated carbon concentration of Scotch pine as 51.96% and 51.80%, respectively, for north-western part of Turkey (Aladağ-Bolu) and for Finland. Güner and Çömez (2017) calculated the weighted carbon concentration as 53.86% for *Pinus nigra* afforested stands sampled in Turkey. Green et al. (2005) and Bert and Danjon (2006) calculated tree carbon concentration as 52.00% and 53.20% respectively, for *Picea sitchensis* and for *Pinus pinaster*.

Guidelines of AFOLU recommend that carbon concentration value should be taken as 51% for conifers for carbon sink reporting in case there is no research specific for related tree species (IPCC, 2006). On the other hand, carbon concentrations of tree components other than stem wood have been excluded from many forest-sector carbon balance calculations so far even if for specific tree species. However, our results in addition to some of the recent research findings showed that carbon concentration of tree components were significantly different from one another (Çömez, 2012; Güner and Çömez, 2017). Therefore, the coefficient calculated taking account of the carbon concentration of weighted tree components will provide a more accurate calculation.

Relationship between Tree Components and Some Stand and Ecological Conditions

Table 3 shows the correlation matrix of tree carbon concentration for tree components, some tree properties and ecological conditions. As shown in the table, not age but Dbh had a significant negative correlation, with $p < 0.05$, with one-, two- and three-year-old needles, but a positive correlation with wood carbon concentration. Similarly, Güner and Çömez (2017) found a significant increase in carbon concentration depending on Dbh in *Pinus nigra* plantations. However, this finding was different from some of the others that were found recently. For example, Bert and Danjon (2006) found an insignificant correlation between needle carbon concentration and tree dimensions like stem height, Dbh and length of the crown for some pine species. Çömez (2012) studied the relationship between carbon concentration of tree components and stand type, which is partly related to Dbh and stand age, and reported an insignificant correlation for Scotch pine. Inclination did not have any correlation with the carbon concentration of tree components except for bark. Site index and ele-

vation were negatively correlated with tree component carbon concentration. However, elevation had a stronger correlation at $p < 0.01$ with one- and two-year-old needle carbon concentration. This may be explained by decreasing in air temperature depending on elevation which cause increase in sugar transfer to roots but decrease to leaves. Therefore, Hartt (1965) found for sugarcane that sugar was transferred to roots or leaves depending on their temperature comparing to air temperature. Namely, if root temperature is higher than air temperature, sugar transfer to roots will be increased but decreased to leaves. We found that slope position was positively correlated with two- and three-year-old needles but negatively correlated with bark in carbon concentration. Radiation index did not have any correlation with any carbon concentration of tree components.

Studies on the relationship between carbon concentration of tree components and ecological conditions did not allow us to discuss it in details, while further research is needed in this area.

CONCLUSION

We can conclude that carbon concentration varies significantly within tree components ranging from 50.94% to 54.75% for Scotch pine forests in Türkmen Mountain Region. This difference should be taken into consideration while calculating the total biomass carbon concentration. Therefore, weighted carbon concentration found to be 52.37% in this study based on biomass ratios of tree components will provide more reliable national carbon reporting. Moreover, geographical locations also have an impact on carbon concentrations and need to be considered for a more accurate calculation. Furthermore, more research on the relationship between ecological conditions and tree component carbon concentrations will help to take account of more factors for more accurate carbon calculations.

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Original Article

Effects of heat treatment on some macroscopic and physical properties of Scots pine sapwood and heartwood

Isıl işlemin sarıçam diri odunu ve öz odununun makroskobik ve fiziksel özellikleri üzerindeki etkileri

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ABSTRACT

Impact of heat treatment (ThermoWood) on the macro structure and physical properties of Scots pine sapwood and heartwood were studied by visual examinations, using the following relevant standard test methods: ASTM D2244 and TS 2472, respectively. In the study, two processes-Thermo-S (190 ℃) and Thermo-D (212 ℃)-were employed for heat treatment. To compare the effect of different types of heat treatment, kiln dried wood samples were used for reference. Macroscopic investigation showed that superficial cracks occurred in all samples, and as the temperature increased, the severity and number of cracks increased. In the Thermo-D process, internal cracks and cupping were seen only in heartwood samples. Physical examination showed that as the temperature increased, color of the samples darkened, the density of the samples decreased, dimensional stability was enhanced. The Anti Swelling-Efficiency (ASE) in the Thermo-S and Thermo-D processes evaluated in sapwood samples was 17.04% and 24.77%, respectively; however, values in the heartwood samples were 11.97% and 30.45%, respectively. The highest reduction ratio of air dried density was 14.04% in the Thermo-D process applied to the heartwood samples. Thus, it can be concluded that this reduction due to the increased temperature is related to the formation of internal cracks.

Keywords: ThermoWood, macro structure, physical properties, scots pine, crack formation

ÖZ

Isıl işlemin (ThermoWood) sarıçam diri odunu ve öz odununun makro yapısı ve fiziksel özellikleri üzerindeki etkileri görsel olarak ve ilgili standartlar (ASTM D2244, TS 2472) aracılığıyla incelenmiştir. Thermo-S için 190 ℃ ve Thermo-D için 212 ℃ olmak üzere iki farklı işlem kullanılmıştır. Isıl işlemin etkilerini karşılaştırmak amacıyla fırın kurusu örnekleri referans alınmıştır. Makroskobik incelemeler sonucunda tüm örneklerde yüzeysel çatlakların oluştuğu ve sıcaklık arttıkça çatlakların sayısının ve şiddetinin arttığı görülmüştür. Sadece Thermo-D uygulanmış öz odun örneklerinde iç çatlak oluşumu ve oluklaşma tespit edilmiştir. Fiziksel incelemeler göstermektedir ki sıcaklık arttıkça örneklerin rengi koyulaşmakta, yoğunluk değerleri düşmekte ve boyutsal stabilizasyon iyileşmektedir. Anti Genişleme Etkisi sırasıyla Thermo-S ve Thermo-D diri odun örnekleri için %17,04 ve %24,77, öz odun örnekleri için %11,97 ve %30,45 olarak belirlenmiştir. Hava kurusu yoğunluk değerlerindeki en yüksek azalma oranı Thermo-D uygulanmış öz odun örneklerinde %14,04 olarak tespit edilmiştir. Sıcaklığın artması sonucu oluşan bu azalma eğiliminin çatlak oluşumu ile ilişkili olduğu düşünülmektedir.

Anahtar Kelimeler: ThermoWood, makro yapı, fiziksel özellikler, sarıçam, çatlak oluşumu

INTRODUCTION

Heat treatment is a thermal modification method that enhances the dimensional stability and increases the durability of wood, yet lowers the strength properties thereof, and increases the tendency for it to crack, while also causing it to acquire a darker color. Different methods for thermal modification of wood have been developed, ThermoWood process being one of the modification methods used in commercial production (Hill, 2006; Metsa-Kortelainen, 2011). The ThermoWood process is mainly based on heating the wood for a few hours at high temperature (190ºC and 212ºC for softwoods) without pressure and under a protective water vapor environment (Anonymous, 2003).

When subjected to higher temperature, wood undergoes degradation in wood substrate and changes in chemical composition. As a result of this degradation, the physical and biological properties of wood change. These changes are induced by the treatment method, and vary according to the time, temperature and wood species. (Fengel and Wegener, 1989; Hill, 2006; Esteves et al., 2008). Changes related to wood species could be explained by different anatomical structures. As is well-known, the structural characteristics of wood vary among different tree species (Kollmann and Cote, 1968; Zobel and Buijtenen, 1989; Schweingruber, 2007). Previous studies revealed that there was a strong interaction between the effects of process conditions and anatomical properties of wood (Ward and Simpson, 1991; Anonymous, 2003; Suttie and Thompson, 2004; Boonstra et al., 2006; Dogu et al., 2015; Dogu et al., 2016). Even though several studies have investigated the effects of heat treatment on anatomical aspects, they are nonetheless quite restricted (Fengel and Wegener, 1989; Hietala et al., 2002; Andersson et al., 2004; Gosselink et al., 2004; Suttie and Thompson, 2004; Yildiz et al., 2004; Abe and Yamamoto, 2005; Sehlstedt-Persson et al., 2006; Boonstra, 2008; Dogu et al., 2010; Dubey, 2010; Awoyemi, 2011; Dogu et al., 2015; Dogu et al., 2016). Moreover, the differences between thermally modified sapwood and heartwood have been studied even less frequently (Boonstra, 2008; Metsa-Kortelainen, 2011; Metsa-Kortelainen and Viitanen, 2012; Esteves et al., 2013).

Figure 1. Cutting plan of trunks
K: reference; T.S.: Thermo-S; T.D.: Thermo-D; W: west; E: East; S: south; N: north

Figure 2. Cutting plan of timbers
Macro. inv.: macroscopic investigation; Phy. inv.: physical investigation

Chemical and physical properties of sapwood and heartwood are different (Hillis, 1987; Rowell, 2005). Therefore, it is expected that their reaction to heat treatment will also be different. The aim of this study was to investigate some macroscopic and physical differences between the sapwood and heartwood of thermally modified Scots pine wood. The effects of the heat treatment process on the macrostructure and physical properties of Scots pine wood were also examined.

MATERIALS AND METHODS

This study was performed on Scots pine wood samples obtained from the trees by controlled cutting from the Western Black Sea region. The trunks were sawn into pieces of timber having dimensions of 5x12.5x200 cm (Figure 1). The pieces of timber were divided into two parts, one part to serve as the control and the other to be used for the heat treatment sample. Kiln dried samples were employed as references for comparing the effect of heat treatment.

Heat treatment was carried out according to VTT (Technical Research Center of Finland)'s ThermoWood schedule with two different final temperatures (Thermo-S: 190°C, Thermo-D: 212°C) (Anonymous, 2003).

After the heat treatment, the pieces of timber were cut into 3-cm-high strips from internal and external parts to compare the effect of the treatment in the macro structure and the remaining parts were used to determine the physical properties (Figure 2). The changes generated in the macro structure as a result of the heat treatment were investigated using a SZX16 Stereomicroscope (Olympus, Tokyo, Japan) and a DP72 digital camera.

Color analysis, air-dried density, kiln-dried density, and ASE (Anti swelling efficiency) were performed to investigate the changes in the physical properties after the heat treatment. For the color analysis, the color measurements of the kiln dried samples were referenced and then the color differences were calculated by color measurements of the heat-treated samples using CR-200 Chroma Meter (Minolta, Osaka, Japan). The color measurements were performed according to the ASTM D 2244 standard test method using the CIELAB color system. The total color difference $\Delta E*ab$ is calculated as follows:

$$\Delta E*ab = [(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2]^{-1/2} \qquad (1)$$

where: L*, a*, b* are chromaticity scales;

$\Delta L*$: lightness-darkness, $\Delta a*$: redness-greenness, $\Delta b*$: yellowness-blueness.

The variation in color was calculated as the difference of L*, a* and b* between treated and untreated wood in percentage of the initial value, as follows:

$$\Delta L* (\%) = (L* \text{ treated} - L* \text{untreated}) / L* \text{ untreated} * 100 \qquad (2)$$
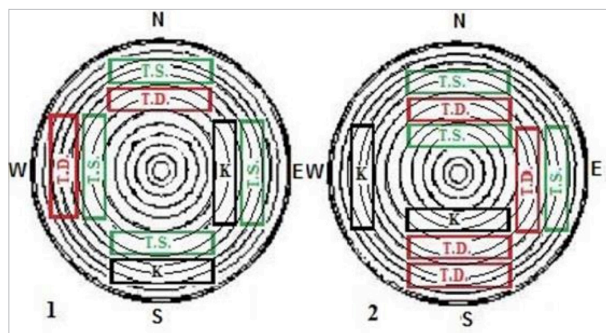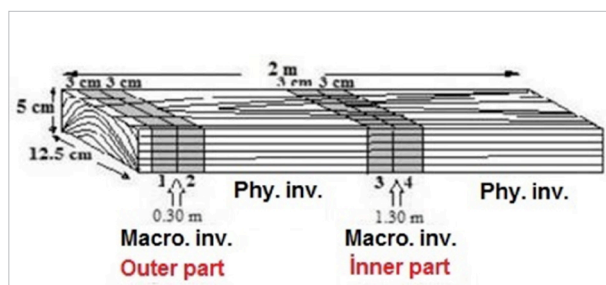
In order to determine the air-dried and kiln-dried density values, samples having dimensions of 20 x 20 x 30 mm were prepared according to the TS 2472 (1976) Standard. The specimens were conditioned at 20°C and 65% relative humidity (RH) to 12% moisture content in order to determine the air-dried density. After that, the specimens were placed in a drying kiln at 103 °C until they reached a constant weight suitable for the determination of the kiln-dried density. The air-dried D_{12} and kiln-dried density D_0 were calculated as follows:

$$D_{0, 12} = W_{0,12}/V_{0,12} \, (g/cm^3) \quad (3)$$

where: D_0: Kiln-dried density (g/cm³), W_0: kiln-dried weight (g), V_0: kiln-dried volume (cm³), D_{12}: air-dried density (g/cm³), W_{12}: air-dried weight (g), V_{12}: air-dried volume (cm³)

Dimensional stability of the heat-treated samples was calculated with ASE (Anti swelling efficiency). The kiln-dried samples were sized measured and then samples were immersed in water at a temperature of 20°C, until a constant weight was reached (fiber saturation point), and the sample sizes were then measured again. Volumetric swelling coefficients (S) were calculated as follows:

$$S \, (\%) = [(V_2 - V_1)/V_1] \times 100 \quad (4)$$

where: V_2: Water-saturated volume, V_1: oven-dried volume

ASE gives the difference between swelling coefficients of treated and untreated samples and was calculated as follows:

$$ASE \, (\%) = [(S_c - S_t)/S_c] \times 100 \quad (5)$$

where: S_c: The volumetric swelling coefficient of reference, S_t: the volumetric swelling coefficient of treated samples

The statistical evaluation of the data in the study was analyzed using a SPSS statistical package program having a 95% confidence level.

RESULTS AND DISCUSSION

This study revealed that crack formation was an important macroscopic change during heat treatment and the formation of cracks in all samples varied in the inner and outer parts of timber and inner/outer parts of timber were differently affected by the crack formation (Figures 3-5). Our research showed that the cracks which formed after drying in the outer parts of the timber did not extend to the inner parts. Therefore, it was determined that these cracks were superficial cracks which could be removed by various types of surface treatment (Figures 3, 4). The examinations made in the reference samples showed that the beginning of the crack formation was based on the technical drying, and the heat treatment applications led to both the formation of new cracks and the aggravation of existing cracks (Figure 4).

In previous studies on heat treatments, superficial cracks based on conventional drying have also been reported. Since these cracks could easily be removed by various types of surface treatment, they were not considered to be a serious defect (Johansson, 2005; Johansson, 2006; Sehlstedt- Person et al., 2006; Kallender and Landel, 2007; Boonstra, 2008; Altgen et al., 2012; Altgen et al., 2015). The wood material exposed to high temperatures shows different reactions in different directions due to its anisotropic nature. Thus many defects occured because the stresses in the different directions of wood were nonequal Thus, stress discrepancies in the different direction emerged as the cause of many defects (Ward and Simpson, 1991). Fengel and Wegener (1989) concluded that the shrinkage in the structure of heat-treated wood due to thermal degradation induced mass loss and volumetric shrinkage. They indicate that this may cause crack formation by creating stress on the cellular basis in the weakest areas of the cell. Heat treatment also caused changes in the chemical structure of wood, like the degradation of polymers due to the breakage of molecular bands. Furthermore, the degradation of polymers led to mass loss and volumetric shrinkage of wood (Fengel and Wegener, 1989; Boonstra, 2008). Many researchers have acknowledged that the basis of the changes in
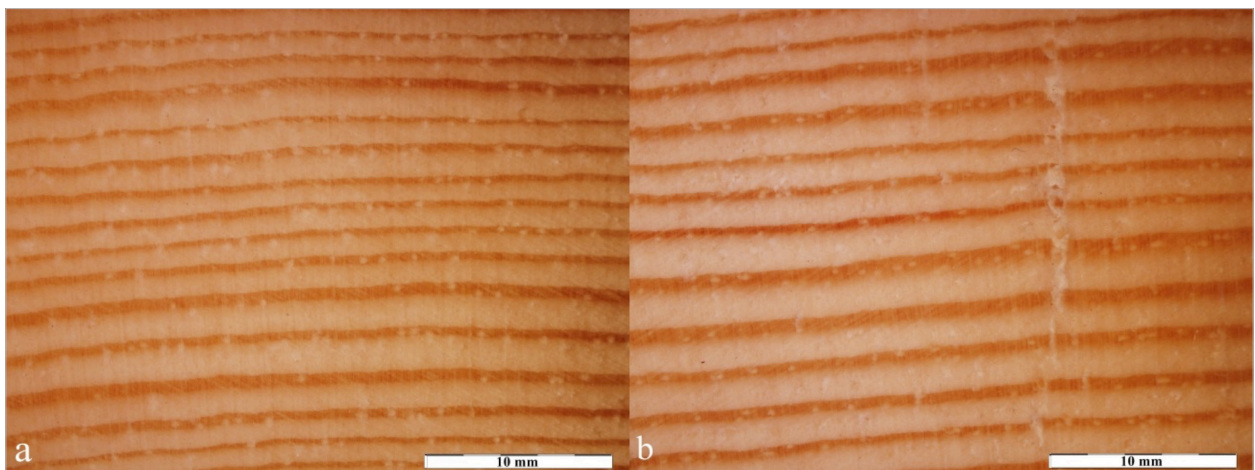
Figure 3. a, b. Kiln dried reference samples (a) inner part, (b) outer part

wood structure during heat treatment is related to the chemical and anatomical nature of the wood which is responsible for all the physical and mechanical changes (Fengel and Wegener, 1989; Ward and Simpson, 1991; Viitanen et al., 1994; Viitaniemi and Jamsa, 1996; Hietala et al., 2002, Anonymous, 2003; Suttie and Thompson, 2004; Johansson, 2005; Boonstra et al., 2006; Johansson, 2006; Kallander and Landel, 2007; Dogu et al., 2015; Dogu et al., 2016). It was thought that the formation of cracks was the result of changes in the chemical and anatomical structure of the wood during the heat treatment.

When the effect of heat treatment on timbers obtained from sapwood and heartwood was examined, only Thermo-D applied heartwood samples showed internal crack formation and cupping (Figures 5, 6). Similar to these findings, internal crack formation was detected in heat treated wood materials in previous studies (Johansson, 2005; Johansson, 2006; Kallander and Landel, 2007). Johansson (2006) also found that internal cracks were formed in boards thicker than 50 mm and since these cracks could not be identified from the outside, they should be considered more serious defects than surface cracks.

Similar to surface cracks, internal cracks are also associated with the changes in the chemical and anatomical properties of wood. The stresses generated in the internal and external part of the timber during drying are different from each other. Studies about the drying of wood (Ward and Simpson, 1991; Johansson, 2005) showed that when the stress level exceeds the recyclable elastic regime of wood, crack formation occurs. It is a known fact that in many wood species, heartwood has different chemical and physical properties from sapwood. In particular, the high content of extractives in heartwood has an effect on many properties, from physical properties to its durability (Kollmann and Cote, 1968). Some extractives can penetrate the secondary wall of cells affecting the shrinkage of wood during drying (Wangaard and Granados, 1967). These various facts about heartwood could reveal the differences between heartwood and sapwood samples undergoing the same process conditions (Thermo-D).

It has also been observed that heat treatment applications lead to the formation of resin flow, especially in the heartwood samples, and they appear like darker spots on the surface of the samples, which is in keeping with the literature (Sehlstedt-Persson et al., 2006; Boonstra, 2008; Esteves et al., 2008).
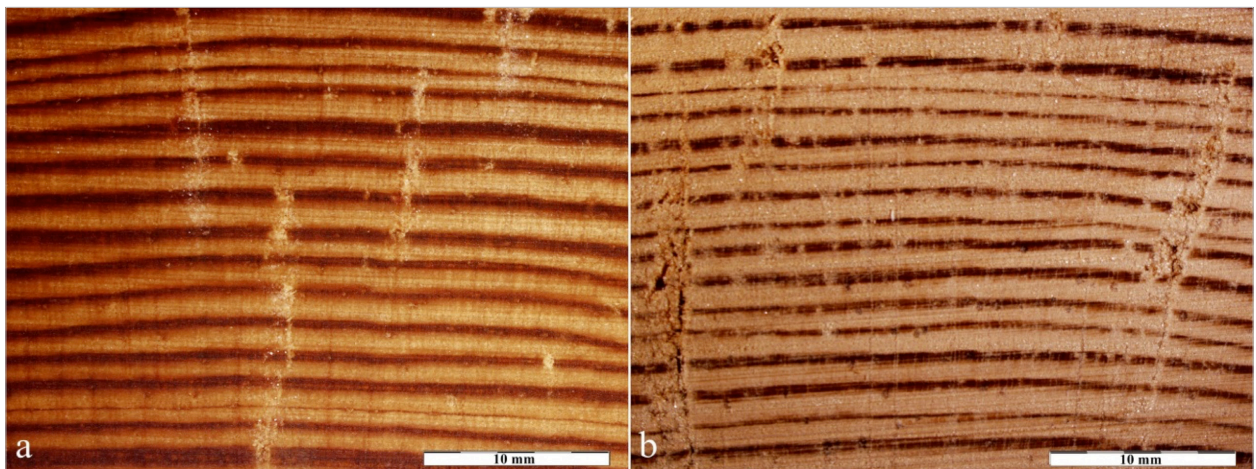
Figure 4. a, b. The outer part of sapwood samples (a) Thermo-S, (b) Thermo-D
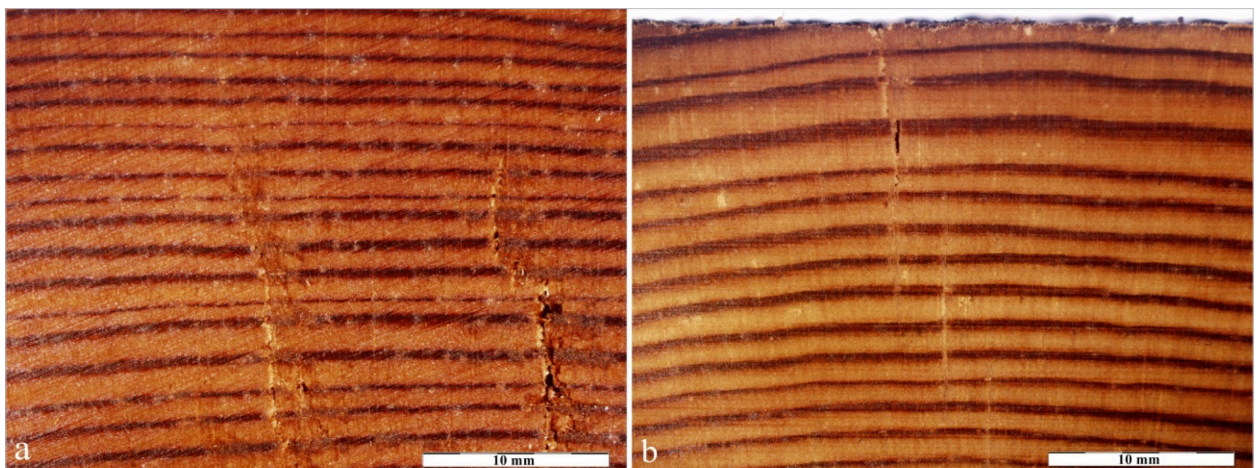
Figure 5. a, b. Thermo-D applied heartwood samples (a) inner part, (b) outer part

Macroscopic studies have shown that as the temperature increases (Thermo-S, 190℃; Thermo-D, 212℃), the darkening of the color of the specimens also increases. The most significant change after heat treatment was observed in the L* value which indicated that the color of the samples became darker, and similar results were found in previous studies (Militz, 2002; Bekhta and Niemz, 2003; Esteves et al., 2008; Gonzalez-Pena and Hale, 2009; Akgul and Korkut, 2012; Guller, 2012; Todorovic et al., 2012).

Color measurements of untreated and treated samples and their comparison with reference samples (%) are shown in Table 1. After heat treatment applications, the color of sapwood samples became redder (+Δa*) and yellower (+Δb*) while the color of heartwood samples became less red (-Δa*) and yellow (-Δb*). It is thought that the removal of volatile extractives such as outflow of resin could be the reason for the color changes in the heartwood samples. After the heat treatment, the color of the samples also became darker, and the changes in color were greater in the Thermo-D process than those in the Thermo-S process. The higher degree of darkening after heat treatment was observed in sapwood samples compared to heartwood

Figure 6. a, b. Thermo-D applied heartwood samples (a) internal crack formation, (b) cupping

samples. The total color changes of samples were higher in the sapwood samples. Todorovic et al. (2012) also found that sapwood parts of beech wood had a higher mean value of total color difference than that of red heartwood. The changes in wood color after heat treatment are mainly associated with the degradation of chemical constituents and the removal or migration of extractives and other compounds (Sundqvist, 2004; Sehlstedt-Persson, 2008; Johansson, 2008; Dubey, 2010). The differences between the chemical components of sapwood and heartwood parts of Scots pine wood could explain the differences in color changes after treatment.

Density values of the treated and untreated samples (a) and their rate of changes (b) are shown in Figure 7. As the heat treatment temperature increased, the density values decreased and the highest decrease in density values was seen in the

Table 1. Color changes

		C	TS	TD	C-TS (%)	C-TD (%)
Sapwood	L*	78.08	54.06	50.25	-24.02	-27.83
	a*	7.04	14.33	14.65	7.29	7.61
	b*	30.64	34.01	32.49	3.37	1.85
			ΔE		25.33	28.91
Heartwood	L*	56.82	57.01	46.53	0.19	-10.29
	a*	16.99	14.46	13.42	-2.53	-3.57
	b*	33.52	32.1	26.67	-1.42	-6.85
			ΔE		2.91	12.87

C: reference; TS: Thermo-S; TD: Thermo-D

Table 2. Anti-Swelling Efficiency (ASE)

	Sapwood		Heartwood		Total	
	TS	TD	TS	TD	TS	TD
ASE (%)	17.04	24.77	11.97	30.45	14.88	24.86

TS: Thermo-S; TD: Thermo-D
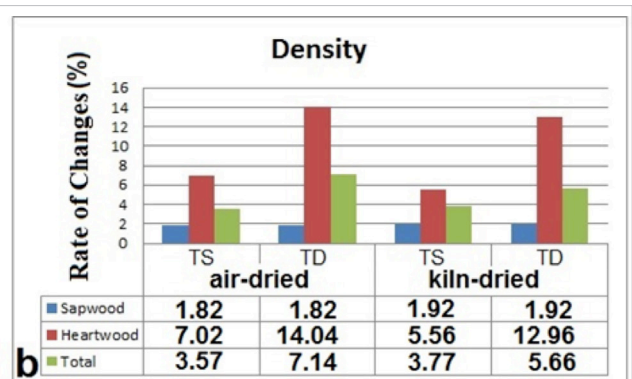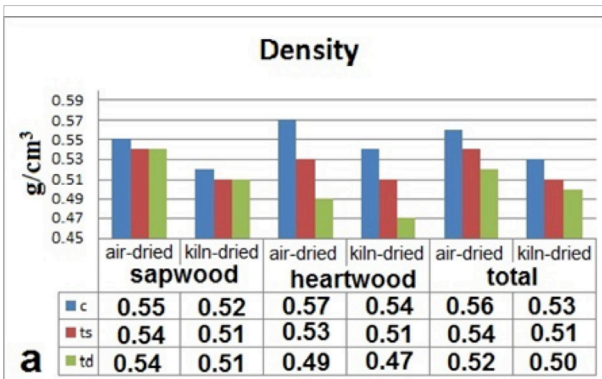
Figure 7. a, b. (a) Density values of the samples, (b) Rate of changes in densities according to reference samples
C: reference; TS: Thermo-S; TD: Thermo-D

Thermo-D applied heartwood samples. Air-dried density values were higher than kiln-dried density in all samples. A higher rate of change in density values after the heat treatment was seen in the heartwood samples. Previously conducted studies have confirmed that the density decreases after the application of heat treatment for various wood species (Boonstra, 2008; Guller, 2012; Percin et al., 2016). The degradation of wood components (mainly the hemicelluloses) into volatile compounds and the evaporation of extractives are considered as the main parameters responsible for the density reduction of wood after heat treatment (Fengel and Wegener, 1989; Boonstra, 2008; Esteves and Pereira, 2009). According to Sehlstedt-Persson (2008), extracted pine heartwood acts in the same way as pine sapwood in moisture diffusion experiments which indicate the extractive content in softwood has a great influence on drying. Moisture diffusivity is one of the main factors that affect the success of drying applications. However, Sehlstedt-Persson (2008) has found that density has greater influence than extractive content on diffusivity. It is a well-known fact that the main difference between heartwood and sapwood is extractive content which is considerably higher in heartwood (Fengel and Wegener, 1989). In light of this information higher density reduction in heartwood samples could be explained with their higher extractive content. It could be concluded that higher density reduction could be the reason for internal crack formation in heartwood samples.

Anti-Swelling Efficiency (ASE) of heat-treated Scots pine wood is shown below in Table 2. The heat treatment improved the dimensional stability of the Scots pine wood in direct proportion to process temperature. The most significant improvement in dimensional stability was seen in the Thermo-D applied heartwood samples (%30.45). Similar to this study, Tjeerdsma et al. (1998) reported that the heat treatment allowed the reduction of swelling for Scots pine from 22% to 40%, respectively. Yıldız (2002) reported that beech wood's ASE increased with the increase of the temperature and time of treatment, reaching 50% at 200°C. Militz (2002) showed that the improvement of dimensional stability depends on the species. Under the same conditions, radial and tangential ASE values were 10% and 13% for beech wood, 13% and 23% for Douglas fir, 11% and 40% for spruce, 35% and 40%, for Radiata pine, and 33% and 41% for Scots pine, respectively. Esteves et al. (2013) reported that after heat treatment *Pinus pinaster* radial ASE reached 52% for sapwood and 50% for heartwood, while tangential ASE reached 50% and 40%, respectively. Several studies have shown that, generally, heat-treated wood loses hygroscopicity leading to an increase in dimensional stability with low shrinkage and swelling values.

The degradation of the hemicelluloses, removal of the volatile extractives, breaking of hydroxyl groups of amorphous cellulose, plasticization of lignin and the reorganization of the lignocellulosic polymeric components of wood were proposed as explanations for the increased dimensional stability of heat treated wood (Bekhta and Niemz, 2003; Weiland and Guyonnet, 2003; Esteves and Pereira, 2009; Korkut and Kocaefe, 2009). These chemical changes may have also some effect on other properties. In this study, these properties were density reduction, color changes and crack formations. Alterations in the chemical structure cause mass losses and breakage of bonding sites for waters, leading to a decrease in density, shrinkage and swelling. While these changes occur in the molecular bonds in the wood structure, stresses emerged in the anatomical structure on the cellular basis. These stresses induced the formation of cracks when they exceeded the recyclable regime. When wood is subjected to heat treatment, the color of the samples darkened, depending on the chemical changes. Several studies found that these color changes also appeared to correlate with the wood density. Density of wood is one of the most important characteristics of heat treatment and is commonly referred to as an indication of quality. Although it was not studied in this work, many researchers have confirmed that mechanical properties are also induced by these physical changes. Each effect created has interrelated reactions on the material. In this study, our main research emphasis has been the effects of heat treatment on certain properties of Scots pine wood. This study revealed that heat treatment affects sapwood and heartwood to different degrees. It was thought that these differences were induced by their different chemical structures.

CONCLUSION

Based on conventional drying, superficial cracks occurred in all heat-treated samples. As the temperature increased the heat treatment led to both the formation of new cracks and the aggravation of existing cracks. Since these defects could easily be removed by surface treatments, they were not considered to be serious defects. However internal crack formation and cupping were determined in the Thermo-D applied heartwood samples. Since internal cracks cannot be detected from outside the material, they have to be considered as a significant defect that reduces the quality of the material.

The color of heat-treated samples was darkened. A higher degree of darkening was observed in the sapwood samples. Limited content of volatile extractives in sapwood leads to less removal of extractives from wood. This slight outflow ends up with higher color change. Therefore, if the darker color is asked for, Thermo-D sapwood samples would be preferable.

With increased temperature, the density of the samples was reduced. Higher reductions were found in air-dried heartwood samples (for the Thermo-S 7.02%, for the Thermo-D 14.04%). Density is the main physical property of wood which affects most of the strength properties. Thus, if the strength properties are required in the usage area, utilization of Thermo-D heartwood samples should be avoided.

The heat treatment improved the dimensional stability of the Scots pine wood, increasing with temperature of treatment. The most significant improvement in dimensional stability was seen in the Thermo-D applied heartwood samples (ASE %30.45). Thus, if there is a need for high stability on the place of use, utilization of Thermo-D heartwood samples would be more suitable.

The highest reduction in density and improvement in dimensional stability was achieved in the Thermo-D applied heartwood samples. These findings indicate the extractives are very effective on the quality of heat treatment.

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Annual water consumption of an Anatolian black pine in a sub-humid region

Yarı-nemli koşullarda yetişen bir Anadolu karaçamının yıllık su tüketimi

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ABSTRACT

The primary aim of this study was to investigate the annual water consumption of an individual Anatolian black pine [*Pinus nigra* Arn. subsp. *pallasiana* (Lamb.) Holmboe] growing in Belgrad Forest, İstanbul. The sample tree was 56 years old, measuring a height of 17 m and a diameter at breast height of 40 cm. The study was conducted over a period of 1 year from January 1, 2016, to January 1, 2017. The minimum and maximum air temperatures were −11°C and 32°C, respectively. The precipitation during this period was recorded as 1,083 mm. Tree water consumption measurements were carried out using the tissue heat balance method. Results showed that water uptake of the tree varied between 0.007 and 71.54 kg day^{-1}, while the average daily and annual water consumptions of the tree were about 27.06 and 9,851 kg, respectively. The daily water consumption varied between 59 kg in July and 3.37 kg in January. These values can be considered as guidance for an effective management of forested watersheds in terms of both water quality and water production.

Keywords: Anatolian black pine, sap flow, tissue heat balance, transpiration, water consumption

ÖZ

Bu çalışmanın amacı İstanbul Belgrad Ormanı'nda yetişen bir Anadolu karaçamının [*Pinus nigra* Arn. subsp. *pallasiana* (Lamb.) Holmboe] yıllık su tüketimini ortaya koymaktır. Örnek ağaç 56 yaşında, 17 metre (m) yüksekliğinde olup göğüs yüksekliğindeki çapı 40 santimetre (cm)'dir. Çalışma 1 Ocak 2016 ile 1 Ocak 2017 tarihleri arasını kapsamaktadır. Çalışma süresi boyunca yağış 1083 milimetre (mm), en düşük sıcaklık -11°C ve en yüksek sıcaklık 32°C olarak kaydedilmiştir. Ağacın su tüketimi ölçümleri gövde/doku ısı dengesi yöntemi kullanılarak yapılmıştır. Sonuçlara göre, örnek ağacın günlük ortalama su tüketimi 27,06 kilogram (kg) olup günlük tüketim 0,007 kg ile 71,54 kg arasında değişiklik göstermektedir. Bu ağacın yıllık toplam su tüketimi 9851 kg'dır. Aylara göre bakıldığında ise en yüksek günlük ortalama tüketim 59 kg ile Temmuz ayında, en düşük günlük ortalama tüketim ise 3,37 kg ile Ocak ayında gerçekleşmiştir. Elde edilen bu veriler ormanlık havzaların yalnızca su kalitesi anlamında değil su üretimi anlamında da verimli yönetilebilmesi için yol gösterici olarak alınabilir.

Anahtar Kelimeler: Anadolu karaçamı, bitki özsuyu akış ölçümleri, gövde ısı dengesi, transpirasyon, su tüketimi

INTRODUCTION

Water is one of the vital necessities for all living organisms and it directly affects the quality of life. Turkey's water distribution per year per capita is around 1519 cubic meter (m³) today. Countries having less water than 1000 m³/per year/per capita are classified as "water poor country" (DSI, 2016). According to population growth projections by the Turkish Statistical Institute (TUIK, 2016), the population of Turkey will reach 90 million by 2030. Therefore, water scarcity will become a critical issue and watershed management and water budget plans will be more important.

The amount of precipitation, topography of the area and vegetation cover of the site are the main factors affecting the water yield of a watershed. While the amount of precipitation cannot be increased by humans continuously, vegetation management practices can be applied to increase water yield

in the watersheds. Hence, it is important to know the water consumption rates of tree species, its relation to the atmospheric variables (i.e. air temperature, air humidity, solar radiation) and its trend according to the seasons for vegetation management and plantations in these watersheds (Özçelik et al., 2016).

Several methods including lysimeter, transpirometer, watershed water balance, potometer, tent, and sap flow methods are available for measuring transpiration from plants (Özhan, 1982). Sap flow method was developed after the pioneer work of Huber in 1932 and several methods have been added based on different principals (thermodynamic, electric, magnetic resonance) ever since (Cermak et al., 2004). These methods have been used in world-wide especially after the development of chip technology with smaller and mobile sensors and less energy consuming data loggers. Thermal sap flow methods are commonly used in forest hydrology and ecophysiology due to their simplicity, cheapness and potential of separate estimation for the transpiration component (Poyatos et al., 2005). Sap flow measurements are also useful in harsh environments such as those that have complex terrain and variable topography (Renninger and Schafer, 2012).

Although sap flow method has a long history in forest hydrology, this method has not been used in Turkey so far. Therefore, the information about exact water consumption of vegetation cover

Figure 1. Study site: Atatürk Arboretum in Belgrad Forest

Figure 2. Electrodes, needle type thermocouples, isolator band and electric supplier hooks on the tree trunk

and its seasonal trend are still being objectives of concern in Turkey. Besides, while there are several researches focused on transpiration rates of pine species such as Scots pine (Köstner et al., 1996; Lagergren and Lindroth, 2002; Cienciala et al., 2002; Moore et al., 2004; Poyatos et al., 2005; Wang et al., 2005; Tor-ngern et al., 2017), Maritime pine (Grainer et al., 1990; Loustau et al., 1996), ponderosa pine (Ryan et al., 2000; Small et al., 2008), slash pine (Martin, 2000), loblolly pine (Martin, 2000; Torngern et al., 2017), Canarian pine (Luis et al., 2005), shortleaf pine (Renninger and Schafer, 2012) and radiata pine (Jackson et al., 1972); data about the water consumption of Anatolian black pine, which is one of the most widespread pine species in Turkey covering more than 2,2 million hectares (ha) (Karadağ, 1999), is not available in the literature.

Therefore, the main objective of this study was to determine the annual water consumption of an individual Anatolian black pine tree growing in İstanbul.

MATERIALS AND METHODS

Study Site and Sample Tree
The study was carried out in the Atatürk Arboretum in Belgrad Forest (Figure 1) on the European side of İstanbul (41° 09′ 48″- 41° 10′ 55″N, 28° 57′ 27″-28° 59′ 27″E). Mean annual precipitation is around 1120 mm and mean annual temperature is 13°C at the site. August is the warmest month and January is the coldest. In general, the soil at the site is shallow with high organic matter, the texture is clay loam and the permeability rates are medium-good. Parent material is characterized Neocene loamy (Serengil et al., 2007). The stand was established in 1960. The basal area of the stand is 54.8 m^2 and the tree density is about 975 stems per hectare. Mean tree height is 14.5 meter (m) and mean diameter at breast height is 24.2 centimeter (cm). The overall topography of the stands is flat. The understory vegetation is scarce and mainly consists of *Erica arborea* L. and *Pteridium aquilinum* (L.) Kuhn. For the study, one individual Anatolian black pine tree was selected as the sample tree from the stand. The tree was 56 years old with a height of 17 m and a diameter of 40 cm at breast height. The study period covered one year between January 1st 2016 and January 1st 2017.

Environmental Data
The meteorological data were recorded using two automatic meteorological stations. One of them was placed in an open field next to the study site measuring solar radiation, air temperature, air humidity and precipitation (EMS Minikin RTHI and EMS Minikin ERI, Environmental Measuring Systems, Brno, Czechia). The other one was a fully equipped automatic weather station 5 km far away from the study area (GRWS 1000, Campbell Scientific, Logan, USA) measuring solar radiation, air humidity, air temperature, wind direction, wind speed, sunshine duration, and precipitation. Air temperature, relative humidity and radiation were measured at 5 minute intervals and precipitation was recorded using a tipping bucket rain gauge type. Soil moisture was recorded at three soil depths (10 cm, 25 cm, and 50 cm) under the forest canopy using calibrated gypsum blocks (Delmhorst Inc, New York, USA) and Microlog SP3 data logger (Environmental Measuring Systems Brno, Czechia) as soil water potential (Ψ, bar) at 60 minute intervals.

Months	Mean air temperature (°C)	Mean air humidity (%)	Maximum Global radiation (W m^{-2})	Soil water potential (bar)	Precipitation (mm)	Transpiration of the tree (daily mean) (kg)
January	4.4	79.55	533	-0.23	167	3.37
February	9.4	77.05	638	-0.20	114.8	9.87
March	9.1	75.86	820	-0.17	88.3	17.40
April	13.6	63.9	1034	-0.28	26.8	36.9
May	16.2	82.69	1149	-1.55	59.0	34.93
June	21.3	81.46	1115	-4.5	73.6	50.45
July	23.0	81.68	1142	-5.83	35.2	59.0
August	23.7	86.82	1054	-9.4	43.8	42.58
September	19.5	82.10	983	-7.93	52.4	33.91
October	14.3	88.75	828	-5.41	50.2	16.49
November	13.1	82.23	568	-5.01	119.4	13.16
December	3.3	90.32	342	-1.35	213.6	5.46

Table 1. Meteorological data, soil water potential and transpiration values according to the months

Sap Flow Measurements

A sap flow sensor (EMS 81, Environmental Measuring Systems, Brno, Czechia) working according to the tissue heat balance method was used to determine water consumption of the sample tree (Cermak et al., 1973, 1982; Kucera et al., 1977).

In the tissue heat balance method, a part of a tree trunk was heated with electrodes using an electric current passing through the tissues. Four electrodes and thermocouples were placed into the tree trunk according to the system (Figure 2). The central electrode was positioned 10 cm down from the other three upper electrodes and only the upper electrodes were heated (Cermak et al., 2004). Needle type thermocouples were used to determine the temperature difference (dT) between upper heated electrodes and the reference one. The method calculates the heat balance of a defined heated space according to the equation below (Cermak et al., 2004):

$$P = QdTcw + dT\lambda$$

Where P is the input power (W), Q is the sap flow rate (kg s^{-1}), dT is the temperature difference between the heated and unheated electrodes (K), cw is the specific heat of water (J kg^{-1} K^{-1}) and λ is the coefficient of heat losses from the measuring point (W, K^{-1}). A pack of polyurethane foam was used to insulate the temperature field around the sensors from the effects of the sun and convective heat loss. The data were evaluated by EMS Mini32 and Microsoft EXCEL software.

RESULTS AND DISCUSSION

During the study period, the total amount of precipitation was 1083.6 milimeter (mm), and mean daily temperature was 11.8°C with a minimum of -11°C and maximum of 32°C. The results showed that the average daily water consumption was 27.06 kilogram (kg) and varied between 0.007 kg and 71.54 kg. Annual total water consumption of the tree was 9851 kg. The highest water consumption was in July with daily average of 59 kg while the lowest was in January of 3.37 kg. Due to the winter precipitations, soil moisture was high until June but it dramatically decreased after this month, especially at 25 cm depth. Soil water potentials at 10 cm and 50 cm depths were higher than at the 25 cm depth, (-10, -9 and -13 bars for 10 cm, 50 cm and 25 cm soil depths respectively). The understory (*Erica arborea* L. and *Pteridium aquilinum* (L.) Kuhn) could be responsible for this difference because their roots mostly expand to 25 cm soil depth. Although the soil moisture decreased after June, the water uptake of the tree increased. This could have been an indication of the tree roots expanding into deeper soil depth.

Some data about climate, soil water potential and transpiration values are given in Table 1. It can be seen that seasonal transpiration percentages were 5.5%, 27.5%, 47.5% and 19.5% for winter, spring, summer and autumn respectively. The table shows that the water consumption of the tree in summer is equal to the sum of the other three seasons. Water consumption of the tree in June was about 17 times greater than that in January. Higher transpiration values can be expected if soil moisture is high enough during the summer months. Other parameters measured in the study site can be seen on Table 1.

The literature includes high daily water consumption rates such as 400 kg per day^{-1} by a 100 years old *Quercus robur* L. growing in a floodplain forest (Cermak et al., 1982) and 1180 kg per day^{-1} by a *Eperua purpurea* Bth. tree growing in the Amazonian rainforest (Jordan and Kline, 1977). However, Wullschleger et al. (1998) reviewed the studies of 67 species from 35 genera and reported that the daily water use of individual trees generally varied between 10 and 200 kg per day^{-1}. Therefore, it can be concluded that the results of this study were consistent with those of previous studies conducted in different regions.

Considering only pine species, the water consumption of the Anatolian black pine was within the range of results from other studies. For instance, Wieser et al. (2014) measured an average 14.5 kg daily water consumption with maximum daily values of 25.4 kg in a dry valley of Austria for Scots pine (*P. sylvetsris* L.). Cienciala et al. (2002) reported similar results with a maximum of 25 kg per day[-1] in Sweden. Köstner et al. (1996) found 4.4-24 kg per day[-1] sap flow rates for the same tree species. Renninger and Schafer (2012) applied two different sap flow methods on the same tree species in USA and they found that transpiration rates varied from 1 to117.9 kg per day[-1] for shortleaf pine (*P. echinata* Mill.). Loustau et al. (1996) examined the transpiration rates of Maritime pine (*P. pinaster* Ait.) in Portugal, and reported a water consumption rate of between 75 and 270 kg per day[-1] for this species. Luis et al. (2005) determined that the Canarian pine (*P. canariensis* C. Sm.) consumed 18.24 to 47.52 kg per day[-1] in the Canary Islands and the annual total transpiration of this species was 2-3 times lower than the transpiration rates of Mediterranean forest ecosystems. Martin (2000) focused on the transpiration of intensively managed slash pine (*P. elliottii* Engelm.) and loblolly pine (*P. taeda* L.) in the winter season and reported that the daily maximum water consumption of these two species were 75.1 and 71.6 kg per day[-1] respectively in winter.

CONCLUSION

It can be seen from the literature that the water consumption of pine trees has been investigated by many researchers under different climate conditions for different purposes. The results of the present study revealed that the water consumption of a single pine tree under sub-humid climate conditions can be high especially in the summer months when the precipitation is minimum and water demand for evapotranspiration is maximum. It is obvious that the knowledge of water consumption of trees and its seasonal variation are necessary for forest hydrology and management. In the forested watersheds of Turkey, only limited data on water consumption of stands and trees are available. Therefore, further work is needed to investigate the potential water consumption of forest stands and plant species of Turkey in order to make reliable projections and plans for water budget on watershed scale.

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Causes of land degradation and rehabilitation efforts of rangelands in Turkey

Türkiye'de arazi bozulmasının sebepleri ve mera ıslahı çalışmaları

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ABSTRACT

Turkey, which is located in an ecological transition zone between subhumid Southern Europe and the arid Middle East, has a long history of land use and civilization. Pressure from expanding human populations, intensified animal production, and transhumant movements in particular, are leading to the complete denudation of many areas of central Turkey (Central Anatolia), with soil erosion emerging as the primary concern. A mountainous topography and semiarid climatic conditions exacerbate the threat of soil erosion and have limited the success of efforts to restore degraded lands. Although afforestation efforts have increased, rangeland areas dominated by shrub and grass species have decreased. Remnant rangeland areas continue to experience overgrazing and severe losses in productivity. Forest remmants and archeological studies indicate that, due to human use, Central Anatolia has lost its original native vegetation, including pine and oak species, and has assumed anthropogenic steppe characteristics. For this reason, the restoration emphasis has been on tree species, without any consideration for shrub or grass species that could help to stabilize soils in denuded and degraded landscapes. In this article, we discuss the socioeconomic and environmental limitations of the natural revegetation of rangeland areas, and the need for restoration efforts with a focus on shrub and grass species in areas vulnerable to high rates of soil erosion.

Keywords: Land degradation, Anatolian steppe, rangeland rehabilitation, overgrazing

ÖZ

Çok uzun ve eski bir arazi kullanım tarihine ve uygarlaşmaya sahip Türkiye, yarı nemli güney Avrupa ile kurak Ortadoğu arasında geçiş zonunda yer almaktadır. İnsan nüfusu ve hayvansal üretim artışının yarattığı baskı, özellikle yayla yaklaşımı, erozyona sebep olarak İç Anadolu'da vejetasyonun kaybına ve arazinin çıplak kalmasına yol açmaktadır. Dağlık topoğrafik yapı ve yarıkurak koşullar toprak erozyonu tehdidini hızlandırmakta ve bozuk alanların restorasyonunun başarılı olmasını kısıtlamaktadır. Ülkemizde ağaçlandırma faaliyetleri artarken, otsu ve çalı türlerinin baskın olduğu mera alanları azalmıştır. Mevcut mera alanları sürekli otlatılmaya maruz kalmakta ve verimlerinde kayıplar meydana gelmektedir. Orman kalıntıları ve arkeolojik çalışmalar, İç Anadolu'nun insan kullanımından dolayı içerisinde çam ve meşe türlerinin de yer aldığı doğal vejetasyon örtüsünü kaybettiğini ve antropojen step özelliği kazandığını göstermektedir. Restorasyon çalışmalarında ağırlık, bozuk ve çıplak alanlardaki toprakları stabil hale getirecek çalı ve otsu türler yerine ağaç türlerine verilmektedir. Bu makalede, mera alanlarının doğal çalı ve otsu türlerle bitkilendirilmesini kısıtlayan sosyo-ekonomik ve çevresel faktörler açıklanarak yüksek derecede erozyona uğrayabilecek alanlardaki otsu ve çalı bitki türlerine restorasyon faaliyetlerinde duyulan ihtiyaç konusu tartışılmıştır.

Anahtar Kelimeler: Arazi bozulması, Anadolu stebi, mera ıslahı, aşırı otlatma

INTRODUCTION

Location, Topography and Land Use

Turkey is located between Latitudes 35°50′-42°06′N and Longitudes 25°40′-44°48′E and covers an area of 77797127 ha (Balcı and Uzunsoy, 1980). The larger part of the country, called Anatolia or Asia Minor, lies in Asia while the smaller part, called Turkish Thrace, lies in Europe. Both land parts meet at two important straits, the Bosphrous and the Dardanelles connecting the Black sea with the Mediterranian sea. Very di-

verse climatical, topographical, sociological, geological, and histor-ical conditions dictate the management of soil and vegetation re-sources. The topography of Turkey can be defined as rugged, apart from the highly mountainous coastal region and Eastern part. The Northern and Southern chains of the mountains running along the coast meet in Eastern Anatolia and form the highest plateau of Anatolia. The mean elevation is 1132 m which is 3.5 times greater than that of the Europen Continent (GDSHW, 2015). The country has more than twenty peaks with elevations higher than 3000 m above sea level and elevation varies from 0 m at sea level to 5165 m at Ararat Mountain. (Balcı and Uzunsoy, 1980). As seen in Table 1, 62% of the total area has a slope of over 12% and "very steep" or "ex-tremely steep" slopes cover 47% of the total land area. These values show the significance of topography in land use and soil erosion as one of the main reasons for land degradation.

According to land capability classification, 34.6% of the land area is suitable for cultivation while 65.4% is not and should be under permanent vegetation cover such as range or forest (Table 2). Although the amount of arable land almost coincides with the actual amount of cultivated land (31.10%), it is believed that there is a significant difference between current land use and the capability classes because several studies conducted around the country showed that some range and forest areas are presently being used for agricultural purposes (Balcı and Uzunsoy, 1980; Gülersoy et al., 2015).

Demography

Turkey has a high annual population growth rate of about 2% and the population increased from 13.6 million in 1927 to ap-proximately 77.7 million in 2014 (Figure 1) (TSI, 2015). Due to rapid migration from rural areas to urban areas, the rural and urban populations changed from 75.8% and 24.2% in 1927 to 8.2% and 91.8% in 2014, respectively (Figure 2).

Migration of people from rural to urban areas also affected livestock population. Similar to human population, the total number of livestock including cattle, sheep, and goats was ap-proximately 26.5 million in 1929, in the early years of the Turkish Republic and increased to 85.5 million in 1981 and then dra-matically decreased to 37.7 million in 2009 (Figure 3) (TSI, 2015). However, livestock population has started to increase in recent years due to changes in the rural development policies of the Turkish government and increases in subsidies paid to farmers for encouraging farming, livestock production, and preventing rural migration.

Actual Land Use

Although the size of cultivated land was used to coincide with the size of arable land with respect to land capability classifica-tion in the mid 1900's, the amount of cultivated land decreased to 31.10% over the last decades (Figure 4). Decreases in the size of the cultivated land can be attributed to abandonment of ar-

Table 1. Distribution of land area in relation to slope degrees (MAFRA, 1987)

Slope degrees (%)	Ratio to total land area (%)
Flat or almost flat (0-2)	12.80
Gentle slope (2-6)	11.18
Moderate slope (6-12)	13.87
Steep slope (12-20)	14.17
Very steep slope (20-30)	17.63
Extremely steep slope (>30)	30.35

Table 2. Distribution of total land area according to land capability classes (MAFRA, 1987)

Land use suitability	Land capability classes	Ratio to total land area[1]
Suited for cultivation	I	6.53
	II	8.81
	III	9.88
	IV	9.39
Not suited for cultivation	V	0.22
	VI	13.35
	VII	47.32
	VIII	4.50
[1]Lake areas are excluded from the land area.		

Figure 1. Trend of human population increase by years in Turkey
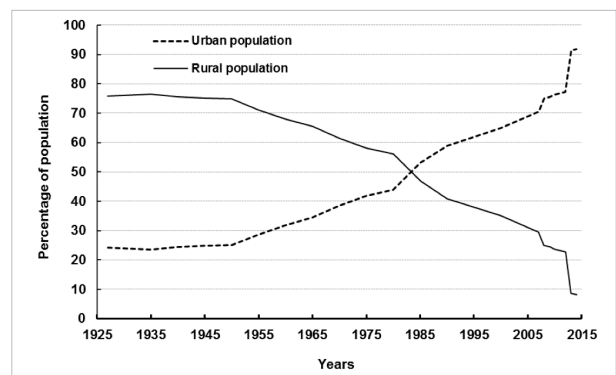
Figure 2. Trend of changes in the urban and rural populations by years
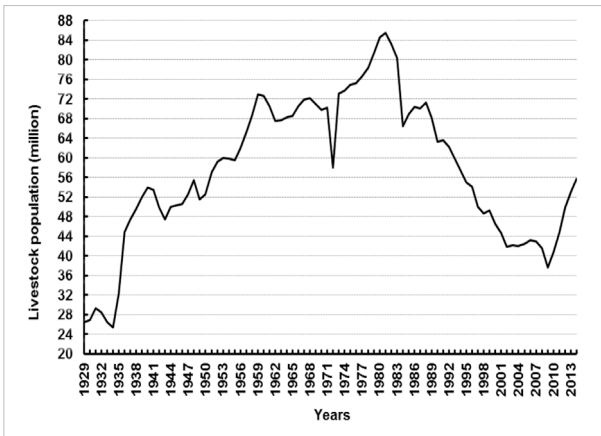
Figure 3. Livestock population changes with respect to years
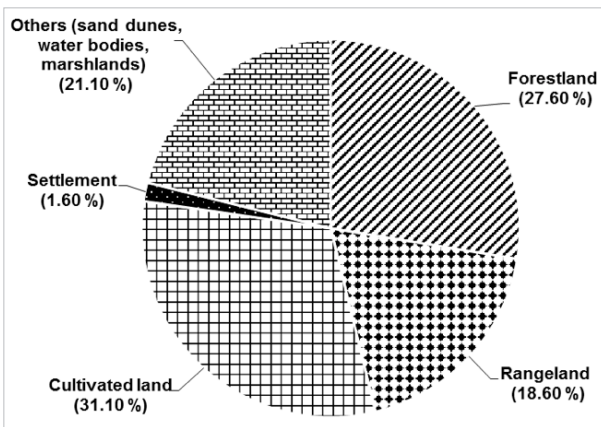
Figure 4. Actual land use in Turkey (GDCDE, 2015)
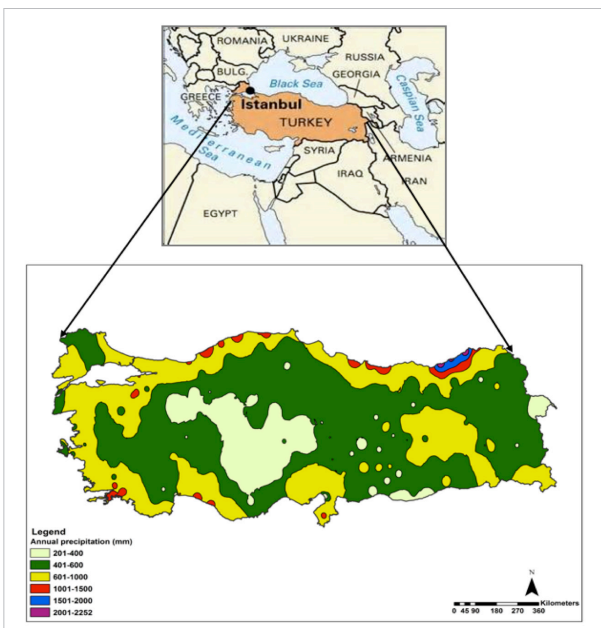
Figure 5. Distribution of annual precipitation in Turkey

able lands due to migration of people from rural areas to urban areas, and allocation of arable lands for new settlements and industrial plants. According to present land use classification, almost one third of the country is used for agricultural purposes while 27% is covered with forest vegetation and about 19% is rangeland (Figure 4).

Climatic conditions

According to the General Directorate of State Hydraulic Works (GDSHW, 2015), mean annual precipitation is around 643 mm with a runoff coefficient of 37% and most of it falls in winter months (Özhan, 2004). Precipitation regime is uneven and its annual amount varies from 200 mm in Central Anatolia to 2250 mm along the Northeast Black Sea coast. About half of Turkey (53%) receives annual precipitation of less than 600 mm and 12.5% receives less than 400 mm (based on 41 years of Turkish State Meteorological Service data covering a period from 1970 to 2011 years (TSMS, 2012). This means that semi-arid conditions prevail in an area equal to greater than half of the country (Figure 5). Mean annual temperature is around 13.1°C and varies from 2.2°C to 24.3°C. Also, temperatures can drop as low as -45.6°C in January and reach 48.6°C in July months in Southeastern Anatolia which is one of the warmest and driest regions on the Anatolian peninsula (TSMS, 2015).

RESULTS AND DISCUSSION

Anatolia has a long history of land use and civilization. Several civilizations flourished and disappeared in Anatolia. The History of cultivation goes back to 7000 years ago, particularly in upper Mesopotamia and some other parts of the country (Brice, 1968). Some wheat, barley and leguminous species were already being cultivated by about 6000 BC (Balcı and Uzunsoy, 1980). Due to this long history of cultivation and conflicts among the civilizations, vegetation cover was destroyed and soil was lost due to erosion. Two ersoion periods have been identified in Anatolian soils. The first period is between 300 years BC and 300 years AD. During this 600 year period, some ports like Ephesus and Miletus were destroyed and abandoned because of siltation (Balcı and Uzunsoy, 1980). There is also evidence showing that Turkey has been experiencing a second period of serious erosion in the last 50 to 100 years. Even though annual soil loss was decreased by afforestation and land rehabilitation studies from some 500 million tons in the 1970's to 168 million tons in 2014 (GDCDE, 2015), soil loss is still greater than in many countries around the world (Walling, 1988). Therefore, soil erosion still remains a serious threat for natural resources in Turkey. Currently, 86% of the total area has experienced soil erosion problems to varing degrees and approximately 59% has severe to very severe erosion problems (Table 3). Wind erosion appears only in a small portion of the country, especially in the sand dune covered areas. Because of soil loss, soil depth has decreased and about 67% of the country has shallow and very shallow soils (Table 4). Moreover, erosion threatens water resources and some reservoirs were shut down and are no longer used due to siltation.

Over grazing and land use tradition are some of the main factors responsible for land degradation and affect the success of restoration works in addition to mountainous topography, semiarid conditions in large areas, extended land use and civilization histories, land misuse, and rapid human and animal population growth. The vast majority of livestock depends on rangelands. Livestock are grazing as long as climatic conditions are suitable without considering the basic principals of range management such as grazing season and systems, and carrying capacity (Koc et al., 2015; Anonymous, 2015a). In rural parts of Turkey, rangelands are allocated to villages and villagers have the right to own as much livestock as they want. All livestock from the villages graze together and no fees are required for the grazing rights. Regardless of region, most livestock owners have long continued to practise their traditional transhumance system,

Table 3. Distribution of total land area with respect to erosion severity (MAFRA, 1987)

Intensity of erosion	Ratio to total land area (%)
None	6.64
Slight	7.22
Moderate	20.04
Severe	36.42
Very severe	22.32
Rock surfaces	3.77
Wind erosion	0.65

Table 4. Distribution of land area in relation to soil depth (MAFRA, 1987)

Intensity of erosion	Ratio to total land area (%)
Very shallow (<20 cm)	37.2
Shallow (20-50 cm)	30.5
Moderately deep (50-90 cm)	11.90
Deep (>90 cm)	14.30

Figure 6. A general view of degraded rangelands in Turkey (GDCDE, 2015)

creating heavy and uncontrolled grazing pressure - especially on most of the steppe rangelands (Cornelius, 1962; Tukel, 1984) Additionally, although regulation of the grazing conditions are specified in the rangeland act of 1998, grazing seasons are not controlled (Koc et al., 2015). Transhumance style grazing has traditionally taken place in Anatolian soils as a lifestyle of Turkish people living in rural areas (Koc et al., 2015). As weather conditions and forage growth becomes suitable, livestock herds are moved to highlands for grazing and shepherds aportion livestock grazing at will, without considering the principals of grazing management. Therefore, some rangelands have been overgrazed and degraded, especially in the Eastern Anatolia (Figure 6). Moreover, with developments in the mechanization of agricultural systems in the last century, conversion of Anatolian steppe rangelands to cultivation lands has increased. This has meant that the size of grazing lands has decreased and grazing pressure on rangeland increased (Tukel, 1984; Fırıncıoğlu et al., 2007; Anonymous, 2015a). Hence, increases in human and livestock population, especially in the early 1900s, are another factor causing degradation and productivity losses in the rangelands. Alper et al. (2010) reported that rangeland was 45 million ha seventy years ago yet has decreased to 21.7 million ha today, and while grazing land was 2.2 ha per animal in 1935 it has dropped to 0.76 ha today.

Although Turkey is considered as a rich country in terms of vegetation diversity with over 15,000 plant species, 13 species have become extinct as a result of severe land degradation (Ekim et al., 2000). Due to heavy and continuous grazing and over carrying capacities, some plant species were removed from range vegetation composition in Turkey (Fırıncıoğlu et al., 2007). Vegetation composition changed and annual vegetation became dominant in some range sites e.g. the ranges of Aegean Turkey (Pringle and Cornelius, 1968). A grazing exclosure study conducted in the Central Anatolian steppe ranges showed that protection of a range site from grazing for 27 years increased species richness and 32 more plant species were identified in the exclosure site compared to grazed sites (Fırıncıoğlu et al., 2007). Several studies are available indicating how the composition of both woody and herbaceous vegetation in Turkey's grasslands have been changed or disturbed because of land degradation and overgrazing. Therefore, present plant composition is totally different from what was seen in the past. In fact, palynological studies on sediment samples collected from different regions of Anatolia showed that forest vegetation had covered a larger area than what is seen in Anatolian steppe today (Boydak and Çalışkan, 2015). Fırıncıoğlu et al. (2009) reported that the range vegetation of the Anatolian steppe changed from tall-grass dominated grassland to *Artemisia santonicum* dominated shrubland, and a sod forming short grass, *Festuca valesiaca* and a prostrate shrub, *Thymus sipyleus* ssp *rosulans* became the dominant plant species due to heavy grazing in the rangelands. Several examples of similar changes in the vegetation compositions of the rangelands can be seen in different parts of the country. In these regions, dominant species are generally either spiny and noxious shrubs like *Astragalus* sp. and *Acantholimon acerosum* or other plant species like *Achillea wilhelmsii*, *Salvia* sp.,

and *Stipa lessingiana* that have relatively little forage value (Gökbulak, 1999; Fırıncıoğlu et al., 2010). In another study conducted in the herbaceous vegetation covered Anatolian steppes, some woody and shrub species such as pine, oak, juniper, oriental hackberry, hawthorn, sumach, and common white beam were identified from forest remnants indicating that the region was once dominated by forest vegetation but this is no longer the

Figure 7. Sizes of rehabilitated rangeland, and the land erosion control works performed per year

Figure 8. a, b. Contour terracing for erosion control (a) and improving soil moisture recharge and forage production (b) (GDCDE, 2015)

case. (Uslu, 1959) Moreover, an archaeological study on pollen analysis of soil samples from a Central Anatolia region which is currently forest absent, proved that forest existed in the region in the pre-historic period and that this forest cover used to consist of some native tree species such as pine, cedar, fir, chesnut, birch, poplar, willow, lime, as well as some shrub species like maquis, and herbecaous species like plantago, and fern (Aytuğ, 1970). All this evidence indicates that the majority of Central Anatolia was covered with a totally different vegetation composition in the past but this region later gained steppe characteristics. In fact, Uslu (1959) claimed that 50% of Central Anatolia is anthropogenic steppe due to human intervention. Moreover, besides overgrazing, browsing and fodder leaf utilization are further problems in maquis covered rangelands and forestlands dominated by oak trees. There are about 10 million goats in Turkey today (TSI, 2015) and the majority of them utilize the maquis vegetation covered areas of Southern Turkey and the oak forest dominated areas of South Eastern Turkey. Browsing was a serious threat in the past and it still continues to create a negative impact on shrub and woody vegetation covered rangelands (Acatay et al., 1978). In some regions in Southeastern Anatolia, tall oak forests have been replaced with pseudo-maquis covered rangelands. Acatay et al. (1978) estimated that 58 million ha of forestland were trampled annually by goats and each of these browsed areas was trampled at least three times per year. In order to meet forage demand (especially that of goats) in the harsh winter conditions, and to cover the shortage of forage production in relation to herd sizes, oak trees are pruned and fresh leaves and twigs are stored in summer for use in winter and other times when forage availability is limited due to the end of growing season and herbaceous plants die or senesce. The use of leaves as fodder is still a common tradition applied in South Eastern Anatolia and causes degradation of lands dominated by shrub and oak trees. It can be said that browsing, together with the prunning of oak trees for leaf fodder have replaced forest cover with pseudo-maquis cover composed of shrub species such as *Artemisia* spp., *Thymus* sp., *Astragalus* spp., and *Acanthalimon* spp. in the South and Southeastern Anatolia steppe ranges. In fact, Mol (1982) studied the effect of prunning on tree growth and found that trees lost regrowth and regeneration capacities and they were dwarfed due to repeated prunning for leaf fodder. Also, East and Southeastern Anatlolian rangelands are invaded by shrub species such as *Peganum* spp. and *Genista* spp., *Artemisia* spp., *Thymus* sp., *Astragalus* spp., and *Acanthalimon* spp. due to overgrazing (Koc et al., 2015).

Both the Ministry of Food, Agriculture and Livestock (MFAL) and Ministry of Forestry and Water Affairs (MFWA) are responsible for land rehabilitation works in Turkey but most of the range rehabilitation works have been carried out by MFAL. MFAL rehabilitated 506,560 ha of land (MFAL 2015) while MFWA rehabilitated 76,512 ha of rangeland (GDCDE, 2015) between the years 2000-2014. As seen from Figure 7, the area of land rehabilitated only by MFWA is increasing from year to year but these efforts are not enough and land degradation still remains a big issue in Turkey. For instance, the areas of rangeland rehabilitated and land protected from erosion by MFWA was 880 and 7,458 ha respectively in 1993.
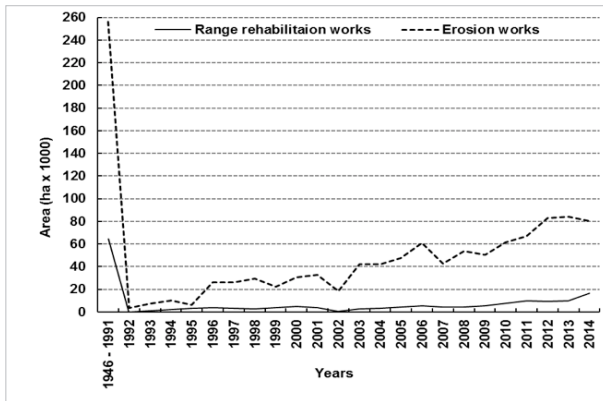
These areas reached 16,383 and 80,517 ha in 2015 (Figure 7). Erosion control works are also mostly carried out on lands that were

Figure 9. A combination of afforestation and contour terracing works in range rehabilitations (GDCDE, 2015)

Figure 10. a, b. Sand dune stabilization works along the Black Sea coast of Northeast Thrace: (a) fence as a combination of herbaceous vegetation and woody material, (b) same site after afforestation (Anonymous, 2015b)

formerly rangelands but which lost their vegetation cover and soil due to heavy grazing. In comparison, MFAL has rehabilitated an area of 586,682 ha for the last fifteen years but all these works are small scale experimental studies carried out by research stations and universities (MFAL, 2015). Range rehabilitation works in general include weed control by mechanical methods (Pringle and Cornelius 1968), construction of new watering facilities to provide a better distribution of grazing animals, and contour terracing for increased soil moisture and protection from erosion. Seeding or revegetation are not commonly applied rehabilitation strategies in degraded rangelands. Most of the range areas are located in East, Central, and Southeast Anatolia and 75% of the range rehabilitations works were conducted in Central and Eastern Anatolia and Black Sea regions where the most degraded rangelands exist and overgrazing takes place (MFAL, 2015).

In most of the rehabilitation works in rangelands, in contrast to MFAL, MFWA prefers contour terracing and planting these terraces with local native tree species to increase species diversity, range productivity, and minimize soil and vegetation disturbance by maintaining native vegetation in the areas beteween terraces (Figures 8a, b) (GDCDE, 2015).

Depending on site conditions, MFWA carries out afforestation on contour terraces with the saplings of drought tolerant native tree species in some rangelands with the purpose of protecting them from human intervention and soil erosion (Figure 9). In general, herbaceous vegetation and shrub species are not preferred in large scale range rehabilitaion works. Afforestation of rangelands in some regions of the country is an effective strategy in Turkey for protecting the lands from misuse, occupation and human interventions because the lands with tall trees are much more valuable and respected by people and receive less disturbance than herbaceous vegetation covered rangelands in Turkey. That is why, the Turkish forest service prefers to rehabilitate some rangelands by afforestation.

Additionally, a lot of wildfires occur every year in the hot dry summer months, especially in the southern and western parts of the country where the Mediterranean climate type is common. As ruled in Turkish Forest Law, the forest service has to afforest burned sites immediatelly after wild fires. Consequently, Turkey is the leading country in the world for increasing forest covered land due to intensive afforestation works in forest lands and partially in rangelands. Forest areas increased from 20.7 million ha in 1972 to 21.7 million ha in 2012 (GDCDE, 2015). In contrast to forestlands, rangelands covered about 56% of the country in 1940 (Karagöz, 2006) but have decreased to below 20% today (Figure 4). Decreases in the rangelands can be attributed to encroachment of urbanization, conversion of rangelands to croplands, deficiencies in the application of agricultural policies and laws (Sayar et al., 2015). Even though wind erosion affects a small portion of the country (Table 3), the forest service has made some successful sand dune stabilization works and Figure 10 shows one such example from Black Sea coast of Northeast Thrace (Anonymous, 2015b). In these works, fences either as a combination of herbecaous vegetation such as *Ammophilla*

Table 5. Some laws enacted for environmental issues		
Name of the acts	Law number	Enactment date
Forest law (MGYGM, 2015a)	6831	September 8, 1956
Environment law (MGYGM, 2015b)	2872	August 11, 1983
National park law (MGYGM, 2015c)	2873	August 11, 1983
Mining law (MGYGM, 2015d)	3213	June 15, 1985
Rangeland act (MGYGM, 2015e)	4342	February 28, 1998
Soil conservation and land use law (MGYGM, 2015f)	5403	July 19, 2005
Agricultural law (MGYGM, 2015g)	5488	April 25, 2006

brevilligulata, Isatis arenaria, and *Allicum spp.* and wood material together or alone were established and sand dunes were stabilized and then planted with saplings of tree species such as *Pinus maritima, Pinus pinea, Pinus brutia, Cupressus pyramidalis, Alnus glutinosa, Robinia pseudoacacia* (Figure 10).

The degradation of soil and soil resources exceeds the progress of land rehabilitation efforts because of lack of administrative regulations as well as insufficient budget, expertise, and labour. The Great Assembly of Turkey has enacted several acts relating directly to environmental issues such as forestry, the environment, national parks, mining, pasturelands, soil conservation and land use, and agriculture at various times (Table 5) All of these laws regulate the major issues of forests, rangeland, agriculture, mining, and national parks in order to minimize degradation of environmental resources such as soil and vegetation. However, poverty is still a serious threat for land resources and forest trees are still cut illegally for fuel and for creating spaces for cultivation, rangelands are repurposed as cropland - especially in low income rural areas where the laws are not properly applied and their results are not monitored effectively enough due to insufficient labour, expertise and finance. For instance, mining law holds the forest service responsible for reclamation and revegetation of mining sites, and mining enterprises for paying all reclamation expenses after mining activities completed - but these actions do not generally take place in Turkey. Another example is the rangeland act. Articles in the act dictate that people who cause the degradation of rangelands are responsible for meeting the expenses for rehabilitating the rangelands, but the law is not implemented or executed properly. In addition to forest law, there are other environment related laws which were enacted 4-5 decades ago as well as amendments which are made time to time depending on the demands of the country and prerequisites for European Union candidacy.

CONCLUSION

Harsh topographical land characteristics, semiarid conditions in large areas, traditional habits, rapid increase in population and livestock, a long history of civilization and land use in Anatolia have made lands fragile and vulnerable to land degradation and - in the case of misuse of land - have caused vegetation disturbance Because of human interference, some woody and herbaceous plant species have become extinct, especially in central Anatolia and these areas have gained anthropogenic steppe characteristics. Restoration efforts have increased since the early years of the Turkish republic in forest, range, and mining areas but soil degradation and limited restoration activities remain important issues. Even though some laws regarding the regulation and organization of land resources have been enacted recently, their applications are not effective. Land abuse such as occupation of state forest and range lands by individuals is still continuing and amnesty laws are issued time to time by the government for those who illegally use or occupy these state lands. In rangeland rehabilitation, herbaceous plants species and shrub species are not commonly preferred and mostly tree species are used for land rehabilitation works. It seems that range rehabilitation studies will not reach a satisfactory level and will not be successful for a long time in Turkey unless at least the basic principles of range management strategy are properly applied.

Ethics Committee Approval: This study does not contain an approach involving humans or animals as a subject. Based on this, ethics committee approval was not necessary for this study.

Informed Consent: No patients participated in this study so written and verbal informed consent was not needed for this study.

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P R E S S

Management of forest areas used for ecotourism and recreation in Turkey

Türkiye'de ekoturizm ve rekreasyon amacıyla kullanılan orman alanlarının yönetimi

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ABSTRACT

Forests have major natural attraction for tourists and play an important role in the interaction between the environment and tourism. Turkey is facing an increasing pressure on its natural resources due to uncontrolled tourism growth that is aimed at achieving short-term economic benefits. Hence, the main objectives of the study are to, describe the main features of Turkey's forest resources that are used for ecotourism and recreation, highlight the related issues in current policy documents, and emphasize the problems that have occurred during its management process. The data was collected by contacting officials and analyzing the contents of national policy documents. It was found out that the use of Turkey's forest resources for the purpose of recreation has increased recently. However, public authorities have not substantially improved the visitor management and monitoring systems. Harmonization of tourism and recreation-related utilization with conservation objectives, prioritization of more effective planning and controlling studies, and enhancing communication, cooperation, and collaboration among the interest groups are the major suggestions of the study.

Keywords: Turkey's forests, ecotourism, recreation, forest-tourism relations, protected areas

ÖZ

Ormanlar, doğal çevrenin temel bir bileşeni olarak, turistler için doğal bir çekim merkezi olup çevre ve turizm arasındaki ilişkilerde önemli bir rol oynamaktadır. Diğer taraftan, Türkiye'de kısa dönemli ekonomik faydalar için kontrolsüz turizm gelişimi ortaya çıkmakta ve doğal kaynaklar üzerinde bir baskı oluşmaktadır. Bu çalışmanın temel amacı; Türkiye'nin orman kaynaklarının ekoturizm ve rekreasyonel kullanımlar açısından genel özelliklerini açıklamak, bu kaynakların yönetimiyle ilgili bilgiler vermek, karşılaşılan sorunları vurgulamak ve çözüm önerileri geliştirmektir. Çalışmadaki veriler yetkililerle görüşülerek ve ulusal politika belgelerinin içerikleri analiz edilerek elde edilmiştir. Çalışmanın bulguları Türkiye'de orman alanlarındaki rekreasyonel kullanım yükünün giderek arttığını, buna karşın ziyaretçi yönetimi ve denetimine ilişkin etkin önlemler alınmadığını göstermektedir. Bu doğrultuda temel öneriler şu şekilde sıralanabilir: korunan alan yönetimi ana amaçları ile turizm ve rekreasyonla ilgili kullanımlar arasındaki uyumun sağlanması, planlama ve denetim çalışmalarının daha etkin hale getirilmesi, karar verme süreçlerinde bilimsel araçların katkısının artırılması ve ilgi grupları arasındaki iletişim, eşgüdüm ve işbirliğinin geliştirilmesi.

Anahtar Kelimeler: Türkiye'nin ormanları, ekoturizm, rekreasyon, orman-turizm ilişkileri, korunan alanlar
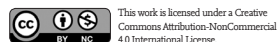
INTRODUCTION

The Global Forest Resources Assessment 2015/FRA 2015 shows that the world's total forest area amounts to almost 4 billion hectares, corresponding to 30.6% of the total land area or an average of 0.6 ha per capita. Between 1990 and 2015 the world's forest areas decreased by 129 million hectares (an area about the size of South Africa). While the annual loss rate was 0.18% in 1990, it has slowed down to 0.08% in the last five-year period. Today, about 31% of the world's forests is designated primarily for the production of wood. Globally, forest resources are increasingly being managed for multiple uses. Close to 28% of forest areas are designated for multiple use, and these areas also

slightly declined in the last 25 years (between 1990 and 2015). 13% of the world's forests is designated primarily for the conservation of biological diversity and 31% is designated for the protection of soil and water (FAO, 2015a).

Moreover, 14.8% of the world's terrestrial areas (including inland waters), 12.7% of marine areas and 5.1% of global oceans were protected in 2016 (UNEP-WCMC and IUCN, 2016). Legally established protected areas cover an estimated 17% of the world's forests. The area of forest within protected areas has increased by 200 million ha since 1990. Globally, about 40% of forest areas is used for ecosystem and sociocultural services (including recreation), and it was reported that there was an increase of 150 million ha. from 1990 to 2015 with 6.0 million annual average. There are currently 1163 million ha forest areas that have ecosystem services, in which cultural or spiritual values are upheld, and almost 93 million ha (close to 8%) of these areas are used for public recreation (FAO, 2015a; FAO, 2015b). Moreover, the protection of forests of ecological significance has increased on a global scale (7.7% of forests were protected in 1990 rising to 16.3% in 2015) (Morales-Hidalgo et al., 2015).

It can be seen that protective and environmental functions (especially for the mitigation of climate change and the conservation of water and soil, as well as biodiversity conservation) and socio-cultural functions (especially providing opportunities for recreation and tourism) have recently become more important (Kuvan, 2005a).

Tourism and recreation have become inevitable aspects of modern life, as they meet important human needs. As noted by Petrosillo et. al., (2007) people's recreation and tourism-related behaviors are indirectly affected by the quality of the environment. In this respect, in many regions of the world forests have become an increasingly important factor in developing and maintaining the attractiveness of a tourism or recreation product as an integral part of the quality of the environment (Kuvan, 2005a; Kuvan, 2005b).

Tourism is the fastest growing and largest industry of the world due to its economic impact and tourist volume increase. Worldwide, international tourist arrivals increased by 3.9% in 2016, a year which saw 1,235 million tourists travel the world. In the same year, international tourism receipts reached US$ 1,220 billion (UNWTO, 2017). Many developing countries have seen tourism become a major source of foreign exchange earnings. However, the rapid and uncontrolled growth of the industry poses significant threats to natural and cultural resources of the countries. The academic community together with environmental groups are drawing attention to the environmental impacts and negative consequences of mass tourism on natural resources. Mass tourism is generally characterized by large-scale or rapid development, a heavy demand for coastal areas and nearby natural resources with a spatial concentration, low or limited contribution to local development, and negative environmental-social impacts (Kuvan, 2012a). On this point, ecotourism can be seen as a tool for mitigating the negative environmental impacts of mass tourism and supporting nature conservation efforts.

The International Ecotourism Society defines ecotourism as "responsible travel to natural areas that conserves the environment, sustains the well-being of the local people and involves interpretation and education" (TIES, 2016). The prominent components of the concept of ecotourism can be listed as nature-based conservation, education and interpretation, sustainability, distribution of benefits; ethics/responsibility, local development, provision of activity diversity (Kuvan, 2012b; Fennel, 2015). It was not possible to find exact statistical data regarding numbers of people involved in ecotourism, but given that it relates closely to adventure tourism, which is characterized by the use of the natural environment and the activities that take place in this environment, statistics from adventure tourism will shed light on the topic. This kind of tourism has been one of the fastest growing categories recently and its receipts increased from US$ 89 billion in 2010 to 263 billion in 2013 and grew by 195% in three years. Natural beauty is the most important factor for adventure travellers when they choose their destinations (UNWTO, 2014).

These facts all require making today's forestry agencies and researchers much more engaged in the use and management of forests for tourism and recreation. To achieve sustainable forest management and to minimize or eliminate the negative impact of tourism and recreation on forested lands, it is necessary to have a sound knowledge of such uses and impacts (Kuvan, 2005a).

In this context, the main objectives of this study are to explain the key features of Turkey's forest resources used for ecotourism and recreation, to highlight the related issues in current policy documents and to emphasize the problems that have occurred during the management process.

MATERIALS AND METHODS

This study has qualitative research characteristics. Thus, the main methods used in the present study involve the collection and analysis of data and the evaluation of the content of national policy documents. In the first stage of the research, the data regarding the properties of national forests was collected using the published and unpublished data that was recorded by the national forestry organization (OGM, 2012; OGM, 2015a; OGM, 2015b; OGM, 2016; OGM, 2017a; OGM, 2017b). In addition, the data in terms of evaluation of Turkey's tourism growth was gathered using published documents of national and international institutions (Ministry of Culture and Tourism, Association of Turkish Travel Agencies and World Tourism Organization) (KTB, 2007; KTB; 2017; TÜRSAB, 2017; UNWTO, 2017). The information about Turkey's forest resources used for the purpose of ecotourism and recreation was collected by both using published documents (DKMPGM, 2018) and contacting officials of the General Directorate of Nature Conservation and National Parks (GDNCNP). Information regarding i. management plans of

national parks, ii. ecotourism plans of protected areas, iii. visitor management, iv. education on ecotourism guidance, v. studies on carrying capacity and also vi. other current projects and studies on ecotourism was requested. The officials were called and e-mails were sent to collect the mentioned data, however they asked for an official application. After completing the process, some general information was given by the related officials but it was not possible to access further data. The findings of this study were also supported by site-specific observations.

Moreover, the current organizational structure was investigated by considering the legal arrangements (Decree-law on Ministry of Forestry and Water Affairs Organization and its Duties no:645, Law on General Directorate of Forestry Organization and its Duties no:3234, Regulation on General Directorate of Forestry's Establishment and Duties, Regulation on Recreational Areas). Also, the content of current forest policy documents was analysed. National Forestry Program (ÇOB, 2004), 10th Development Plan Expert Commission Report on Sustainable Forest Management (KB, 2014), the strategic plan of the Ministry of Forestry and Water Affairs (2013-2017) and two strategic plans of the General Directorate of Forestry (GDF) (2013-2017/2017-2021) (OGM, 2012; OGM, 2017b) were evaluated in the context of the research. In this regard tourism, ecotourism and recreation-related topics were examined in a qualitative way with respect to forest policy.

RESULTS AND DISCUSSION

General Features of Turkish Forestry
Turkey's total forest area covers an area of 22.3 million ha or 28.6% of the country's total land area (Turkey has 78.004.644 ha land area). Productive (undisturbed or slightly disturbed) natural forests comprise an area of 12.7 million ha or 57% of the country's forests (forest area with canopy cover more than 10% is defined as productive forest while the area with a canopy cover of 1-10% is called degraded forest). A large part of the country's forests is located in the northeastern and southern regions of Turkey (OGM, 2015a).

According to the Turkish Constitution of 1982 and other forest-related legal arrangements, the State has the responsibility for the management and planning of the forested lands in Turkey. Almost all of the country's forests are publicly owned (99.9%). The managerial activities in forests of public institutes and private forests are performed by their owners under the control of the State as specified by the related legal provisions. The Ministry of Forestry and Water Affairs is responsible for making and implementing decisions and policies with management activities in forest areas.

The main state organizations conducting various forestry activities under this Ministry are the following: The General Directorate of Forestry, the General Directorate of Combating Desertification and Erosion and The General Directorate of Nature Conservation and National Parks. The GDF generally focuses on the production of wood and non-wood forest products, afforestation and rural development studies, whereas the other

Directorates carry out the activities related to ecological-environmental, recreational-touristic, and water-soil conservation functions. There are also various regional directorates and attached provincial and field units under these general directorates.

The Forest Law No. 6831 of 1956 categorized the country's forests into three groups in terms of quality: production forests, conservation forests and national parks. The National Park Law No. 2873 of 1983 defines protected areas within the forest regime and stipulates managerial rules and principles. According to this law, the country's protected forest areas are National Parks, Nature Parks, Nature Monuments, and Nature Protection Areas. There are also wildlife conservation and development areas under the Land Hunting Law No. 4915 of 2003.

The General Directorate of Forestry produced around 16.6 million m^3 of industrial wood and 5.02 million steres of fuel wood in 2015. This production provided for about 77% of the domestic industrial wood consumption. Private forests and agricultural land (mostly private eucalyptus and poplar plantations that are not considered to be forest) provide 3.4 million m^3 of industrial wood to the market. The remaining demand was met by imports. The Ministry of Forestry and Water Affairs is also responsible for controlling erosion and stabilizing sand dunes. Erosion control activities have reached 754.852 ha and also a green belt has been established around 212 dams and ponds (OGM, 2015b; OGM, 2016). There are 7.1 million forest villagers (OGM, 2017a) whose incomes depend heavily on forests and Turkish forestry organization provides some economic opportunities to support them.

When the country's forestry-related legal arrangements, development plans and the national forestry program (2004-2023) are evaluated from the standpoint of forest policy objectives, and it can be said that a set of objectives such as the production of wood and non-wood forest products, nature conservation (especially through protected areas), meeting the public's recreational and tourism-related needs, and improving the quality of life of forest villagers are mostly put in place within the framework of sustainability and multiple use principles. Although wood production continues to be an important function of the country's forests, the service production functions of forests in relation to supplying environmental or protective services and touristic-recreational opportunities have become more important today, in keeping with global forestry trends.

Tourism Growth and Turkey's Forest Resources Used for the Purpose of Ecotourism and Recreation
Providing touristic-recreational opportunities has become more important in recent times in Turkish Forestry. In the country, the use of forests for the purposes of tourism and recreation can be classified under two headings (Table 1): a) the allocation of forest lands for tourism (especially mass tourism) to build tourist facilities and b) the provision of opportunities for nature-based tourism and ecotourism with recreation activities without building tourist facilities (Kuvan, 2005a). This

study focuses on the provision of opportunities for ecotourism and recreation.

Tourism is one of the most rapidly growing sectors in Turkey, similar to many other parts of the world. From the 1990s until today, both in terms of tourist arrivals and tourism receipts, Turkey has shown faster growth than the world average and Europe's average, and has increased its share of global tourism in the last two decades. In 2016, Turkey moved down 4 places to 10th in international tourist arrivals and went down 5 places to 17th in receipts (UNWTO, 2017). International tourist arrivals dramatically declined by 25% in 2016 to 31.3 million. In the same year international tourism receipts declined to 22,107 billion from 31,464 billion in 2015 (TÜRSAB, 2017; KTB, 2017). Tourist numbers and income from tourism have grown rapidly with a substantial tourism-related facility expansion. In this direction, the allocation of forestlands for tourism and its consequences generates ongoing problems leading to clearing forestland or degradation of forest ecosystems. Rapid tourism development based on mass tourism has enormously increased the pressure on the country's coastal areas and nearby forests for the purpose of tourism and is creating serious environmental problems for natural habitats. While the economic benefits of tourism are emphasized by tourism businesses and government authorities, the academic community and environmental groups are drawing attention to environmental impacts, mainly to show the negative consequences of mass tourism on natural resources.

All areas allocated to mass tourism-related facilities are located within undisturbed forests comprising an area of 12.7 million hectares. The vast majority of the allocated forested lands are mainly concentrated in the Mediterranean and Aegean coastal regions. The conversion of forests into mass tourism facilities and associated deforestation or forest fragmentation are the most common characteristics of mass tourism development in Turkey (Kuvan, 2010).

According to the Tourism Strategy of Turkey-2023 The GAP Ecotourism Corridor (GAP Corridor and Winter Corridor) has been identified as the top priority ecotourism development zone in terms of biodiversity and high ecotourism potential. This corridor covers the cities of Bolu, Zonguldak, Bartın, Kastamonu, Sinop (Black Sea Region) and inland parts of East Antalya and Mersin near the Taurus Mountains. In addition, Terra Merre which is located in the Lake District of Turkey (and which includes the cities of Konya, Isparta, Afyon and Burdur) has been designated to become an ecotourism development zone. Moreover, two cities, İğneada-Kıyıköy and Datça, were determined as ecotourism regions in the strategy (KTB, 2007).

The other use of forests in Turkey is "the provision of opportunities for nature-based tourism and ecotourism with recreation activities" and these can be seen in various forest resources in the country. The main areas used for this aim are as follows: National parks, nature parks, nature monuments, forest recreation areas and urban forests (Table 1). National parks, nature parks and nature monuments are also protected forest areas which are designated by the National Parks Law No. 2873 of 1983. It should be mentioned that natural monuments provide limited recreational opportunities.

As seen in Table 1, the number of national parks and nature parks in the country has gradually expanded since the first national park was created in 1958. Today, there are 42 national parks covering an area of 845,814 ha, 209 nature parks covering an area of 99,378 ha and 111 nature monuments covering an area of 7,142 ha (DKMPGM, 2018).

Marmaris, the Dilek Peninsula-Menderes Delta, Kuşcenneti, Göreme, Köprülü Canyon, Kazdağı, Kaçkar Mountains, Küre Mountains and the Altındere Valley are the most popular and most visited national parks for ecotourism-oriented and other recreational activities. Additionally, there are many large-scale

Table 1. The Use of Forests for the Purpose of Tourism and Recreation*

Use Type / Allocation Purpose				
a-Allocation of forest lands for tourism	b-Provision of opportunities for ecotourism and recreation			
	Type of areas		Numbers	Areas (ha) 2016
	Protected forest areas (managed by GDNCNP)	National parks	42	845,814
		Nature parks	209	99,378
		Nature monuments	111	7,142
Forest lands covered by tourism-related facilities		Total	362	952,334
	Other forest areas (managed by GDF)	Forest recreation areas (A,B,C)*	1304	16,266
		Urban forests (D)	145	10,550
		Total	1449	26,816
	TOTAL		1811	979,15

*Forest Recreation Areas have four types which are classified as A, B, C, D; D type recreation areas and are also called urban forests in the regulation. Numbers and areas in the table were taken from two directorates (DKMPGM, 2018; OGM, 2017a)

tourism facilities in the Uludağ National Park which is a winter tourism center and in the Abant Nature Park used for general ecotourism activities and daily recreational use. It should be emphasized that such large-scale facilities are not compatible with the national park management objectives. Recreation and tourism-oriented uses should be in harmony with the conservation objectives of protected areas.

The country's national parks and other protected areas provide many opportunities and facilities for ecotourism activities. These activities can be listed as trekking, hiking, mountain biking, horse riding, bird and butterfly watching, wildlife viewing, climbing, camping, picnicking, water sports and rafting, botany tours, nature photography, photo safari, plant observation, nature education, winter sports and historical and cultural tours.

Forest recreation areas and urban forests are mainly established to meet the outdoor recreational demands of urban society. While forest recreation areas provide opportunities for both daily recreational uses and accommodation, urban forests provide opportunities only for daily use. On the other hand, urban forests are located in or near the cities (especially metropolitan cities), whereas forest recreation areas may be located far from the cities. There is a total of 1304 forest recreation areas covering 16,266 ha, and 145 urban forests covering 10,550 ha (Table 1) (OGM, 2017a).

Provincial units of GDNCNP have prepared Nature Tourism Master Plans since 2012. These master plans including ecotourism activities, were prepared for almost all cities of the country. The above-mentioned plans contain some sections regarding historical structure and general characteristics of the cities (topography, geomorphological situation, geological structure, climate properties, soil structure, forest area, flora-fauna, settlements, population, economical activities, transportation, accommodation opportunities etc.), nature tourism resources, protected areas and possible activities in terms of nature tourism.

In Turkey, 37 national parks have management plans, 23 of which have been made or revised since 2012. Management plans for 94 nature parks have also been prepared in the same period. However, only Beyşehir Lake National Park has an ecotourism plan, while Ilgaz Mountain and Küre Mountains National Parks have sustainable tourism and visitor management plans. Additionally, similar planning studies for ecotourism and sustainable tourism are in progress in Göreme National Park. The preparation of ecotourism plans for all the protected areas which have a master plan are being planned for the immediate future. In addition to the ecotourism plans, some ecotourism activities were fulfilled in the context of certain projects like the GEF-II Project and TUBITAK Nature Education and Science Schools Project. The GDNCNP also provides training activities for local guides in some national and nature parks. These activities had taken place for eleven National Parks and two Nature Parks by the end of 2016. Today there are 372 certificated local guides who work in protected areas.

Management of Forest Recreation and Tourism Areas and Related Approaches in Current National Policy Documents

The majority of the country's forest resources utilized for recreation and ecotourism purposes have protected area status. These resources are managed by the GDNCNP under the Ministry of Forestry and Water Affairs. There are also 15 Regional Directorates that have responsibilities for provincial organization of the ministry (Figure 1). These units are responsible for planning, surveying, project designing, implementation, maintenance, and monitoring activities at regional level. As seen in Figure 1 "Division of National Parks", provincial directorates and "National Park Directorates" have duties for nature conservation, ecotourism and recreation related activities in Turkey's protected areas.

The problems regarding human resources management in the GDNCNP and management capacity in its provincial organizations has drawn attention. In this context, national parks are generally managed by one technical staff member, and forest rangers are in limited numbers (Yurdakul et. al, 2011). On the other hand, one technical staff member is responsible for a region which contains various types of protected areas (except national parks) with large amounts of land area. The other prominent problems connected with human resources are lack of effective human resources plans and policies, low personnel motivation and job satisfaction, inadequately qualified staff and deficiency of specialization (OSİB, 2017a; OSİB, 2017b).
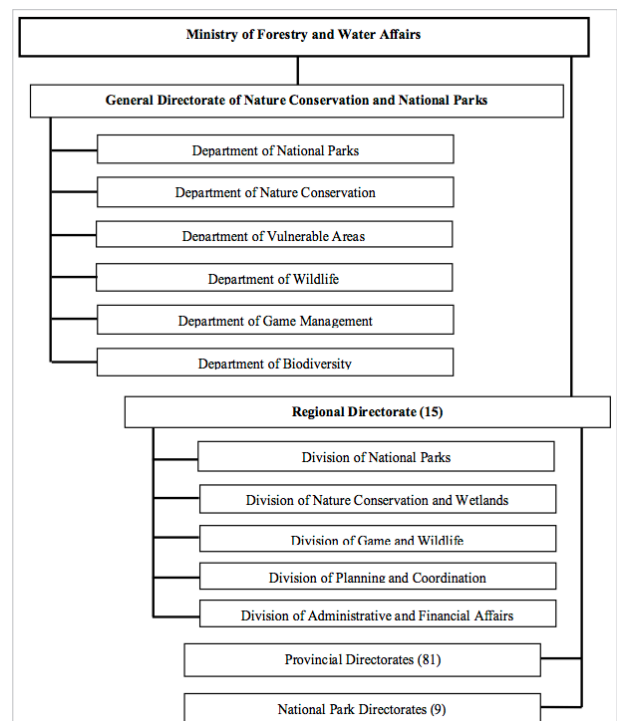
Figure 1. Central and Provincial Organizational Chart on Nature Conservation- Ecotourism and Recreation of GDNCNP (it only shows the related divisions of the organizational chart)

Urban forests and forest recreation areas are managed by the GDF. The Department of Non-wood Forest Products and Services, which operates under this directorate, has detailed duties related to these aspects together with supporting ecotourism activities and recreational utilization. Responsibilities for preparing development and management plans belong to the regional directorates, which work under the general directorate. Forest Enterprise Directorates and forest chief units also support the related activities at local levels (Figure 2).

Organizational structures and country level policies are important components of a natural resources management system. One of the main policy documents related to the forestry sector is the National Forestry Program (ÇOB, 2004), which was prepared for the period between 2004 and 2023. This long-term plan places the "assessment of protected areas and recreational resources" among national forestry policies. This document also stresses the importance of urban forests and plantations in terms of creating recreational areas, the increasing need and demand for recreational resources, and the contribution of recreational and touristic activities to rural development. "Enlargement of recreational areas and development of nature" and "rural dwellers focused eco-tourism projects" are points which are emphasized in the related strategies. The issues highlighted in strategies and action programs can also be listed as the contribution of these areas to sustainable development and rural development, participatory management approach, coordination and cooperation with stakeholders, organizational capac-

ity building, financial, educational, technical supports, creating awareness, and also supporting related scientific research.

The 10th Development Plan Expert Commission Report on Sustainable Forest Management (KB, 2014), which was produced for the period between 2014 and 2018, is another current national document on forestry. The gap between conservation value analysis, ecosystem relations, and visitor capacities is described as an important problem in terms of the management of protected areas and recreational resources. The increasing demands of tourism enterprises with respect to land allocation was also determined as one of the threats on forests and protected areas, which are important resources for recreation and ecotourism. This plan emphasized the importance of visitor awareness and satisfaction, plans and projects focused on sustainability of the resources, effective monitoring mechanisms, and also multi-dimensional research.

In addition to this, the strategic plan of the Ministry of Forestry and Water Affairs (2013-2017) (OSİB, 2012) emphasized preparing and implementing ecotourism plans and programs for protected areas. This plan included game tourism in terms of supporting rural development, increasing awareness, and protecting biodiversity. The plan also focused on visitor management and conservation of resources and sustainable management of protected areas. The following strategic plan (2017-2021) highlighted the need of improving nature-based tourism activities in protected areas and increasing the alternative sources of income by considering conservation-utilization balance (OSİB, 2017a).

Another forestry-related document is the strategic plan of GDF (2013-2017) (OGM, 2012), which noted the increasing demands regarding the use of forest resources for tourism and forest recreation. In this plan, there were some goals and strategies related to the extension of urban forests and recreation areas, public relations activities, functional planning on social and cultural services of forests, participatory planning and management processes, effective control mechanisms, and an increment of economic input for these services to forestry organizations by improving the costing system. The next strategic plan (OGM, 2017b) prepared for the period between 2017 and 2021 added the need for the establishment of new forest recreation areas and urban forests especially near the big settlement regions and the requirement of the preparation of sustainable plans.

As can be seen, the increase in utilization of forest areas for tourism, ecotourism and recreation is mentioned in all the examined national documents. This trend requires improving the country's management capacity on forest-tourism/recreation relations. Currently, the public agencies in positions of responsibility have carried out some implementations (automatic vehicle entry system (HGS) in the entrance gate of national parks, free entrance on some public holidays, land allocation to municipalities etc.) which cause extensive use. However, these agencies have not focused on making decisions and implementations for improving visitor management (carrying capacity) and a visitor monitoring system.
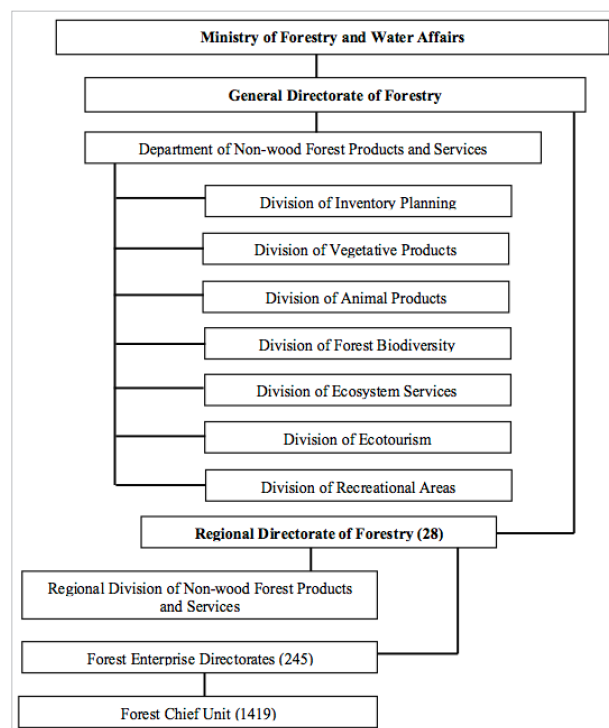
Figure 2. Central and Provincial Organizational Chart on Recreation of GDF (It only shows the related divisions of the organizational chart)

Additionally, the essential problems regarding the management of Turkey's forests for recreation and ecotourism can be listed as follows: a) controlling and limiting visitor use related problems (explained above), b) inability to benefit from relevant representatives and experts in the planning process, c) overlapping of authority between "Ministry of Environment and Urbanization" and "Ministry of Forestry and Water Affairs" regarding the planning of studies, d) the presence of two General Directorates responsible for the management of recreational activities and associated coordination/collaboration problems, e) inadequate numbers of staff and equipment in provincial units of GDNCNP, f) lack of education and interpretation services, g) problems of creating and supplying a database on the uses of the country's protected areas and h) ineffective cooperation among the tourism sector, national protected area authorities and local people. Atmış et. al (2012) also expressed the following problems regarding urban forests in Turkey: absence of management plans for most of them, lack of information centers and service units, inadequate numbers of technical staff.

CONCLUSION

The mass tourism-related and outdoor recreation-focused demands have enormously increased the pressure on the country's forests located near cities and coastal areas for the purpose of tourism-recreation, and this has created serious environmental problems for natural habitats. In this context, to create well-planned forest recreation areas and urban forests is of critical importance to overcome urbanization pressure and to meet the recreational needs of the urban population. On this point Mann et al. (2010) mentioned the need of detection of societal demands for outdoor recreation opportunities, infrastructure and uses to ensure sustainable use of natural resources. Moreover, there are various environmental and social impacts that can result from outdoor recreation. In this context, these kinds of uses can impact soil, vegetation, water, wildlife, air and also historical and cultural components (Manning and Anderson, 2012). Thus, tourism and recreation-related uses should be in harmony with the primary protected area management objectives such as conservation of biodiversity and natural-cultural resources, and maintenance of environmental services. Ecotourism-based activities should be preferred in the protected areas and other forest areas used for recreation and tourism.

The country's forest areas used for recreation and tourism should be well planned and managed taking into account scientific tools or methods such as carrying capacity, limits of acceptable change, environmental impact assessment and effective monitoring studies. To ensure coordination, recreation-related activities should be managed by the GDNCNP (GDF should delegate recreation-related authority to the GDNCNP). Atmış (2018) also emphasized that transfer of the authority of GDNCNP reduces effectiveness of protected area management and it was also suggested that the authority and responsibilities of this directorate should be increased to improve the effectiveness of conservation activities. Besides, provincial units of the GDNCNP

should be strengthened in terms of personnel and equipment. Communication and cooperation among the responsible protected area units, local people, NGOs and the tourism industry should be enhanced. "Coordination between public institutions and local governments" and also "establishing an association in local level" are among the aims of national tourism strategy-2023 (KTB, 2007). Erdoğan and Erdoğan (2016) also emphasized the necessity of linking local people, tourism industry and investors to maintain conservation and to develop ecotourism opportunities. Also, the Turkish Forestry Organization should improve its policies on public relations and make greater efforts to enhance public awareness.

Nature protection-oriented policy objectives and the uses of resources in harmony with nature should be essential for all relations between the natural environment and tourism-recreation. Ecotourism activities should be more effectively included in the protected area planning process. Much attention should be paid to interpretation, education activities and local development. Türker et al. (2014) found out in a case study that ecotourism activities contribute to increasing local people's awareness of environmental protection. In addition, Tucker (2016) highlighted the necessity of building the capacity of local people regarding product development, business knowledge and marketing. Thus, it might be possible to further utilize Turkey's ecotourism potential. Moreover, it is essential to have visitor management plans and apply an effective visitor impact monitoring system in accordance with the qualities of the related areas.

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P R E S S

Taxonomy for the optimization in forest management: a review and assessment

Orman amenajmanında optimizasyon için taksonomi: derleme ve değerlendirme

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ABSTRACT

In this review, we have developed a new taxonomic framework for the classification of forest management optimization studies. In the proposed taxonomy, we consider: the study type; model structure; methodology; modeling type; problem objectives, level and type; plan type; and forest structure. We have used the proposed taxonomy to classify 111 articles from the literature, providing a comprehensive overview of optimization approaches in forest management. Based on this classification, we suggest that some developments may be underrepresented in the forest management optimization literature. Accordingly, the most studied is deterministic modelling regarding harvest scheduling and the least studied are fuzzy and stochastic modelling regarding risk and uncertainty.

Keywords: Forest management, optimization, taxonomy, review

ÖZ

Bu derlemede, orman amenajmanında optimizasyon çalışmalarının sınıflandırılması için yeni bir taksonomi geliştirilmiştir. Önerilen sınıflandırmada: çalışma şekli; model yapısı; yöntem; modelleme tipi; problem amaçları, seviyesi ve tipi; plan tipi ve orman kuruluşu dikkate alınmıştır. Orman amenajmanında optimizasyon yaklaşımlarına kapsamlı bir genel bakış sunarak, literatürdeki 111 makaleyi sınıflandırmak için önerilen taksonomiyi kullanılmıştır. Bu sınıflandırmaya göre, orman amenajmanında optimizasyon literatüründeki bazı gelişmeler yeterince temsil edilemeyebilir. Buna göre, kesim düzeni oluşturmaya ilişkin en çok çalışılan deterministik modelleme ve en az çalışılan, risk ve belirsizlik ile ilgili bulanık ve stokastik modelleme çalışmalarıdır.

Anahtar Kelimeler: Orman amenajmanı, optimizasyon, taksonomi, derleme, kesim düzeni

INTRODUCTION

As the population grows, the demand for both timber and non-timber use of forest resources is increasing (Farrell et al., 2000). The harvesting of timber and non-timber forest products involves the assessment of many criteria such as the intangible and tangible values of ecosystem services (Uhde et al., 2015). Forest management plans have been developed to handle the contradictions between the goods and services demanded by society, and in particular to regulate the time and place of forestry activities (Bettinger et al., 2015). Forest policy allows for trade offs between ecological, socio-economic and political processes and values (Gregory and Keeney, 1994). Therefore, forest planning decisions are often characterized by complexity, irrevocability, and uncertainty. A large part of this complexity is due to the multi-use nature of forest products and services, to the difficulty in the monetary appreciation of ecological services, and to the participation of a large number of beneficiaries (Ananda and Herath, 2003).

In the 1960s, the complexity of social demands increased, and foresters faced many difficulties as they sought to integrate the conflicting demands into planning (Vacik and Lexer, 2014). As the complexity of decisions increases, it becomes more difficult for decision makers to determine a

management plan that optimizes all decision criteria. Planning should be considered in a framework that minimizes disputes by taking into account the many political, economic, environmental and social dimensions. Therefore, analytical methods are required that examine a multi-perspective approach and provisions (Ananda and Herath, 2009). As a result of this, interest in decision support systems in forestry has been increasing since the 1980s (Vacik and Lexer, 2014).

The planning of forest resources includes various problems which need to be considered simultaneously during the decision-making process. These problems can be gathered under three main headings (Diaz-Balteiro and Romero, 2008):

1- Economic problems (timber, feed, animal, hunting, etc.)
2- Ecological problems (soil erosion, carbon accumulation, protection of biodiversity, etc.)
3- Social problems (recreation, level of employment, population arrangement, etc.)

Decision-making plays an important role at almost every stage of these planning problems. Quantitative and qualitative methods are used during the decision-making process. These methods are necessary to help land managers and landowners make the right choices when faced with many alternatives. The results of planning processes help to direct the activities of land managers and to ensure that land managers and landowners understand how to implement the strategies which optimize predetermined performance measures (Bettinger et al., 2010).

Figure 1. Taxonomy of forest management optimization literature

In the forest industry, optimization models have been utilized for many years to solve planning problems (Rönnqvist, 2003, Weintraub and Romero, 2006). Optimization approaches in forest planning are often used to develop the optimal harvest scheduling that will best accomplish the objectives of landowners or land managers (Kaya et al., 2016). But with the increase of types of forest planning problems, optimization has become important not only for harvest scheduling problems, which are the most typical problems in forest planning, but also for other ecological and social problems. Economic, ecological and social objectives in forestry are considered as multiple objectives by using optimization methods (Chen et al., 2016). However, the usage of simulation and optimization in forest management practices is still not widespread in the world (Jin et al., 2016).

In this study, a literature review is carried out with the aim of revealing current trends and gaps in forest management optimization literature. For this purpose, a taxonomic framework, which is used to classify the forest management optimization literature, is proposed and the reviewed studies are examined in detail. With this classification, the aim is to make several inferences about the recent forest management optimization literature and to determine the potential research areas for further studies.

The rest of this paper is organized as follows. The next section gives a detailed explanation of a proposed taxonomy for forest management optimization. The subsequent section presents findings derived from a taxonomic review of recently published articles. Finally, the last section summaries our conclusions.

MATERIALS AND METHODS

A Taxonomy for Optimization in Forest Management
In this study, a taxonomic framework is proposed to classify and analyze optimization studies in forest management. The proposed framework is presented in Figure 1. We consider the main categories to be the study type; model structure; methodology; modeling type; problem objectives, level and type; plan type; and forest structure. In the first category, the study types are classified as application with hypothetical data, application with real data, or review. Since no theoretical papers were found within the scope of this study, "theory" is not added as a particular sub-category.

In the second category, articles are investigated with respect to their model structure, namely deterministic, stochastic, fuzzy, and based on information technology. The last sub-category, based on information technology, includes studies carried out with information technology to realize a reliable forest plan without giving any numerical results of the models. The technology includes software packages such as HYDRUS (Garcia-Prats et al., 2016), BIOME-BGC (Gonzalez-Sanchis et al., 2015), GUROBİ (Vopenka et al., 2015), AFM ToolBox (Rammer et al., 2014), logilab (Mansuy et al., 2015), ETÇAP (Baskent et al., 2014).

The third category, the methodologies used for optimization, is divided into five sub-categories, namely exact methods, heuristics, metaheuristics, approximation algorithms, and simulation. The techniques which guarantee an optimal solution for an optimization problem are classified as exact algorithms, such as branch and bound algorithm, Dijkstra algorithm, etc. Although heuristics and metaheuristics do not guarantee optimal solutions, several efficient techniques have been proposed to find sufficiently good results in a reasonable computational time. However, they do not give any information about the quality of the obtained solutions. Contrary to heuristics and metaheuristics, approximation algorithms investigate an approximate solution which is guaranteed to be within some factor of the optimum. Sample average approximation is one of the most widely used approximation algorithms applied to stochastic programming problems.

The fourth category is reserved for modelling type, and includes eleven sub-categories: linear programming, mixed integer linear programming, mixed integer non-linear programming, goal programming, stochastic programming, integer linear programming, non-linear programming, dynamic programming, fuzzy programming, and other types. (The sub-category "other" is added to classify the models which are not used as widely as the aforementioned models in the literature) .

The aim of forest planning is to obtain an optimal decision which has the best value performance measure under various constraints (Robinson et al., 2016). Although in many countries of the world forest management plans have typically focused on production and economic concerns for a long time, there is also an increasing awareness of the ecological functions of forests, such as wildlife, biological diversity, recreation, and water regulation (Dong et al., 2015). As a result of this awareness, new developments are needed in forest planning and it can be seen that the non-economic objectives of forests have begun to be studied in recent times as well as their economic functions. Therefore, in this study, objectives of forest optimization studies constitute the fifth category of the proposed taxonomy and have been divided into three sub-categories: the number of objectives, financial objectives, and non-financial objectives. In general, the number of objectives can be classified as either single objective or multi-objective. The most widely used financial and non-financial objectives in forest management optimization studies are seen in Figure 1. "Other" is added under both the financial and non-financial objectives sub-categories in order to satisfy the comprehensiveness of the proposed taxonomic framework.

The sixth category, problem level, is included using the classification scheme proposed by Kaya et al. (2016). It is divided into four sub-categories: tree level, stand level, forest level, and landscape level. Problems including decisions like "cut or not cut", "how to separate tree trunk according to product types", and "determination of the minimum time required to reach predetermined dimensions (diameter+height) that increase the ability to withstand the effects of fire" are classified as tree level (Kaya et al., 2016). Tree level optimization requires the determination of trees to be removed while the value of the remaining trees is expect-

ed to increase (Vauhkonen and Pukkala, 2016). It is not always economically possible to abide by the general rules, which stipulate the cutting down of mainly low-value trees. Moreover, it is claimed that cutting only high-quality trees will reduce the stagnation of the genetic pool (Nolet et al., 2014). Stand level optimization includes problems such as the determination of rotation periods according to the desire of each stand (for even-aged forests), spacing problems (even-aged, uneven-aged), and the planning of stand density (frequency) (Kaya et al., 2016). Forest level optimization problems include area control, volume control and/or minimum cutting. Area control includes area restriction model (ARM) or unit restriction model (URM) (Kaya et al., 2016). The landscape level optimization problems also include other land uses such as forest, pasture, farmland, cropland and plantation.

The seventh category, problem type, is the extension of the classification scheme proposed by Diaz-Balteiro and Romero (2008). The most typical problem in forest management is the harvest schedule problem. These are typical problems which include the ARM, URM and Green-up restriction constraints, which are commonly used in planning. The second sub-category, extended harvest scheduling problems, includes road maintenance, habitat patch, silvicultural operation, biodiversity, tree marketing, charcoal production, water supply, reindeer corridor, fire, and sedimentation. The most typical uncertainties in forest planning are market uncertainties, natural variations in future growth and yields, and the effects of fires and pests (Martell et al., 1998). The growth model, inventory data, future prices of timber products, climate, fire, and spatial uncertainty are also common uncertainties. Adaptive forest management (AFM) performs forest planning taking into account environmental factors, such as water supply, climate change, etc. by means of artificial regulation of forest structure and density.

The eighth category includes the plan type. Since the planning horizon is generally long-term in forest management, planning is typically done in a structure divided into three planning stages (Kong and Ronnqvist, 2014, Kuhlmann et al., 2015). Firstly, the long-term (strategic) forest management model is drawn up, in which the time and place of the cutting activity is decided. Secondly, the volumes of different types of wood to be produced (logs, firewood, etc.) for a medium-term period are decided. Finally, the planner works on logistical and harvest planning at the tactical level (Kong and Ronnqvist, 2014, Kuhlmann et al., 2015). The planning horizon is considered to be 10 years for strategic (long-term) planning, from 2 to 10 years for tactical planning, and up to 1 year for operational planning (Pasalodos-Tato et al., 2013, Nobre et al., 2016). Therefore, in this review, planning horizon is considered in three sub-categories, at the strategic, tactical, and operational levels.

In forestry terminology, the age of a tree refers to the age-class distribution of a forest. According to this age-class distribution, the forest structure is divided into two main sub-categories, even-aged and uneven-aged forest. Although plantation and coppice forests are even-aged forests, since different established forms are obtained by planting and coppicing, these forests were added as sub-categories in this review. "Forest + other land

use" is the plan formed by considering other land uses such as pasture, farmland, cropland, and plantation, along with forest planning. The any-aged management system does not bring with it any requirements on the sequences of post-cutting diameter distributions (Pukkala et. al., 2014). Therefore, this system differs from the even-aged or uneven-aged management systems.

Classification of the Literature

The "Web of Science" (https://webofknowledge.com) database was used to search for articles classified in this study. The words "optimization" and "forest management" were entered into the "Title/Keywords/Abstract" field options. Three hundred and forty nine articles were identified without considering unlimited time. Then, the publication year of the studies was limited to between 2013 and 2016. A total of 127 articles published within this period were accessed on 27.01.2017. Furthermore, an additional search was performed with the keywords "optimization" and "forest planning", and 47 articles were found on 03.15.2017. Twenty-two of these articles overlapped with the articles located by the previous review. A total of 152 articles were accessed on 03.15.2017. However, 35 of these were related to issues such as forest genetics, stand density, growth and yield model, wildlife habitats, forest roads, afforestation, soil and biomass, which do not deal directly with forest planning. Therefore, these 35 papers were not taken into account in this paper. Moreover, 6 papers were not included in the classification because their full texts

were not available, they were written in a language other than English, or they were conference papers. As a result, 111 papers about forest management optimization were classified using the proposed taxonomic framework given in Figure 1. The investigated articles for the taxonomic review are listed in Figures 2a-d. The abstracts of the articles were primarily evaluated during this classification. However, articles were examined in detail when the required information was not achieved from the abstracts.

RESULTS AND DISCUSSION

Hundred and two of these 111 papers are research articles while 9 of them are reviews (Figure 3). These literature review studies describe the development of forestry and its basic concepts. Pasalodos-Tato et al. (2013) investigated the risks and uncertainties in different forestry matters including forest management. Hujala et al. (2013) evaluated 32 research articles published between the years 2002 and 2011, according to computerized techniques for problem structuring in forest planning. Chen et al. (2016) reviewed 101 articles published between the years 1994 and 2016 which consist of articles on economic and ecological trade-offs for sustainable forest systems. Memmah et al. (2015) presented a review of 50 articles applying metaheuristics for land use optimization. Uhde et al. (2015) focused on hybrid multi-criteria decision-making approaches in forest management problems that demand analytic assessments as well as the consideration of multiple ecosystem services. Myllyviita et al. (2014) evaluated the benefits of hybrid approaches in actual case studies of natural resource management. Segura (Segura et al., 2014) focused on the models and methods that have been used in developing decision support systems (DSS) for forest management problems, and problems were assessed based on temporal scale, spatial context, spatial scale, number of objectives, and stakeholders. Kaya et al. (2016) reviewed forest management optimization articles published by 30 international journals between 2001 and 2015. They classified 85 articles according to the journal title, publication date, optimization method, problem level (tree, stand, forest, landscape), objectives and constraints. In the present study, a taxonomic framework, which is more comprehensive than the ones in previous review studies, is proposed. This taxonomic review is the first systematic study which allows the literature to be analyzed from a variety of aspects.

Although the numbers of papers published in 2014 and 2015 were the same, there was an increasing trend between 2013 and 2016 (Figure 4). It can also be said that approximately 32% of the forest management optimization studies have been carried out during the last 4 years (between 2013 and 2016).

Figure 5 shows the distribution of the publications by countries. Countries have been identified by looking at the institutional affiliation of the authors. The authors from the same country are counted once. It is observed that Finland (27) and the USA (26) published the highest number of papers between 2013 and 2016 in 34 countries (Figure 5). Table 1 shows the number of papers for each journal where at least two articles have been published. It can be inferred that more than 30.6% of the articles have been published by the top three journals in the list.

Table 1. Number and percentage of papers published between 2013 and 2016 for each journal

Source Titles	# articles	Percentage
CANADIAN JOURNAL OF FOREST RESEARCH	14	12.6
FOREST SCIENCE	9	8.1
SCANDINAVIAN JOURNAL OF FOREST RESEARCH	8	7.2
FOREST POLICY AND ECONOMICS	8	7.2
ANNALS OF OPERATIONS RESEARCH	7	6.3
SILVA FENNICA	5	4.5
FORESTS	5	4.5
EUROPEAN JOURNAL OF FOREST RESEARCH	5	4.5
FOREST ECOLOGY AND MANAGEMENT	4	3.6
FOREST SYSTEMS	3	2.7
EUROPEAN JOURNAL OF OPERATIONAL RESEARCH	3	2.7
ECOLOGICAL MODELLING	3	2.7
COMPUTERS AND ELECTRONICS IN AGRICULTURE	3	2.7
JOURNAL OF FORESTRY RESEARCH	2	1.8
JOURNAL OF FOREST ECONOMICS	2	1.8
JOURNAL OF ENVIRONMENTAL MANAGEMENT	2	1.8
FORESTRY	2	1.8
ENVIRONMENTAL MANAGEMENT	2	1.8
CERNE	2	1.8

Papers	1.	1.1.	1.2.	1.3.	2.	2.1.	2.2.	2.3.	2.4.	3.	3.1.	3.2.	3.3.	3.4.	3.5.	4.	4.1.	4.2.	4.3.	4.4.	4.5.	4.6.	4.7.	4.8.	4.9.	4.10.	5.	5.1.	5.1.1.	5.1.2.	5.2.	5.2.1.	5.2.2.	5.2.3.	5.2.4.	5.2.5.	5.2.6.	5.2.7.	5.2.8.	5.2.9.	5.2.10.
(Ager et al., 2016)			X			X						X			X							X						X													
(Bagdon et al., 2016)			X			X									X					X								X													
(Belavenutti et al., 2016)			X			X															X							X						X							
(Bilbao-Terol et al., 2016)			X					X											X											X											
(Borges et al., 2016)			X			X									X			X										X				X									
(Bugalho et al., 2016)			X			X																		X				X		X											
(Chen et al., 2016)				X																																					
(Corrigan and Nieuwenhuis, 2016)			X			X											X											X													
(Eyvindson and Kangas, 2016a)			X				X							X						X								X													
(Eyvindson and Cheng, 2016)			X				X								X					X								X													X
(Eyvindson and Kangas, 2016b)			X				X								X					X								X											X		X
(Ezquerro et al., 2016)				X																																					
(Ferreira et al., 2016)			X				X			X													X					X								X					
(Feuerbacher et al., 2016)			X			X												X										X							X						
(Garcia-Prats et al., 2016)			X						X																			X					X								
(Hartl et al., 2016)			X				X								X						X							X													X
(Jin et al., 2016b)			X			X						X			X													X									X				
(Matthies and Valsta, 2016)			X			X				X													X					X													X
(Nakajima et al., 2016)			X			X								X	X													X					X								
(Ochoa et al., 2016)			X			X									X													X													X
(Palma and Vergara, 2016)			X			X											X											X		X				X							X
(Pasalodos-Tato et al., 2016)			X				X					X			X					X								X							X						
(Peura et al., 2016)			X			X									X													X	X			X									
(Robinson et al., 2016)			X			X									X		X							X				X													
(Rode et al., 2016)			X			X											X											X				X									
(Roessiger et al., 2016)			X			X															X							X				X									
(Ruppert et al., 2016)			X			X						X												X				X				X									
(St John et al., 2016)			X			X												X										X				X									
(Tahvonen and Ramo, 2016)			X			X													X									X				X									
(Tang et al., 2016)			X			X									X													X													
(Augustynczik et al., 2016)			X			X								X										X				X				X									
(Pascual et al., 2016)			X			X								X	X													X													
(Garcia-Gonzalo et al., 2016)			X				X																					X				X									
(Jin et al., 2016a)	X					X						X	X															X													
(Kaspar et al., 2016)	X					X				X										X								X													
(Dragicevic et al., 2016)			X				X								X									X						X			X			X					
(Yoshimoto and Konoshima, 2016)	X					X											X											X													
(Dong et al., 2016)			X			X								X														X													
(Vauhkonen and Pukkala, 2016)			X				X								X									X				X													X
(Bettinger et al., 2015)			X			X								X					X									X		X											
(Bettinger and Tang, 2015)			X			X						X							X									X													
(Borges et al., 2015)			X			X												X										X				X									
(Dems et al., 2015)			X			X												X										X				X							X		
(Dong et al., 2015)			X			X								X														X				X									
(Ferreira et al., 2015)			X			X												X										X										X			
(Gautam et al., 2015)			X			X												X										X											X		
(Gonzalez-Sanchis et al., 2015)			X					X							X													X													
(Kuhlmann et al., 2015)			X				X								X									X				X				X									X
(Mansuy et al., 2015)			X					X		X																		X													X
(Marusak et al., 2015)			X			X				X											X									X											
(Memmah et al., 2015)				X																																					
(Nghiem, 2015)			X			X																		X				X												X	
(Palma et al., 2015)			X			X												X										X													
(Pereira et al., 2015)			X			X									X													X				X									
(Repo et al., 2015)	X					X																	X					X													X
(Ronnqvist et al., 2015)			X																																						

Figure 2a. Classifications of the forest management optimization studies

Review studies constitute 8.1% of articles reviewed in this study, while the rest are classified as research papers. 80.2% of the research papers used real data, 4.5% used hypothetical data, and 7.2% used both real and hypothetical data. Figure 6 shows the model structure of research papers. 68.6% of the surveyed research studies include deterministic models. They are followed in descending order by stochastic models (24.5%), models based on information technologies (5.9%), and fuzzy models (1.0%). Fuzzy logic helps the decision makers to model the vagueness and ambiguousness in a problem. Forest planning is a decision issue that utilizes the qualitative judgements and opinions of decision makers as well as quantitative metrics. The ratio of fuzzy models used in the forest management optimization literature shows us that there is a significant lack of fuzzy models to represent decision makers' and/or stakeholders' qualitative opinions.

Papers	5.3.	5.3.1.	5.3.2.	5.3.3.	5.3.4.	5.3.5.	5.3.6.	6.	6.1.	6.2.	6.3.	6.4.	7.	7.1.	7.2.	7.3.	7.4.	7.5.	7.6.	7.7.	7.8.	7.9.	7.10.	7.11.	7.12.	7.13.	7.14.	8.	8.1.	8.2.	8.3.	9.	9.1.	9.2.	9.3.	9.4.	9.5.	9.6.
(Ager et al., 2016)							X					X															X	5	X				X					
(Bagdon et al., 2016)					X					X	X				X													45	X				X					
(Belavenutti et al., 2016)										X					X													5		X					X			
(Bilbao-Terol et al., 2016)						X					X				X													35	X								X	
(Borges et al., 2016)										X				X														50	X				X					
(Bugalho et al., 2016)		X									X									X													X					
(Chen et al., 2016)																																						
(Corrigan and Nieuwenhuis, 2016)		X									X									X								70	X				X					
(Eyvindson and Kangas, 2016a)			X							X				X		X	X											30	X				X					
(Eyvindson and Cheng, 2016)										X				X		X	X											30	X				X					
(Eyvindson and Kangas, 2016b)										X				X		X	X											30	X				X					
(Ezquerro et al., 2016)																																						
(Ferreira et al., 2016)										X				X		X	X											65	X							X		
(Feuerbacher et al., 2016)										X					X													15	X				X	X				
(Garcia-Prats et al., 2016)															X																							
(Hartl et al., 2016)										X						X	X											100	X				X	X				
(Jin et al., 2016b)											X	X																60	X				X	X				
(Matthies and Valsta, 2016)										X								X		X								60	X				X					
(Nakajima et al., 2016)										X	X			X														200	X						X			
(Ochoa et al., 2016)											X								X									20	X								X	
(Palma and Vergara, 2016)									X					X														1		X								
(Pasalodos-Tato et al., 2016)										X				X						X								17	X				X					
(Peura et al., 2016)			X								X			X						X								50	X				X					
(Robinson et al., 2016)			X							X	X			X		X	X											20	X				X	X				
(Rode et al., 2016)										X				X														18	X						X			
(Roessiger et al., 2016)										X				X														100	X					X				
(Ruppert et al., 2016)							X			X					X													100	X				X					
(St John et al., 2016)										X					X													50	X				X					
(Tahvonen and Ramo, 2016)										X				X				X		X								140	X				X	X				
(Tang et al., 2016)							X			X					X					X								1		X					X			
(Augustynczik et al., 2016)											X			X														16	X					X				
(Pascual et al., 2016)							X			X				X														30	X				X	X				
(Garcia-Gonzalo et al., 2016)											X			X			X												X					X				
(Jin et al., 2016a)							X				X			X														30	X				X					
(Kaspar et al., 2016)			X								X			X															X				X					
(Dragicevic et al., 2016)			X	X						X						X									X													
(Yoshimoto and Konoshima, 2016)			X								X			X														10pe.	X				X					
(Dong et al., 2016)					X						X			X																X			X					
(Vauhkonen and Pukkala, 2016)									X	X						X	X			X								5		X			X	X				
(Bettinger et al., 2015)					X						X			X														30	X				X					
(Bettinger and Tang, 2015)						X			X																	X		100	X						X			
(Borges et al., 2015)										X				X														50	X				X					
(Dems et al., 2015)										X													X					1		X			X					
(Dong et al., 2015)										X				X														30	X				X					
(Ferreira et al., 2015)									X		X			X	X													40	X				X					
(Gautam et al., 2015)										X													X					1		X					X			
(Gonzalez-Sanchis et al., 2015)						X				X												X														X		
(Kuhlmann et al., 2015)										X					X	X													X									
(Mansuy et al., 2015)										X					X	X							X	X			10	X									
(Marusak et al., 2015)			X		X					X				X													100	X				X					
(Memmah et al., 2015)																																						
(Nghiem, 2015)										X					X		X											50	X						X			
(Palma et al., 2015)			X							X													X					90	X				X	X				
(Pereira et al., 2015)										X				X						X								100	X				X					
(Repo et al., 2015)										X															X			50	X				X					
(Ronnqvist et al., 2015)																																						

Figure 2b. Classifications of the forest management optimization studies

Since simulation is used to generate data for optimization models, simulation is the most used approach in the reviewed literature. 39 papers used simulation and the others can be listed as metaheuristics (16), heuristics (10), exact methods (8), and approximation algorithms (1) respectively. The simulators utilized in these studies are GAYA (Borges et al., 2016), SİMO (Eyvindson and Cheng, 2016), YAFO (Hartl et al., 2016), MELA (Lappi and Lempinen, 2014), and MOTTİ (Peura et al., 2016). Simulated annealing, genetic algorithms and the tabu search algorithm are the most widely applied metaheuristics in forest management optimization studies. Only a few papers encountered in the review use hybridizing algorithms to improve the computational performance and solution quality. Hybrid algorithms can be developed in further research.

Papers	1.	1.1.	1.2.	1.3.	2.	2.1.	2.2.	2.3.	2.4.	3.	3.1.	3.2.	3.3.	3.4.	3.5.	4.	4.1.	4.2.	4.3.	4.4.	4.5.	4.6.	4.7.	4.8.	4.9.	4.10.	5.	5.1.	5.1.1.	5.1.2.	5.2.	5.2.1.	5.2.2.	5.2.3.	5.2.4.	5.2.5.	5.2.6.	5.2.7.	5.2.8.	5.2.9.	5.2.10.
(Shahi and Pulkki, 2015)		X					X						X		X													X						X							
(Trivino et al., 2015)		X				X																			X			X				X	X								
(Uhde et al., 2015)			X																																						
(Vopenka et al., 2015)		X							X								X											X													
(Wei and Murray, 2015)		X				X											X											X							X						
(Xavier et al., 2015)		X					X																		X			X													X
(Zhou, 2015)	X						X																					X											X		
(Fotakis, 2015)		X					X						X															X													
(Veliz et al., 2015)		X					X													X								X									X				
(Liu and Lin, 2015)	X						X						X	X														X													
(Alam et al., 2014)		X				X					X												X					X											X		
(Alvarez and Vera, 2014)		X					X				X						X						X					X									X				
(Baskent et al., 2014)		X							X								X											X													
(Bont et al., 2014)		X				X											X											X					X								
(Borges et al., 2014a)		X				X											X								X			X				X	X							X
(de-Miguel et al., 2014a)		X				X							X		X													X													
(de-Miguel et al., 2014b)		X				X						X										X						X							X						
(Eyvindson and Kangas, 2014)		X					X								X				X									X													X
(Hahn et al., 2014)	X	X					X															X						X					X							X	X
(Hartl and Knoke, 2014)	X						X								X							X						X					X							X	X
(Hernandez et al., 2014)		X				X							X									X										X	X								
(Kangas et al., 2014)		X				X							X			X												X								X					X
(Kong and Ronnqvist, 2014)		X				X						X				X											X					X									
(Manso et al., 2014)		X					X					X		X													X														
(Marshalek et al., 2014)		X				X								X			X											X													
(Monkkonen et al., 2014)		X				X																			X			X				X	X							X
(Mur et al., 2014)	X	X				X									X										X			X				X						X			
(Myllyviita et al., 2014)			X																																						
(Nolet et al., 2014)		X				X							X		X													X													
(Palma and Nelson, 2014)		X				X									X		X											X													
(Pukkala et al., 2014)		X				X									X													X					X								
(Rammer et al., 2014)		X							X								X											X													
(Segura et al., 2014)			X																																						
(Lappi and Lempinen, 2014)		X				X									X		X											X					X								
(Garcia-Gonzalo et al., 2014)		X					X					X		X													X					X									
(Borges et al., 2014b)	X						X						X	X													X					X									
(Konnyu et al., 2014)		X				X											X											X					X								
(Ager et al., 2013)		X				X									X													X													
(Baskent and Celik, 2013)		X				X									X		X											X													
(Burns et al., 2013)	X	X				X															X								X				X								
(Carvajal et al., 2013)		X				X															X							X					X								
(Cerda and Martin-Barroso, 2013)		X				X																			X			X											X		
(Gimenez et al., 2013)		X				X																							X				X								
(Hartl et al., 2013)		X				X									X							X						X					X							X	
(Konnyu and Toth, 2013)	X	X				X						X										X						X											X		
(Moreira et al., 2013)		X				X													X									X										X			
(Najafi and Richards, 2013)		X				X											X											X					X								
(Neuner et al., 2013)		X					X								X										X			X				X								X	X
(Niinimaki et al., 2013)		X				X																			X			X								X					
(Pasalodos-Tato et al., 2013)			X																																						
(Rabotyagov et al., 2013)		X				X																			X								X				X				
(Tahvonen et al., 2013)		X				X																						X					X								
(Hujala et al., 2013)			X																																						
(Toth et al., 2013)	X	X				X															X							X											X		
(Strimbu and Paun, 2013)		X					X						X															X													

Figure 2c. Classifications of the forest management optimization studies

The distribution of publications according to modeling type is given in Figure 7. As stated by Dong et al. (2015), it can be also inferred from our classification that integer variables are mostly preferred to model operations. Mixed integer linear programming (17) has mostly been used to formulate forest planning in the past four years. The models considering uncertainty have not been studied widely. Only 4 of the studies used stochastic programming, while none of them used fuzzy programming. Modeling the uncertainties in forest management could be a potential research area for further studies.

Problems with a single objective represent 81.4% of the total, the remaining problems include multi-objectives. Forestry planning concentrates on a single objective through timber harvest-

Papers	5.3.	5.3.1.	5.3.2.	5.3.3.	5.3.4.	5.3.5.	5.3.6.	6.	6.1.	6.2.	6.3.	6.4.	7.	7.1.	7.2.	7.3.	7.4.	7.5.	7.6.	7.7.	7.8.	7.9.	7.10.	7.11.	7.12.	7.13.	7.14.	8.	8.1.	8.2.	8.3.	9.	9.1.	9.2.	9.3.	9.4.	9.5.	9.6.
(Shahi and Pulkki, 2015)										X							X						X					1			X							
(Trivino et al., 2015)			X								X				X													50	X				X					
(Uhde et al., 2015)																																						
(Vopenka et al., 2015)		X								X				X														30	X				X					
(Wei and Murray, 2015)						X				X				X		X												1 pe.		X								
(Xavier et al., 2015)						X					X			X	X																						X	
(Zhou, 2015)										X				X		X	X																X					
(Fotakis, 2015)		X				X				X					X													50	X				X					
(Veliz et al., 2015)											X*				X	X												3		X			X					
(Liu and Lin, 2015)		X												X																								
(Alam et al., 2014)																						X						50w.		X								
(Alvarez and Vera, 2014)																			X			X						1		X								
(Baskent et al., 2014)		X								X				X														160	X				X					
(Bont et al., 2014)															X															X								
(Borges et al., 2014a)										X				X														50	X				X	X				
(de-Miguel et al., 2014a)		X										X							X										X				X	X				
(de-Miguel et al., 2014b)										X									X									150	X									
(Eyvindson and Kangas, 2014)										X				X		X												30	X				X					
(Hahn et al., 2014)										X				X		X	X											30	X				X					
(Hartl and Knoke, 2014)										X				X		X												30	X		X		X	X				
(Hernandez et al., 2014)				X		X				X				X														30	X							X		
(Kangas et al., 2014)										X				X														10	X	X			X					
(Kong and Ronnqvist, 2014)										X												X														X		
(Manso et al., 2014)						X			X	X				X										X														
(Marshalek et al., 2014)				X								X		X														8 pe.	X						X			
(Monkkonen et al., 2014)												X							X									50	X				X					
(Mur et al., 2014)									X																	X		200	X				X					
(Myllyviita et al., 2014)																																						
(Nolet et al., 2014)						X			X	X																X		40	X						X			
(Palma and Nelson, 2014)											X				X													9		X								
(Pukkala et al., 2014)										X				X														20	X						X			X
(Rammer et al., 2014)												X									X							100	X									
(Segura et al., 2014)																																						
(Lappi and Lempinen, 2014)										X	X			X														50	X				X					
(Garcia-Gonzalo et al., 2014)										X					X															X					X			
(Borges et al., 2014b)															X													100	X				X					
(Konnyu et al., 2014)										X					X													40	X				X					
(Ager et al., 2013)				X								X														X		10	X						X			
(Baskent and Celik, 2013)			X							X	X			X														120	X				X					
(Burns et al., 2013)				X	X					X										X																		
(Carvajal et al., 2013)										X					X													3 pe.	X									
(Cerda and Martin-Barroso, 2013)										X										X								100	X				X	X				
(Gimenez et al., 2013)			X	X						X					X													40	X							X		
(Hartl et al., 2013)										X				X		X	X											60	X				X					
(Konnyu and Toth, 2013)										X				X														60	X				X					
(Moreira et al., 2013)															X																					X		
(Najafi and Richards, 2013)															X															X								
(Neuner et al., 2013)										X						X								X					X				X					
(Niinimaki et al., 2013)									X								X		X										X				X					
(Pasalodos-Tato et al., 2013)																																						
(Rabotyagov et al., 2013)	X		X												X													45	X				X					
(Tahvonen et al., 2013)										X	X			X		X		X											X				X					
(Hujala et al., 2013)																																						
(Toth et al., 2013)										X				X														60	X				X					
(Strimbu and Paun, 2013)			X							X				X														100	X				X					

Figure 2d. Classifications of the forest management optimization studies

ing. However, society has various expectations from the forests. In other words, the variety of objectives expected from forest planning increases while the number of stakeholders increases. These ratios show us that there is a potential need for more research into multi-objective optimization, in which several objectives are optimized at the same time.

Generally, forest planning is done by maximizing an objective such as the net present value of a product (Robinson et al., 2016). Although social values have changed recently, forest management plans have focused on production and economic concerns for a long time in many countries (Dong et al., 2015). This situation is also verified by the findings of this review. 69.9%
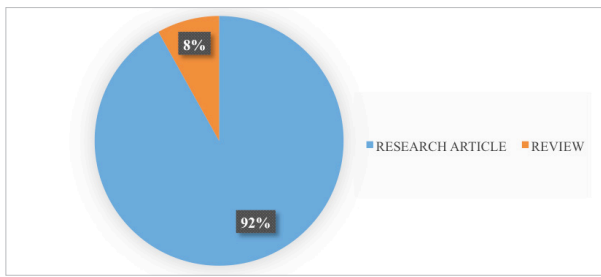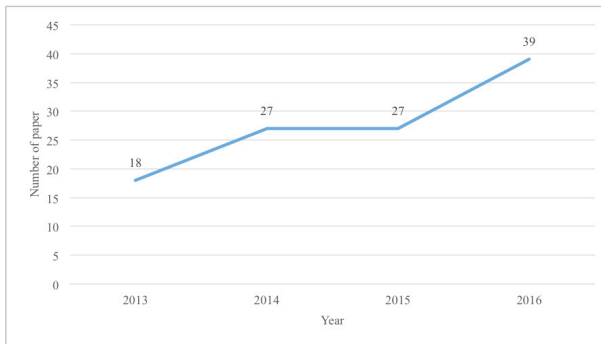
Figure 3. Study type

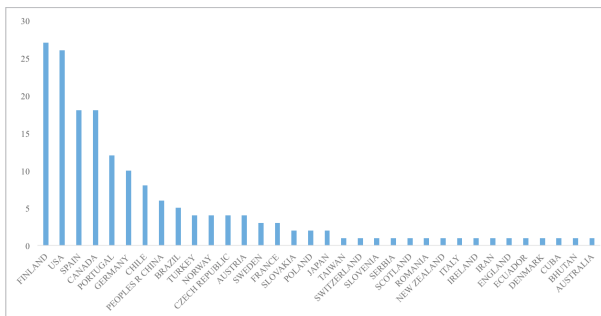Figure 4. Number of paper by year (between 2013 and 2016)
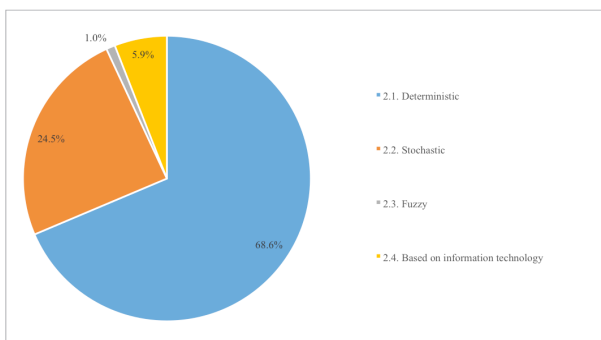

Figure 5. Number of articles with respect to countries

Figure 6. Distribution of models

widely used financial objective is the maximization of the net present value (Figure 8). It is observed in this review that the non-financial objectives of forests have increasingly been studied recently as well as economic functions. As is shown in Figure 9, the most widely used non-financial performance measure is the production amount which cannot be seen as an ecological factor. Today, there is an increasing awareness of the ecological functions of forests (e.g. wildlife, biological diversity, recreation, and water regulation) (Dong et al., 2015). As a result of this awareness, new developments considering ecological concerns are needed in forest planning. Our findings show that, in addition to economic factors, objectives which are related to ecological factors should also be studied.

The problems dealt with in the investigated studies were mostly modeled at the forest level (42). This is followed by the stand level (38), the landscape level (15), and the tree level (6), respectively. In real life, new methods that would explore how forest sustainability – protecting water and wildlife, replanting trees, etc. – is ensured are studied at the landscape level. Therefore, further research should focus on the landscape level in terms of sustainability.

Figure 10 shows the number of papers according to the type of inspected problem. According to Borges et al. (2016) and Baskent et al. (2014), harvest scheduling is the most studied forest planning problem considering temporal and spatial constraints. We have seen that this result has not changed in the last four years. A majority of the papers (65.8%) studied either harvest scheduling or extended harvest scheduling problems. Dealing with uncertainties is also a very important topic in forest planning and these are usually ignored in real-life cases. In these problems, the growth models are assumed to be deterministic (Eyvindson and Cheng, 2016). Uncertainties on natural degradation processes, the future cost of collecting and processing forest resources, the prices of forest products to be sold, and social preferences make forest management much more complicated (Kuhlmann et al., 2015). Therefore, the number of studies on forest management planning under uncertainty have increased in recent years (Kuhlmann et al., 2015). This inference can easily be observed in Figure 10, which shows that risks and uncertainties are the most studied subjects after harvest scheduling problems. After cutting, small trees, branches, tops and unmerchantable wood are left in the forest and collected for bioenergy. This results in a decrease of carbon storage, and the capacity of the forest declines. Repo et al. (2015) aimed to create a financially suitable management plan to compensate for the loss of carbon resulting from the extraction of forest harvest residuals. According to the taxonomic review, forest residue harvesting is one of the least studied subjects in the literature. When habitat availability and potential to produce economic values of the forests, considered as adaptive forest management problems, are examined, it has been concluded that habitat availability can be improved significantly with a few economic losses (Monkkonen et al., 2014). In many countries, when planning is addressed with reference to the ecosystem with living beings in forests, planning tends towards a reduction of clearcutting and planting and an increase of continuous cover management (Pukkala et

of studies having single objective are financial and 30.1% are non-financial. 26.3% of multi-objective optimization studies have financial objectives, 26.3% have non-financial, and 47.4% have both financial and non-financial objectives. The most
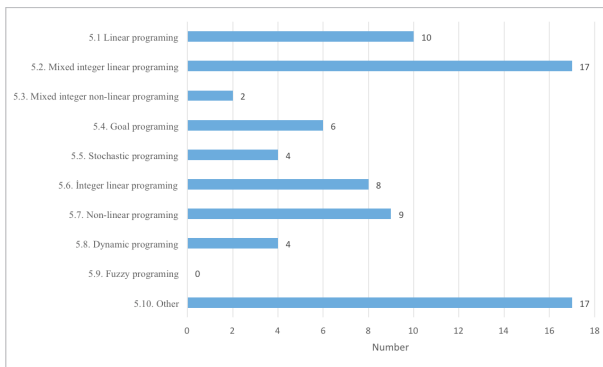
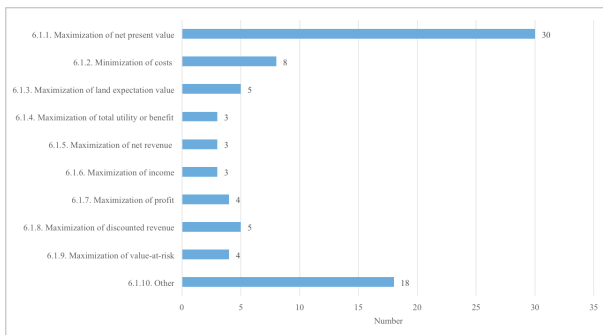Figure 7. Distribution of publications according to the modeling type

Figure 8. Distribution of publications according to financial objectives
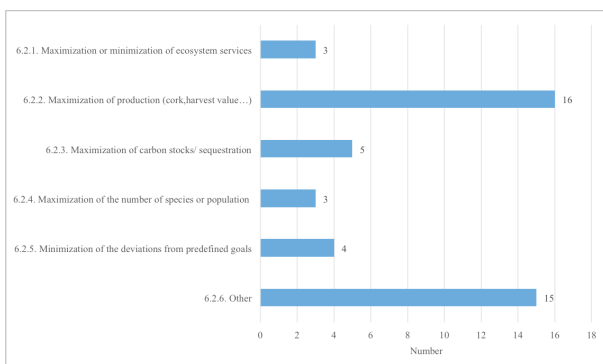

Figure 9. Distribution of publications according to the non-financial objectives
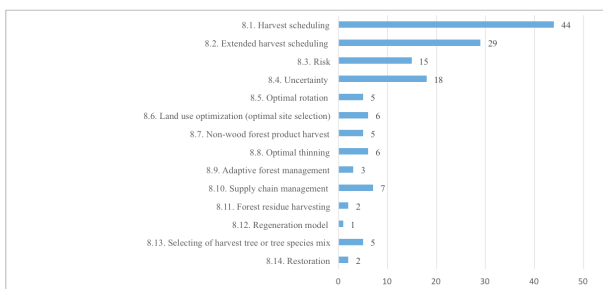

Figure 10. Problem type

al., 2014). Therefore, it can be said that adaptive forest management is a significant issue in terms of sustainable forestry. The review shows that research into adaptive forest management is greatly needed, a topic which was only studied in 3 papers in the last four years.

Since some papers have an unspecified time horizon or infinite time horizon, 91 papers are evaluated within the category of "Plan type". The majority of these articles are at strategic level (78.0%). The reason for this is that the planning horizon needs to be at least 10 years to ensure consistent implementation of sustainable forest management activities and to ensure the necessary stability (FAO, 2017). The strategic level is followed by tactical (9.9%) and operational levels (9.9%). 2.2% of the papers are hybrid, or multi-level. Mid-term tactical and short-term operational planning are also necessary for forest management practices. For instance, a successful "best practice" from the world is seen in Canada's northeast forest areas, in which the strategic planning horizons last for 100 years or more, while tactical plans for a few years, and daily, weekly and monthly operational plans are also developed and implemented (Kuhlmann et al., 2015).

Forest structure is examined in only 83 papers since this topic is not specified in the rest of them. Even-aged forests constitute 56.5% of the studies. The percentages for uneven-aged is 8.2%, plantation 16.5%, coppices 1.2%, forest+other land use 3.5%, and any-aged 1.2%. The reason why even-aged forests are the most studied structure is that this forest structure is not as complicated as the uneven-aged forests, so the decision-making process is much easier.

CONCLUSION

This paper employs a comprehensive taxonomic framework to classify recent studies on optimization of forest management and to make inferences about further research directions. In the proposed taxonomy, we consider the main categories to be: the study type; model structure; methodology; modeling type; problem objectives, level and type; plan type; and forest structure. 111 articles published between 2013 and 2016 in forest management optimization field are classified according to the proposed framework. Finland and USA are the leading countries working on the optimization of forest management. Approximately 21% of the papers were published in the Canadian Journal of Forest Research and Forest Science. The findings obtained from this review are given as follows:

√   The majority of the papers (92%) are classified as research studies. 95% of these research studies include real applications while the rest use only hypothetical data. In many countries, a big proportion of forests belong to private owners or companies who seek for optimal forest plans. This could be an important reason for the high ratio of real applications.

√   Most of the optimization problems in forest management are handled as deterministic (68.6%), in which the fluctuations, uncertainties and risks have not been taken into ac-

count. There is an obvious need to model forest planning problems taking uncertainties into account. Stochastic and fuzzy models could be utilized to meet this requirement. Fuzzy models in particular, which are studied in only 1% of the investigated papers, constitute a great potential for further research in forest management optimization.

√ The modeling types utilized in the papers were quite diverse and were led by mixed integer linear programming and linear programming.

√ Harvest scheduling, i.e. the process that specifies where, when and how much to harvest, is the most common planning problem. The applications of extended harvest scheduling problems, which need a broad point of view, and the problems dealing with uncertainties and risks, have also been increasingly studied in recent years. On the other hand, adaptive forest management, which has been examined in only a few studies, is still an important field for further research.

√ The percentage of harvest scheduling and extended harvest scheduling problems with single objectives is much greater than that of multi-objective cases. Single objectives are more frequently analyzed in the papers involving stand and forest level. However, multiple objectives are more frequently analyzed in the papers involving landscape level and forest level.

√ Simulation is the most widely applied approach in the literature. Several exact algorithms, heuristics, metaheuristics, and approximation algorithms were also used for optimization. Hybridizing various algorithms to improve the computational performance and solution quality of these algorithms is another research direction for further studies.

Although about 50% of the Earth is covered with forests, there is a limited number of optimization studies in forestry. This paper presents directions for further optimization studies in forest management. The proposed taxonomic framework can also be utilized and improved by adding new categories for further state-of-the-art reviews.

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P R E S S

Comparing Shannon entropy with Deng entropy and improved Deng entropy for measuring biodiversity when a priori data is not clear

Öncü verinin belirsizliği durumunda biyoçeşitliğin belirlenmesinde Shannon entropisinin Deng entropisi ve geliştirilmiş Deng Entropisi ile karşılaştırılması

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ABSTRACT

The various diversity measures used to measure biodiversity include the Margalef index, McIntosh index, Simpson index, Brillouin index, and Shannon entropy. Of these measures, the most popular is Shannon entropy (H). In this study, with respect to measuring biodiversity, we compare Shannon entropy-the essential aspect of information theory-with the Deng and improved Deng entropies, as proposed within the framework of the Dempster–Shafer evidential theory. To do so, we used a hypothetical dataset of three complexes. Based on this hypothetic data, ecologically speaking, we obtained the most reasonable result from the improved Deng entropy. There are two reasons for this result: 1) Mass functions cannot be used when computing the Shannon entropy, and 2) Deng entropy does not take into consideration the scale of the frame of discernment.

Keywords: Improved belief entropy, information theory, uncertainly, mass function, basic probability assignment, frame of discernment, alpha diversity

ÖZ

Biyolojik çeşitliliğin belirlenmesinde Margalef indeksi, McIntosh indeksi, Simpson indeksi, Brillouin indeksi ve Shannon entropisi gibi birçok çeşitlilik indisi kullanılmaktadırlar. Bu indisler arasındaki en popular olanı Shannon entropisidir. Bu çalışma biyolojik çeşitlilik ölçümüne yönelik olarak bilgi teorisinin temel eşitliği olan Shannon entropis ile Demster-Shafer Delil Teorisi'nin ölçümlerinden olan Deng entropisi ve Geliştirilmiş Deng entropisini karşılaştırmak için gerçekleştirilmiştir. Çalışmada 3 kompleksten oluşan hipotetik bir veri kullanılmıştır. Kullanılan hipotetik veri ile gerçekleştirilen hesaplamaların sonucunda, ekolojik açıdan en makul sonuçlar Geliştirilmiş Deng entropisi ile elde edilmiştir. Bu sonucun iki sebebi bulunmaktadır. Birincisi Shannon entropisi hesaplanırken kütle fonksiyonları kullanılamamaktadır. İkincisi ise Deng entropisinin sezgisel yapı ölçeğini dikkate almamasıdır.

Anahtar Kelimeler: Geliştirilmiş kanaat entropisi, bilgi teorisi, belirsizlik, kütle fonksiyonu, temel olasılık ataması, sezgisel yapı, alfa çeşitliliği

INTRODUCTION

Biodiversity is one of the most central topics in conservation biology, community ecology, and environmental geography. There is a wide variety of indices to measure biodiversity**.** In this context, Shannon entropy, a theory for uncertainty measurement first introduced by Claude Shannon (Shannon, 1948), is the most well-known measure (Gorelick, 2006).

Even though Shannon entropy is the most popular theory for uncertainty measurement, it cannot be used directly in the framework of Dempster-Shafer Evidential Theory (DSET) which is effective in uncertain information processing (Zhou et al., 2017). This is because, unlike Shannon entropy, DSET provides the frame of discernment (FOD) and the basic probability assignment (BPA). It has, therefore, been frequently used in many fields such as pattern recognition (Liu et al., 2013; Liu et
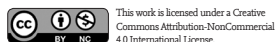
al., 2016), fault diagnosis (Su et al., 2012; Jiang et al., 2016c; Jiang et al., 2016d; Yuan et al., 2016), multiple attribute decision-making (Chin et al., 2015; Fu et al., 2015), risk evaluation (Wang and Elhag, 2007; Su et al., 2012; Chin et al., 2015; Fu and Wang, 2015; Du and Hu, 2016; Jiang et al., 2016a; Jiang et al., 2016c; Jiang et al., 2016d; Yuan et al., 2016), controller design (Yager and Filev, 1995; Tang et al., 2016), and so on (Wang et al., 2009; Ma et al., 2015; Zhou et al., 2015).

In the Dempster Shafer framework, many methods have been proposed to measure the uncertain degree of evidence, such as discord measurement (Klir and Ramer, 1996), weighted Hartley entropy (Dubois and Prade, 1985), dissonance measurement (Yager, 1983), total conflict measurement (George and Pal, 1996), distance-based total uncertainty measurement (Yang and Han, 2016), Deng entropy (Deng, 2016), Improved Deng entropy (Zhou et al., 2017) and so on (Song et al., 2015; Song et al., 2016).

Deng entropy was first introduced by Deng (Deng, 2016) and has started to be used in many real applications. Deng entropy is the generalization of Shannon entropy. When the BPA is degenerated as a probability distribution, it is degenerated as Shannon entropy (Deng, 2016). Deng entropy may therefore be considered for use in measuring biodiversity. However, Deng entropy does not take the scale of the FOD into consideration, which means a loss of information while processing information. Improved Deng entropy proposed by Zhou et al. (2017) overcomes this limitation.

This paper was organized to compute Shannon entropy, Deng entropy and Improved Deng entropy using an unclear priori hypothetical data. The results of these entropic measures were then compared and discussed from an ecological perspective.

Shannon Entropy

In information theory, Shannon entropy is often used to measure the information volume of a process or a system, and quantify the expected value of the information contained in a message. Information theory denoted as H (Shannon, 1948), is defined as:

$$H = -\sum_{i=1}^{N} p_i \log_b p_i$$

Where N is the number of basic states, p_i is the probability of state i and p_i satisfies and b is the basis of the logarithm which accounts for the scaling of H. Although b is arbitrary, b is usually chosen to be 2, and the unit of information entropy is bit. If b is the nature base, then the unit of information entropy will be Nat.

Deng Entropy

Deng proposed a new belief entropy called Deng entropy (Deng, 2016). It is presented to measure the uncertainty degree of basic probability assignment as a generalized Shannon entropy in Dempster-Shafer evidence theory. Deng entropy is given by:

$$E_d = -\sum_i m(F_i) \log \frac{m(F_i)}{2^{F_i} - 1}$$

Where F_i is a proposition in mass function m, and $|F_i|$ is the cardinality of F_i. Deng entropy is similar to Shannon entropy in form. The difference is that the belief for each proposition F_i is divided by a term (2^{F_i}-1) which represents the potential number of states in F_i (The empty set is not included). So Deng entropy is the generalization of Shannon entropy, which is used to measure the uncertainty degree of BPA (Deng, 2016).

Deng entropy can definitely degenerate to the Shannon entropy if the belief is only assigned to single elements. The process is shown as follows.

$$E_d = -\sum_i m(\theta_i) \log \frac{m(\theta_i)}{2^{|\theta_i|} - 1} = -\sum_i m(\theta_i) \log m(\theta_i)$$

Improved Deng Entropy

In Dempster-Shafer framework, the Improved Deng Entropy (Zhou et al., 2017) is proposed as follows:

$$E_{Id}(m) = -\sum_{A \subseteq X} m(A) \log_2 \left(\frac{m(A)}{2^{|A|-1}} e^{\frac{|A|-1}{|X|}} \right)$$

Where X is the FOD, $|A|$ denotes the cardinality of the focal element A, and $|X|$ is the number of elements in the FOD. Compared with some other uncertainty measures in Yager (1983), Dubois (1985), Klir and Ramer (1990), George and Pal and (1996), Song et al. (2015), Improved Deng Entropy addresses more information in a BOE. The uncertain information addressed by the new belief entropy includes the information represented by the mass function, the cardinality of each proposition, the scale of FOD (denotes as $|X|$, and the relative scale of a focal element with respect to the FOD (denoted as (($|A|$-1)/$|X|$)).

Numerical example

Assume that the data is taken from 3 different sites or complexes (C_1, C_2 and C_3) of a given ecosystem. In this hypothetic data, each complex is divided into 9 subsamples and plant species (S) are recorded in each subsample. C_1 and C_2 include 15 species whereas C_3 has 6 species (Table 1).

If we decide to use Shannon entropy, we have to use proportional values for each species (p_i). Proportional values (p_i) of the species (S) from S_1 to S_{15} in C_1 are 0.0625; 0.0625; 0.0625; 0.0625; 0.0625; 0.0625; 0.125; 0.0625; 0.0625; 0.0625; 0.0625; 0.0625; 0.0625; 0.0625 and 0.0625 respectively. Proportional values (p_i) from S_1 to S_{15} in C_2 are 0.04348; 0.04348; 0.08696; 0.04348; 0.21739; 0.04348; 0.08696; 0.04348; 0.13043; 0.04348; 0.04348; 0.04348; 0.04348; 0.04348 and 0,04348 respectively. With regards to C_3, proportional values (p_i) are 0,25; 0,25; 0,19; 0,13; 0,06; 0,13 from S_1 to S_6 respectively. When the Shannon entropy values of the complexes are computed using p_i values, those values (H values) are found to be 2.686; 2.522 and 1.7 for C_1, C_2 and C_3 (Figure 1).

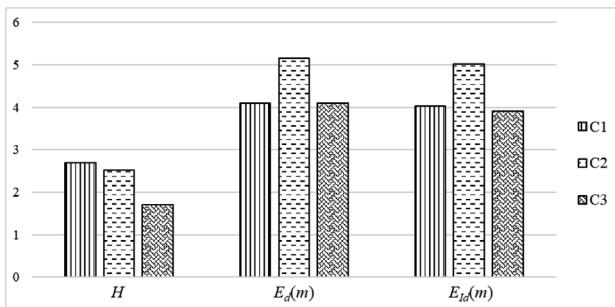| Table 1. A hypothetical data composed of 3 complexes			
C1	S1, S2	S3, S4, S5	S6
	S7	S7	S8, S9
	S10, S11	S12, S13, S14	S15
C2	S1, S2, S3	S3,S4, S5	S5, S6
	S5, S7	S5, S7	S5, S8, S9
	S9, S10, S11	S9, S12, S13, S14	S15
C3	S1, S2	S1,S2, S3	S1
	S2	S2	S1, S3
	S3, S4	S4, S5, S6	S6

Figure 1. H, E_d and E_{ld} values of the complexes

If we prefer to use Deng entropy and/or Improved Deng entropy, then we will use mass function, m. In this case, the mass functions of C_1 are $m_1(\{S_1, S_2\})=0.11111$; $m_2(\{S_3, S_4, S_5\})=0.11111$; $m_3(\{S_6\})=0.11111$; $m_4(\{S_7\})=0.22222$; $m_5(\{S_8, S_9\})=0.11111$; $m_6(\{S_{10}, S_{11}\})=0.11111$; $m_7(\{S_{12}, S_{13}, S_{14}\})=0.11111$ and $m_8(\{S_{15}\})=0.11111$. The mass functions of C_2 are $m_1(\{S_1, S_2, S_3\})=0.11111$; $m_2(\{S_3, S_4, S_5\})=0.11111$; $m_3(\{S_5, S_6\})=0.11111$; $m_4(\{S_5, S_7\})=0.22222$; $m_5(\{S_5, S_8, S_9\})=0.11111$; $m_6(\{S_9, S_{10}, S_{11}\})=0.11111$; $m_7(\{S_9, S_{12}, S_{13}, S_{14}\})=0.11111$ and $m_8(\{S_{15}\})=0.11111$. Lastly, the mass functions of C_3 are $m_1(\{S_1, S_2\})=0.11111$; $m_2(\{S_1, S_2, S_3\})=0.11111$; $m_3(\{S_1\})=0.11111$; $m_4(\{S_2\})=0.22222$; $m_5(\{S_1, S_3\})=0.11111$; $m_6(\{S_3, S_4\})=0.11111$; $m_7(\{S_4, S_5, S_6\})=0.11111$ and $m_8(\{S_6\})=0.11111$. According to mass function values, Deng entropy (Ed) values of C_1, C_2 and C_3 are found to be 4.09988; 5.157836 and 4.09988 whereas Improved Deng entropy (Eld) values are 4.025074; 5.008223 and 3.912864 for C_1, C_2 and C_3 respectively (Figure 1).

Comparisons and Interpretations

H value is the maximum in C_1. This result is not confirmed by the results of E_d and E_{ld}. Because the maximum values of E_d and E_{ld} are found in C_2. In addition to this, it seems that C_3 has minimum entropic value in accordance with the results of H and E_{ld}. However, C_1 and C_3 have the same entropic value when using E_d (Figure 1).

It is clear that the computed results of the entropic measures include disagreements in terms of grading by considering entropic values of the complexes. It should be explained why the differences of the results among the entropic measures has occurred. More importantly, it should be decided which entropic measure gives the most reasonable grading ecologically speaking.

C_1 and C_2 have the same number of species. Namely, 15 plants are found in each of C_1 and C_2. However, the total number of the individuals found in C_1 is 16 compared with 23 in C_2 (Table 1). In this case, we conclude that C_2 should have a higher entropic value compared to C_1. This result could be provided by E_d and E_{ld} but H. As explained before, the reason of the incomplete result of H compared to E_d and E_{ld} is due to the fact that proportional values (p_i) are only used to compute the Shannon entropy (H) value while Deng entropy (E_d) and Improved Deng entropy (E_{ld}) are computed by using mass function value, m. In other words, since the information is not clear in the hypothetic data (Table 1), as usual, the values of Deng entropy and Improved Deng entropy show differences from the values of the Shannon entropy.

With regard to the grading difference between C_1 and C_3 considering the computed values of E_d and E_{ld}, as explained by Zhou et al. (2017), E_d does not take into consideration the scale of the FOD, which means a loss of information while processing information. However, E_{ld} overcomes this limitation. Unlike E_d, the entropic value differences can therefore be detected between C_1 and C_3 when using E_{ld}. In other words, even though the number of the elements found in the mass functions of C_1 and C_2 includes the same values, these mass functions of C_1 and C_2 do not include the same species. When E_d is computed, this difference is ignored. When E_{ld} is computed, this difference is taken into consideration.

CONCLUSION

Biodiversity plays a very important role in maintaining the balance and protecting the health of ecosystems and has attracted increasing interest in recent years. This topic was stressed specifically at the Rio Declaration and again at the Lisbon Conference in 1988. Biodiversity should always be defined using quantities (Özkan, 2016a).

There are a wide variety of quantities available for computing biodiversity such as the Margalef index, McIntosh index, Simpson index, Fisher alpha, Brillouin index, Shannon entropy and so on (Özkan, 2016b). Among these measures, the most popular metric of biodiversity, derived from information theory, is the Shannon entropy (Shannon, 1948). In fact, Shannon entropy originating in physics and engineering has been frequently used not only to measure biodiversity but also to process data in many areas of science such as chemistry, genetic, music, architecture, urban planning, computer languages and human languages (Robinson, 2008; Doyle, 2009).

Even if Shannon entropy is the most popular measure, as explained by Jost (2006), it cannot be relied upon to measure biodiversity in all conditions. That is particularly valid when a

priori information is not clear. In this case, the application of the various forms of Shannon entropy is reasonable. Deng entropy and Improved Deng entropy in the Dempster-Shafer framework are the alternative measures to Shannon entropy (Jiang et al, 2016b). Because Deng entropy is the generation form of Shannon entropy (Deng, 2016) and Improved Deng entropy is the entropy-based Deng entropy (Zhou et al., 2017).

According to the entropic measure values obtained using the hypothetical data given in this study, the most reasonable result was obtained using Improved Deng entropy from an ecological point of view. The reason for this is due to the fact that Shannon entropy merely uses proportional values of the species, Deng entropy ignores the scale of FOD, but Improved Deng entropy takes into consideration not only BPA but also FOD.

Although this study indicated that Improved Deng entropy is the best option for measuring biodiversity compared to Shannon entropy and Deng entropy when a priori information is not clear, further studies should be generated to confirm the inference obtained from this study using various types of real ecological data.

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