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Land use/land cover change as a major driver of current landscape flammability in Eastern Mediterranean region: A case study in Southwestern Turkey

El uso del suelo/cambio en la cobertura del suelo como un factor importante de la inflamabilidad del paisaje actual en la región del Mediterráneo oriental: un estudio de caso en el suroeste de Turquía

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SUMMARY

Land use/land cover (LULC) change has been one of the main drivers of landscape changes in the Mediterranean region where there has been an increase in the forested lands. LULC change in the region has not only changed forest stand structure and composition but also resulted in increase in the available combustible fuels. There have been few studies on fuel accumulation in relation to LULC, however, no study explaining quantitatively the relationship between LULC change and canopy fuel load in the Mediterranean region. The objective of this study is to evaluate the effects of LULC changes on overall crown fire hazard through examining stand structure, composition, and canopy fuel loads in Eastern Mediterranean forests for 35 years. Forest stand type maps generated from the stereo interpretation of aerial photographs and field survey data were used for the analyses. The results of the study showed significant changes in LULC during the period of 1977-2012. There was a 16.6 % decrease in agricultural areas, 144.5 % increase in settlement areas and 6.8 % increase in pine forests. As for the structural and compositional changes in forested lands, open pine stands that included Mediterranean shrub communities decreased (77.2 %); nonetheless, closed pure pine stands increased (49.9 %), resulting in an increase in the total canopy fuel load in pine stands (86.4 %). Results indicated that landscapes tended to become more homogeneous, fully closed pine stands, resulting in an increase in the continuity and the buildup of fuels available for combustion.

Keywords: forest fires, agricultural abandonment, landscape changes, canopy fuel load, fire management.

RESUMEN

El cambio en el uso del suelo/cobertura del suelo (LULC) ha sido uno de los principales impulsores de los cambios en el paisaje en la región mediterránea, donde ha habido un aumento de las tierras forestales. El cambio de LULC en la región no solo ha cambiado la estructura y composición de los rodales forestales, sino que también ha resultado en un aumento de los combustibles disponibles. Ha habido pocos estudios sobre la acumulación de combustible en relación con LULC, sin embargo, ningún estudio explica cuantitativamente la relación entre el cambio de LULC y la carga de combustible del dosel en la región mediterránea. El objetivo de este estudio es evaluar los efectos de los cambios de LULC en el riesgo general de incendios de copas mediante el examen de la estructura, la composición y las cargas de combustible del dosel de los rodales en los bosques del Mediterráneo oriental durante 35 años. Para los análisis se utilizaron mapas de tipos de masas forestales generados a partir de la interpretación estereoscópica de fotografías aéreas y datos de estudios de campo. Los resultados del estudio mostraron cambios significativos en LULC durante el período 1977-2012. Hubo una disminución del 16,6 % en las áreas agrícolas, un aumento del 144,5 % en las áreas de asentamiento y un aumento del 6,8 % en los bosques de pino. En cuanto a los cambios estructurales y composicionales de los terrenos forestales, disminuyeron los rodales abiertos de pino que incluían comunidades de matorral mediterráneo (77,2 %), pero aumentaron los rodales cerrados de pino puro (49,9 %), lo que se tradujo en un aumento de la carga total de combustible del dosel en los rodales de pino (86,4 %). Los resultados indicaron que los paisajes tendían a volverse más homogéneos, pinares completamente cerrados, lo que resultó en un aumento en la continuidad y la acumulación de combustibles disponibles para la combustión.

Palabras clave: incendios forestales, abandono agrícola, cambios en el paisaje, carga de combustible del dosel, manejo de incendios.

INTRODUCTION

Land use/land cover (LULC) change is one of the main drivers of global change and has many effects on landscape structure in the Mediterranean Region (Viedma *et al.* 2006). The decrease in firewood demand and grazing, and an increase in land abandonment have changed LULC patterns (Moreira *et al.* 2011, Pérez *et al.* 2003), significantly affecting the structure and composition of forested lands (Falcucci *et al.* 2007). Stand structure and composition have also been affected by large scale afforestation efforts using pine species (Moreno *et al.* 1998, Pausas *et al.* 2004) and transformation of

some open pine/broadleaved mixed stands into more closed, productive pure pine stands through management activities in the region. As a result, landscapes tended to become more homogeneous (Pérez *et al.* 2003, Viedma *et al.* 2006) with large continuous patches of even aged and fully closed pine stands, thus resulting in an increase in the buildup of fuels available for combustion (Moreira *et al.* 2001, Moreno *et al.* 1998). This exacerbates the problem of forest fires and extreme fire behavior over large areas in the Mediterranean Region.

Mediterranean forests have always been subjected to forest fires, and fires are the most important disturbance agents in forested lands. Changes in stand structure, composition and canopy fuel load directly affect fire hazard (Mitsopoulos and Dimitrakopoulos 2007), fire behavior and vulnerability of stands to intense and severe crown fires (Cruz *et al.* 2003). However, little information exists on the relationship between LULC change and canopy fuel loads in pine stands in the Mediterranean Region.

Many studies have analyzed LULC changes in different parts of the Mediterranean Region for different time periods (Ales *et al.* 1992, Debussche *et al.* 1999, Falcucci *et al.* 2007). Studies have clearly indicated a dependency of biodiversity (Falcucci *et al.* 2007), soil conservation and forest fire hazard and occurrence (Viedma *et al.* 2006) on LULC change. There have been few studies on fuel accumulation regarding land use/land cover change (Moreira *et al.* 2001), and no study explaining quantitatively the relationship between LULC change and canopy fuel load in the Mediterranean Region.

The objective of this study is to evaluate the effects of LULC changes on overall crown fire hazard through examining stand structure, composition, and canopy fuel loads in Eastern Mediterranean forests for 35 years. The hypothesis of this study is: LULC has no major effect on the flammability of the stands in the Eastern Mediterranean Region. The results obtained from this study may be invaluable in the understanding of the dynamics of Mediterranean forest lands and developing genuine management strategies to reduce crown fire hazard in the future.

METHODS

Study site. The study site is located at Karabortlen State Forest Enterprise in Mugla, southwestern Turkey. The site is located at 37° 01′ 32″ N, 28° 25′ 16″ E and at sea level with an average slope of 5 - 10° (figure 1). The site is characterized by typical Mediterranean climate with long hot summers and mild short winters. Mean annual temperature is 15.1 °C and annual rainfall on the site is 1,214.8 mm with precipitation being mainly from December to May. The fire season in Mugla Region generally lasts from late May until mid-September. Turkish red pine (*Pinus brutia* Ten.) stands dominate the forest canopy throughout the study area. Also included in the canopy is Stone pine (*Pinus pinea* L.) accompanied by such broadleaved species as *Liquidambar orientalis* L. and *Eucalyptus camaldulensis* Dehn. Common understory woody species are *Quercus coccifera* L., *Pistacia terebinthus* L.*, Laurus nobilis* L., *Arbutus andrachne* L.*, Myrtus communis* L. and *Cistus* spp. Soil type is brown forest soil.

The land area of the study site is 14,640 ha of which nearly 60 % is covered by Turkish red-pine dominated stands. Turkish red pine is the most widely distributed forest conifer species in fire prone areas in Turkey. Most fires occur in pure or mixed Turkish red pine stands. The study site is near the Gulf of Gokova (figure 1), a major destination for summer tourism in the summer. The human population peaks in the area during summer months (May to September) contribute to human caused fires. Almost all fires originate from human activities, resulting in a 1 % area burn on average in the study area. There are 14 settlements located within the borders of the study area with a local population of 6,966 according to population census in 2007.

Data acquisition and processing. Geographic information system (GIS) and remote sensing technologies were used to acquire, build, and manage spatial database for the study area. The stand type maps of the study area were used to assess spatiotemporal land use/land cover, stand structure and crown fuel load changes. Stand type maps were obtained from forest management plans of Karabortlen State Forest Enterprise. The stand type maps, used as ground data, were originally generated from both the stereo interpretation of aerial photographs with an average 1:25,000 scale and ground measurements with 300 ×300 m sampling points for 1977, 1990, 2000 and 2012. This intensive data gathering process was part of forest inventory conducted by the Turkish Forest Service.

Coarse level stand structure and fuel load classification approach was used in the study area. The coarse level approach refers to a broad classification of vegetation covers in relation to major land use types such as agricultural and settlement areas and stand types described by species composition, development stages and canopy closure. The stand volume (m^3), number of trees and stand volume increment (m^3) were acquired from forest inventory data for the years 1977, 1990, 2000 and 2012.

Stand type maps were first scanned and later georeferenced using 1:25,000 scaled topographical maps with UTM projection (ED50 UTM Zone 35 N Datum) using first order nearest neighbor rules with a maximum root mean square (RMS) error under 10 m in a GIS software (ArcGIS 10.2). Rectified forest stand type maps were digitized with a 1:3,000 to 1:5,000 screen view scale. Afterwards, associated attribute data were entered into the computer to create a spatial database for the study area.

Classification of land use/land cover, stand structure and composition. The landscape was divided into four major land use categories (Gregorio and Jansen 2000) to monitor LULC change for the study period. Categories included: *i*) forest, *ii*) agricultural areas, *iii*) settlements

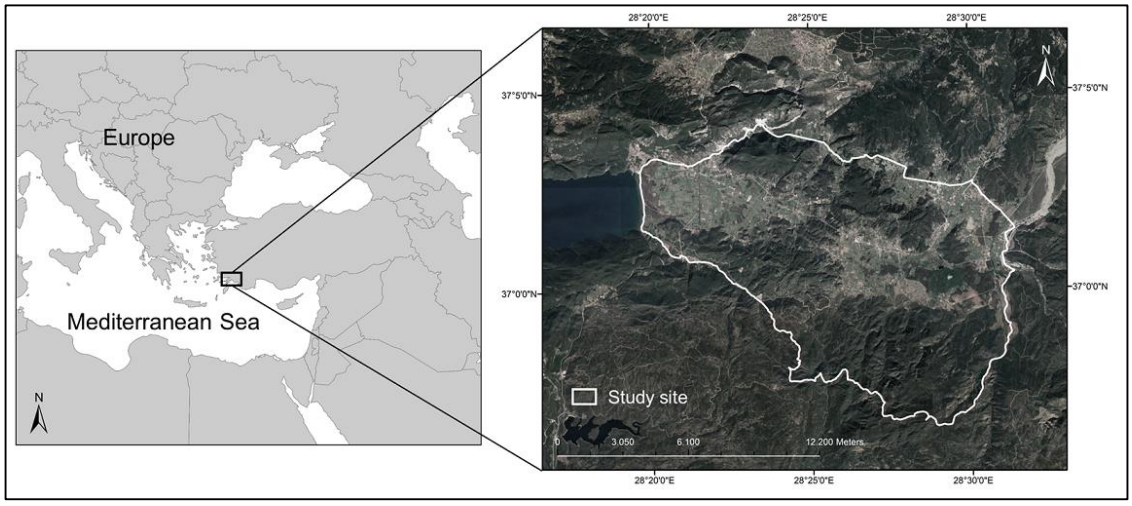

Figure 1. Geographic location of the study site near the Mediterranean Sea (Mugla, Turkey).
Ubicación geográfica del sitio de estudio cerca del mar Mediterráneo (Mugla, Turquía).

and *iv*) open areas (some swamp areas, dune fields and other non-forested areas). The stand structure was classified according to the canopy closure of the stands. Stands with canopy closure under 10 % were classified as "Open stands" and the rest as "Closed stands" (figure 2A, B). The open stands were mainly covered by Turkish red pine (*Pinus brutia* Ten.) with Mediterranean shrub plant communities (*i.e. Quercus coccifera* L., *Pistacia terebinthus* L., *Arbutus andrachne* L., *Myrtus communis* L.*, Cistus* spp.) in the understory (figure 2A). The stand composition was classified into two major groups; *i*) pine stands dominated by *Pinus brutia* Ten. and *ii*) eucalyptus stands *Eucalyptus camaldulensis* Dehn.) and *iii*) broadleaved (*Liquidambar orientalis* L.) and mixed stands (figure 2C, D, E).

Quantitative stand characteristics such as the number of trees (trees ha^{-1}), stand volume ($m^3 ha^{-1}$) and stand volume increment ($m^3 ha^{-1}$) were analyzed only in the closed (productive) pine stands with an average diameter at breast height (DBH) larger than 8 cm, as the inventory data were only available for these stands. The quantitative stand characteristics of some eucalyptus, broadleaved and mixed stands, for which no or little inventory data were available, were not considered. To monitor temporal changes in the quantitative stand characteristics, pine stands were classified into three groups regarding developmental stages as; *i*) young (DBH = 8 - 19.9 cm), *ii*) mature (DBH = 20 - 35.9 cm) and *iii*) over mature (DBH > 36 cm).

Evaluation and prediction of canopy fuel load. Within the present study, the term 'crown' is used to describe aerial fuels at tree level and 'canopy' at stand level in line with literature (Cruz *et al.* 2003). The canopy fuel load in pine stands was classified according to the standard fuel size classes (Scott and Reinhardt 2002). Total canopy fuel load (CFL, kg m^{-2}) means the oven-dry mass of the canopy fuels (needles, branches < 0.3 cm (very fine branch), 0.3 - 0.6 cm (fine branch), 0.6 - 1 cm (medium branch) and 1 - 2.5 cm (thick branch) in diameter) per unit ground area (figure 3). However, it is known that only the fine fuels involving needles and fine branches smaller than 0.6 cm in diameter are considered available canopy fuel (Fernández-Alonso *et al.* 2013, Mitsopoulos and Dimitrakopoulos 2007) consumed in a crown fire (Scott and Reinhardt 2002, Stocks *et al.* 2004). Canopy fuels were assessed in pine stands as available and total CFL in this study.

There are some models available in literature for the estimation of crown fuel load for Turkish red pine using tree (Gungoroglu *et al.* 2018, Kucuk and Bilgili 2008, Kucuk *et al.* 2008) and stand characteristics. The models developed by Gungoroglu *et al.* (2018) were used to predict crown fuel load of Turkish red pine. Limitations of the inventory data allowed the use of Gungoroglu *et al.* (2018) models only. Crown fuel loads (kg) were determined on a tree basis using mean diameter at breast height at 1.30 m (DBH). Available and total CFL for the stand were calculated using stand density (trees ha^{-1}). The calculated CFL (kg) were then converted into kg m^{-2} with the area (m^2) of each stand. The CFL calculations were made only for the pine stands with an average DBH larger than 8 cm, as there is no inventory data available for younger stands in the management plans.

RESULTS

The change in LULC, stand structure and composition between 1977 and 2012. The landscape was dominated by forest (56.7 - 60.6 %), followed by agricultural land (34.2 - 41.1 %), settlement (1.2 - 2.9 %) and open areas (1.0 - 2.2 %) (table 1, figure 4A). Results indicated an increase

in forest, settlement, and open areas in the study area between 1977 and 2012 (figure 4A, table 1). Increases were 6.8 % (567.7 ha), 144.5 % (255.1), 117.8 % (174.7 ha) in forest, settlement, and open areas, respectively. However, there was a 16.6 % (997.5 ha) decrease in agricultural land area between 1977 and 2012 (figure 4A, 5A). There was a gradual increase in human population in the study area from 5,194 to 6,966 during the study period. The mean population of the study area was 6,022 with a 34.1 % increase (table 1).

Results indicated a 49.9 % increase in the closed and a 77.2 % decrease in open stands between 1977 and 2012 (figure 4B, 5B, table 1 and 2). Most increases in the closed stands were accounted for by the decrease in open stands

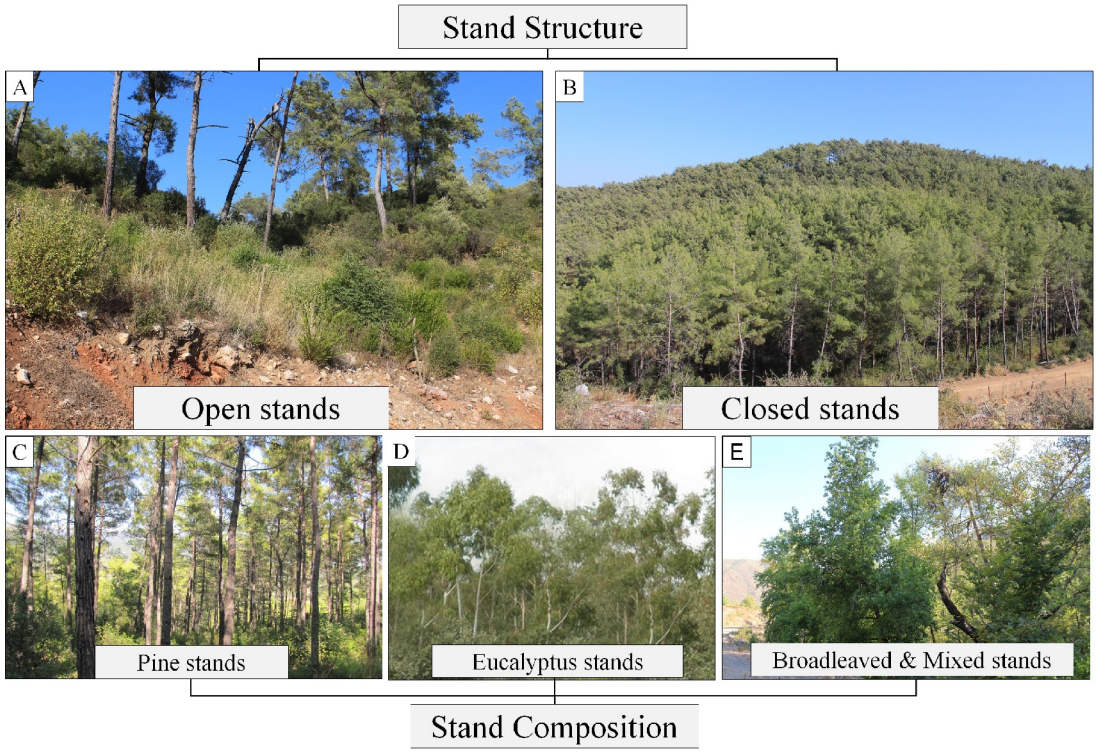

Figure 2. Classification of stand structure (A, B) and composition (C, D, E) in the study area.

Clasificación de la estructura del stand (A, B) y composición (C, D, E) del área de estudio.

Figure 3. Classification of crown fuel load of Turkish red pine according to the standard fuel size classes.

Clasificación de la carga de combustible de corona de pino rojo de Turquía según las clases de tamaño de combustible estándar.

(2,080.7 ha), followed by agricultural land area (933,1 ha) between 1977 and 2012 (table 2, figure 4B and 5B). There was a decrease in agricultural land area., Decreases in these lands were accounted for by the increase in settlement areas (335,3 ha) between 1977 and 2012 (table 2, figure 4A).

The stands were dominated by pine (*Pinus brutia* Ten.) (52.8 - 55.3 %), eucalyptus (*Eucalyptus camaldulensis* Dehn.) (2.1 - 2.6 %) and broadleaved and pine - broadleaved mixed stands (B&M) (1.3 – 3.3 %) from 1977 to 2012. Results indicated an increase in both pure pine and broadleaved-mixed stands, and the decrease in eucalyptus stands (figure 4C, 5C and table 1). The total area of pine stands increased by 4.7 % (365.7 ha), broadleaved-mixed stands by 148.3 % (284.2 ha) and the total area of eucalyptus stands decreased by 21.4 % (82.2 ha) between 1977 and 2012 (table 1, figure 5C).

The change in stand characteristics between 1977 and 2012. Results indicated significant changes in stand characteristics throughout the study period. The number of trees (trees ha^{-1}) increased by 141.8 % (244) from 1977 to 2012 (figure 5D). The increase in the number of trees per hectare was more pronounced in young stands (1,513.1 % (194)) as compared to mature stands (58.2 % (66)). However, there was a decrease of 35.6 % (16) in over mature stands.

Similar trends were observed in stand volume and volume increment (figure 5D, F). The increase in stand volume was 1086.8 % (22.5 m^3 ha^{-1}) in young, and 64.9 %

Table 1. Evolution of LULC, stand structure, composition, and human population in the study area from 1977 to 2012.
Evolución de LULC, estructura del rodal, composición y población humana en el área de estudio de 1977 a 2012.

LULC	1977		1990		2000		2012		Change (1977 - 2012)	
	ha	%	ha	%	ha	%	ha	%	ha	%
Forest	8,305.0	56.7	8,497.2	58.0	8,907.5	60.8	8,872.7	60.6	567.7	6.8
Agriculture	6,010.2	41.1	5,560.7	38.0	5,225.2	35.7	5,012.7	34.2	-997.5	-16.6
Settlement	176.5	1.2	256.1	1.7	298.4	2.0	431.6	2.9	255.1	144.5
Open Areas	148.3	1.0	325.9	2.2	208.9	1.4	322.9	2.2	174.7	117.8
Total	14,640	100	14,640	100	14,640	100	14,640	100	0	
Year	1977		1990		2000		2012		Change (1977 - 2012)	
Structure	ha	%	ha	%	ha	%	ha	%	ha	%
Closed stands	5,490.3	37.5	6,778.2	46.3	7,057.8	48.2	8,231.3	56.2	2,740.9	49.9
Open stands	2,814.7	19.2	1,719.0	11.7	1,849.7	12.6	641.5	4.4	-2,173.2	-77.2
Other	6,335.0	43.3	6,142.8	42.0	5,732.5	39.2	5,767.3	39.4	-567.7	-9.0
Total	14640	100	14640	100	14640	100	14640	100	0	
Year	1977		1990		2000		2012		Change (1977 - 2012)	
Composition	ha	%	ha	%	ha	%	ha	%	ha	%
Pine	7,728.5	52.8	7,959.8	54.4	7,821.5	53.4	8,094.2	55.3	365.7	4.7
Eucalyptus Stands	384.9	2.6	327.2	2.2	312.5	2.1	302.7	2.1	-82.2	-21.4
B&M Stands[1]	191.6	1.3	210.3	1.4	773.5	5.3	475.9	3.3	284.2	148.3
Non-Forest	6,335.0	43.3	6,142.8	42.0	5,732.5	39.2	5,767.3	39.4	-567.7	-9.0
Total	14,640	100	14,640	100	14,640	100	14,640	100	0	
Year	1977		1990		2000		2012		Change (1977 - 2012)	
	No.	PD[3]	No.	PD	No.	PD	No.	PD	No.	PD
Population	5,194	35.5	5,600	38.3	6,330	43.2	6,966	47.6	1,772	34.1

[1]B&M = Broadleaved and Pine - Broadleaved mixed stands. [2]The percent values indicate area distribution in each year in the study area. [3]PD = Population density (inhabitants km^{-2}).

(27.7 m^3 ha^{-1}) in mature stands. However, there was an 18.5 % (7.3 m^3 ha^{-1}) decrease in over mature stands. Total change in stand volume was 42.9 m^3 ha^{-1} (50.9 %) between 1977 and 2012 (figure 5E). The trend in stand volume increment was similar to that of stand volume. There was an increase in both young 1,171.1 % (1.16 m^3 ha^{-1}) and mature stands 81.5 % (1.09 m^3 ha^{-1}). However, there was a 6.0 % (0.05 m^3 ha^{-1}) decrease in over mature stands. Total change in stand volume increment was 2.21 m^3 ha^{-1} (100.5 %) between 1977 and 2012 (figure 5F).

Table 2. Transition matrix of land use/land cover change in the study area from 1977 to 2012.

Matriz de transición de cambio de uso de suelo/cobertura de suelo en el área de estudio de 1977 a 2012.

		2012						Change (%)
	Land Cover	CS (ha)	OS (ha)	A (ha)	S (ha)	O (ha)	Total (ha)	
1977	Closed Stands (DS)	5,142.7	107.7	147.8	15.5	76.6	5,490.3	49.9
	Open Stands (OS)	2,080.7	467.2	223.9	15.2	27.7	2,814.7	-77.2
	Agriculture (A)	933.1	65.7	4,544.2	335.3	131.8	6,010.2	-16.6
	Settlement (S)	19.7	0.9	91.0	64.8	0.0	176.5	144.6
	Open Areas (O)	55.0	0.0	5.8	0.7	86.7	148.3	117.8
	Total (ha)	8,231.3	641.5	5,012.7	431.6	322.9	14,640.0	0.0

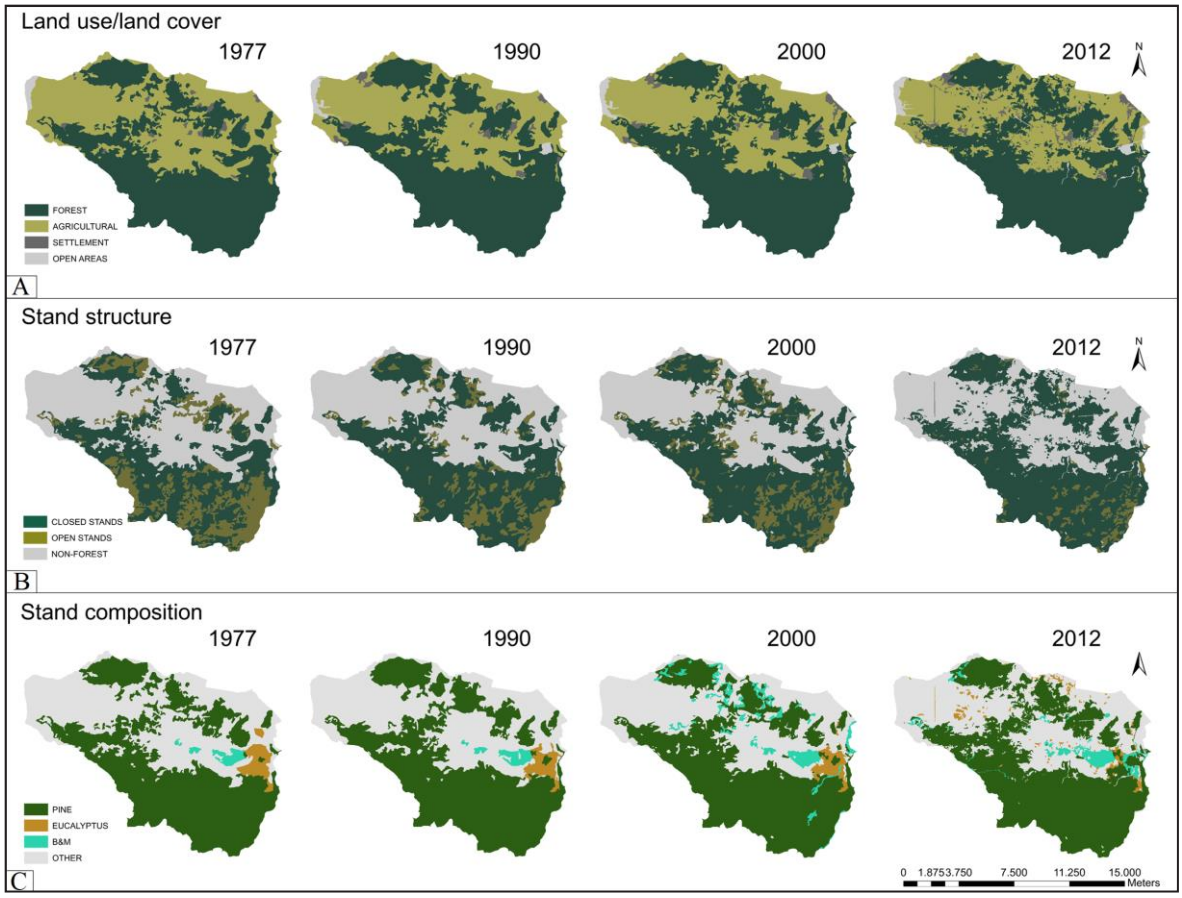

Figure 4. Spatial distribution and transition maps of land use/land cover (A), stand structure (B) and composition (C) of Karabortlen State Forest Enterprise in 1977, 1990, 2000 and 2012.

Mapas de distribución espacial y transición del uso de la tierra / cobertura del suelo (A), estructura (B) y composición (C) del rodal de Karabortlen State Forest Enterprise en 1977, 1990, 2000 y 2012.

The change in canopy fuel load between 1977 and 2012. Results indicated an increase in the canopy fuel load (CFL) in pine stands between 1977 and 2012 (figure 6). While the increase was more pronounced between 1977 and 2000, the rate of increase in the available and total CFL (kg m^{-2}) diminished after 2000 (figure 6A). The increase in the available CFL (needle and branches < 0.6 cm) was 90.8 % (0.27 kg m^{-2}) and the total CFL was 86.4 % (0.51 kg m^{-2}) between 1977 and 2012 (figure 6A). There was also an increase in total available CFL and total CFL (tons) (figure 6B). Increases were 177.3 % (24,738.5 tons) in available CFL and 171.0 % (46,438.5 tons) in total CFL from 1977 to 2012 (figure 6B).

DISCUSSION

Change in Land use/land cover. Results showed a gradual increase in forest, settlement, and open areas from 1977 to 2012 in the study area. However, there was a 16.6 % decrease in agricultural land area from 1977 to 2012 (table 1,

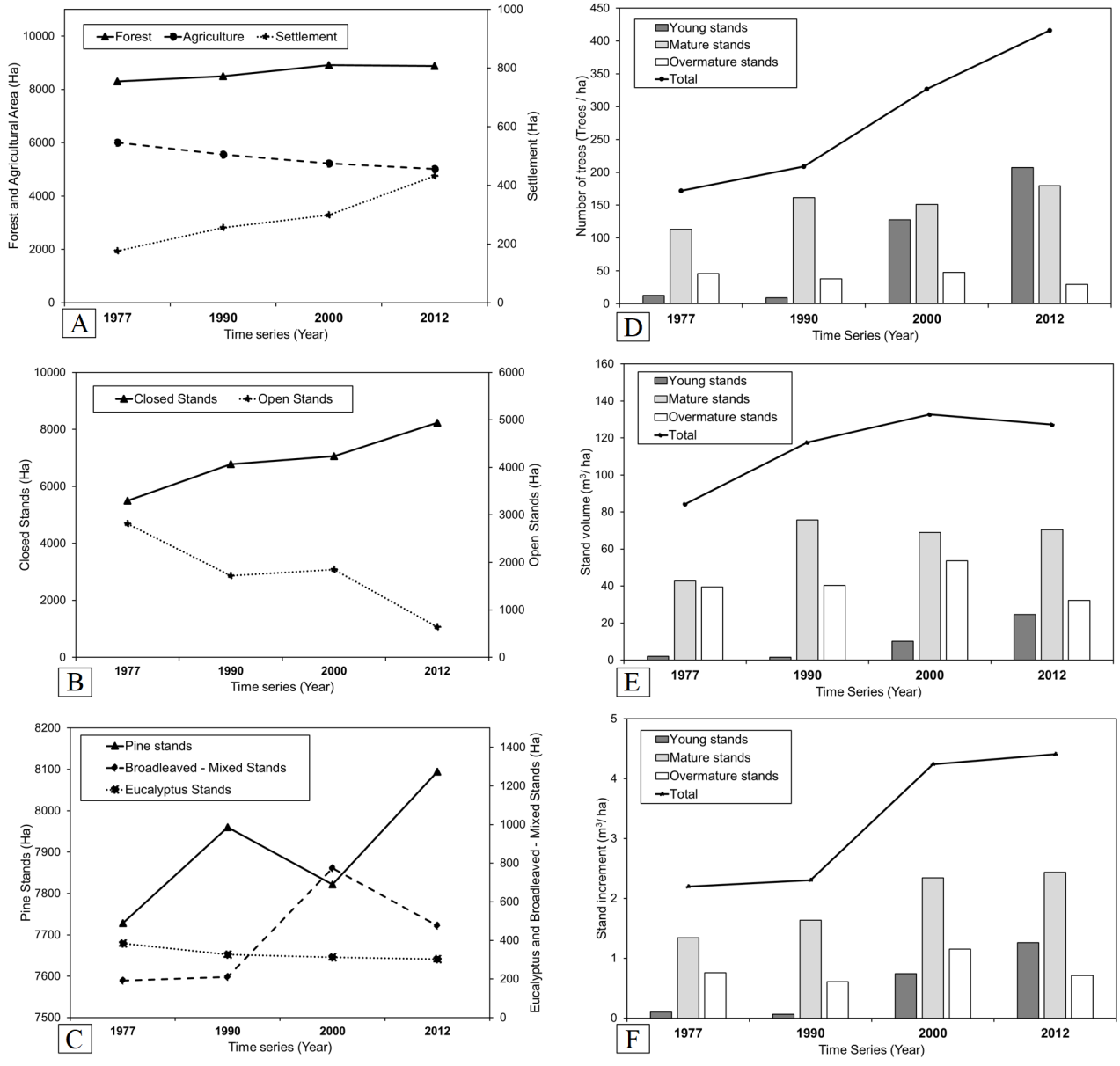

Figure 5. State of land use/land cover (A), stand structure (B), stand composition (C) and stand characteristics: number of trees (trees ha^{-1}) (D), stand volume (m^3 ha^{-1}) (E), and stand volume increment (m^3 ha^{-1}) (F) in pine stands (DBH > 8 cm) in 1977, 1990, 2000 and 2012.

Estado del uso del suelo / cobertura del suelo (A), estructura del rodal (B), composición del rodal (C) y características del rodal: número de árboles (árboles ha^{-1}) (D), volumen del rodal (m^3 ha^{-1}) (E), e incremento de volumen del rodal (m^3 ha^{-1}) (F) en rodales de pino (DAP > 8 cm) en 1977, 1990, 2000 y 2012.

figure 5A). Similar findings were reported in the case studies from the Mediterranean Region (Ales *et al.* 1992, Moreira *et al.* 2001). The decline was reported as 29 % from 1958 to 1995 and the possible reasons of decline were attributed to the land abandonment and depopulation of rural areas. The decline in the population and in the number of farmers in the case area was accompanied by a sharp reduction in the farming activities (Moreira *et al.* 2001).

The decline in agricultural lands is correlated with the increased job opportunities brought about by tourism in the study area. The site is near the Gulf of Gokova which is famous for its nature, beaches, and bays (figure 1). The population of the region has significantly increased since the 70s. The population increase was 34.1 % in the study area from 1977 to 2012 (table 1). Moreover, parallel to the population increase, settlement areas also increased in the zone by 144.5 % from 1977 to 2012 (table 1). The transition matrix showed that most of the increase in settlement areas was accounted for the decrease in agricultural land area (335.3 ha) between 1977 and 2012 (table 2). The increase in the spatial distribution of settlement areas was more pronounced after 2000 (figure 4A).

There was a 6.8 % increase in forest areas from 1977 to 2012 in the study area (table 1). Similar results were reported in the Mediterranean Region (Debussche *et al.* 1999), with up to 74 % increases in forest cover in some areas (Falcucci *et al.* 2007). The increase in forested lands could be attributed to the abandonment of agricultural areas and a reduction in farming activities in the study area (table 2). Inhabitants, particularly young generations, prefer working at touristic places rather than considering traditional sources of incomes such as grazing, wood harvesting and farming. This results in the abandonment of agricultural lands which in turn reduces social pressure on forestlands.

The increase in the settlement areas accompanied by a population growth near forestlands and the expansion of forest areas may increase forest fire risk and hazard (Moreira *et al.* 2011). Fires are strongly related to human activity in the Mediterranean Region (Chergui *et al.* 2018). In Turkey, nearly 90 % of forest fires are caused by human activities. The trend in the land use/land cover change pattern may contribute to the increase in fire problem in this region.

Recent observations made in the study area clearly indicated a population influx into the region as a result of the COVID-19 pandemic in 2020. People prefer living in a separate house preferably far from city centers and apartment complexes. This may further exacerbate fire problem. The trend may help to understand possible increases in forest fire occurrences, particularly in wildland/urban interface, in the future.

Change in stand structure, composition, and characteristics. The forest areas in the study area are dominated by pine (*Pinus brutia* Ten.) (52.8 - 55.3 %), eucalyptus stands (2.1 - 2.6 %) and broadleaved and pine - broadleaved mixed stands (B&M) (1.3 – 3.3 %) (table 1). All stand types, except eucalyptus stands, increased in area during the study period (table 1, figure 4C, 5C). The increase percentages in pine and B&M were 4.7 and 148.3, respectively. The forest management plans indicated that the increase in broadleaved stands resulted from plantations of broadleaved species for essential oil production. Some areas were also acquired through draining some swamp areas and planting for pulp production. New Turkish sweetgum (*Liquidambar orientalis* L.*)* stands were established to increa-

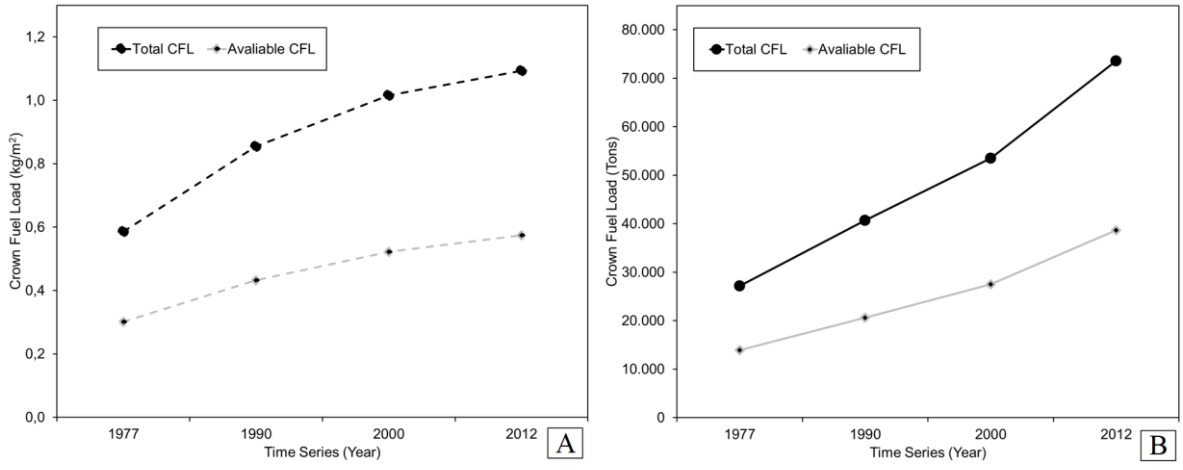

Figure 6. Changes in crown fuel load of pine stands over the study period (1977, 1990, 2000 and 2012). The dashed lines indicate available crown and total crown fuel load (kg m^{-2}) and solid lines indicate available and total crown fuel load of pine stands (tons).

Cambios en la carga de combustible de la copa de los rodales de pino durante el período de estudio (1977, 1990, 2000 y 2012). Las líneas discontinuas indican la corona disponible y la carga total de combustible de la corona (kg m^{-2}) y las líneas continuas indican la carga de combustible disponible y la corona total de los rodales de pino (toneladas).

se essential oil (crude levant storax) production in the study area particularly in the 70 - 80s. In addition, *Eucalyptus camaldulenis* Dehn. was used in afforestation activities to drain some swamp areas and maximize wood pulp production. Results indicated that there was a gradual decrease in the land area of eucalyptus stands (figure 5C, table 1). This may be a positive contribution to the decrease of the flammability of the stands in the study area. As eucalyptus is an extremely flammable species (Dimitrakopoulos and Papaioannou 2001) containing excessive amounts of essential oils. Although *Eucalyptus camaldulensis* Dehn. may be a preferred plantation species for timber, it should be kept in mind that it may significantly contribute to the flammability of the stands in the study area.

Results showed a 49.9 % increase in closed and 77.2 % decrease in open stands between 1977 and 2012 (Table 1, 2). The open stands were mainly composed of Turkish red pine (*Pinus brutia* Ten.) with Mediterranean shrub plant communities (Maquis) (*i.e. Quercus coccifera* L., *Pistacia terebinthus* L., *Arbutus andrachne* L., *Myrtus communis* L., *Cistus* spp.) in the understory. The possible reasons of decline in open stands could be ascribed to the land use/land cover (LULC) and socioeconomic changes in the study area:

i) The availability of alternative energy sources (*i.e.* natural gas) decreased the demand for fuelwood traditionally acquired from the forested lands.
ii) The decline in grazing might have contributed to the reduction in open (degraded) stands. Overgrazing was one of the main causes of forest degradation in the 70 - 80s in the Eastern Mediterranean Region (Arianoutsou 1985). However, subsequent reduction in grazing probably resulted in less pressure on pine forests in the study area.
iii) Afforestation / reforestation efforts may have contributed to the reduction in open stands. Open stands have a priority for afforestation/rehabilitation activities in Turkish forestry practices (GDF 2008) in managed forests. Therefore, the open stands were subjected to rehabilitation programs using Turkish red pine with an overall increase in stand density and productivity in the region. The increase in stand productivity can be easily seen in quantitative stand characteristics from 1977 to 2012 (figure 5). The number of trees (figure 5D), stand volume (figure 5E) and stand volume raise (figure 5F) increased during the study periods. The increase in the number of trees was almost linear in mature (DBH = 20 - 35.9 cm) stands and exponential in young (DBH = 8 - 19.9 cm) stands. This increase was more pronounced between 2000 and 2012 (figure 5D). Similar trends were seen in stand volume (figure 5D) and stand volume increment (figure 5E) in pine stands between 1977 and 2012.

Large scale pine plantations promoted in the Mediterranean Region have resulted in large, continuous, and homogeneous areas composed of even-aged pine stands supporting flammability (Pausas *et al.* 2004) and fire hazard (Moreira *et al.* 2011). Fire hazard is associated with fuel condition. Fully closed young pine stands with lower crown base constitute high fire hazard areas (Ruiz-González and Álvarez-González 2011) and are more vulnerable to crown fire risk than are mature pine stands (Mitsopoulos and Dimitrakopoulos 2007). The increase in young pine stands may, therefore, contribute to the increased crown fire risk in the region.

Change in canopy fuel load of pine stands. Assessment of canopy fuels is essential for fire management. Canopy fuels are the main fuel layer supporting crown fire spread. Crown fuel load is essential for predicting crown fire intensity, fuel consumption (Stocks *et al.* 2004) and fire effects on ecosystems as well as carbon emission to atmosphere (Amiro 2001). Results showed an increase in available crown fuel load (CFL) (90.8 %) and total CFL (86.4 %) from 1977 to 2012. The increase was more pronounced between 1977 and 2000; however, the rate of increase in available and total CFL (kg m^{-2}) decreased after 2000 (figure 6A). The rate of decrease in available and total CFL can be related to the changes in the quantitative stand characteristics in mature and over mature pine stands. As can be seen from figure 5E, the stand volume of mature pine stands was nearly stable, although there was a decrease in stand volume in over mature stands between 2000 and 2012. Similarly, the number of trees in mature pine stands increased slightly, whereas over mature pine stands decreased after 2000 (figure 5D). The crown fuel load of pines is linearly correlated with tree characteristics such as diameter at breast height, tree height, crown length and width (Gungoroglu *et al.* 2018, Kucuk *et al.* 2008). Moreover, an increase in stand basal area and tree density results in an increase in CFL because of the higher fraction of available crown fuel load (Cruz *et al.* 2003, Mitsopoulos and Dimitrakopoulos 2007).

Total available CFL (needle and branches < 0.6 cm) and total CFL increased in pine stands during 1977 - 2021 (figure 6B). This was related to the increase in both density and land area of pine stands in the study area during the study period (table 1). Results clearly indicated that pine stands would become more vulnerable to crown fires in the region, and increase in crown fuel loads would foster large, intense, and catastrophic forest fires (Ferry *et al.* 1995) in the future. Therefore, the hypothesis of this study "LULC has no major effect on the flammability of the stands in the Eastern Mediterranean Region" was rejected.

In this study, canopy fuel load (kg/m^2) was only used to evaluate crown fire potential in pine stands because of the limited dataset for the stands. Indeed, Canopy bulk density (kg m^{-3}) is also an important factor to assess and compare crown fuel flammability and fire spread (Cruz *et al.* 2003) among vegetation types, between and, even within, the same forest species. Therefore, new studies are needed to assess temporal changes in crown fire potential in Mediterranean forests. Moreover, forest fires generally

start in the surface fuels (*i.e.* fine dead fuels) and depending on the surface fuel load, properties and environmental conditions, grow in size and intensity and develop into crown fires (Mitsopoulos and Dimitrakopoulos 2007). Consequently, surface fuel load should be addressed along with canopy fuels for the assessment of crown fire hazard. In this study, due to the lack of the surface fuel load prediction models for Turkish red pine stands, the effects of LULC change on the surface fuel load of pine stands in the study period were not evaluated. Thus, further studies are necessary to assess crown fire hazard in pine stands with all combustible fuels from surface to crown in the Eastern Mediterranean Region.

CONCLUSIONS

Land use and land cover change has been one of the main drivers shaping landscape in the Eastern Mediterranean Region during the last decades. Abandonment of agricultural lands, decreased grazing, decreased fuelwood utilization, increased reforestation / afforestation efforts and increased human activities constitute the underlying reasons for the landscape dynamics in the region. Results revealed that landscape tends to become more homogeneous resulting in large and homogeneous areas covered with fully closed and productive pine stands. This will probably exacerbate forest fire problem and extreme fire behavior over large areas in the Eastern Mediterranean Region. An appreciation of the emerging trends in land use/land cover change in the dynamics of forest lands from a social, economic, and ecological perspective in the Eastern Mediterranean Region could help managers make sound decisions concerning the sustainable management of forest resources. Information derived from this study may be useful in developing genuine management strategies to reduce crown fire hazard in the future.

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REFERENCES

Ales RF, A Martin, F Ortega, EE Ales. 1992. Recent changes in landscape structure and function in a mediterranean region of SW Spain (1950–1984). *Landscape Ecololgy* 7(1): 3-18. DOI: https://doi.org/10.1007/BF02573953

Amiro BD. 2001. Paired-tower measurements of carbon and energy fluxes following disturbance in the boreal forest. *Global Change Biology* 7(3): 253-268. DOI: https://doi.org/10.1046/j.1365-2486.2001.00398.x

Arianoutsou M. 1985. Desertification by overgrazing in Greece: the case of Lesvos island. *Journal of Arid Environments* 9: 237-242.

Chergui B, S Fahd, X Santos, JG Pausas. 2018. Socioeconomic Factors Drive Fire-Regime Variability in the Mediterranean Basin. *Ecosystems* 21(4): 619-628. DOI: https://doi.org/10.1007/s10021-017-0172-6

Cruz MG, ME Alexander, RH Wakimoto. 2003. Assessing canopy fuel stratum characteristics in crown fire prone fuel types of western North America. *International Journal of Wildland Fire* 12(1): 39-50. DOI: https://doi.org/10.1071/WF02024

Debussche M, J Lepart, A Dervieux. 1999. Mediterranean landscape changes: evidence from old postcards. *Global Ecology and Biogeography* 8(1): 3-15. DOI: https://doi.org/10.1046/j.1365-2699.1999.00316.x

Dimitrakopoulos AP, KK Papaioannou. 2001. Flammability Assessment of Mediterranean Forest Fuels. *Fire Technology* 37(2): 143-152. DOI:https://doi.org/10.1023/A:1011641601076

Falcucci A, L Maiorano, L Boitani. 2007. Changes in land-use/land-cover patterns in Italy and their implications for biodiversity conservation. *Landscape Ecology* 22(4): 617-631. DOI: https://doi.org/10.1007/s10980-006-9056-4

Fernández-Alonso JM, I Alberdi, JG Álvarez-González, JA Vega, I Cañellas, AD Ruiz-González. 2013. Canopy fuel characteristics in relation to crown fire potential in pine stands: analysis, modelling and classification. *European Journal of Forest Research* 132(2): 363-377. DOI: https://doi.org/10.1007/s10342-012-0680-z

Ferry GW, RG Clark, RE Montgomery, RW Mutch, WP Leenhouts, GT Zimmerman. 1995. Altered fire regimes within fire-adapted ecosystems. 'Our Living Resources: a report to the nation on the distribution, abundance, and health of U.S. plants animals, and ecosystems'. Washington, DC, USA. p. 222-224.

GDF (General Directorate of Forestry, TR). 2008. Forest Management Regulations in Turkey. Ankara, Turkey. 52 p.

Gregorio AD, LJM Jansen. 2000. Land cover classification System (LCCS): Classification concepts. Food and Agriculture Organization (FAO, IT). Rome, Italy.

Gungoroglu C, CO Guney, A Sari, A Serttas. 2018. Predicting crown fuel biomass of Turkish Red Pine (*Pinus brutia* Ten.) for the Mediterranean Regions of Turkey. *Sumarski List* 142(11-12): 601-610. DOI: https://doi.org/10.31298/sl.142.11-12.4

Kucuk O, E Bilgili. 2008. Crown fuel characteristics and fuel load estimates in young Calabrian pine (*Pinus brutia* Ten.) stands in Northwestern Turkey. *Fresenius Environmental Bulletin* 17(12b): 2226-2231.

Kucuk O, E Bilgili, B Saglam. 2008. Estimating crown fuel loading for Calabrian pine and Anatolian black pine. *International Journal Wildland Fire* 17(1): 147-154. DOI: https://doi.org/10.1071/WF06092

Mitsopoulos ID, AP Dimitrakopoulos. 2007. Canopy fuel characteristics and potential crown fire behavior in Aleppo pine (*Pinus halepensis* Mill.) forests. *Annals of Forest Science* 64(3): 287-299. DOI: https://doi.org/10.1051/forest:2007006

Moreira F, FC Rego, PG Ferreira. 2001. Temporal (1958–1995) pattern of change in a cultural landscape of northwestern Portugal: implications for fire occurrence. *Landscape Ecology* 16(6): 557-567. DOI: https://doi.org/10.1023/A:1013130528470

Moreira F, O Viedma, M Arianoutsou, T Curt, N Koutsias, E Rigolof, A Barbati, P Corona, P Vaz, G Xanthopoulos, F Moui-

llot, E Bilgili. 2011. Landscape - wildfire interactions in southern Europe: Implications for landscape management. *Journal of Environmental Management* 92(10): 2389-2402 DOI: https://doi.org/10.1016/j.jenvman.2011.06.028

Moreno JM, A Vázquez, R Vélez. 1998. Recent history of forest fires in Spain. *In* Moreno JM ed. Large forest fires. Leiden, Netherlands. Backhuys Publishers. p. 159-185.

Pausas JG, C Bladé, A Valdecantos, JP Seva, D Fuentes, JA Alloza, A Vilagrosa, S Bautista, J Cortina, R Vallejo. 2004. Pines and oaks in the restoration of Mediterranean landscapes of Spain: New perspectives for an old practice - a review. *Plant Ecology* 171(1): 209-220. DOI: https://doi.org/10.1023/B:VEGE.0000029381.63336.20

Pérez B, A Cruz, F Fernández-González, JM Moreno. 2003. Effects of the recent land-use history on the postfire vegetation of uplands in Central Spain. *Forest Ecology and Management* 182(1): 273-283. DOI: https://doi.org/10.1016/S0378-1127(03)00069-0

Ruiz-González AD, JG Álvarez-González. 2011. Canopy bulk density and canopy base height equations for assessing crown fire hazard in *Pinus radiata* plantations. *Canadian Journal of Forest Research* 41(4): 839-850. DOI: https://doi.org/10.1139/x10-237

Scott JH, ED Reinhardt. 2002. Estimating canopy fuels in conifer forests. *Fire Management Today* 62: 45–50.

Stocks BJ, ME Alexander, BM Wotton, CN Stefner, MD Flannigan, SW Taylor, N Lavoie, JA Mason, GR Hartley, ME Maffey, GN Dalrymple, TW Blake, MG Cruz, RA Lanoville. 2004. Crown fire behaviour in a northern jack pine and black spruce forest. *Canadian Journal of Forest Research* 34(8): 1548-1560. DOI: https://doi.org/10.1139/x04-054

Viedma O, JM Moreno, I Rieiro. 2006. Interactions between land use/land cover change, forest fires and landscape structure in Sierra de Gredos (Central Spain). *Environmental Conservation* 33(3): 212-222. DOI: https://doi.org/10.1017/S0376892906003122

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