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Spatial and temporal changes of stone pine forests in Turkey: A case study in Ayvalik forest planning unit

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Abstract. Timber and pine nuts are considered main products from the stone pine (*Pinus pinea*) forests in Turkey. Stone pine woodlands are approximately 89,000 ha and pine cone and nut production is about 3,500 tons/year and 280 tons/year, respectively. The forests covered by stone pine also present other services and products such as hunting, carbon sequestration, resin, bark and wood. The production and marketing of pine nut in particular has grown dramatically over the last two decades. The great social and economic importance of stone pine in non-wood forest production (NWFP) distinguishes it from other pines, generating employment and supplementary incomes for forest villagers who live in and near the forests. Additionally, villagers prefer incomes from NWFP, because pine nut production is more profitable than timber production. Understanding the landscape dynamics as a historical legacy of disturbances is necessary for sustainable management of NWFP to help to better design the future forest management practices and policies. In this study, spatial and temporal changes in forest cover types in Ayvalık Forest Planning Unit, were analyzed with GIS and Patch Analyst. The analysis was conducted with forest cover type maps from 1989 and 2002. Results indicate that there are marked changes in the temporal and spatial dynamics of land use and forest cover in the study area. Between 1989 and 2002, we observed an increase of 25% in total forested areas with an increase of 43% in stone pine areas. On the other hand, the analysis of canopy cover changes and development stages over 13 years find out an increase of total forest area and stone pine area with medium canopy cover and with trees in “a-regenerated” stage of development.

Keywords. Stone pine (*Pinus pinea*) – NWFP – GIS – Forest dynamics – Land use.

I – Introduction

Pinus pinea is one of the most important non-wood forest products (NWFPs) in the Mediterranean area due to the economic importance of tree seeds and cones. While the cones have been used as wood based panel (Ayrilmiş *et al*., 2009), the nuts are highly valued for food industry (Mutke *et al*., 2012).Other ecosystem services such as soil protection, recreational use and carbon sequestration make stone pine one of the most valued Mediterranean pine species.

The cones and nuts provided by stone pine forests, generates employment and supplementary incomes for forest villagers living in and near the forests. The incomes from NWFP, namely pine nuts, are more profitable than timber production and therefore preferred for villagers. Turkey is one of the largest producers of pine nut in the world and the marketing of pine nut from stone pine in Turkey has grown dramatically over the last two decades. Total annual production of pine nut kernel from Stone pine in Turkey increased from about 166 ton to 1,000 tons and estimated pine nut income changed from 2 million dollars to 38 million dollars based on 2000-2015 exportation statistics (TUIK, 2015). In order to maintain competitiveness and guarantee sustainable incomes from stone pine forests, a diversification of products such as timber and nuts may be required in future management plannings for avoiding excessive cone production.

Understanding historical forest dynamics in terms of spatial and temporal scales helps to better design the future forest management practices and policies. Geographic Information Systems (GIS)

are common and effective tool to monitor changes in forest area and other variables in a regional scale. Many studies use remote sensing and geographic information systems to monitor forest development stages, cover types and canopy cover as a surrogate of stand quality for the Turkish forests over time (Mumcu *et al*., 2008; Kadıoğulları, 2005) but none specifically addresses the spatial and temporal changes of NWFP.

The objective of this study was to analyze the spatial and temporal changes of landscape structure in Ayvalık Forest Planning Unit by using stand cover type maps from forest management plans between 1989 and 2002. Temporal changes were examined in terms of land use, developing stage and canopy cover with a detailed analysis on stone pine areas. In this way, susceptibility of forest to further abrupt changes in the future would be examined, as well as sustainability of forest resources and resilience of the ecosystem mainly for biodiversity for stone pine or all forest areas.

II – Materials and methods

The study was conducted in Ayvalık forest planning unit in western part of Turkey, province of Balıkesir, covering about 60,883 ha of which 34% is forested areas. The study area is covered by even aged pure stands of stone pine, black pine and red pine (*Pinus pinea, Pinus nigra* and *Pinus brutia*, respectively). The elevation ranges from 0 m to 1200 m above sea level. Mean annual temperature of study area is 17 °C and mean annual precipitation is 643 mm, based on the average 1975-2005 (DMI, 2008). To analyze the spatial and temporal structure of stone pine forest areas, stand type maps obtained by interpretation of aerial photographs for forest management plans from 1989 and 2002 (OGM, 1989; 2002) were digitized and a spatial databases were built with Arc/Info GIS. Changes of forest structure such as forest species, stand development, canopy cover as well as changes in land use were analyzed with some functions of Arc/GIS such as Query and Analyzing. The spatial configuration, that is the physical distribution in space and spatial character of elements in forest, was evaluated with Patch Analyst. The Patch Analyst tool of Arc/GIS was used to analyse land use changes between 1989 and 2002. In this analysis the "*patch*" is the basic "element" or "unit" of the landscape and "*number of patches (NP)*" is the amount of elements in each classes. It is an important indicator for forest fragmentation, and the increasing in NP indicates increased fragmentation with more patches of smaller size. "*Class area (CA)*" is the sum of areas of all patches belonging to a given class. *"Mean patch size (MPS)"* is the average patch size of all classes. *"Edge Density (ED)"* is the ratio of perimeter to area ratio for each patch and the unit is metres/hectare therefore it is useful for comparing landscapes of varying size. "*Area Weighted Shape Index (AWMSI)*" is the average perimeter-to-area ratio for a class, weighted by the size of its patches. Patchiness in forested area has special importance because it serves as an important indicator of natural habitat fragmentation (Kammerbauer and Ardon, 1999). Hence these parameters are regarded as an important indicator for habitat fragmentation due to their effect on species. The description of used classes in land use, canopy cower and development stages types are explained in Table 1 and Table 2.

Table 1. Land use/land cover classes descriptions

Land Use/Land Cover Classes	Description
Non forest	Agriculture, settlement, dune and moss areas
Private áreas	Non state forest areas
Degraded stone pine	Sparsely distributed stone pine forest 0-10% cover
Open áreas	Treeless and open areas
Degraded forest	Sparsely distributed forest 0-10% cover
Stone pine	Pure *Pinus pinea* stands
Black pine	Pure *Pinus nigra* stands
Red pine	Pure *Pinus brutia* stands

Table 2. Classification of canopy cover and development stage types

Canopy cover type	Criteria (% cover)	Development stage	Criteria (average dbh)
0 regenerated	no crown cover yet	a (regenerated)	< 8 cm
1 (low coverage)	11%-40%	b (young)	8-19.9 cm
2 (medium coverage)	41%-70%	c (mature)	20-35.9 cm
3 (full coverage)	>71%	d (overmature)	> 36 cm
Degraded forest	0-10%		

III – Results and discussion

1. Temporal change in land use/land cover classes

The change of land use/land cover classes in Ayvalık planning unit between 1989 and 2002 were mapped using forest cover type maps. The results showed that while open areas decreased about 2,845 ha, stone pine, black pine, red pine, Degraded and Non-forest areas increased about 670, 58, 581, 1276 and 366 ha, respectively between 1989-2002 years (Table 3). One reason for such increase relates with afforestation activities. There was also a change of species composition from red pine to stone pine: according to the transition table, about 16% of red pine (532 ha), 2.5% of forest open areas (247 ha), 5.2% of degraded areas (274 ha) and 0.7% of non forest areas (292 ha) changed to stone pine or degraded stone pine areas (Table 4).

Table 3. Changes of land use/ land cover classes in Ayvalık (based on 1989-2002 forest type cover maps)

Land Use/Land Cover Classes	1989		2002		Difference (+ -)	
	Area (ha)	%	Area (ha)	(%)	Area (ha)	(%)
Stone pine	1,463	2.4	2,133	3.5	670	1.1
Black pine	390	0.6	448	0.7	58	0.1
Red pine	3,228	5.3	3,809	6.3	581	0.4
Degraded	4,885	8.1	6,161	10.1	1,276	2.1
Degreaded stone pine	255	0.4	321	0.5	-66	0.1
Open spaces	10,458	17.2	7,614	12.5	-2,845	-4.7
Private forest	161	0.3	156	0.3	-5	-0.0
Non forest	39,876	65.7	40,241	66.1	366	0.4
Total	**60,717**	**100**	**60,883**	**100**		

Table 4. Transitions between land use classes from 1989 to 2002, expressed as percentage [%] of original LU class (based on forest management plans)

1989 \ 2002	Degraded	Degraded stone pine	Stone pine	Black pine	Red pine	Private forest	Oak	Non-forest	Open spaces
Degraded	49	2	3	1	14	0	0	23	8
Degraded stone pine	0	16	48	0	1	0	0	36	0
Stone pine	10	8	53	0	10	0	0	14	5
Black pine	1	0	0	80	5	0	0	9	6
Red pine	9	0	16	0	55	0	0	15	5
Private forest	4	0	0	0	3	88	0	3	2
Non-forest	5	0	1	0	1	0	0	90	4
Open spaces	12	0	2	1	6	0	0	31	49

2. Temporal changes in canopy cover

Changes in forest structure were also analyzed in terms of canopy cover classes (Table 5). Between 1989 and 2002, there was a net decrease in regenerated areas (40 ha), stands with low coverage cover (869 ha) and open spaces (2,845 ha). However, there was a net increase in stands with medium (776 ha) and full coverage (1,441 ha), as well as in degraded forest areas (1,342 ha). The results indicate that in some stands, canopy cover changed in favor of more dense areas, in other to degradation.

For stone pine forests, the changes between 1989 and 2002 in terms of canopy cover, revealed an increase in regenerated areas, and to a medium and full canopy cover stands (Table 5), possibly explained by reforestation activities and with stand management for cone production, respectively.

Table 5. Changes in canopy cover classes, according to forest cover type maps between 1989-2002

	All forest area			Stone pine forest		
Canopy cover	**1989**	**2002**	**Difference (+ -)**	**1989**	**2002**	**Difference (+ -)**
(Criteria, % cover)	**Area (ha)**	**Area (ha)**	**Area (ha)**	**Area (ha)**	**Area (ha)**	**Area (ha)**
0 (Regenerated areas)	1,375	1,336	-40	635	1,023	388
1 (low coverage, 11%-40%)	2,060	1,191	-869	718	367	-351
2 (medium coverage, 41%-70%)	1,533	2,309	776	110	612	503
3 (full coverage, >71%)	113	1,554	1441	0	130	130
Degraded forest (0-10%)	5,141	6,482	1342	255	321	66
Open spaces	10,458	7,614	-2845	–	–	–
Private Forest	161	156	-5	–	–	–
Non-Forest	39,876	40,241	366	–	–	–
Total	**60,717**	**60,883**		**1,718**	**2,454**	**736**

3. Temporal changes in development stages

Stands in mature and over mature development stages correspond to 1,941 ha and 1,753 ha, respectively in 1989, the forests were mostly clumped into regenerated and mature stands in 2002 year (Table 6). The changes between 1989 and 2002 indicate an increase in regenerated, young and mature stands with 850 ha, 753 ha and 40 ha, respectively. Over-mature stands decreasing about 335 ha were in early regeneration phase concomitantly with a promotion of regenerating activities in the forest opening areas or degraded areas.

Table 6. Changes in development stages according to forest cover type maps between 1989-2002

	All forest area			Stone pine forest		
Development Stages	**1989**	**2002**	**Difference (+ -)**	**1989**	**2002**	**Difference (+ -)**
(criteria, average dbh)	**Area (ha)**	**Area (ha)**	**Area (ha)**	**Area (ha)**	**Area (ha)**	**Area (ha)**
a (regenerated, <)	1,375	2,225	850	635	1,266	631
b (young, 8 –)	42	794	753	0	14	14
c (mature, 20 –)	1,941	1,981	40	521	160	-361
d (overmature, >)	1,724	1,389	-335	307	694	387
Open spaces	10,458	7,614	-1,845	–	–	–
Private forest	161	156	-5	–	–	–
Degraded forest	5,140	6,482	1,343	255	321	66
Non-Forest	39,876	40,241	410	–	–	–
Total	**60,717**	**60,883**	**–**	**1,718**	**2,454**	**736**

When the changes of development stages between 1989 and 2002 were analyzed for only stone pine forest, we observed that regenerated areas increased prominently (630.47 ha) and about 300 ha mature stone pine stands moved to over mature developmental stages (Table 6).

4. Spatial analysis of changes in forest structure

The results indicated that the total number of patches (NP) increased from 380 to 705 between 1989 and 2002, when all land use/land cover classes were taken into account. The mean patch size (MPS) decreased from 986 ha to 703 ha. While it is decreasing in all land use classes, it is increased for black pine. Similarly Edge Density (ED) and Area Weighted Shape Index (AWMSI) values in almost all classes increased and total values changed from 34 to 45 and 26 to 30, respectively. Specifically in the stone pine and degraded stone pine stand classes, the NP increased from 13 to 41 and from 9 to 20, respectively. The MPS's of stone pine and degraded stone pine stands decreased from 113 ha to 52 ha and from 28 ha to 16 ha, respectively. Also ED and AWMSI values in stone pine areas increased from 1 to 3 and from 3 to 4, respectively. Similarly in degraded stone pine areas these values changed from 0.5 to 0.8 and 2 to 2 (Table 7). The results indicate an increase in forest area fragmentation which can increase further in the future, becoming a threat to conservation as well as the sustainable use of all forest values.

Table 7. Changes of landscape pattern in Ayvalık (1982-2002 forest cover type maps)

Land use	CA (ha)		NP(#)		MPS (ha)		ED(#)		AWMSI(#)	
	1989	2002	1989	2002	1989	2002	1989	2002	1989	2002
Non forest	39,876	40,241	79	187	505	215	10	15	5	7
Red pine	3,228	3,809	76	95	42	40	5	6	3	4
Open space	10,458	7,614	121	166	86	46	10	10	5	3
Degraded	4,885	6,161	74	192	66	32	6	10	4	5
Stone pine	*1,463*	*2,133*	*13*	*41*	*113*	*52*	*1*	*3*	*3*	*4*
Private	161	156	2	2	81	78	0.1	0.1	1	1
Degr. stone pine	*255*	*321*	*9*	*20*	*28*	*16*	*0.5*	*0.8*	*2*	*2*
Black pine	390	448	6	2	65	224	0.6	0.5	3	4
Total	**60,717**	**60,883**	**380**	**705**	**986**	**703**	**34**	**45**	**26**	**30**

IV – Conclusions

This study evaluated the spatial changes of forest structure between 1989 and 2002, including canopy cover, development stages and land use/land cover classes. The results were also specifically analyzed for stone pine areas. The total forested areas decreased slightly from 34.3% in 1989 to 33.9% in 2002. Total stone pine areas (Pure stone pine and degraded stone pine) showed a net increase of 43% (736 ha). Regeneration and low canopy cover areas decrease about 909 ha, while medium and full canopy cover areas increased about 2,217 ha in total. Most forests were in *a young* regeneration development stage.

The results on spatial structure of stone pine areas shows a more fragmented structure. Such changes of forest areas provide a more susceptible forests for further abrupt changes in the future. These parameters analyzed in this study are known to be relatively good indicators for the sustainability of forest resources and the resilience of the ecosystem mainly for biodiversity for stone pine or all forest areas.

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