Macedonian Journal of Ecology and Environment
Vol. 23, issue 2
pp. 99 - 113
Skopje (2021)
ISSN 1857 - 8330 (on-line)
ISSN 0354-2491 (print)
Original scientific paper
Available online at www.mjee.org.mk

Environmental-spatial variations in secondary forests on mountain pasturelands under climate change in Northeastern Turkey

Просторно-средински варијации на секундарните шуми на планинските пасишта при климатски промени во Североисточна Турција

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Abstract

This study explores the effects of environmental-spatial factors (parent material, altitude, slope, topographic solar radiation index, distance from forest edge) on the spatial distribution of secondary forests that naturally grows on pasturelands under climate change in Şebinkarahisar located in the northeastern of Turkey during the period 1987 – 2013. The Mann-Kendall and Sen's trend analyses determined significant increases in average temperatures (average temperature annual, average temperature spring and average temperature autumn), variables of precipitation and actual evapotranspiration during vegetation period, and significant decreases in the variable of precipitation outside vegetation period. Our results showed that secondary forests developed on pasturelands under the domination of *Pinus sylvestris*, *Abies nordmanniana*, *Populus tremula* and *Quercus macranthera*. According to the principal component analysis (PCA), the decrease in topographic solar radiation index showed increase in the spatial distribution of *P. tremula*, *Q. macranthera* and *A. nordmanniana* despite the increase in altitude and slope, while the increase in altitude, slope and topographic solar radiation index increased the spatial distribution of *P. sylvestris*. During the secondary forest succession, the human population in the villages situated in the study area significantly decreased. Decrease in anthropogenic pressure, the history of land cover change, climate change, and environmental and spatial variations jointly interact to determine the advances in forest regeneration on pasturelands. Improving our understanding of these interactions will provide information about the ecosystem dynamics and facilitate land management and planning. In this context, this study is important since it gives valuable ideas to decision makers for management of open lands such as pastures and grasslands in arid or semi-arid ecosystems similar to the study area.

Key Words: Land cover change, productive forests, anthropogenic pressure, succession, tree phenology

Апстракт

Оваа студија ги истражува ефектите на просторно-срединските фактори (матичен супстрат, надморска височина, топографски индекс на соларна радијација, растојание од шумскиот раб) на просторната дистрибуција на секундарните шуми кои природно растат на пасишта подложни на климатски промени во Шебинкарахисар, лоциран во североисточна Турција, за време на периодот 1987 – 2013. Ман-Кендаловите и Сеновите анализи на тренд покажаа значајни зголемувања на

Submitted: 29.07.2021
Accepted: 09.09.2021

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просечните температури (годишен температурен просек, пролетен температурен просек и есенски температурен просек), варијаблите на преципитација и вистинска евапотранспирација за време на вегетативниот период, и значајни намалувања во варијаблите на преципитација надвор од вегетативниот период. Нашите резултати покажуваат дека секундарните шуми се развиваат на пасишта со доминација на *Pinus sylvestris*, *Abies nordmanniana*, *Populus tremula* и *Quercus macranthera*. Според анализата на главните компоненти (PCA), намалувањето во топографскиот индекс на соларна радијација покажува раст на просторната дистрибуција на *P. tremula*, *Q. macranthera* и *A. nordmanniana* и покрај зголемувањето на надморската височина и наклонот, додека зголемувањето на надморската височина, наклонот и топографскиот индекс на соларна радијација ја зголемуваат просторната дистрибуција на *P. sylvestris*. За време на секундарната шумска сукцесија, човековата популација во селата лоцирани во истражуваното подрачје е значајно намалена. Намалувањето на антропогениот притисок, историјата на промена на покровноста на земјиштето, климатските промени и просторните и срединските варијабли во заедничка интеракција го одредуваат напредувањето на регенерацијата на шумите на пасиштата. Подобрувањето на разбирањето на овие интеракции ќе обезбеди информации за динамиката на екосистемот и ќе го олесни управувањето со земјиштето и планирањето. Во овој контекст, оваа студија е значајна затоа што дава вредни идеи на донесувачите на одлуки за управување со отворените површини какви што се пасиштата и тревниците во аридни или семиаридни екосистеми слични со проучуваното подрачје.

Клучни зборови: промена во покровноста на земјиштето, продуктивни шуми, антропоген притисок, сукцесија, фенологија на дрвја

Introduction

In high mountainous areas, the negative effects of low temperatures, solar radiation, wind and storm, as well as insufficient water availability directly or indirectly limit the life of forest trees (Körner & Larcher 1988). Climate warming may partially change the boundaries of some tree species and ecosystems (Peters & Darling 1985). In addition to climate, changes in the site and land use may also affect the spatial distribution of tree species. The changes in land cover due to settling of forest trees to abandoned pastures may occur in parallel with the global climate warming (Rabasa et al. 2013). Reflecting the mutual effects of land use decisions and projected climate change is very important to manage ecosystems (Keane et al. 2004). Mechanical simulations of climate change, land management, degradation, and ecological succession after degradation are needed for decision makers to provide an effective management (Bone et al. 2013; Keane et al. 2013). Succession after degradation does not follow similar paths and mainly develops depending on the performance of species that behave differently to the land and existing species, environmental constraints, ecological desires of tree species, and biotic interactions (Pickett & McDonnell 1989). Biotic processes such as population (demography) and competition affect forest composition and structure in the site and interact with regional and land-scale processes (Normand et al. 2014; Wang et al. 2017).

Ecological succession is process of ecosystem change through time (Finegan 1984; Botkin 1993). While primary succession occurs on the lands that were not plowed, secondary succession occurs as a result of many degradations such as fire, insects, diseases, forestry activities and urbanization (Fernández et al. 2004; Uotila and Kouki 2005). In particular, forest dynamics and a secondary forest succession usually vary depending on the form of degradation, land characteristics, and the ecophysiological characteristics of the species (Donnegan & Rebertus 1999). The spatial change of climate, topography, parent material and soil properties were among the most important factors determining the succession process (Turner et al. 1998). Almost every piece of land has a complex history of land use and natural degradation. World forests have been continuously affected by agricultural activities, animal husbandry or other land uses. In most of the sites, these areas are later abandoned and then covered with tree cover again (Compton & Boone 2000; Donohue et al. 2000). These forest patches depending on succession stage constitute a major component of forest ecosystems, and these regenerations have significant economic and ecological consequences (Motzkin et al. 1996; Compton & Boone 2000; Donohue et al. 2000).

The ecological consequences of land abandonment were examined in many study areas to bring secondary successions into the forefront (Cain and Shelton 2001; Kennard 2002; Thomas et al. 2003; Fernández et al. 2004; Moir et al. 2005; Wang et al. 2006). The composition of species in the early stages of succession is controlled by local micro-environmental conditions (soil moisture, temperature, pH, organic matter etc.) and the effects of land use before abandonment. In particular, the availability of nutrients and the suitability of the area where the seed will be planted have a significant role in future forest composition (Wunderle 1997). Secondary forests grown in abandoned grasslands cannot be distinguished from mature growth forests in terms of root density and trunk surface area (basal area) (Aide et al. 2000). In some abandoned grasslands, the first forest regeneration is slower since it occurs after other natural or anthropogenic degradations (Aide et al. 1995), however, recovery is accelerated after 10 to 15 years when woody plants are saved from weed pressure (Rivera & Aide 1998).

Studies concerned with natural forest regeneration basically reveal the existing situation and do not establish a relation between spatial land characteristics accompanying the succession (Faber-Langendoen 1992; Helmer 2000; Perz & Skole 2003; Sann et al. 2016). Nevertheless, how spatial factors may affect the development of forest and biodiversity in natural regenerated forests is discussed less often because most of the spatial studies are carried out in afforestation areas (Geri et al. 2010; Qi et al. 2013). The recovery of forest structure is an important process to maintain ecosystem processes (e.g., hydrological and biogeochemical cycles) at the site. Accounting for site specifics along with different times of abandonment is an important method to evaluate the form of vegetation recovery (Grau et al. 2003).

The aim of the study is to (i) explore the sites covered with secondary productive forests that developed following land abandonment under climate change between 1987 and 2013 on pasturelands in Şebinkarahisar, a highland in the Eastern Black Sea Region and (ii) account for the environmental-spatial factors (parent material, altitude, slope, topographic solar radiation index, distance from forest edge) that determine forest regeneration. The study was carried out in productive forest ecosystems that naturally grow on pasturelands.

Material and methods

Study Area

Geographic Region

The study area is located on mountainous area in the Eastern Black Sea region between 38°21‘ – 38°38‘ eastern longitudes and 40°20‘ – 40°29‘ northern latitudes in the northeast of Turkey (Figure 1). The study was carried out on a total area of 131.1 km^2.

Climate

The altitude of the study area located within the boundaries of Şebinkarahisar district of Giresun province varies between 1450 m and 2250 m. Eastern Black Sea mountains partially prevent the north-northwest winds and the humid air coming from the Black Sea from reaching the study area. The study area, which receives relatively low humid air coming from the sea, was distinguished as the Canik-Giresun Mountains Coast Site. In the Eastern Black Sea coast area, the humid air entering from west along the Kelkit River valley is slightly felt in the Mesudiye-Şebinkarahisar direction (Kantarcı 1995).

Floristic Region

The study area is located in the Euxine province of the Euro-Siberian floristic region. Broad-leaved forest mixed with conifers spread in the higher parts of the Euxine province (Davis 1971).

The vegetation of Şebinkarahisar, located in the south of the Giresun-Canik mountains, is different from the northern slopes. *Picea orientalis* (L.) Link, which spreads on the northern slopes, leaves its place to *Pinus sylvestris* L. mostly in pure community on the southern slopes. Mixed forests of *Pinus sylvestris* L., and *Abies nordmanniana* (Stev.) Spach. subsp. nordmanniana occur at higher altitudes, while forests of *Carpinus betulus* L. and *Quercus macranthera* F. Mey. subsp. syspirensis spread at lower altitudes. In addition, trees such as *Populus tremula* L. and *Salix alba* L. spread along the streams in the district (Anşin 1981, Kınalıoğlu and Uzun 2016).

Dominant tree species in study area are *Pinus sylvestris* L. (Scp), *Abies nordmanniana* (Stev.) Spach. subsp. Nordmanniana (F), *Quercus macranthera* F. Mey. subsp. syspirensis (Q) and *Populus tremula* L. (P).

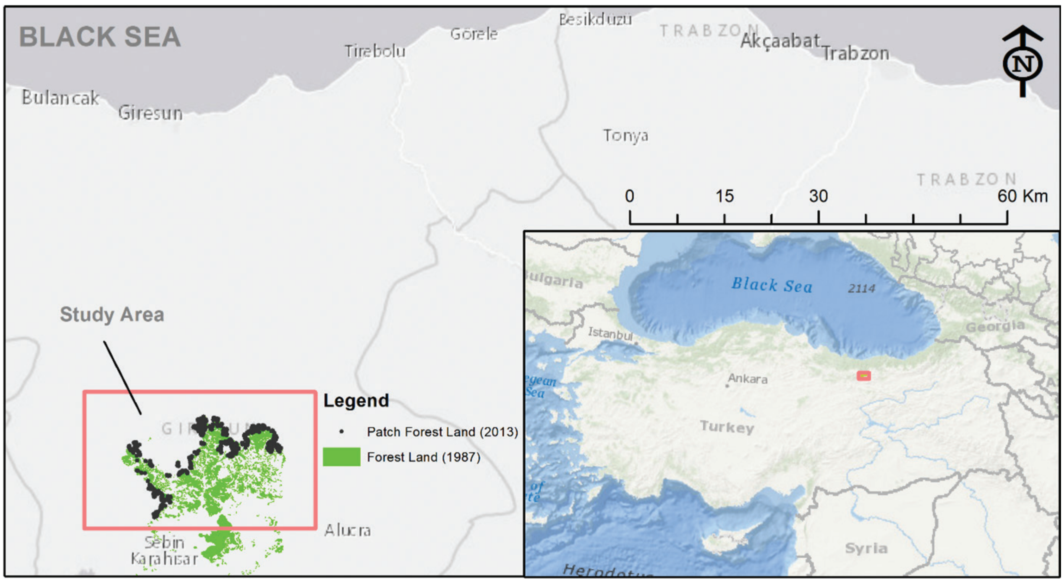

Figure 1. Location of the study area

Demographics

The population (1990, 2000 and 2010) of Şebinkarahisar-Center and its villages were obtained from the Turkish Statistical Institute (TSI 2019). The population of the central district (57,4%) and Altınçevre village (7,7%) increased in 2000, however, it decreased significantly in 2010. The population of all villages and center decreased significantly between 1990 and 2010 (Table 2).

Climate Trend Analyses

The climate data between 1984 – 2017 of Şebinkarahisar meteorological station were used for trend and climate analysis. The climate data was provided by the Turkish State Meteorological Service (TSMS) in Ankara. Mann-Kendall and Sen's trend analyses were applied to the annual temperature (average, maximum and minimum) and annual total precipitation (1984-2017). The rapid increase in global average temperature after 1980 was effective in taking this period in trend analyses (WMO 2012).

Mann Kendall Trend Analysis

This test is a commonly used method in determining the trends of hydro-meteorological time series (Zhang et al. 2001, Yue et al. 2002). This method is useful since it allows the presence of missing data and does not require data to be complied with a specific distribution (Yu et al. 1993). Trend analyses were performed using MAKESENS 1.0 (Salmi et al. 2002).

Sen Trend Analysis

If there is a rectilinear trend in a time series, then the actual inclination (change in unit time) can be estimated using a simple nonparametric procedure developed by Sen (1968). The Sen Method allows statistical determination of the calculated inclination from zero. The upper and lower confidence limits are determined in the rank correlation, and the confidence interval and the inclination values corresponding to these rank limits are determined (Partal & Kahya 2006).

Thornthwaite Climate Analysis

Thornthwaite method is based on the relationship between temperature and precipitation and evapotranspiration. According to the method, water balance of an area is calculated by using the monthly average temperature, monthly average precipitation and monthly evapotranspiration values of that area (Thornthwaite 1948).

Thornthwaite climate analysis (Thornthwaite 1948) was performed using the climate data of Şebinkarahisar (1965-2017) meteorological station. Some results of climate analysis are presented in Table 1.

Spatio-Temporal Change

The forest stand maps of the management plans of Şebinkarahisar Forestry Management (GDF 1987; GDF 2013) were processed in ArcGIS (ESRI 2013) to determine the temporal change for the two planning periods (during the period 1987-2013). The stands that went through transformation from pasture lands in the first forest management plan into productive forests in

Table 1. Annual average values of climate analysis results (Şebinkarahisar) (Temp: Temperature, Prec: Precipitation, AET: Actual Evapotranspiration)

Climate Parameters						
Temp °C	Prec mm	AET mm	Water Deficit mm	Water Surplus mm	Dominant Wind Direction	
					Annual	March and November
9.3	566.2	384.6	232.8	181.6	NE	SW

Table 2. Populations of centers and villages close to the research area

Provinces/Districts	Years			Change (in %)	
	1990	2000	2010	1990-2000	1990-2010
Center	23330	36713	11786	57.4	-49.5
Villages					
Altınçevre	286	308	186	7.7	-35.0
Gökçetaş	157	100	79	-36.3	-49.7
Gürpınar	368	179	142	-51.4	-61.4
Konak	412	365	256	-11.4	-37.9
Şaplıca	409	349	218	-14.7	-46.7
Toplukonak	404	325	288	-19.6	-28.7

Table 3. Mann Kendall and Sen trend statistics of climate variables (ns: nonsignificant, +: 0.1, *: 0.05, **: 0.01, ***: 0.001, Z: The presence of a statistically significant trend is evaluated using the Z value (Mann Kendall method), Q: Slope (Sen's Method), β: Constant (Sen's Method))

Climate Variables	*Z*	*Sig.*	*Q*	B
AvTemp	4.09	***	0.06	7.35
AvTempSp	2.54	*	0.05	6.52
AvTempAu	2.60	**	0.06	8.57
pTotal	-1.39	ns	-2.77	665.93
PinVEG	1.90	+	1.85	136.00
PoutVEG	-2.28	*	-3.99	469.84
AETveg	1.81	+	1.20	251.18

the second plan (according to the dominant tree species) were taken into account in the temporal change. The spatial analyses of tree species (distance from forest edge, altitude, slope and aspect) were performed using GIS. For this purpose, the study area was divided into equal size squares and point features were generated systematically within each 10x10 m square. The altitude, slope and aspect values of the points were obtained using the SRTM data with a resolution of 30 m (USGS 2013). The aspect variable was converted into a topographic solar radiation index used by Roberts & Cooper (1989) for statistical evaluation. Topographic solar radiation index (Radind) is calculated by the following equation:

$$Radind = \frac{1 - Cos\left(\left(\frac{\pi}{180}\right)(aspect - 30)\right)}{2}$$

This conversion assigns value “0” to the field in the north-northeast direction (typically the coldest and most humid direction) and value “1” to the warmer, drier slopes in the south-southwest direction (Moisen & Frescino 2002).

Statistical Analyses

In the study, the comparison of dominant tree species according to the spatial characteristics (distance from forest edge, topographic solar radiation index, slope and altitude) of systematic 10x10 m points (18342 points) placed on the study area was performed by variance analysis (One-Way Anova) and the data variability was presented using Box-Whisker's plot. The subgroups were compared with the SNK (Student-Newman-Keuls) test for spatial characteristics. Data frequency of distance from forest edge was presented by grouping (0-20, 20-40, 40-60, 60-80, 80-100, 100-200, 200-300, 300-400, 400-500, 500-600 m). Principal Component Analysis (PCA) was applied to explore the relationships between spatial characteristics (altitude, slope and topographic solar radiation index) as independent variables and the spatial distributions of dominant tree species as a dependent variable. Statistical analyses were performed in SPSS (SPSS 2015).

Results

Climate Change

Mann-Kendall and Sen‘s trend analyses were applied to the annual values for the 1984-2017 period of: (i) annual average temperature (AvTemp); (ii) spring annual temperature (AvTempSp); (iii) autumn average temperature (AvTempAu); (iv) total precipitation (pTotal); (v) precipitation during vegetation period (PinVEG); (vi) precipitation outside vegetation period (PoutVEG) from the Şebinkarahisar meteorological station in the study area; and (vii) to the annual values of the climate variable (AETveg) calculated for the vegetation period as a result of the thornthwaite climate analysis (Table 3).

According to trend analysis, significant increases were determined in the variables of AvTemp ($p<0.001$), AvTempSp ($p<0.05$) and AvTempAu ($p<0.01$) in Şebinkarahisar (Figure 2). In the trend analysis performed for the vegetation period, significant increases were found in the variables of PinVEG ($p<0.1$) and AETveg ($p<0.1$) while a significant decrease was found in the PoutVEG ($p<0.05$) variable (Figure 2). According to Sen‘s trend analysis, it was determined that there was 1.9 ^{o}C increase in AvTemp, 1.7 ^{o}C increase in AvTempSp and 2.0 ^{o}C increase in AvTempAu. According to the analysis, there was 61.1 mm increase in PinVEG, 39.5 mm increase in AETveg and 131.8 mm decrease in PoutVEG.

Land Cover Change in Pasturelands

The study was carried out on the lands that were transformed from pasture areas into natural productive forests in Şebinkarahisar. According to

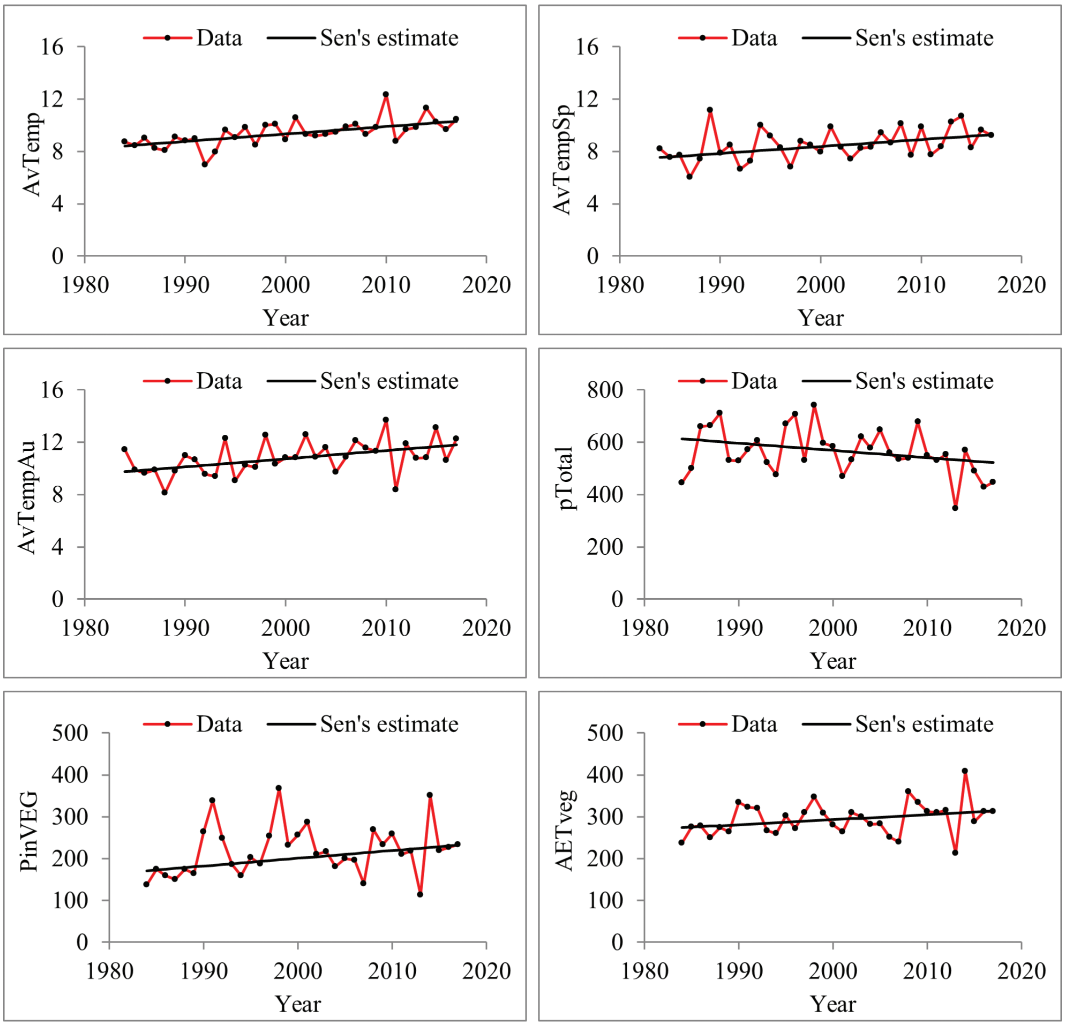

Figure 2. Sen's estimate trends of climate parameters for Şebinkarahisar (AvTEMP: Average Temperature, AvTEMPSp: Spring Average Temperature, AvTEMPAu: Autumn Average Temperature, pTotal: Total Precipitation, PinVEG: Precipitation during Vegetation Period, PoutVEG: Precipitation outside Vegetation Period, AETveg: Actual Evapotranspiration during Vegetation Period)

the forest management plan of Şebinkarahisar (1987), the pasturelands were 13109.8 ha. In the next forest management plan (year 2013), 483 ha of pasturelands were transformed into 183.2 ha productive forests and 299.8 ha degraded forests (Table 4). In productive forest areas, *P. sylvestris* covers an area of 78.6 ha, *A. nordmanniana*, *P. tremula* and *Q. macranthera* cover areas of 57.9 ha, 41.1 and 5.6 ha, respectively.

Table 4. Land use/land cover (LULC) change in pasturelands (Scp: *P. sylvestris*, F: *A. nordmanniana*, P: *P. tremula*, Q: *Q. macranthera*, Rc: Rocky, Pst: Pasture, Agr: Agriculture, St: Settling)

	LULC (2013)												
	Productive Forest (ha.)				Degrade Forest (ha.)				Open Space (ha.)				Total (Ha.)
	Scp	F	P	Q	Scp	F	P	Q	Rc	Pst	Agr	St	
LULC (1987)	78.6	57.9	41.1	5.6	155.5	41.0	42.7	60.6	80.4	12448.0	72.3	26.1	13109.8
Total	183.2				299.8				12626.8				

Parent Material

Parent materials in the study area are andesite-basalt, granite and volcanoclastic sedimentary. From the dominant tree species, on andesite-basalt and granite, *P. sylvestris* and *Q. macranthera* had the highest spread and the lowest spread, respectively. On volcanoclastic sedimentary, *P. tremula* and *A. nordmanniana* had the highest spread and the lowest spread, respectively. *A. nordmanniana* did not spread on the granite compared to other tree species (Table 5).

Variance Analysis

The comparison of tree species according to the spatial factors (distance from forest edge, topographic solar radiation index, slope and altitude) was performed by variance analysis and box-plot graphs. Significant differences at a level of significance of $p<0.001$ were obtained among dominant tree species according to spatial factors (Table 6). Box-Plot graphs of spatial factors are presented in Figures 3.

The altitude of the study area ranges between 1485 – 2246 m. Accordingly, the average altitude was found to be the highest in *A. nordmanniana* (1997±120 m) and the lowest in *Q. macranthera* (1811±139 m) (Table 6). According to the graph, 1st - 3rd quartile values varied between 1917 m and 2085 m in *A. nordmanniana* and between 1736 m and 1893 m in *Q. macranthera* (Figure 3). The distance from forest edge of the tree species growing in the pasturelands varied between 0 and 532 m (Table 6). It was determined that the average distance from forest edge was the highest in *P. tremula* (75±119 m) and the lowest in *Q. macranthera* (24±25 m). According to the graph, 1st - 3rd quartile values varied between 10 m and 70 m in *P. tremula* and between 6 m and 33 m in *Q. macranthera* (Figure 3).

Table 5. Spatial distribution of tree species on parent materials

Species	Andesite-Basalt (ha)	Granite (ha)	Volcanoclastic Sedimentary (ha)	Total (ha.)
P. sylvestris	64.9 (45.3%)	9.6 (57.1%)	4.1 (17.7%)	78.6
A.nordmanniana	56.4 (39.4%)	-	1.5 (6.5%)	57.9
P. tremula	18.8 (13.1%)	6.5 (38.7%)	15.8 (68.4%)	41.1
Q. macranthera	3.2 (2.2%)	0.7 (4.2%)	1.7 (7.4%)	5.6
Total (ha.)	143.3 (100%)	16.8 (100%)	23.1 (100%)	183.2

Table 6. Variance analysis results

Statistic	*A. nordmanniana*	*P. tremula*	*Q. macranthera*	*P. sylvestris*	*F-Rate*	*Sig. Level*
Altitude (m)						
Min.	1674	1616	1485	1660	1407.89	0.001
Max.	2246	2185	2044	2238		
Median	2017	1865	1869	1999		
Mean±SD	1997±120d	1881±109b	1811±139a	1985±100c		
Distance (m)						
Min.	0	0	0	0	76.57	0.001
Max.	440	532	143	475		
Median	22	26	15	25		
Mean±SD	57±84b	75±119d	24±25a	69±99c		
Radind						
Min.	0.00	0.00	0.03	0.00	1072.21	0.001
Max.	1.00	1.00	1.00	1.00		
Median	0.24	0.54	0.45	0.75		
Mean±SD	0.35±0.34a	0.55±0.34c	0.50±0.29b	0.67±0.31d		
Slope (%)						
Min.	4	6	9	7	518.57	0.001
Max.	99	82	69	94		
Median	52	39	45	45		
Mean±SD	51±14d	41±13a	42±12b	44±14c		

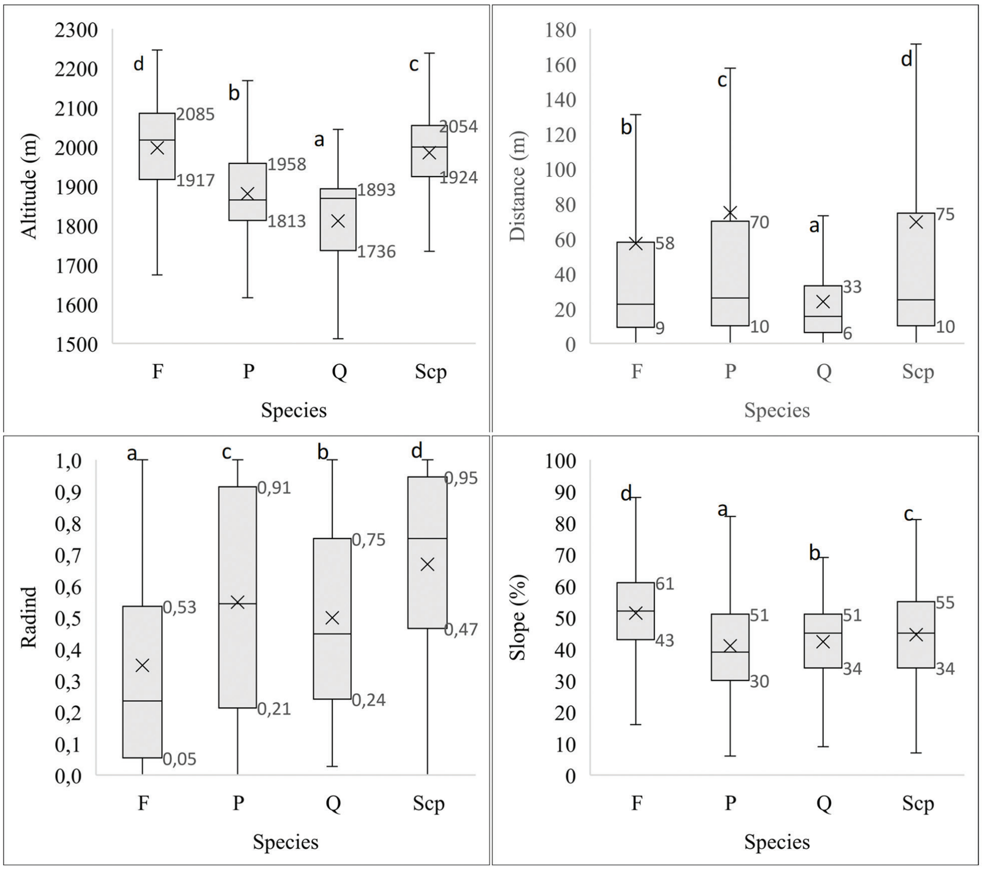

Figure 3. Change of environmental variables according to tree species (groups that do not have a letter in common differ significantly (SNK's significant differences test: P <0.001). Scp: *P. sylvestris*, F: *A. nordmanniana*, P: *P. tremula*, Q: *Q. macranthera*, Radind: Topographic Solar Radiation Index)

The topographic solar radiation index (Radind) of tree species varied between 0.00 and 1.00. It was determined that the average topographic solar radiation index value was the highest in *P. sylvestris* (0.67±0.31) and the lowest in *A. nordmanniana* (0.35±0.34) (Table 6). According to the graph, 1st - 3rd quartile values were between 0.47 – 0.95 in *P. sylvestris*, between 0.05 – 0.53 in *A. nordmanniana*, between 0.21 – 0.91 in *P. tremula*, and between 0.24 – 0.75 in *Q. macranthera* (Figure 3).

The slope of tree species varied between 4% – 99%. The average slope was found to be highest in *A. nordmanniana* (51±14) and lowest in *Q. macranthera* (41±13) (Table 6). According to the graph, 1st - 3rd Quartile values varied between 43% – 61% in *A. nordmanniana* and between 30% – 51% in *P. tremula* (Figure 3).

Regarding the percentage of data distribution, while distance from forest edge was the highest at 0-20 m in all tree species, the data density rapidly decreased to 80-100 m. Apart from *Q. macranthera*, the other tree species (*A. nordmanniana*, *P. sylvestris* and *P. tremula*) increased at 100 – 200 m and started to decline again. However, *P. tremula* started to increase again at 400-500 m (Figure 4).

PCA Analysis

When the two plan periods (1987 - 2013) were taken into account, principal component analysis (PCA) was applied to explore the relationships between spatial factors and tree species in productive forest areas

Table 7. Results of principal component analysis of species and spatial variables. (Scp: *P. sylvestris*, F: *A. nordmanniana*, P: *P. tremula*, Q: *Q. macranthera,* Radind: Topographic solar radiation index)

	Variables			Species				Eigenvalues	Variance	Cumulative Variance
Components	Altitude	Radind	Slope	P	Scp	Q	F			
I. Component	**0.732**	**-0.524**	**0.703**	**0.764**	0.051	**0.504**	**0.877**	1.31	43.49	43.49
II. Component	**0.224**	**0.845**	**0.397**	0.125	**0.608**	0.145	0.104	0.92	30.71	74.20

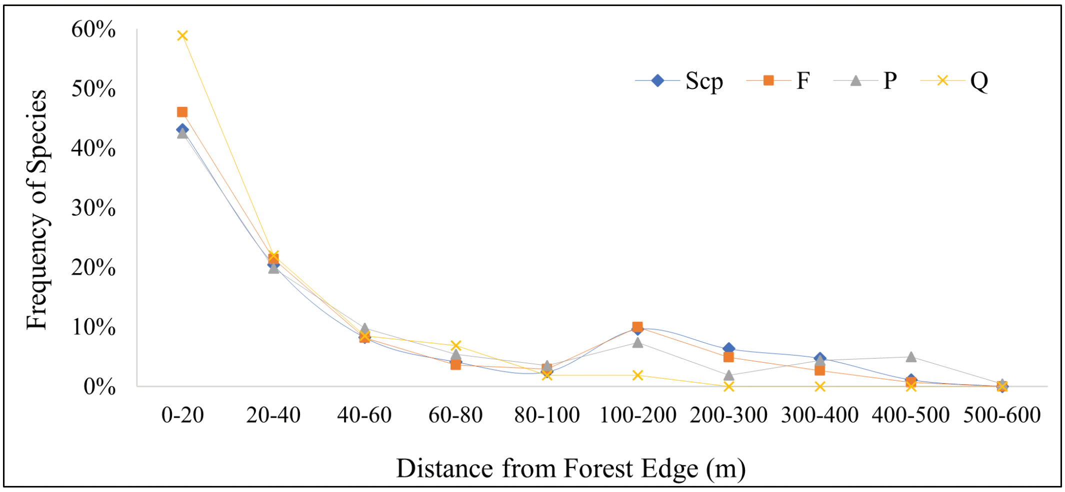

Figure 4. Frequency of species in distance from forest edge (Scp: *P. sylvestris*, F: *A. nordmanniana*, P: *P. tremula*, Q: *Q. macranthera*)

growing on pasturelands. The results of the principal component analysis were presented in Table 7.

According to Table 7, the first two principal components explained 74.20% of the total variance. Component I met 43.39% of the total variance while Component II met 30.71% of the total variance. Biplot results for Components I and II of PCA showed the distribution of dominant tree species associated with spatial variables (Figure 5).

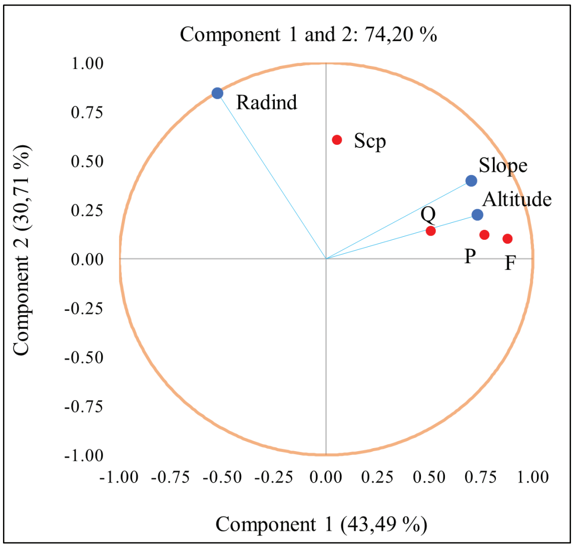

Figure 5. Spatial variables and tree species in PCA (Scp: *P. sylvestris*, F: *A. nordmanniana*, P: *P. tremula*, Q: *Q. macranthera*)

In the correlation analysis, Component I axis showed a positive correlation coefficient with *P. tremula*, *Q. macranthera*, *A. nordmanniana*, altitude and slope and showed a negative correlation coefficient with topographic solar radiation index. Component II axis showed a positive correlation coefficient with *P. sylvestris*, altitude, topographic solar topographic solar radiation index and slope. The decrease in topographic solar radiation index in response to the increased altitude and slope compared to Component I increased the spatial distribution of *P. tremula*, *Q. macranthera* and *A. nordmanniana*. The increase in altitude, slope and topographic solar radiation index compared to Component II resulted with increase of the spatial distribution of *P. sylvestris* (Table 7).

Discussion

Climate change and land cover change

The Sen's trend analysis showed significant increases in all average temperature variations (AvTemp, AvTempSp and AvTempAu). These increases allow for the early onset and late end of the vegetation period. The vegetation period gets warm and extends (Ruosteenoja et al. 2011). The early onset of the vegetation period affects phenological events occurring in spring, e.g., earlier leafing of trees (Chmielewski & Rötzer 2001). The extension of the vegetation period is strongly affected by the climate change (Goetz et al. 2005; Piao et al. 2010). It was suggested that longer vegetation seasons, that stand out especially in the form of early spring vegetation greening, significantly increased the vegetation productivity in temperate regions (Kimball et al. 2004; Hu et al. 2010).

The early start of the vegetation period in late winter and its late end in late autumn is expected to cause changes in the distribution of precipitation during the year. Although the trend analysis showed not significant relationship for pTotal, an increase (61.1 mm) was found in the PinVEG variable while a decrease (131.8 mm) was found in the PoutVEG variable. Accordingly, it was found that the amount of increased PinVEG and decreased PoutVEG variables could not balance each other. In pTotal, that consider the difference between the PinVEG and PoutVEG variables, showed quite significant amount of precipitation decrease (70.7 mm). The increase in average temperatures led to increases (39.5 mm) in the variable AETveg (actual evapotranspiration during vegetation period). It means that the increase in AETveg can be compensated by the increase in PinVEG (61.1 mm) in the present. However, it is likely that serious water deficits in the upcoming years could occur, if climate warming continues. Any change in climate parameters due to climate warming may also affect the evapotranspiration (Goyal 2004). Climate warming is expected to increase drought conditions, especially in arid and semi-arid regions (Moratiel et al. 2010). Local and regional climate patterns constantly affect the response of vegetation cover depending on time. While feedback between climate and vegetation cover manage the distribution and growth dynamics of terrestrial vegetation cover, changing climatic conditions have potential to cause rapid and irreversible land changes (Allen and Breshears 1998). In particular, the transformation of pasturelands into natural productive forests is the most important evidence of it. In the study, according to the next forest management, total of 483 ha of pastures were transformed to 183.2 ha productive forests and 299.8 ha degraded forests. In productive forest areas, *P. sylvestris* covers an area of 78.6 ha, *A. nordmanniana*, *P. tremula* and *Q. macranthera* cover areas of 57.6 ha, 41.1 and 5.6 ha, respectively. The decrease in rural population can be shown as the reason for the increase in productive forest areas. In addition, the abandonment of grazing practices along with the decrease in population is another important factor contributing to the increase in productive forest areas with climate change. The population of the central district and Altınçevre village increased in 2000, however, it decreased notably in 2010 (Table 2). The population of other villages decreased between 1990 and 2010. The decrease in anthropogenic pressure (Rudel et al. 2005; Perz 2007; Perz & Skole 2003) due to the decrease in population and the negative effects of rapid improvements in industry may contribute to the increase in forest areas. Here, the change in climate and the response of tree species to this change in a 27-year period along with the decreasing anthropogenic pressure is noteworthy. In general, the most obvious response to climate change is observed in vegetation cover (Hobbs & Humphries 1995; White et al. 2005).

Environment-spatial variations in secondary productive forests

In the study area, parent materials are andesite-basalt, granite and volcanoclastic sedimentary (conglomerate, sandstone, limestone, siltstone, claystone, mudstone, and gypsum) (Karakaya 1998). Sandy loam and loamy sand soils with high water and air permeability and poor plant nutrients are derived from granite. On the other hand, sandy clay loam and loamy clay soils with better water holding capacity and plant nutrient are derived from andesite-basalt (Kantarcı 2000). Conglomerates are thick bedded and coarse graveled (Ege 2015). In a study carried out in an area where volcanoclastic sedimentary was found, it was reported that the availability of horizontally bedded sandstone and hard conglomerate decreased the water and nutrient retention due to the high ratio of skeletons although the physiological depth was appropriate site dependent (Karatepe & Koyun 2017). From the dominant tree species, *P. sylvestris* and *Q. macranthera* had the highest spread and the lowest spread, respectively, on andesite-basalt and granite, and *P. tremula* and *A. nordmanniana* had the highest spread and the lowest spread, respectively, on volcanoclastic sedimentary. *A. nordmanniana* did not spread on the granite compared to the other tree species. *A. nordmanniana* mainly spreads on the andesite-basalt. *Abies sp.* develops on different parent materials but grows in deeper soils with high water holding capacity (Caudullo & Tinner 2016). Therefore, *Abies sp.* forests that grow at low altitudes, on shallow soils and southern slopes face the biggest threats (Alizoti et al. 2011). Nevertheless, *P. sylvestris* (Mátyás et al. 2004), *Q. macranthera* (Ducousso & Bordacs 2003) and *P. tremula* (von Wühlisch 2009) can grow on well-ventilated sandy soils with poorer plant nutrients and water permeability. The findings of this study show that during the 27-year period, the regeneration process of forest trees on pasturelands does not develop randomly and a combination of factors such as location, soil, climate-climate change, human and others plays a significant role in the regeneration of tree species on pasturelands.

The altitude of the study area varies between 1485 m and 2246 m (Table 6). The recovery of forests tends to occur at high altitudes where the land is first abandoned (Thomlinson et al. 1996). In the PCA analysis, it was observed that the increase in altitude increased the spatial distribution of all tree species (*P. sylvestris*, *A. nordmanniana*, *P. tremula* and *Q. macranthera*). In general, pasturelands are alpine areas above the forest boundary, and these areas allow the seeds to spread and settle in the area. However, the temperature increasing due to climate change that occurred in the study area may have an effect on seed germination, seed formation and growth. Indeed, it was previously stated that there were significant increases (1.7 ^{o}C in AvTempSp, 2.0 ^{o}C in AvTempAu) in the trend analysis performed for average temperatures during vegetation period. The increase in temperatures allows forest boundary to be moved up to higher altitudes on pasturelands. As the altitude increased, the plant life in mountainous regions was limited directly and indirectly due to direct or indirect effects of low temperatures, radiation, wind and storm, or insufficient water availability (Körner & Larcher 1988). The first-order approach in the response of vegetation cover to climate change is that species will move upward in finding climate conditions similar to today's conditions in tomorrow's climate (Peters & Darling 1985).

The distance from forest edge of the tree species growing in the pastureland varied between 0 and 532 m (Table 6). It was determined that the average distance from forest edge was the highest in *P. tremula* (75 m) and the lowest in *Q. macranthera* (24 m) (Figure 3). Distance from forest edge (m) values varied between 10 m and 70 m in *P. tremula* and between 6 m and 33 m in *Q. macranthera*. Distance from forest edge plays the most important role affecting the settling of tree species in the areas and its duration and has long-term effects on forest dynamics (Oikonomakis & Ganatsas 2012). Heavy-seeded species are characterized by low distribution capacity (Wagner et al. 2010). Thus, forest expansion is lower in heavy-seeded species compared to light-seeded species (Oikonomakis & Ganatsas 2012). Bird's feathers help the wind distribution of *P. tremula* seeds the capsules of which are opened during maturity (von Wühlisch, 2009). Thus, distance from forest edge was found to be higher in *P. tremula* compared to other species. Nevertheless, acorn-shaped seeds of *Q. macranthera* are heavier, and distance from forest edge is expected to be lower than other species. Mammals and birds are important for the propagation of *Q. macranthera* seed. In particular, Eurasian jay (*Garrulus glandarius*) is an important bird species that can be considered as a primary spreader (Eaton et al. 2016). In previous studies, it was reported that forest lands were a seed source for open areas such as pasturelands and serve as a critical site for animal seed dispensers (Uhl et al. 1988; Chazdon 2003). The seeds of *P. sylvestris* (Mátyás et al. 2004) and *A. nordmanniana* (Alizoti et al. 2011) are carried by wind. Furthermore, the seeds of *P. sylvestris* have high migration ability (Mátyás et al. 2004). The study shows that while distance from forest edge on pastureland was the highest at 0-20 m in all tree species, the data density rapidly decreased to 80-100 m. Apart from *Q. macranthera*, other tree species increased at 100 – 200 m and started to decline again. However, *P. tremula* started to increase again at 400-500 m.

The direction of forest regeneration in pasturelands is generally north-trending from old forest areas (Figure 1). The annual dominant wind direction of the study area is in the NE direction, which has a positive effect on the transport of humid air masses from the north to the study area (Rudel et al. 2000; Daly et al. 2003). Nevertheless, it inhibits the transport of matured seeds by wind. Namely, dominant wind direction and forest regeneration are almost reverse. However, according to meteorological station data in the study area, dominant wind blows from the SW especially in March and November. The start time of fall of matured seeds of tree species and maximum falling time are in February-May for *P. sylvestris*, in October-November for *A. nordmanniana* and in November for *Quercus sp.* (Ürgenç 1998). In *P. tremula* species, the seeds are distributed in spring (Yaltırık 1994). During these months, the dominant wind direction which is mainly in the SW direction is expected to contribute significantly to the distribution of tree seeds.

The highest and lowest average topographic solar radiation index were determined in *P. sylvestris* and *A. nordmanniana*, respectively. The topographic solar radiation index were between 0.47 – 0.95 in *P. sylvestris*, 0.05 – 0.53 in *A. nordmanniana*, 0.21 – 0.91 in *P. tremula*, and 0.24 – 0.75 in *Q. macranthera* (Figure 3). The topographic solar radiation index assigns the value "0" to the land in the north-northeast direction (typically the coldest and most humid direction) and the value "1" to the warmer and drier slopes in the south-southwest direction (Moisen & Frescino 2002). The topographic solar radiation index indicates that *P. sylvestris* prefers more arid areas while *Abies sp.* prefers more humid areas. When tree species are evaluated according to the topographic solar radiation index, it can be said that the ecological requirements of tree species come to the forefront and also climate change that acts as a driving force. The PCA analysis (Figure 5) showed that the increase of topographic solar radiation index increased the spatial distribution of *P. sylvestris*. Hence, *P. sylvestris* was mostly shifted to dry lands. *P. sylvestris*, which is a heliophytic and also a pioneer species, is tolerant to frost and drought (Durrant et al. 2016). It can establish forests in degraded sites with low competition and grazing pressure (Matyas et al. 2004). *P. sylvestris* can grow in the sites that are mostly sunny, partly shaded and generally poor in nutrients (Farjon 2010). Firs are typically shade-tolerant species. This species grows in humid regions and is frost-tolerant under the shield. Its humidity requirement is quite high (Ürgenç 1998).

The PCA analysis (Figure 5) showed that the decrease in topographic solar radiation index increased the spatial distribution of *P. tremula* and *Q. macranthera* species. However, Figure 3 clearly shows that both species had a wide tolerance range. Furthermore, it can be said that *P. tremula* and *Q. macranthera* have a wider tolerance compared to *P. sylvestris* and *A. nordmanniana*. When the PCA analysis and the variability outside the upper and lower quartiles of Box-Whiskers plots are jointly considered, the *P. tremula* that can adapt to extreme climatic conditions (very humid - very arid) mainly prefers humid areas. On the other hand, *Q. macranthera* that avoids extreme climatic (very humid - very arid) conditions mainly prefers humid areas, as in the *P. tremula* species. Although *Quercus sp.* prefers humid and fertile soils, they are strong trees with high ecological tolerance (Ellenberg 2009). This drought-tolerant species has a high light requirement (Praciak 2013; Savill 2013), and its canopies support the regeneration of many tree species and enrichment of biodiversity (Ellenberg 2009). *P. tremula* has the ability to grow quickly in the sites suitable for the light and humidity requirement. Rapid growth continues until the age of about 20 with increased top cover competition. After that, the increase in growth is slower and ends at about 30 years old (von Wühlisch 2009).

The average slope of the tree species (41-51%) were found to be high for all tree species (Figure 3). While high slope in the study area decreases the anthropogenic pressure, it promotes the natural distribution of the species. Proximity to old forest areas, the increase in distance to roads, and steeper slopes are quite effective in the conversion of pasturelands to forests (Helmer 2000; Chazdon 2003; Crk et al. 2009). Furthermore, urbanization is less likely to occur on rugged terrains and supports the regeneration of forests on steep lands (Helmer 2004; Lopez et al. 2001). The PCA analysis (Figure 5) shows that the increase in slope promotes distribution of all tree species. While the degree of slope varies according to tree species, it may increase up to a maximum of 69 - 99% (Table 6). Steep slopes on high attitude create further challenges for using the mountainous pasturelands as agricultural areas. Hence, the decrease in anthropogenic pressure in the villages.

Conclusion

In conclusion, the development of productive forest areas in mountainous pasturelands under climate change occurred dynamically with a secondary forest succession process. Undoubtedly, the decrease in anthropogenic pressure was effective in the realization of this process in a dynamic way. The secondary forest succession observed in mountainous pasturelands was significantly affected by spatial-environmental factors such as parent material, aspect, altitude and slope. In the 27-year period, the measure of distance from forest edge was an important spatial factor on the forest dynamics contributing to the settling and development of tree species that established productive forests in the pasturelands. Although the dispersion and distribution of seeds depends on wind and animal carriers, following the dispersal, the germination rate of the seedlings largely depends on the species ecological requirements. Indeed, this study finds out that tree species were affected by environmental-spatial variations depending on their ecological requirements in the sites. The history of land cover change, climate changes, and environmental and spatial differences that constitute have the potential to interact in a complex way in determining the success of forest regeneration. Improving the understanding of these interactions may improve land management and provide arguments for a better approach towards preserving ecosystem dynamics, particularly with reference to open areas such as pasture and pasture in semi-arid ecosystems like the study area.

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