Kastamonu Uni., Orman Fakültesi Dergisi, 2023, 23(3): 186-198 Research Article
Kastamonu Univ., Journal of Forestry Faculty
Doi:10.17475/kastorman.1394879

Assessing Spatio-Temporal Change and Dynamics of Forest Ecosystem Succession Using Patch Analysis

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Received Date: 08.05.2023 Accepted Date: 23.08.2023

Abstract

Aim of study: This study focuses on creating a secondary forest succession (SFS) map between 1972 and 2014 according to the Clementsian theory based on land cover, assessing the spatio-temporal pattern of forest succession change, and determining the factors affecting the forest ecosystem.

Area of study: This study was conducted at the Çermik Forest Enterprise (FE) in Diyarbakır city, located in the Southeastern Anatolia Region of Türkiye.

Material and methods: Clementsian theory, Remote Sensing (RS), and Geographical Information System (GIS) were used to generate the SFS map. Patch Analyst 4.0 was used to determine changes in spatiotemporal patterns with landscape indices.

Main results: The total forested area increased from 32405.1 ha (13% of the study area) in 1972 to 45054.7 ha (18% of the study area) in 2014, with a net increase of 12649.6 ha. It was determined that the progressive succession area was 87736.7 ha, the regressive succession area was 39216.5 ha, and the unchanged succession area was approximately 129989.6 ha. The number of patches increased over a 42-year period.

Research highlights: The forest ecosystem was more fragmented, with patches becoming more irregular, complex, and edgy.

Keywords: Fragmentation, GIS, Landscape Metrics, Patch Analyst, Succession

Patch Analizi ile Orman Süksesyonunun Konumsal ve Zamansal Değişiminin Değerlendirilmesi

Öz

Çalışmanın amacı: Bu çalışmanın amacı, Clements'in yaklaşımına göre 1972 ve 2014 yılları için sekonder orman süksesyon haritasını düzenlemek, süksesyonun konumsal ve zamansal değişimini değerlendirmek ve değişimi etkileyen faktörleri ortaya koymaktır.

Çalışma alanı: Bu çalışma, Türkiye'nin Güneydoğu Anadolu Bölgesi'nde yer alan Diyarbakır ilinde bulunan Çermik Orman İşletmesi'nde gerçekleştirilmiştir.

Materyal ve yöntem: Sekonder orman süksesyon haritasını oluşturmak için Clements'in yaklaşımı, Uzaktan Algılama (UA) ve Coğrafi Bilgi Sistemi (CBS) kullanıldı. Parçalılık indeksleri yardımıyla konumsal ve zamansal değişiklikleri belirlemek için Patch Analyst 4.0 kullanıldı.

Temel sonuçlar: Toplam ormanlık alan 1972'de 32405.1 hektardan 2014'te 45054.7 hektara yükseldi (12649.6 hektar artış). İleri süksesyon 87736.7 ha, geri süksesyon 39216.5 ha ve değişmeyen süksesyon alanı yaklaşık 129989.6 ha olarak belirlendi. Parça (patch) sayısının 42 yıllık bir zaman diliminde arttığı tespit edildi.

Araştırma vurguları: Orman ekosistemi, parçaların daha düzensiz, karmaşık ve köşegen hale gelmesiyle birlikte daha parçalı bir hale geldi.

Anahtar Kelimeler: Parçalılık, CBS, Arazi Metrikleri, Yama Analizi, Süksesyon

Introduction

Succession is the turnover of different species compositions and vegetation cover over a certain period. The formation and change of species composition and structure in forest ecosystems take place over a long period of time. The forest succession grows after forest clearance for agriculture, clearcutting for harvesting activities, and natural hazards such as fire, storms, and insect

Citation (Atıf): Sivrikaya, F., & Cakir, G. (2023). Assessing Spatio-Temporal Change and Dynamics of Forest Ecosystem Succession Using Patch Analysis. *Kastamonu University Journal of Forestry Faculty*, 23 (3), 186-198.

damage (Guariguata & Ostertag, 2001; Fernandez et al., 2004; Uotila & Kouki, 2005; Çakır et al., 2007a; Çakır et al., 2007b; Terzioğlu et al., 2010). Succession in forest ecosystems is one of the main ecological processes that can affect many terrestrial functions, such as the water cycle, carbon sequestration, and biodiversity. The relationships between successional processes and biotic and physical environments are complicated and influenced by various factors, including climate, topography, and anthropogenic activities (Çakır et al., 2007b; Terzioğlu et al., 2010; Kidd, 2017; Çakır, 2019).

An accurate understanding of vegetation dynamics is essential for forestry practice as well as theoretical studies. Therefore, knowing the historical dynamics of succession stages is important for understanding the forest ecosystem (Song et al., 2006; Çakır et al., 2007a). According to recent studies, human activities, succession, land cover type, and topography have had a significant impact on the spatio-temporal change of vegetation patterns (Turner et al., 1996; Cohen et al., 2002; Günlü et al., 2009; Bozali et al., 2015). The spatial structure of forest ecosystems, as well as the size of patches and forest cover types, have been altered by human activities (Manier & Laven, 2002; Sivrikaya et al., 2007; Terzioğlu et al., 2010; Bozali et al., 2015).

As ecosystems confront rising anthropogenic impacts, it is critical that we figure out how to better monitor SFS. It may be determined using a variety of methodologies based on RS (Çakır et al., 2007b; Chraibi et al., 2021; Osińska-Skotak et al., 2021). RS and GIS have the ability to aid in the study of ecological processes at the landscape level in forest ecosystem (Sivrikaya, 2002; Akay et al., 2012). RS has been widely used for vegetation monitoring (Anderson, 2018; Luque et al., 2000), biodiversity analyses (Wang & Gamon, 2019; Rocchini et al., 2021), species diversity estimation (Draper et al., 2019), and the mapping of SFS (Çakır et al., 2007b). RS and GIS provide a useful approach for determining land cover change over time (Çakır et al., 2008; Akay et al., 2014; Bozali et al., 2015; Sivrikaya & Yıldırımer, 2017). Analyzing land cover-based SFS using RS and GIS is a new development in coppice forests; there is not much study relevant to succession mapping in Türkiye (Çakır et al., 2007a; Terzioğlu et al., 2010).

The main purpose of the study was to monitor the SFS change between 1972 and 2014, to reveal the factors that affect it, and to evaluate it in terms of biodiversity according to the Clementsian theory based on land cover using Patch Analyst. The study was carried out in the Çermik FE located in the Southeastern Anatolia Region of Türkiye. RS and GIS were used to determine succession categories and create the SFS maps. The results will assist ecosystem managers in enhancing their understanding and control of SFS dynamics and their implications for forest ecosystems.

Material and Methods

Study Area

The study area is located in the Southeastern Anatolia Region of Türkiye, between latitudes 37⁰ 47' 30" and 38⁰ 20' 24" N and longitudes 39⁰ 06' 15" and 39⁰ 56' 59" E (Figure 1). The Çermik FE encompasses a land area of approximately 257056 hectares. Nearly 20% of the study area (49989 ha) is forest area, and approximately 80% (207067 ha) is non-forest area. The primary forms of vegetation encompass Quercus species, *Pinus nigra* J.F. Arnold, and *Cedrus libani* A. Rich. The oak stands were managed as coppice forests until 2014, and later these stands were converted to high forests.

The primary sources of livelihood for the residents of Çermik FE are generally agriculture, marble, and sheep breeding. The total number of farmer families in Çermik is 5300, 4500 of which live in the village, whereas 800 live in the district center. The number of farmer families officially registered with the farmer registration system is 3384. The arable agricultural area of the district is 36216 hectares. 88% of the population is engaged in agriculture and cattle breeding. Generally, cotton, wheat, barley, millet, lentils, chickpeas, and feed crops are grown in Çermik. Rice, pistachio, and grape cultivation are becoming more widespread in some villages.

Forests are primarily utilized to meet the needs for firewood and animal feed. Due to the destruction of forest vegetation and the high slope, the soil has been considerably eroded, and bedrock has been exposed in most places. The erosion negatively affected the balance of soil, water, and forest vegetation in the case study area. The forest ecosystem is destroyed by the supply of firewood and overgrazing. Unplanned farming negatively affects afforestation activities. The branches of the trees are cut with leaves and stored in order to be fed to animals in the winter season. This way of utilizing forests causes the deterioration of forest ecosystems.

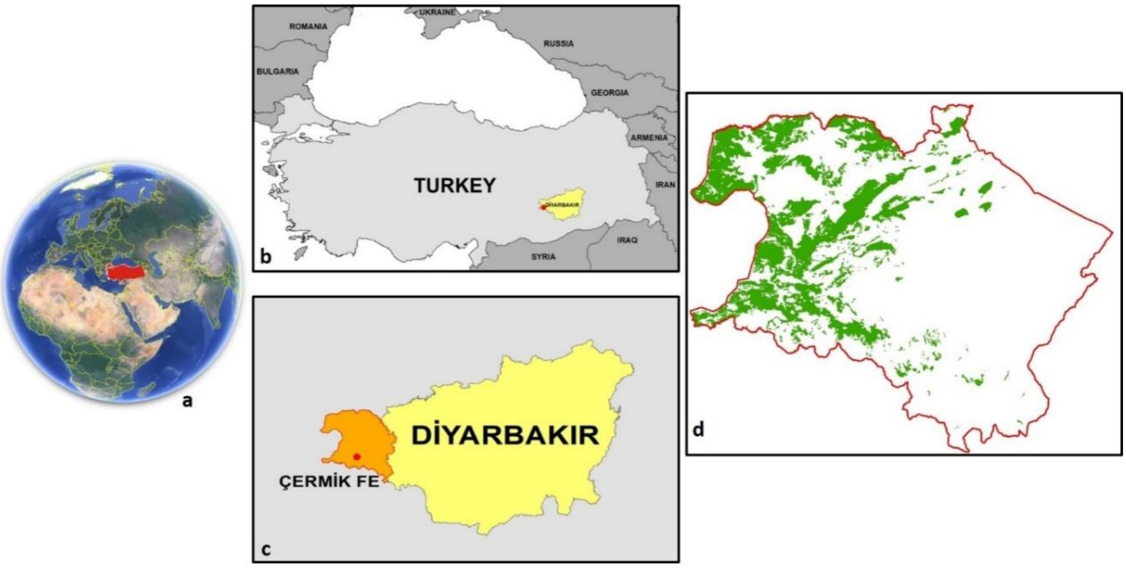

Figure 1. Location of study area. Maps show overviews of the (a) world scale, (b) national scale, (c) regional scale, and (d) forest stands in Çermik FE.

Database Development

The spatial database included forest cover type maps, which were acquired from the General Directorate of Forestry (GDF), SFS maps for 1972 and 2014, as well as attribute data. Both maps were created using digital aerial photographs with 35 cm spatial resolution (color infrared; red, green, and blue bands) and field surveys (Çakır, 2006; Çakır et al., 2006; Çakır, 2019). The GDF provided digital aerial photographs of the study area for the year 2014. The photographs were obtained with a specified overlap in and across the track to enable stereo analysis and to generate gapless photo mosaics during an airborne inspection using a digital camera. The forward overlap ratio was 60%, and the side overlap ratio was 30%. Aerial triangulation is a very important stage of photogrammetry. It presents the 3D positions of the measured points on the photographs. Aerial triangulations were carried out with Match-AT (Inpho and Intergraph) and Pat-B software. Multispectral mosaics were created in orthophoto aerial photographs with a UTM coordinate system (WGS 84 datum). Thus, digital aerial photographs were made ready for the forest cover type map and forest succession stage evaluation. Using ArcGIS 10.6 software, circular sample plots were scattered throughout the forest at 300-meter intervals during the field survey. The sample plot sizes were determined based on the stand crown closure, with sizes of 400, 600, and 800 m^2 corresponding to crown closures >70%, 70-41%, and 40-11%, respectively (Anonymous, 2008). In each sample plot, tree species, crown closure, development stage, and site index were measured. A hand-held GPS with a ground accuracy of 5 meters was used to locate sample plots. After the field survey, a digital forest cover type map was created by evaluating the field data together with the RS data. The spatial database of the digital forest cover type map included crown closure, stand type, development stages, and successional stages. The paper forest cover type map for 1972 was scanned, digitized, and processed using ArcGIS 10.6, with sufficient accuracy. To create forest succession maps and estimate changes and spatio-temporal changes in each succession stage, spatial analysis in GIS was utilized.

The utilization of landscape metrics is advantageous in the quantification of landscape structure and the development of effective strategies for managing spatial development in landscapes. These metrics also serve as indicators of qualitative attributes associated with land cover types, thereby conveying information about the characteristics of the landscape. The concept of forest landscape spatial dynamics encompasses the temporal variations in various characteristics, including patch size, patch number, patch shape, patch adjacency, and patch proximity within a given landscape. The indices employed in this study were utilized to acquire significant data regarding the overall land structure and ecological indicators, including fragmentation, habitat suitability, heterogeneity, edge effect (irregularity), and biodiversity of the ecosystem. The quantification of spatial and temporal patterns was conducted by calculating landscape indices using Patch Analyst 4.0 within the ArcGIS 10.6 software. In this study, four different statistical categories were used to evaluate the spatial structure of the forest ecosystem: (a) patch density and size metrics; (b) shape metrics; (c) edge metrics; and (d) diversity metrics. Eleven indices were considered: (1) Number of Patch (NP), (2) Mean Patch Size (MPS), (3) Mean Patch Edge (MPE), (4) Mean Shape Index (MSI), (5) Area Weighted Mean Shape Index (AWMSI), (6) Patch Size Standard Deviation (PSSD), (7) Patch Size Coefficient of Variation (PSCoV), (8) Total Edge (TE), (9) Edge Density (ED), (10) Shannon's Diversity Index (SDI), and (11) Shannon's Evenness Index (SEI)

Estimating Secondary Forest Succession Based on Land Cover Type

Various methodologies have been employed to ascertain the process of SFS (Clements, 1936; Odum, 1969; Kojima, 1981). The present study assessed SFS based on the Clementsian theory, which encompasses six distinct categories as outlined in Table 1. A successional value of zero (0) is also employed to represent areas of water and settlement where no plant species are present.

Table 1. Definition of Clementsian theory

	Categories	Definition
1	Nudation	The disruption of vegetation on a place where succession can occur.
2	Migration	Arrival of plants at the open site
3	Ecesis	The establishment of plants in the field
4	Competition	The interaction of plants at the field
5	Reaction	The alteration of the field by the plants
6	Stabilization	Development of a stable climax

Based on forest cover type, the following fundamental land cover types were identified: degraded forest, productive forest, forest opening area, settlement, agricultural, water, sandy area, and pasture. A field survey was carried out in 2013. The estimation of successional stages in each sample plot was conducted based on the Clementsian theory. After the field study was completed, the SFS stages observed in the sample plots were utilized to ascertain the succession values, which were subsequently categorized according to stand type. Then, the forest cover type map was finalized. In addition, digital aerial photographs were used to confirm the successional stages. The SFS maps from 1972 and 2014 were simply prepared by using succession stages for each stand type. To better understand successional changes, Clementsian theory was integrated with land cover categories such as forest opening area, settlement, agriculture, sandy area, water, productive forest, degraded forest, and rangeland areas. Consequently, both successional and land cover changes were examined simultaneously.

Results and Discussion

Between the years 1972 and 2014, there was an observed increase in the total forest area within the study area. Specifically, the forest area expanded from 32,405.1 hectares, which accounted for 13% of the study area, to 45,054.7 hectares, representing 18% of the study area (Table 2). The forest area included degraded and productive forest areas. The primary reason for the increase in forest areas from 1972 to 2014 was the conversion of forest opening areas into productive and degraded forest areas (13397.0 ha of degraded forest and 1570.9 ha of productive forest). The main reason for the increase in forest area is afforestation activities in forest-opening areas. Afforestation activities were carried out on an area of 3848.8 ha in the study area. Another reason is the conversion of 5738.9 ha of agricultural land into degraded forest due to population movement and the decline in rural population. In addition, successful silvicultural prescriptions have also increased the quality of the forest structure. In this context, 3616.3 ha of degraded forest areas have been transformed into productive forest areas.

Between 1972 and 2014, the spatio-temporal change of SFS was shown in Table 3 and Figure 2. According to the spatio-temporal change of SFS results, it was determined that the progressive succession area was 87736.7 ha, the regressive succession area was 39216.5 ha, and the unchanged succession area was 129989.6 ha. The results of this study indicate that the process of succession in the study area is characterized by a progression towards the climax community, and that this progressive succession persists over time. Of the 284.4 ha agricultural area, 3 ha have been converted to water and 23.6 ha to forest openings. Furthermore, 56220.1 ha of agriculture area was converted to forest opening, 2540.2 ha of agriculture area was converted to settlement area, 17253.5 ha of forest opening was converted to agriculture area, 3848.8 ha of forest opening was transformed to afforestation area, 6712.0 ha of degraded forest was transformed to forest opening, 3243.1 ha of degraded forest was converted to agriculture area, and 222.2 ha of degraded forest was converted to settlement area.

Table 2. Temporal changes of SFS

SFS	1972		2014		Difference
	Area (ha)	%	Area (ha)	%	Area (ha)
0 Settlement (0S)	284.4	0.1	3648.7	1.4	3364.3
0 Water (0W)	-	-	2784.2	1.1	2784.2
1 Agriculture (1A)	148718.8	57.9	101633.8	39.6	-47085.0
1 Sand (1S)	-	-	65.1	-	65.1
2 Afforestation (2AF)	-	-	4912.5	1.9	4912.5
2 Forest Opening (2FO)	71130.4	27.7	95695.1	37.2	24564.7
2 Rangeland (2R)	-	-	3148.7	1.3	3148.7
2 Rocky Area (2RA)	4404.1	1.7	-	-	-4404.1
3 Degraded Forest (3DF)	32405.1	12.6	39414.7	15.3	7009.6
3 Productive Forest (3PF)	-	-	5624.6	2.2	5624.6
4 Productive Forest (4PF)	-	-	15.4	0.0	15.4

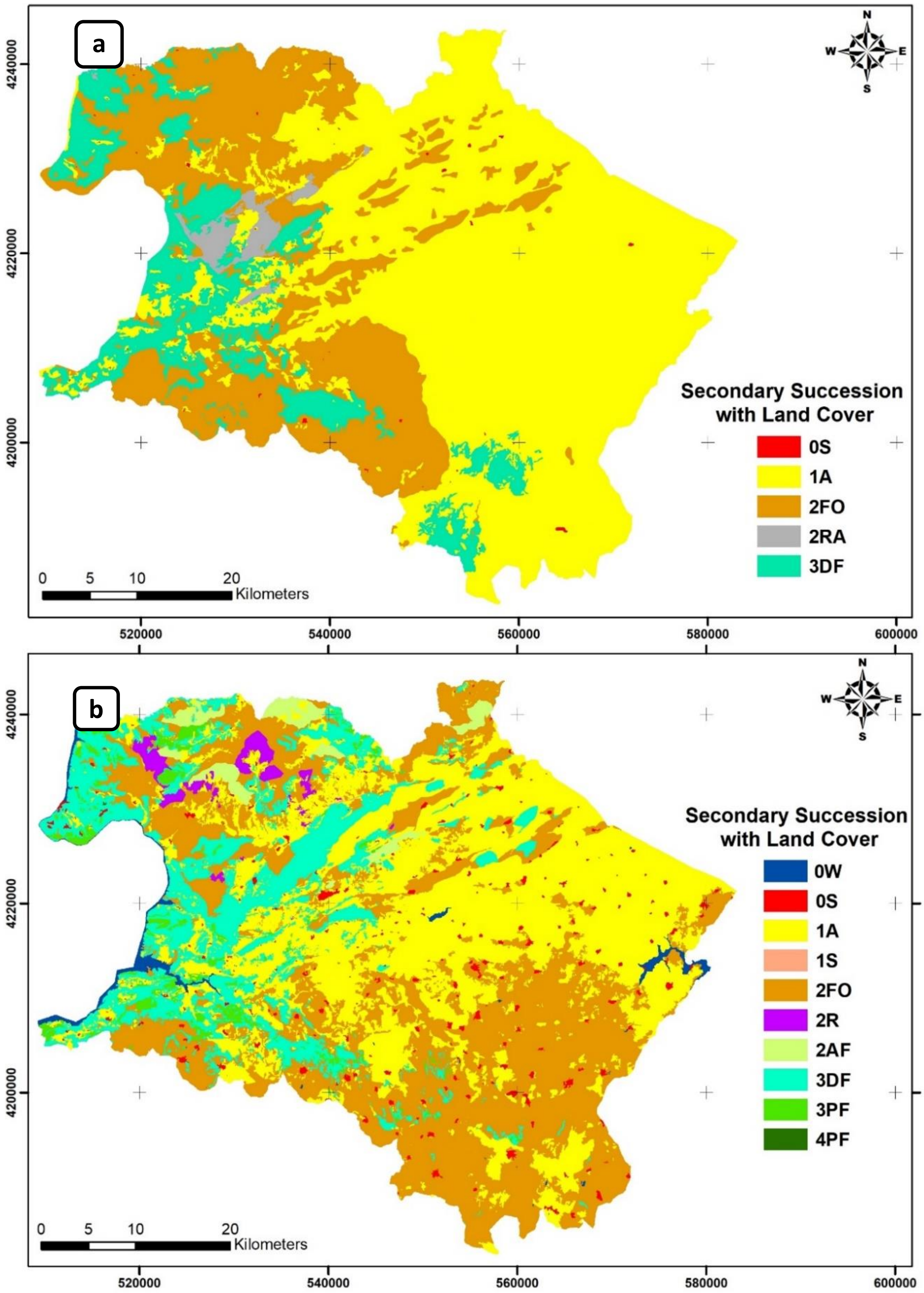

Figure 2. The SFS maps in a) 1972, b) 2014

Table 3. Spatial changes of secondary forest succession

	0S	0W	1A	1S	2AF	2FO	2R	2RA	3DF	3PF	4PF	Total (ha)
0S	176.1	3.0	78.6		0.9	23.6	0.3	-	1.8	0.1	-	284.4
0W	-	-	-	-	-	-	-	-	-	-	-	-
1A	2540.2	1610.3	80693.3	54.8	1055.0	56220.1	386.3	-	5738.9	419.9	-	148718.8
1S	-	-	-	-	-	-	-	-	-	-	-	-
2AF	-	-	-	-	-	-	-	-	-	-	-	-
2FO	683.1	388.1	17253.5	9.4	3848.8	31351.2	2628.4		13397.0	1570.9	-	71130.4
2R	-	-	-	-	-	-	-	-	-	-	-	-
2RA	27.1		365.3			1388.2	98.1		2508.0	17.4	-	4404.1
3DF	222.2	782.8	3243.1	0.9	7.8	6712.0	35.6		17769.0	3616.3	15.4	32405.1
3PF	-	-	-	-	-	-	-	-	-	-	-	-
4PF	-	-	-	-	-	-	-	-	-	-	-	-
Total	3648.7	2784.2	101633.8	65.1	4912.5	95695.1	3148.7	-	39414.7	5624.6	15.4	256942.8

Succession is a process, and anthropogenic or natural causes can disrupt successional stages. The important factors affecting this process are fire, insects, forestry activities, harvest schedules, silvicultural treatments, population growth, land demand for timber products and agriculture, and urbanization (Frelechoux et al., 2003; Fernandez et al., 2004; Blatt et al., 2005; Çakır et al., 2007a; Özcan et al., 2022; Sivrikaya & Küçük, 2022; Yilmaz et al., 2023). The most common tree species observed within the study area was oak, a tree species characterized by its minimal susceptibility to fire. The study site was situated in a region characterized by highly fire-resistant properties attributed to its specific climatic and ecological factors. Consequently, there has been a minimal occurrence of forest fires, thereby indicating that the fires have had negligible impact on the process of successional change. Insects have an effect on species composition and SFS. The insect effect on successional change is generally regressive (Çakır et al., 2007a). The insect had no effect on the SFS change in the Çermik FE between 1972 and 2014.

Anthropogenic disturbances, such as harvesting techniques and silvicultural treatments, play a significant role in influencing forest succession (Çakır et al., 2007b). Çermik FE was managed based on a maximum wood production approach until 2014. With the adoption of the ecosystem-based multi-purpose planning approach in Türkiye, the management plan in 2014 was prepared according to this approach, and the intensive wood production was abandoned. The General Directorate of Forestry (GDF) carried out a project in oak forests managed as coppice in order to obtain the highest yield and increase forest areas in terms of quality and quantity. In the context of this study, the majority of coppice forests, both those classified as productive and degraded, have undergone a transformation into high forests, with the aim of achieving an important enhancing in forest productivity. When examining the research domain from this particular standpoint, it was observed that all coppice forests underwent a transformation into high forest. The key factors that explain forest succession changes and increasing forest stand productivity in the study region are effective silvicultural prescriptions and the conversion of coppice forests to high forests.

The majority of changes in land and forest cover are related to human populations. Human population pressure and increased land demand from forests for agricultural and timber products are the major drivers of deforestation (Ochoa-Gaona, 2001; Çakır et al., 2008; Keleş et al., 2008; Bozali et al., 2015). High population density causes forest areas to decrease and species to face extinction (Wakeel et al., 2005). Urbanization is recognized as a significant contributor to the decline of numerous biological populations and the consequential alterations in plant species diversity (Kondratyeva et al., 2020). Rapid urban growth, in most cases, leads to the destruction of natural vegetation and the replacement of it with roads, buildings, and imported plants and trees. The population of Çermik between 1972 and 2014 increased by 34% (from 38046 to 50928), and the settlements expanded. Changes in living standards, migration from rural to urban areas, and a decline in village population have decreased the pressure on forest stands. This situation has led to an increase in forest areas and progressive succession in terms of quantity and quality.

Oikonomakis & Ganatsas (2012) examined the alterations in land cover and the patterns of secondary forest regeneration between the years 1945 and 2009 in Greece. A spatial analysis was conducted using cartographic data. Based on the results, a significant expansion of forested areas was documented in the region, with nearly the entire landmass (96.79%) being encompassed by forests as a result of a SFS process. The remaining land types within approximately half of the studied area in 1945 underwent a transformation into forested areas. Nevertheless, the secondary forest succession that was observed did not lead to a homogeneous forest type, thereby confirming the relationships between environmental factors and successional trends. Three primary succession trends were identified in the observed area. The observed trends encompass the establishment and growth of *Pinus sylvestris* forests, *Picea abies* forests, and *Fagus sylvatica* forests. It is important to highlight that these forests exhibited a uniform distribution across the entire region.

Variations in the land cover types of Phu Yen Province were investigated through the establishment of land cover changes in 2010, 2015, and 2020. During the time frame from 2010 to 2015, there was a notable decline in the extent of natural forests, shrubs, grasslands, and bare lands, while there was a substantial increase in the coverage of deliberately cultivated forests, industrial trees, and crops. The landscape of Phu Yen Province has undergone a secondary ecological succession over the past 50–60 years that has been significantly shaped by human activities. The notable forms of succession in Phu Yen's agroforestry landscape involve the sequential process of converting a natural forest into a plantation forest or agricultural land across various stages (Dang & Trung, 2022). In Peña-Claros' (2003) study, a categorization was made to distinguish four distinct groups of tree species. The first group consists of species that exhibit the highest abundance during the initial phase of succession. The second group comprises species that dominate during the second phase. The third group includes species that reach their maximum abundance in the third phase, which corresponds to old-growth forests. Lastly, the fourth group encompasses mid-successional species that do not display any discernible trend in abundance as stand age progresses. The species belonging to the third group exhibited variability in terms of their initial colonization period. Certain species were observed in stands as young as 2–3 years old, while others were only observed in stands that were 20 years old (Peña-Claros, 2003).

The NP is a measure of landscape aggregation or division (Berila & Isufi, 2021). It is seen that the NP increased from 430 to 2365. The MPS decreased from 2475.0 ha to 1351.9 ha in the period from 1972 to 2014. Accordingly, the PSCoV increased from 2548.1 to 5148.1, and the PSSD decreased from 18033.2 to 6869.1 (Table 4). The results clearly showed an increased variation in patch sizes. The increase in the NP and PSCoV and the decrease in the MPS and PSSD reveal that the forest became more fragmented over a 42-year time period. Although the amount of forested area in the study region increased dramatically, the spatial quality of the forest ecosystem diminished. The primary factors contributing to the degradation and fragmentation observed in the study area encompass the establishment of diverse land use categories, the transformation of degraded coppice forest into high forest, and ineffective silvicultural interventions. The AWMSI increased from 24.2 to 57.6, and the MSI increased with a value from 8.8 in 1972 to 20.6 in 2014. The MSI value evaluates average part shapes, and the AWMSI value evaluates area-weighted part shapes. Large patches have a greater impact on the forest ecosystem than small patches. According to MSI and AWMSI values in the research area, the shape of the patches in 2014 is more irregular than in 2014. The results indicate the complexity and irregularity of patches and a more rounded shape in an edgy environment. The TE, the ED, and the MPE increased over a 42-year time period. Environmental and biological changes are greatly influenced by edge effects (Mumcu-Küçüker & Sarı, 2021). Furthermore, external impacts such as fire, exotic species, pests, and viruses enter fragmented areas through forest borders (Benitez-Maldiva & Rodrigez, 2008). Shannon's indices are frequently employed in the evaluation of landscape composition through the analysis of the diversity and extent of landscape components, with a focus on the coherence of land cover types (Malinowska & Szumacher, 2013). The Shannon measurements for richness and evenness can be used to quantify the variety of a landscape. Evenness is a measure of the relative area of land cover classes, whereas richness is a measure of their abundance. The SDI increased from 1.01 to 1.34. However, the SEI decreased from 0.62 to 0.58 ha in the period from 1972 to 2014. All results showed that the forest ecosystem became more fragmented, and patches became more irregular, complex, and edgier in spite of increasing forest area.

Table 4. Spatio-temporal change of the SFS categories between 1972 and 2014

Class	NP		MPS		MPE		MSI		AWMSI		PSSD		PSCoV		TE		ED	
	1972	2014	1972	2014	1972	2014	1972	2014	1972	2014	1972	2014	1972	2014	1972	2014	1972	2014
0S	76	319	3.7	11.4	716.7	1656.6	1.2	1.5	1.2	1.6	6.0	13.8	160.2	120.5	54472.4	528463.0	0.21	2.06
0W	-	21	-	132.6	-	11364.9	-	2.1	-	8.8	-	424.1	-	319.9	-	238662.0	-	0.93
1A	144	870	1032.8	116.8	10495.8	4759.0	1.8	1.8	6.4	13.0	11639.6	2434.1	1127.0	2083.6	1511400.0	4140360.0	5.88	16.11
1S	-	3	-	21.7	-	6153.1	-	3.1	-	5.7	-	26.8	-	123.3	-	18459.2	-	0.07
2AF	-	8	-	614.1	-	20008.9	-	2.3	-	2.5	-	364.5	-	59.4	-	160072.0	-	0.62
2FO	121	455	587.9	210.3	11678.4	8129.8	1.7	2.0	6.2	11.2	3785.5	2603.7	643.9	1238.0	1413090.0	3699030.0	5.50	14.40
2R	-	27	-	116.6	-	5916.1	-	2.0	-	2.4	-	228.5	-	195.9	-	159734.0	-	0.62
2RA	10		440.4		14843.6		2.0		4.3		1035.9		235.2		148436.0		0.58	-
3DF	79	397	410.2	99.3	14662.3	6554.3	2.1	2.1	6.1	7.9	1566.2	718.2	381.8	723.4	1158320.0	2602040.0	4.51	10.13
3PF	-	263	-	21.4	-	2658.6	-	1.9	-	2.7	-	52.4	-	244.9	-	699212.0	-	2.72
4PF	-	2	-	7.7	-	1693.6	-	1.8	-	1.8	-	3.0	-	39.2	-	3387.3	-	0.01
Total	430	2365	2475.0	1351.9	52396.8	68894.9	8.8	20.6	24.2	57.6	18033.2	6869.1	2548.1	5148.1	4285718.4	12249420.5	16.68	47.67

Conclusions

It is very important to realize the current SFS stages and the vegetation dynamics in order to guarantee the long-term viability of the natural structure and biological diversity of the forest ecosystem. Temporal and spatial changes in SFS based on Clementsian theory were revealed according to four different landscape indices. Although there has been an increase in forest area and progressive succession, the forest ecosystem has deteriorated and fragmented over the 42-year period. These results indicate that the forest ecosystem is potentially in danger of habitat loss and plant biodiversity loss. The method developed in this study to determine the stages of SFS based on land cover is simple, easy to use, and practical. Understanding SFS and succession stages is critical for determining which silvicultural prescription should be used in the forest ecosystem and will help decision-makers better describe the optimal structure of a forest stand. The assessment of current succession stages and consideration of temporal and spatial distributions are crucial factors in the development of forest management plans, as they play a significant role in ensuring the long-term sustainability of the forest ecosystem.

Acknowledgements

We wish to extend our appreciation to the General Directorate of Forestry for the supply of forest management plans and associated data.

Ethics Committee Approval

N/A

Peer-review

Externally peer-reviewed.

Author Contributions

Conceptualization: F.S., G.Ç.; Investigation: F.S., G.Ç.; Material and Methodology: F.S., G.Ç.; Supervision: F.S., G.Ç.; Visualization: F.S., G.Ç.; Writing-Original Draft: F.S., G.Ç.; Writing-review & Editing: F.S., G.Ç.; All authors have read and agreed to the published version of manuscript.

Conflict of Interest

The authors declare no conflict of interest.

Funding

The authors declared that this study has received no financial support.

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