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Use of GUIDOS to analyze fragmentation features and test corridor creation for a fragmented forest ecosystem in Northern-Central Turkey

Verwendung von GUIDOS zur Analyse von Fragmentierungsmerkmalen und zur Prüfung der Korridorbildung in einem fragmentierten Waldökosystem im nördlichen Zentrum der Türkei

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Keywords: forest fragmentation, afforestation, landscape ecology, GUIDOS

Schlüsselbegriffe: Waldfragmentierung, Aufforstung, Landschaftsökologie, GUIDOS

Abstract

Fragmentation of forest habitats is an environmental challenge that is often caused by unsuitable forest management applications and socioeconomic reasons. Habitat fragmentation is considered as one of the most important causes of biodiversity loss. Establishing tree corridors using silvicultural approaches has shown to be beneficial for ecosystem restoration efforts. Various fragmentation and corridor analyses supported by remote sensing, geographic information systems and mapping of habitats in the field are now frequently used to determine the fragmentation status of forests and to create the most suitable corridors. In this study, the fragmentation status of all forest habitats within the boundaries of Çankırı State Forest Enterprise (ÇSFE) located in the north-central region of Turkey was determined, and opportunities to improve connections between fragmented forest clusters with the corridor approach were explored. We used the Graphical User Interface for the Description of Image Objects and their Shapes (GUIDOS) Version 3.0 for fragmentation analysis and corridor formation tests, structural assessment, network, and component-connection analyses.

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We found that forest area increased by +23% within the last 30 years, but habitat fragmentation was identified in nearly all forest textures. One of the reasons were afforestation activities, that did not consider the principles of landscape ecology. If the recommendations proposed here are implemented, will help ensure long-term sustainable management in light of landscape ecology principles for forests with different fragmentation conditions, not just in the study area but also in different regions of Turkey with similar environmental conditions.

Zusammenfassung

Die Fragmentierung von Lebensräumen in Wäldern ist eine ökologische Herausforderung, die oft durch ungeeignete Waldbewirtschaftung und sozioökonomische Gründe verursacht wird. Fragmentierung von Lebensräumen gilt als eine der Hauptursachen für den Rückgang der biologischen Vielfalt. Schaffung von Baumkorridoren mittels geeigneter waldbaulicher Techniken kann bei der Renaturierung von Ökosystemen helfen. Verschiedenste Fragmentierungs- und Korridoranalysen, unterstützt durch Fernerkundung, Geoinformationssysteme und Feldkartierung von Lebensräumen, werden häufig eingesetzt, um den Fragmentierungsstatus von Wäldern zu quantifizieren und die am besten geeigneten Korridore zu schaffen. In dieser Studie wurde der Fragmentierungsstatus aller Waldlebensräume innerhalb der Grenzen des Çankırı State Forest Enterprise (ÇSFE) im nördlichen Zentrum der Türkei ermittelt und Möglichkeiten zur Stärkung der Konnektivität fragmentierter Waldgebiete getestet. Wir verwendeten das Graphical User Interface for the Description of Image Objects and their Shapes (GUIDOS) Version 3.0 für die Fragmentierungsanalyse, die Korridorbildungstests sowie die Strukturbewertung, Netzwerk- und Komponentenverbindungsanalysen. Die Waldfläche hat in den letzten 30 Jahren um etwa +23 % zugenommen, dennoch wurde in fast allen Waldstrukturen eine Fragmentierung der Lebensräume festgestellt. Einer der Hauptgründe dafür waren eine fehlerhafte Aufforstung, bei der die Grundsätze der Landschaftsökologie nicht beachtet wurden. Eine Umsetzung der hier vorgeschlagenen Empfehlungen kann helfen, eine langfristige, nachhaltige Bewirtschaftung unter Berücksichtigung der Grundsätze der Landschaftsökologie für Wälder mit unterschiedlichen Fragmentierungsbedingungen sicherzustellen, nicht nur im Untersuchungsgebiet, sondern auch in verschiedenen Regionen der Türkei mit ähnlichen Umweltbedingungen.

1 Introduction

Habitat fragmentation can be defined as transforming the original habitat into a different habitat matrix comprising small isolated patches (Wilcove *et al.*, 1986). Many studies proposed that habitat fragmentation is one of the important leading causes of biodiversity loss (Bascompte *et al.*, 2002; Fahrig, 2002; Hanski, 2005). This is linked to the misconception that partial fragmentation involves separation and living area/habitat loss (Fahrig, 2003). Several studies about habitat fragmentation to date focussed on the ecological outcomes faced by organisms living in patches/land fragments emerging linked to the change in many land use forms (MacArthur and Wilson, 1967; Collingham and Huntley, 2013).

The fragmentation of forest ecosystems is often caused by inadequate forest management techniques and some socioeconomic issues (Sharma and Roy, 2007; Riitters *et al.*, 2002). Fragmentation often occurs due to urbanization, agriculture, deforestation for timber, land clearing, or natural causes like topographical and/or climatic conditions (snow and ice), fire, insects (Coops *et al.*, 2006), or invasion of non-forest plant species (Forman and Collinge, 1995; Babbar *et al.*, 2020). This causes a reduction in the forest area and the quality of the habitat (Carranza *et al.*, 2015; Sahana *et al.*, 2015; Batar *et al.*, 2017). According to Wulder *et al.*, 2009, the fragmentation of forests may cause irreversible destruction of biotic life due to genetic bottlenecks and abiotic elements within these ecosystems in the long term (Fischer and Lindenmayer, 2007). So, the deforestation of forests due to fragmentation is accepted as one of the primary causes of reduced terrestrial biodiversity (Long *et al.*, 2010; Mengist *et al.*, 2022).

Studying forest habitat fragmentation with a comprehensive approach – including its structure, function, and evolution – is a crucial part of the forest landscape management approaches and applications (Kerr and Ostrovsky, 2003; Linke *et al.*, 2006; Rose *et al.*, 2014). It represents the most visible dynamic aspect of forest stand evolution (Long *et al.*, 2010), that is a basic element of forest landscape change patterns at stand level in space and time (Innes and Koch, 1998; Healey *et al.*, 2018) and that can be modeled using integrated techniques of remote sensing and geographic information systems at different scales, from local to regional (Newton *et al.*, 2009; Healey *et al.*, 2018).

Forest fragmentation can be studied using a combination of comprehensive forest change analyses and time series of forest cover maps (Mengist *et al.*, 2022). In order to carry out fragmentation and corridor analysis, raw data such as satellite images or aerial photographs (Harper *et al.*, 2007) to be taken from two or more different time series belonging to the study area, as well as processed data such as stand maps, habitat maps, land use maps can be used as a baseline (Gergel, 2006). However, geostatistical techniques and software tools enabled the generation of large volumes of new data from satellite imagery archives (Olariu *et al.*, 2022). The structural pattern of a landscape comprises three elements of matrix, patch, and corridor. Matrix is broad areas formed by similar ecosystems or vegetation types. Corridors are defined as narrow lands. Patches are land surfaces that are non-linear and have different appearances than surrounding land (Weiers *et al.*, 2004). Patches may display differences in terms of location, size, shape, type, and boundary features; and their structures are very important in terms of the continuity of function and quality offered to ecosystems (Theobald *et al.*, 2011). Forest clusters linked by corridors have preserved genetic diversity, and in this way, the survival capacity and sustainability of species increases. Providing connections between forest clusters, or strengthening existing connections has shown to be effective in ecology and land use management (Areendran *et al.*, 2020). The size and shape of forest fragments, the interior area contained within their boundaries, and available corridor systems are assessment criteria used for the status of forest habitats (Richard, 2011).

Biological corridors, which are developed as an alternative solution to the fragmentation problem, strengthen the interaction between forest fragments (Forman and Godron, 1986; Sharma and Roy, 2007). Biological corridors are forest clusters that ensure the integrity between forest fragments, and they have a significant potential to contribute to ecological and economic sustainability in forest ecosystems (Myroniuk *et al.*, 2020). Studying the fragmentation patterns will provide the foundation knowledge for management strategies. When creating or strengthening corridors, afforestation processes should begin after considering the topography, hydrological and soil characteristics, and the current threats to the area. It is important to thoroughly consider these factors to better support the policy and decision-making processes in forest management (Myroniuk *et al.*, 2020; Mengist *et al.*, 2022).

In this study, we attempt to guide forest managers by highlighting that fragmentation and corridor analyses can be used as tools in the management of forest fragmentation problems. Within the scope of this research, the fragmentation status, causes, and priorities of forest habitats in the study area were identified, and solution proposals were developed about creating integrated forest textures with the corridor/connectivity approach.

2 Materials and methods

2.1 Study area

The study area in this research comprised Çankırı State Forest Enterprise (ÇSFE) located from 40° 30' and 41° 00′ north latitude and 32° 30' and 34° 00′ east longitude in north-central Turkey (Figure 1). A continental inland climate is found throughout the study area. Winters are harsh and cold and summers are hot and dry. Precipitation happens as snow in winter, with an annual precipitation sum of between 397-410 millimeters. The temperature range between +42 °C and -25 °C. In the study area, there are five types of large soil groups: alluvial, colluvial, chestnut-colored, brown forest, and non-calcareous brown forest soils. The soils in the region composed of many bare mountains and plateaus are under the threat of severe erosion. In consequence the study area cannot be cultivated as pasture.

The habitat fragmentation status of the forest habitats within the boundaries of this study area was determined to test the connectivity between fragmented forest clusters using the corridor approach.

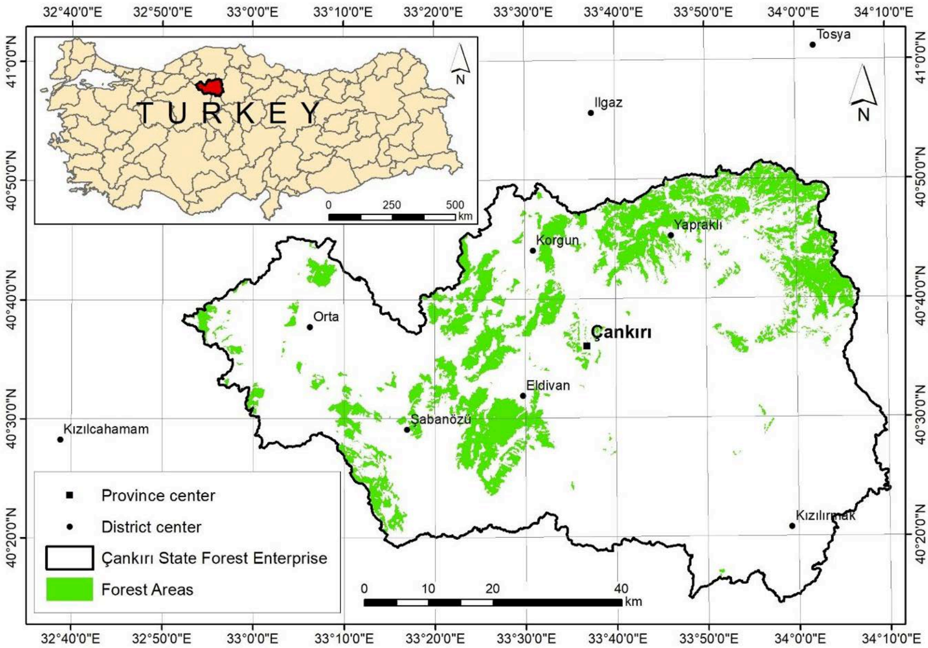

Figure 1: Location map of the study area.

Abbildung 1: Lage des Untersuchungsgebiets.

The study area, with a total size of 458,877 hectares, generally contains forests covering 76,206.9 hectares. The dominant vegetation of the study area is composed of forest trees such as larch, yellow pine, juniper, spruce, and fir, and fruit-bearing trees such as pear and dogwood. Conifer species occur in typically zoned belts with *Pinus nigra* found between 1100-1400 m, Pinus sylvestris between 1300-1700 m and *Abies nordmanniana* subsp. *equi-trojani* is located between 1500-1900 m above sea level. 43,256.8 hectares are productive forests and 32,950.1 hectares are forests with degraded quality. The forests experienced habitat degradation at varying degree in recent years linked to demands for different land uses by humans including road expansion, establishing agricultural areas, creation of settlement areas, development of mining sites, and dam construction. This situation carries a risk of disrupting the long-term sustainable use of forest assets (Sharma and Roy, 2007). It can cause quantitative and qualitative disruption of habitat quality to be experienced within wildlife management (Srivastava and Tyagi, 2016). For example, in a wildlife survey covering the years 2016-2017 specific to the study area done by Çankırı Branch Office of Nature Conservation and National Parks, 16 large mammal species were found to live in this area. It was also observed that 12 of them were directly exposed to death or injury cases as a result of traffic accidents during 2015-19 years on highways, which is an indicator of habitat fragmentation in the region (Güven, 2019).

2.2 Data

In the first stage, the basic topographic maps including information like slope, aspect, and elevation of the study area were prepared with the ArcGIS 10.5 program. Then, the Coordination of Information on the Environment (CORINE) land cover data was used with the aim of identifying the temporal variation in forest assets and other land use in the study area by comparing data from 1990, 2000, 2006, and 2018. According to CORINE and European Environment Agency (EEA), land cover/use classification, and land cover/use data were produced with the visual interpretation method supported by a computer on the satellite images. According to EEA criteria and classification units (44 classes), variations in land cover/use observed on satellite images were identified with the aid of remote sensing and geographical information systems (GIS).

With the aim of investigating the current forest assets and revealing other habitat types in the study area, the current stand map for 2018 belonging to ÇSFE was used to prepare a European Union Nature Information System (EUNIS) habitat map. EUNIS defines habitat types in Europe and is a system to classify these habitats (EEA, 2021). The classification area is very large and is a habitat classification type accepted at a regional scale encompassing all land units and seas in Europe.

2.3 Methods

First of all, in order to determine the approximately 30-year areal change in both forest cover and all other habitat types, the areal data from CORINE and EUNIS for the years 1990 and 2018 were examined in terms of percentage change (Eq. 1).

Change between 1990 and 2018 = (Area 2018 - Area 1990)/ Area 1990

Then, for specific fragmentation analyses and corridor creation tests specific to forest habitats, structural assessment, network, and component-connection analyses were applied using the Graphical User Interface for the Description of image Objects and their Shapes (GUIDOS-Version 3.0) software program based on the ArcGIS program.

This program was developed by the European Commission Joint Research Centre, Institute for Environment and Sustainability.

GuidosToolbox actually contains a wide variety of generic raster image processing routines which include free software. These tools are based on geometric principles and can thus be applied at any scale and to any kind of raster data (Soille and Vogt, 2009; Vogt and Riitters, 2017). With the aid of this program, fragmentation analysis was performed for the study area in the first stage. The foreground area density (FAD) was analyzed on 5 separate observation scales in 6 classes for forest fragmentation in the GUIDOS software. These fragmentation classes were intact, interior, dominant, transitional, patchy, and rare. The rare class includes rare patches between fragmented forests, while the patch class involves scattered forest patches without clustering. The transitional class represents forest patches undergoing habitat change, while the dominant class involves the most frequently encountered forest patches in fragmented habitats. The interior class includes areas with a core of a certain size showing central features, while intact areas are forests with no change as a result of fragmentation (Gülçin, 2020).

GuidosToolbox includes morphological spatial pattern analysis (MSPA) which is a customized sequence for analyzing the connectivity of the image components. MSPA is based on mathematical morphology concepts and defines a single land cover map of the spatial relationships between land classes forming centers and connections (Soille and Vogt, 2009). To identify the center (core area) and connections (corridors) for MSPA, a range of image processing programs are used. Each forest pixel area in the input data only represents one geometric class (Vogt and Riitters, 2017).

In order to perform more advanced analyses using graphic-theory applications, MSPA analysis results are converted to network analyses. The components in network analyses comprise core and corridor areas. With this analysis, only a few components are present in the area. Area sizes for the core and corridors comprising these components were determined.

Then, component sensitivity analysis (connectivity importance) was used to calculate the ranked importance (sensitivity) of connectivity for each core and corridor area located in the study area. The connectivity importance was calculated with the related equations in the GUIDOS program (Saura and Rubio, 2010).

The map of the target area in the GUIDOS program was uploaded as 8-bit geotiff (raster). This map had 2 data classes foreground and background. Foreground data included forest areas, while background data included regions outside of the forest area. The forest polygons on these maps were converted to 30x30 resolution raster data with ArcMap and then assigned values of 2 bytes for the foreground data class and 1 byte for the background data class.

Program parameters comprised 4 basic variables.

Variable 1 – Foreground Data Connectivity: For foreground data (forest area), connections were assumed based on diagonal or lateral faces in 3x3 adjacent pixels. In this way, the areas between two fragments were classified as corridors instead of areas with a high threat of destruction.

Variable 2 – Margin width: This is used to determine the widths of areas that are not core areas. The margin width is determined by the pixel size of the map and the selected pixel numbers. In the program, the margin width was chosen as 4 pixels; in other words, 20 m.

Variable 3 – Transition areas: Transition areas are regions where interior or exterior margins intersect with corridors and where interior corridors intersect with core areas. This variable along with margin and interior margins represents closed boundaries.

Variable 4 – Intext: This variable ensures the differentiation of interior and exterior shapes.

After producing spatial data, more specific fragmentation analyses and corridor formation tests were begun unambiguously for forest habitats. To begin with, current fragmentation definitions are only descriptive, and as a result, quantifying the degree or changes in fragmentation for a given image is impossible (Vogt and Ritters, 2017). To quantify fragmentation, the foreground area density (FAD) approach was used from the fragmentation analyses in GUIDOS. FAD is calculated by measuring foreground density (P2) over five observation scales using a moving window analysis and foreground masking with square neighborhood areas of length 7, 13, 27, 81, and 243 pixels (Riitters et al., 2002, 2012a, 2012b).

Following the fragmentation analyses, Corridor-Connectivity Analyses of MSPA have been performed: MSPA statistics window displays basic statistics for seven fundamental MSPA foreground, missing, background, opening classes, etc. The left column of the table displays the percentage that equals the number of class pixels per foreground area and per data area. The frequency equals the number of unique objects of the given class and, where applicable, the area equals the number of background pixels covered as shown in the right column.

Table 1: Area by land cover types from CORINE land cover from years 1990, 2000, 2006 and 2018 and the percent changes in area between 1990 and 2018.

Tabelle 1: Fläche der Bodenbedeckung aus CORINE Landbedeckung für die Jahre 1990, 2000, 2006 und 2018 sowie die prozentuelle Änderung der Fläche zwischen 1990 und 2018.

Code	Description	Area 1990 (ha)	Area 2000 (ha)	Area 2006 (ha)	Area 2018 (ha)	Change in % between 1990-2018
111	Continuous urban fabric	43	43	117	117	+ 171
112	Discontinuous urban fabric	2750	2750	2752	3044	+ 11
121	Industrial or commercial units	305	451	425	750	+ 146
122	Road and rail networks and associated land	70	0	0	30	-57
133	Construction sites	0	0	51	26	+ 26
141	Green urban areas	0	0	34	34	+ 34
211	Non-irrigated arable land	107691	108471	103659	110799	+ 3
212	Permanently irrigated land	31996	31970	32094	26865	-16
213	Rice fields	6760	6810	6799	7138	+ 6
221	Vineyards	280	280	0	0	-100
222	Fruit trees and berry plantations	48	48	186	186	+ 287
231	Pastures	7542	6585	7538	5365	-29
242	Complex cultivation patterns	22053	22080	19423	18988	-14
243	Land principally occupied by agriculture with significant areas of natural vegetation	61942	61740	57948	55645	-10
311	Broad-leaved forest	1070	738	489	518	-52
312	Coniferous forest	18952	19898	21988	22277	+ 18
313	Mixed forest	1655	2003	949	838	-49
321	Natural grasslands	92136	92364	101958	104446	+ 13
324	Transitional woodland-shrub	19913	18950	21145	27529	+ 38
331	Beaches dunes sands	1815	1803	1527	1400	-23
332	Bare rocks	20983	20983	19019	9226	-56
333	Sparsely vegetated areas	61902	61902	62084	64474	+ 4
411	Inland marshes	1111	1111	841	840	-24
511	Water courses	992	977	963	853	-14
512	Water bodies	216	268	236	839	+ 289
TOTAL		**462225**	**462225**	**462225**	**462225**	**0**

3 Results

With the aim of testing temporal change of the forestry assets and other land use features in the study area, CORINE satellite images were used with distribution maps prepared for land cover classes for the years 1990, 2000, 2006, and the most up-to-date data from 2018. Then the variations in land cover classes were tested for the periods 1990-2000, 2000-2006, and 2006-2018 with the aim of periodically observing changes to the land use structure during this time (Table 1).

Finally, all these changes observed in land cover from 1990-2018 were summarized and investigated in depth specific to the existence of forests (Figure 2, Table 2).

Table 2: Comparison of 1990-2018 forest area based on CORINE land cover.

Tabelle 2: Vergleich der Waldflächen 1990–2018 auf der Grundlage der CORINE Landbedeckung.

Code	Area 1990 (ha)	Area 2018 (ha)	Change in % between 1990 and 2018
311 (Broadleaf forests)	1070	518	-52
312 (Coniferous forests)	18952	22277	+ 18
313 (Mixed forests)	1655	838	-49
324 (Transitional woodland/shrub)	19913	27529	+ 38
TOTAL	**41590**	**51162**	**+ 23**

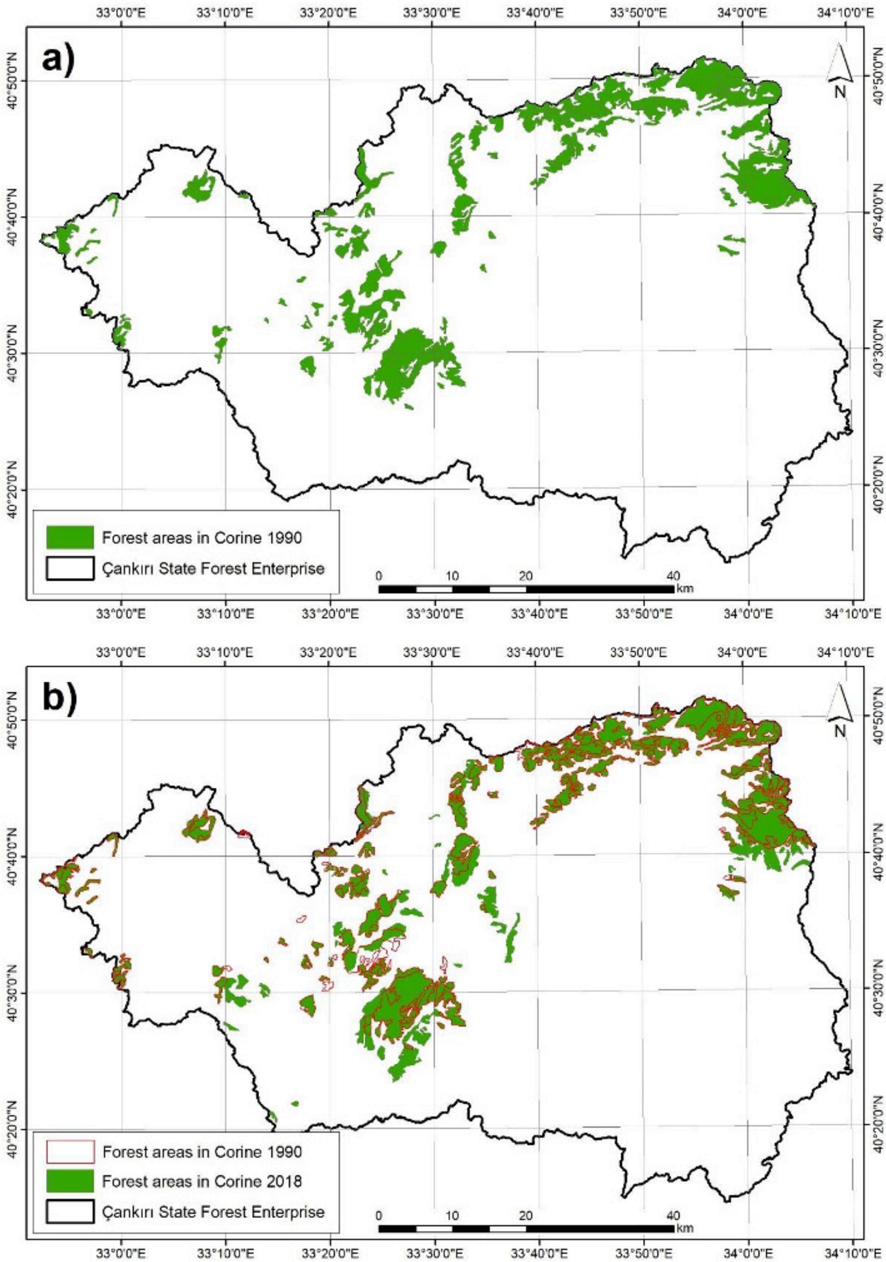

Figure 2: Changes of forest area in the study area based on CORINE land cover for 1990 (a) and 2018 (b).

Figure 2: Veränderung der Waldfläche im Untersuchungsgebiet unter Verwendung von CORINE Landbedeckungskarten für 1990 (a) und 2018 (b).

As CORINE data only contains 44 classes for classification units using a variety of criteria based on pure remote sensing, relatively rough data could be obtained about habitat structures (Ürker and Özen, 2020). For this reason, the current stand maps (ÇSFE, 2021) for 2018 produced during forest management planning based on data measured in the field were used as a digital substrate, and habitat characteristics were assessed in more detail under the EUNIS classification system (EEA, 2021). EUNIS habitat types were extracted at the second level based on the 2004 revision of the EUNIS habitat classification (Table 3, Figure 3).

To separately assess the current status of forest texture among all habitat types, spatial data, and habitat patch numbers were compared with each other for all habitat types in the study area (Table 3).

Table 3: 2018 EUNIS Habitat Types.

Tabelle 3: 2018 EUNIS-Lebensraumtypen.

EUNIS Codes of Habitat Types	**Area (ha)**	**Number of habitat patches**
C1 - Surface standing waters	684	64
C2 - Surface running waters	688	31
E1.2E - Irano-Anatolian steppes	112642	868
E2.6 - Agriculturally-improved, re-seeded and heavily fertilized grassland, including sports fields and grass lawns	70681	289
F9.31 - [Nerium oleander], [Vitex agnus-castus] and [Tamarix] galleries	4520	336
G1.37 - Irano-Anatolian mixed riverine forests	1455	42
G1.7A2 - Irano-Anatolian steppe [Quercus] woods	25615	341
G1.A1 - [Quercus] - [Fraxinus] - [Carpinus betulus] woodland on eutrophic and mesotrophic soils	6	1
G1.A72 - Sub-Euxinian mixed [Quercus] - [Carpinus betulus] forests	132	2
G1.D2 - [Juglans] groves	7	1
G3.17 - Balkano-Pontic [Abies] forests	2369	30
G3.4E - Ponto-Caucasian [Pinus sylvestris] forests	5337	159
G3.4F - European [Pinus sylvestris] reforestation	193	3
G3.5 - [Pinus nigra] woodland	32813	408
G3.57 - [Pinus nigra] reforestation	3235	99
G3.75 - [Pinus brutia] forests	83	6
G3.9C - [Cedrus] woodland	1074	79
G4.4 - Mixed [Pinus sylvestris] - [Betula] woodland	242	27
G4.7 - Mixed [Pinus sylvestris] - acidophilous [Quercus] woodland	128	1
G4.71 - Subcontinental nemoral [Pinus] - [Quercus] forests	9698	277
G4.8 - Mixed non-riverine deciduous and coniferous woodland	630	27
H5.37 - Boulder fields	246	5
H5.52 - Sparsely vegetated burnt areas	305	7
I1.1 - Intensive unmixed crops	179903	1269
J1.2 - Residential buildings of villages and urban peripheries	8996	319
J2.2 - Rural public buildings	7	2
J3.2 - Active opencast mineral extraction sites, including quarries	322	40
J4 - Transport networks and other constructed hard-surfaced areas	3	1
J4.7 - Constructed parts of cemeteries	210	59
TOTAL	**462225**	**4793**

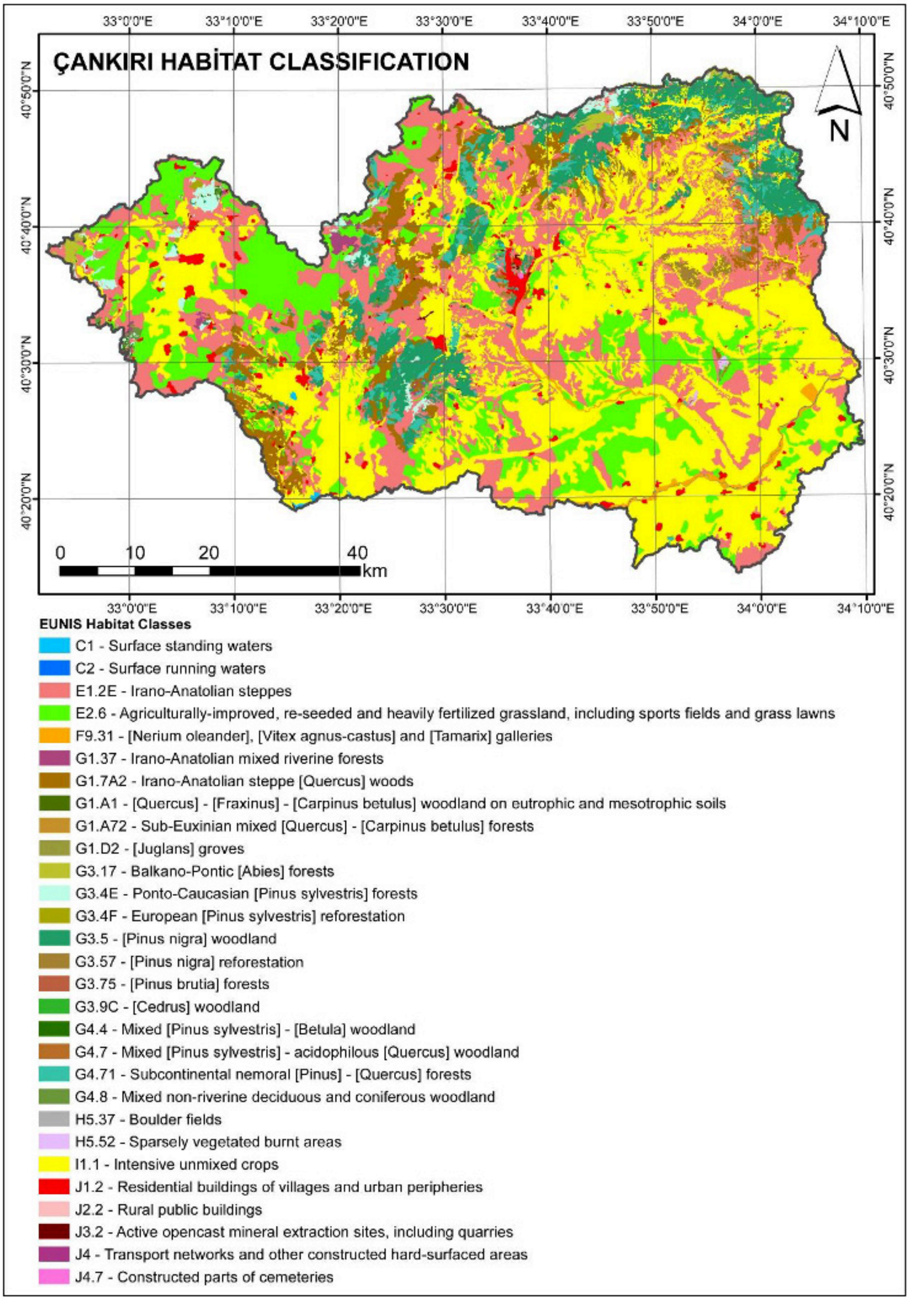

Figure 3: EUNIS habitat map for the study area in 2018.

Figure 3: EUNIS-Lebensraumkarte für das Untersuchungsgebiet im Jahr 2018.

According to FAD analyses, there were no intact forest patches; forest areas with a core area of a certain size comprised 15.5%, which was very consistent with MSPA values; habitat transition was observed in 15.88% of the area; and scattered forest patches covered 3.81% of the total area (Table 4, Figure 4).

Before beginning MSPA analysis, simplified pattern analysis (SPA) was performed. Of the 458,877-hectares study area, 69,562 hectares comprised core areas (15.5%), 9268 hectares were exterior margins (2%), 1180 hectares were areas with high destruction threat and 218 hectares (0.05%) were corridors (Table 5).

According to upper spatial class analysis comprising component, core area, and corridor classes, the study area was identified to contain 1511 forest components (Table 6). The degree of significance was created for a total of 1511 components according to corridor and core areas.

According to Table 6, 0.10% of the foreground area is made up of islet pixels, while 0.02% of the area (= Foreground + Background) is made up of islet pixels, there are also 107 islets (regardless of their own size).

Similarly, all statistics for class perforation reveal that the image contains 314 perforations in total, and entire perforation pixels together makeup 2.17% of the foreground area or 0.39% of the data area (foreground area + background area).

Table 4: Fragmentation classes for forest in the study area.

Tabelle 4: Fragmentierungsklassen für den Wald im Untersuchungsgebiet.

Foreground area density (FAD): FragmClass\ObsScale:	**1 (7pix)**	**2 (13pix)**	**3 (27pix)**	**4 (81pix)**	**5 (243pix)**	**Summary**
Rare: FAD <10%	0.002168	0.012466	0.127374	0.848583	2.39182	0.001301
Patchy: 10≤FAD<40%	1.48177	2.99703	6.02073	14.6635	30.5022	3.81851
Transitional: 40≤FAD<60%	6.59256	9.54472	14.5733	23.333	31.4493	15.8862
Dominant: 60≤FAD<90%	19.3461	28.8573	38.4128	48.3906	34.7041	64.7892
Interior: 90≤FAD<100%	11.8577	19.8802	25.5826	11.859	0.95265	15.5047
Intact: FAD=100%	60.7196	38.7082	15.2832	0.905278	0	0

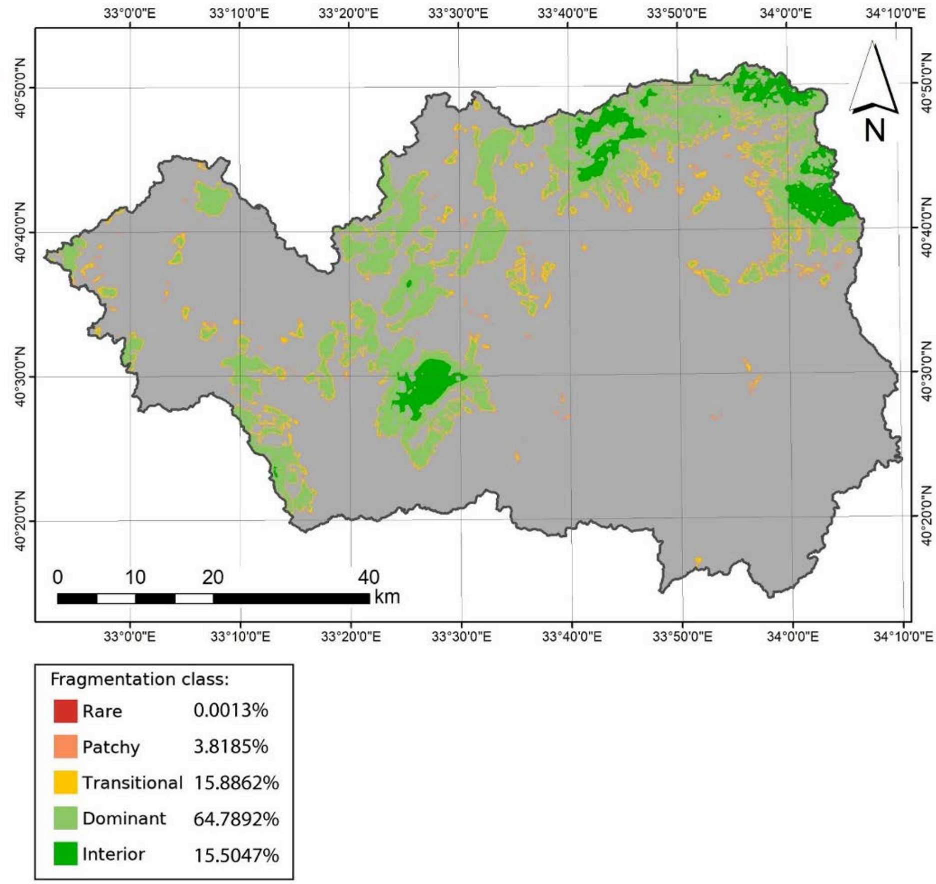

Figure 4: Fragmentation map (above) for forest in the study area and summary graph (below) of fragmentation classes.

Figure 4: Fragmentierungskarte (oben) für den Wald im Untersuchungsgebiet und zusammenfassende Grafik (unten) der Fragmentierungsklassen.

Table 5: Table of Simplified Pattern Analysis (SPA) for the study area.

Tabelle 5: Tabelle der vereinfachten Musteranalyse (SPA) für das Untersuchungsgebiet.

Total area	**Core area**		**External edge**		**Corridor present**		**Areas with high threat of destruction**	
ha	%	ha	%	ha	%	ha	%	ha
458877	15.1591821	69562	2.01971334	9268	0.04750728	218	0.25714952	1180

Table 6: Summary of Morphological Spatial Pattern Analysis (MSPA).

Tabelle 6: Zusammenfassung der morphologischen Raummusteranalyse (MSPA).

	Foreground (FG) / data [%]	# / Background (BG) area
CORE(s)	--/--	0
CORE(m)	83.68/15.14	910
CORE(l)	--/--	0
ISLET	0.10/ 0.02	107
PERFOR	2.17/ 0.39	314
EDGE	11.71/ 2.12	628
LOOP	0.19/0.03	415
BRIDGE	0.27/ 0.05	500
BRANCH	1.88/ 0.34	6403
Background	--/81.91	1511/417620
Missing	39.31	2/3304238
Opening	94.14 Integrity	1413/57384
CoreOpen	--/0.69	639/35388
BorderOpen	--/ 0.43	774/21996

4 Discussion

4.1 Assessments of the analyses of fragmentation and connectivity on forest habitats

According to Table-3 and Figure-3, 6 different main habitat types including 44 sub-habitat types were determined. When the general CORINE data are investigated, areas belonging to the urban ecosystem like continuous and temporary settlement areas, and industrial-commercial units increased in stages from 1990 to the present. Though spatial variation in agricultural areas displayed variations through the years, in a cumulative sense no serious change was notable (Bascompte *et al.*, 2002). When shores-beaches-dunes (on the shores of rivers), swamps, water routes, and water masses are assessed, though a yellow undulating variation was observed through the years, no serious spatial variation trend was experienced specific to aqueous habitats linked to rivers in the region when assessed cumulatively. Though pasture areas are reduced, when natural meadows, coniferous forests, broad-leaf forests, transitional woodland areas, and mixed woodland are considered, an increase in all forestry assets is notable. However, specific to sub-units, a low rate of broad-leaf woodland was converted to agricultural areas.

To compare the forest assets and use in the past with the present day, to investigate the impact of anthropogenic constraints on habitat fragmentation, and to measure the impact and effectiveness of forest villages on habitat fragmentation, CORINE satellite images from 1990-2018 were used for detailed examination of the changes in habitat types/land use structure. When the data are evaluated specific to forest habitats, firstly, the 41590 hectares forest area in 1990 was identified to reach 51162 hectares with a 23% spatial increase cumulatively up to 2018. When the CORINE units are assessed separately, nearly half of the broad-leaf woodland and mixed woodland were destroyed, while transitional woodland increased by 17.5% and coniferous woodland increased by 38.2%.

The most important causes of the stepped increase in forest assets over time in the study area are agricultural land abandoned due to external migration converting to forestry, and forest margins and forest openings becoming forestry as a result of afforestation-maintenance-rehabilitation work. The most basic cause for the relative increase in coniferous woodland assets is that coniferous species have been dominantly used in regular afforestation-maintenance-rehabilitation work completed over the last 30 years.

When the CORINE data (extracting codes related to forestry) from 1990 to 2018 were compared, the general forestry assets in the ÇSFE appear to have a clear net increase of 23%. According to Table 2, during nearly 30 years, the presence of broad-leaved and mixed forests was both reduced by nearly 50%, while the presence of transitional woodland/shrub increased by 38% and coniferous forests increased by 18%.

Contrary to the 23% net increase in woodland spatial area in the last 30 years, it is interesting that nearly all forest textures were identified to have habitat fragmentation (Biswas and Khan, 2013). One of the main reasons for this is mistaken afforestation work not paying attention to landscape ecology principles (Fahrig, 2003; Collingham and Huntley, 2013).

Considering Table 3, the general status is that 83017 hectares of the 462225-hectares study area – in other words, nearly 20% - is covered with forest habitats with different characteristics. When data are examined in terms of the number of habitat patches, forest textures existed in 1839 of 4793 habitat patches and this encompasses nearly 40% of this area.

When both Table 4 and Figure 4 are investigated, margin effects were present at a very high rate of 64.78% of the fragmented forest texture in the study area.

The overall area of the background contained by perforation pixels (core openings) is 35388 pixels. All MSPA statistics were computed for foreground borders that were closed. Forest integrity is a statistic that takes into consideration the total area of all openings in a forest (= forest + openings). If there are no openings in the forest, its integrity is 100%. According to Table 6, 5.86% of the integrated forest area has openings, implying that forest integrity is reduced to 94.14%.

The foreground region has 1413 apertures with a total count of 57,384 pixels. 639 of the 1413 openings are core openings within the forest's core region, representing a total area of 35,388 pixels (inside the perforations). Border vacancies account for the remaining 774 openings had a total size of 21996 pixels at the outside forest boundary (edge). The following network options were available after MSPA analysis. In Saura and Rubio (2010), the connection significance is computed using Equation 4. Accordingly, the corridor connections, interaction areas, connection zones, and network components specific to the study area are summarized on the map below (Figure 5). According to this network analysis, there are 275 individual components in the network. The equivalent connected (node/core) area (ECA; measured in area units, such as hectares, or in the general instance, pixels) is 229,173 pixels. The degree of network connectivity (DOC) is 29.69%.

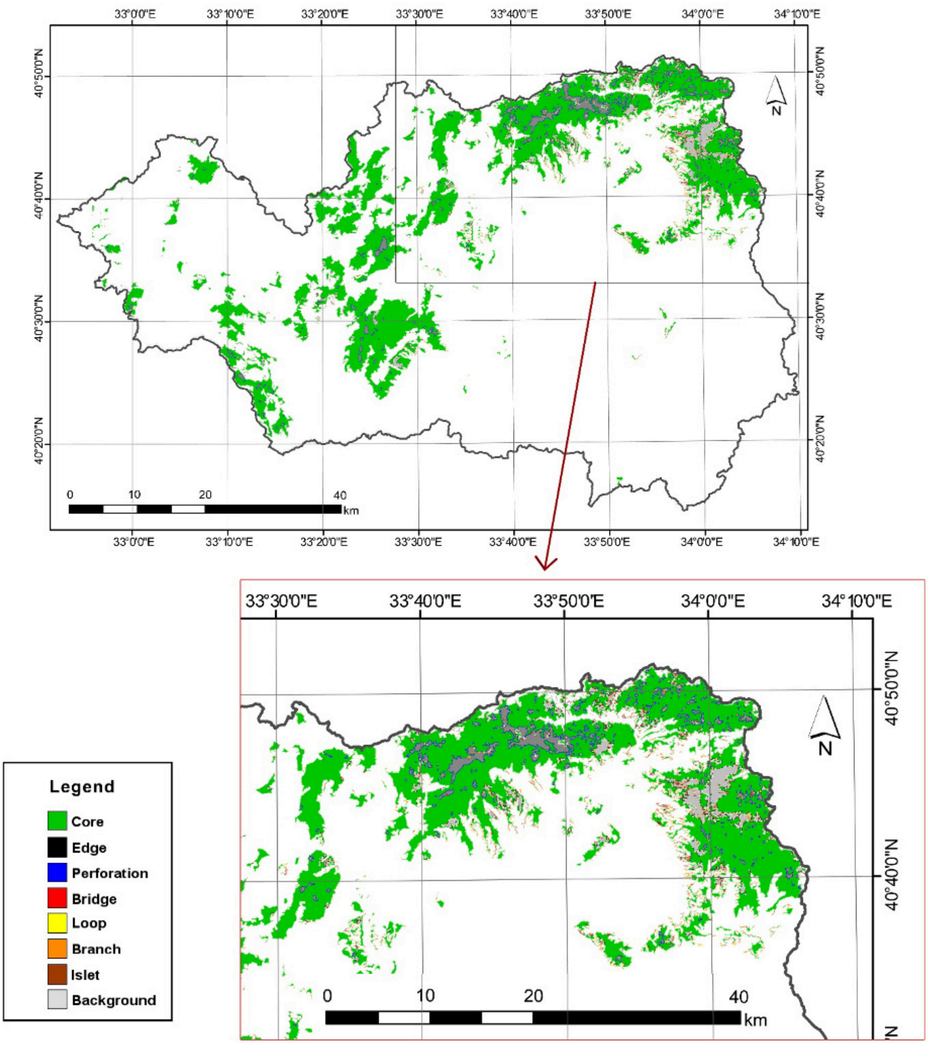

Figure 5: General corridor map of the study area according to MSPA analysis.

Figure 5: Allgemeine Korridorkarte des Untersuchungsgebiets gemäß der MSPA-Analyse.

As a result of the disrupted fragmentation in the study area in general and the increase in distance between forest patches, the ecological integrity, and communication between forest patches are lost (Backhaus *et al.*, 2002). As a result, both plant species and wildlife are trapped in distant forest patches (Forman and Collinge, 1995). In a general sense, this is one of the reasons why biodiversity is endangered in general and is a situation that planners should consider (Bürgi, 1999; Sharma and Roy, 2007). It is necessary to connect separated areas with corridors to ensure the mutual transition of species (Batar *et al.*, 2017). The presence of many patches is due to afforestation activities in these areas. For this reason, forest management chiefs linked to Çankırı Forestry Management Directorate should ensure patches are joined during renewal processes in forestry management plans, and as a result, forest integrity should be ensured (Srivastava and Tyagi, 2016). Additionally, with the aim of ensuring linkages and continuity of the patchy forest ecosystem, the forest ecosystem should be improved by uniting patchy areas (Saura and Rubio, 2010; Theobald *et al.*, 2011; Srivastava and Tyagi, 2016; Hu *et al.*, 2020).

4.2 Contributions of the survey studies

During the field controls in the area, a 24-item survey was administered to headmen in 25 different forest villages and the findings were assessed with descriptive analyses in the SPSS program. When the headmen participating in the survey were requested to assess the temporal variation in forestry for their region, 32% stated that no change had been experienced while 52% stated that there was an increase in forestry, contrary to a reduction. They indicated that the underlying causes for this were the slow transformation to the woodland of agricultural areas following reduced human intervention after being abandoned and the afforestation-maintenance work performed in forest openings and margins by forest management units.

When participants were questioned about the relative change compared to past years in the use of relationships for forests in their area, 92% of headmen participating in the survey stated that these relationships had reduced a lot. When questioned about the reasons underlying this change, the most important cause was stated to be external migration during the last 30-40 years (92%). Among these responses, it is notable that no participant marked choices related to restrictions on the use of the forest by the private sector (mining, energy, dam, etc. projects). When answers to another question about the variation of wildlife in forestry in the area are examined, though there was a choice for wildlife has much reduced, no headman marked this, but most stated that wildlife had visibly increased (96%). When responding to this question, headmen stated that wild boars had increased a lot, followed by roe deer observed with the increase in forestry in recent years, while herbivore and carnivore mammals began to be seen intensely linked to the construction of artificial ponds in the region. When questioned about whether judicial-administrative cases involving punitive procedures were experienced related to the forestry in the areas, 88% of headmen participating in the survey stated that none of these cases were currently known, while 12% stated that very few isolated cases were known at present. Most of these cases occurred linked to illegal tree cutting or illegal grazing.

5 Conclusions

In this study, the aim was to determine the fragmentation status of forest habitats within ÇSFE boundaries located in the north-central region of Turkey and to create infrastructure to strengthen the connectivity between fragmented forest clusters with the corridor approach (Batar *et al.*, 2017).

With the integration of analysis results obtained as a result of the research with the forestry management plans of ÇSFE, the potential to benefit from this data when updating these plans is high (Saura and Rubio, 2010). In this situation, in addition to direct short-term economic contributions to the forestry area, improvements will be provided for habitat qualities of living organisms linked to the forest and wildlife elements in the region in the long term and it will be possible to ensure maximum benefit in terms of ecosystem services (Collingham and Huntley, 2013; Batar *et al.*, 2017).

Areas between forest patches located in the study area comprise open areas for agriculture, forest soil (FS), and pastures. From this aspect, these patches should be joined over time with afforestation studies to create ecological corridors and thus, some areas will be allocated as ecological interaction zones (Srivastava and Tyagi, 2016). For this reason, it is necessary to give priority to afforestation studies for this type of area.

If the afforestation studies that are recommended to be updated in the light of the corridor approach developed by taking into account the fragmentation and connectivity analyses obtained from this study, are implemented, it will be possible to ensure long-term sustainable management in light of landscape ecology principles about forest structures with different fragmentation conditions in different regions (Forman and Collinge, 1995; Fahrig, 2003; Hanski, 2005; Yadav *et al.*, 2020) not only in the study area but in Turkey and the surrounding geography.

Author’s Contribution

All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by Okan Urker, Alkan Gunlu, and Murat Ataol. The first draft of the manuscript was written by Okan Urker and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript. Research and publication ethics were complied with in the study. We declare that the figure or figures obtained from external sources within the study are materials that do not require copyright permission, by citing the relevant source. All authors read and approved the final manuscript.

Competing Interests

The authors declare that they have no competing interests or conflicts of interest.

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References

Areendran, G., Raj, K., Sharma, A., Bora, P.J., Sarmah, A., Sahana, M., Ranjan, K. (2020). Documenting the land use pattern in the corridor complexes of Kaziranga National Park using high resolution satellite imagery. Trees, Forests and People, Volume 2, December 2020, https://doi.org/10.1016/j.tfp.2020.100039.

Babbar, D., Areendran, G., Sahana, M., Sarma, K., Raj, K., Sivadas, A. (2020). Assessment and prediction of carbon sequestration using Markov chain and InVEST model in Sariska Tiger Reserve, India J. Clean. Prod., 278 (2020).

Backhaus, R., Bock, M., Weiers, S. (2002). The spatial dimension of landscape sustainability. Environment, Development and Sustainability, 4, 237–251. doi:10.1023/A:1021138602157.

Bascompte, J., Possingham, H., Roughgarden, J. (2002). Patchy populations in stochastic environments: critical number of patches for persistence. Am. Nat. 159:128—37.

Batar, A.K., Watanabe, T., Kumar, A. (2017). Assessment of Land-Use/Land-Cover Change and Forest Fragmentation in the Garhwal Himalayan Region of India. Environments 2017, 4, 34; doi:10.3390/environments4020034.

Biswas, S., Khan, D.K. (2013). Habitat Fragmentation and Nutrient Dynamics in Tropical Dry Deciduous Forests of West Bengal, India. ARPN J. Sci. Technol. 2013, 3, 109–119.

Bürgi, M. (1999). A case study of forest change in the Swiss lowlands. Landscape Ecology, 14, 567–575. doi:10.1023/A:1008168209725.

Carranza, M.L., Hoyos, L., Frate, L., Acosta, A.T., Cabido, M. (2015). Measuring forest fragmentation using multitemporal forest cover maps: Forest loss and spatial pattern analysis in the Gran Chaco, central Argentina Landsc. Urban Plan., 143 (2015), pp. 238-247.

Collingham, Y.C., Huntley, B. (2013). Impacts of Habitat Fragmentation and Patch Size upon Migration Rates. Ecol. Appl. 2013, 10, 131–144.

Coops, N.C., Wulder, M.A., White, J.C. (2006). Identifying and Describing Forest Disturbance and Spatial Pattern: Data Selection Issues and Methodological Implications. In Understanding Forest Disturbance and Spatial Pattern. Remote Sensing and GIS Approaches; Wulder, M., Franklin, S., Eds.; CRC Press: Boca Raton, FL, USA, 2006; pp. 31–62.

ÇSFE. (2021). Forest Asset Tables. (https://ankaraobm.ogm.gov.tr/cankiriOIM/Sayfalar/default.aspx accessed on 2021-01-15).

European Environment Agency-EEA, (2021). The EU Habitats Directive Annex I habitat types – Inquiry System of EUNIS Habitat Types. (https://eunis.eea.europa.eu/habitats.jsp accessed on 2021-02-02).

Forman, R.T.T., Collinge, S.K. (1995). The spatial solution to conserving biodiversity in landscapes and regions. In Conservation of Faunal Diversity in Forested Landscapes. Pp. 537-568, London. R. M. DeGraaf and R. I. Miller, eds. Chapman & Hall.

Forman, R.T.T., Godron, M. (1986). Landscape ecology. New York. John Wiley, 1986.

Fahrig, L. (2002). Effect of habitat fragmentation on the extinction threshold: a synthesis. Ecol. Appl. 12:346—53.

Fahrig, L. (2003). Effects of habitat fragmentation on biodiversity. Annu. Rev. Ecol. Evol. Syst. 2003, 34, 487–515.

Fischer, J., Lindenmayer, D.B. (2007). Landscape modification and habitat fragmentation: A synthesis. Glob. Ecol. Biogeogr. 2007, 16, 265–280.

Gergel, S.E. (2006). New directions in landscape pattern analysis and linkages with remote sensing. In Understanding Forest Disturbance and Spatial Pattern. Remote Sensing and GIS Approaches; Wulder, M., Franklin, S., Eds.; CRC Press: Boca Raton, FL, USA, 2006; pp. 173–208.

Gülçin, D. (2020). Orman Ekosisteminde Habitat Parçalanmasının Mekânsal ve Zamansal Değişiminin Analizi: Muğla Örneği, In: Mimarlık Biliminde Akademik Çalışmalar, Eds: Hale Kozlu, Livre de Lyon, V:1, Pages:332, ISBN:978-2-38236-057-6, Related pages:241 -262 (In Turkish).

Güven, Y. (2019). Effects of Traffic and Highways on Mammals in Çankırı Province. Thesis of Master of Science. Çankırı Karatekin University, Graduate School of Natural and Applied Sciences, 60 pages, Çankırı (In Turkish).

Hanski, I. (2005). The Shrinking World: Ecological consequences of Habitat Loss. Oldendorf/Luhe. International Ecology Institute.

Harper, G., Steininger, M., Tucker, C., Juhn, D., Hawkins, F. (2007). Fifty Years of Deforestation and Forest Fragmentation in Madagascar. Environ. Conserv., 34, 325–333.

Healey, S.P., Cohen, W.B., Yang, Z., Kenneth Brewer, C., Brooks, E.B., Gorelick, N., Hernandez, A.J., Huang, C., Joseph Hughes, M., Kennedy, R.E., et al. (2018). Mapping forest change using stacked generalization: An ensemble approach. Remote Sens. Environ., 204, 717–728. https://doi.org/10.1016/j.rse.2017.09.029.

Hu, S., Longqian, C., Li, L., Zhang, T., Yuan, L., Cheng, L., Wang, J., Wen, M. (2020). Simulation of Land Use Change and Ecosystem Service Value Dynamics under Ecological Constraints in Anhui Province, China. Int. J. Environ. Res. Public Health, 17(12), 4228; https://doi.org/10.3390/ijerph17124228.

Innes, J.L., Koch, B. (1998). Forest Biodiversity and Its Assessment by Remote Sensing. Glob. Ecol. Biogeogr. Lett., 7, 397–419. https://doi.org/10.2307/2997712.

Kerr, J.T., Ostrovsky, M. (2003). From space to species: Ecological applications for remote sensing. Trends Ecol. Evol., 18, 299–305. https://doi.org/10.1016/S0169-5347(03)00071-5.

Linke, J., Betts, M., Lavrige, M., Franklin, S. (2006). Structure, Function and Change of Forest Landscapes. In Understanding Forest Disturbance and Spatial Pattern. Remote Sensing and GIS Approaches; Wulder, M., Franklin, S., Eds.; CRC Press: Boca Raton, FL, USA, pp. 1–29.

Long, J.A., Nelson, T.A., Wulder, M.A. (2010). Characterizing forest fragmentation: Distinguishing change in composition from configuration. Appl. Geogr. 30, 426–435. https://doi.org/10.1016/j.apgeog.2009.12.002.

MacArthur, R.H., Wilson, E.O. (1967). The Theory of Island Biogeography. Princeton, Princeton University Press, 1967.

Mengist, W., Soromessa, T., Feyisa, G.L. (2022). Forest fragmentation in a forest Biosphere Reserve: Implications for the sustainability of natural habitats and forest management policy in Ethiopia. Resources, Environment and Sustainability. 8(1), 1-13. https://doi.org/10.1016/j.resenv.2022.100058.

Myroniuk, V., Kutia, M., Sarkissian, A.J., Bilous, A., Liu, S. (2020). Regional-Scale Forest Mapping over Fragmented Landscapes Using Global Forest Products and Landsat Time Series Classification. Remote Sensing. 12(1):187. DOI:10.3390/rs12010187.

Newton, A.C., Hill, R.A., Echeverría, C., Golicher, D., Rey Benayas, J.M., Cayuela, L., Hinsley, S.A. (2009). Remote sensing and the future of landscape ecology. Prog. Phys. Geogr. Earth Environ., 33, 528–546. https://doi.org/10.1177/0309133309346882.

Olariu, B., Vîrghileanu, M., Mihai, B.-A., Savulescu, I., Toma, L., Savulescu, M.-G. (2022). Forest Habitat Fragmentation in Mountain Protected Areas Using Historical Corona KH-9 and Sentinel-2 Satellite Imagery. Remote Sens., 14, 2593. https://doi.org/10.3390/rs14112593.

Richard, M.H. (2011). 5 Things You Need to Know About Wildlife Corridors. Retrieved from https://www.treehugger.com/natural-sciences/five-things-you-need-to-know-about-wildlife-corridors.html.

Riitters, K.H., Wickham, J.D., O'Neill, R.V., [and others]. (2002). Fragmentation of continental United States forests. Ecosystems 5:815–822.

Riitters, K.H., Coulston, J.W., Wickham, J.D. (2012a). Fragmentation of forest communities in the eastern United States. Forest Ecology and Management 263:85-93. DOI 10.1016/j.foreco.2011.09.022.

Riitters, K.H., Wickham, J.D. (2012b). Decline of forest interior conditions in the conterminous United States. Scientific Reports 2, Article number: 653. DOI 10.1038/srep00653.

Rose, R.; Byler, D.; Eastman, J.; Fleishman, E.; Geller, G.; Goetz, S.; Guild, L.; Hamilton, H.; Hansen, M., Headley, R., et al. (2014). Ten Ways Remote Sensing Can Contribute to Conservation. Conserv. Biol., 29, 350–359. https://doi.org/10.1111/cobi.12397.

Sahana, M., Sajjad, H., Ahmed, R. (2015). Assessing spatio-temporal health of forest cover using forest canopy density model and forest fragmentation approach in Sundarban reserve forest, India Model. Earth Syst. Environ., 1 (2015), pp. 1-10.

Saura, S., Rubio, L. (2010). A common currency for the different ways in which patches and links can contribute to habitat availability and connectivity in the landscape, Ecography, 33 (3), 523–537, 2010/06/01. DOI. 10.1111/j.1600-0587.2009.05760.x.

Sharma, S., Roy, P.S. (2007). Forest fragmentation in the Himalaya: A Central Himalayan case study. Int. J. Sustain. Dev. World Ecol. 2007, 14, 201–210.

Soille, P., Vogt, P. (2009). Morphological segmentation of binary patterns. Pattern Recognition Letters, 30, 4:456-459, DOI: 10.1016/j.patrec.2008.10.015.

Srivastava, R., Tyagi, R. (2016). Wildlife corridors in India: viable legal tools for species conservation. Environ. Law Rev., 18 (3) (2016), pp. 205-223.

Theobald, D.M., Crooks, K.R., and Norman, J.B. (2011). Assessing effects of land use on landscape connectivity: loss and fragmentation of western U.S. forests. Ecological Applications, 21 (7), 2445-2458.

Ürker, O., Özen, A. (2020). Işıklı Gölü ve Gökgöl Sulak Alanlarında Avrupa Doğa Bilgi Sistemi (EUNIS) Habitat Sınıflandırmasının Değerlendirilmesi. Erzincan Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 13 (2), 518-531. DOI: 10.18185/erzifbed.646077 (In Turkish).

Vogt, P., Riitters, K. (2017). GuidosToolbox: universal digital image object analysis. European Journal of Remote Sensing 50:1, 352-361, DOI: 10.1080/22797254.2017.1330650. Software available for free at: (https://forest.jrc.ec.europa.eu/en/activities/lpa/gtb/ accessed on 2021-04-02).

Weiers, S., Bock, M., Wissen, M., Rossner, G. (2004). Mapping and indicator approaches for the assessment of habitats at different scales using remote sensing and GIS methods. Landscape and Urban Planning, 67(1–4), 43–65. doi:10.1016/S0169-2046(03)00028-.

Wilcove, D.S., McClellan, C.H., Dobson, A.P. (1986). Habitat fragmentation in the temperate zone; Pp. 237-256 in M.E. Soule, ed. Conservation biology: the science of scarcity and diversity. Sinauer Associates, Sunderland, MA.

Wulder, M., White, J.C., Andrew, M.E., Seitz, N.E., Coops, N. (2009). Forest fragmentation, structure, and age characteristics as a legacy of forest management. Forest Ecology and Management 258(9):1938-1949. DOI:10.1016/j.foreco.2009.07.041.

Yadav, N., Areendran, G., Sarma, K., Raj, K., Sahana, M. (2020). Susceptibility assessment of human–leopard conflict in Aravalli landscape of Haryana using geospatial techniques. Model. Earth Syst. Environ. (2020), 1-15.