Chapter 25

Understanding Landscape Structure Using Landscape Metrics

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/55758

1. Introduction

Landscapes are dynamic systems. Human affects them continuously. Depending on intensive human effects, pressure was increased on landscapes. Consequently, landscapes were altered over time.

There are negative effects of pressures on landscape and species living in the area. The negative effects are especially vulnerable more intense to the human effected landscapes. In these landscapes, fragmentation increased. Habitats have been damaged. Depending on these effects material flow and transactions of the species are limited.

Landscape ecology investigates landscape structure and changes in the landscape. Change expresses any modification occurring in the landscape over time. Landscape structure evaluates land mosaic as measure, number, size and shape.

Landscape metrics are important tools which are used to understand landscape structure and landscape changes. To use metrics, numeric data is obtained related to landscape structure. Numeric data is produced from satellite images and air photos. Also, landscape metrics are used as compatible with geographical information systems. Landscape metrics allow doing objective reviews on landscape structure.

In this study it was aimed to understand the landscape metrics. To do this, Landscape ecology and its characteristics (structure, function and change) must be emphasized. So, firstly these topics explained. After landscape metrics explained and a case study done on landscape metrics.

2. Landscape ecology

Landscape Ecology is a science branch in Ecology which uses the numbers. Researchers intensively investigate on landscape structure and landscape change in this science.

Landscape is the most important research material. What is the "Landscape"? Researchers made a lot of definition on landscape.

Landscape was defined firstly by Alexander Von Humbdolt as "all of the characteristics of a land" (Farina 2000). Landscape as a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar from throughout (Forman and Godron 1986). Farina (2000) defines landscape as "heterogeneous land area, consisting of interaction sets between ecosystems". Landscape was defined in European Landscape Convention as "means an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors" (http://conventions.coe.int).

Landscape became an integrative concept in many disciplines (Antrop 2005). All of Landscape definitions have in common expressions. These are (Antrop 2005):

- is seen as a spatial entity, having a variable extent and scale, and has territorial properties,
- is perceived and experienced,
- is composed of many very different elements and components that interact and are structured in some way,
- with a spatial organization and management that is largely influenced by humans,
- Is dynamic and changes are an inherent property of landscape.

Landscape ecology is a young but well-recognized ecological discipline dealing with the spatial distribution of organisms, patterns and processes (Farina 2010). Landscape ecology is a science branch of ecology to make contributions related to complexity studies (physical, biological, and ecological) of ecology. Landscape ecology uses numbers related to complexity studies. Also, it uses remote sensing, geographical information systems and geo-statistical tools. These tools have been developed for landscape ecology studies (Farina 2000).

As simplest expression, landscape ecology investigates internal dynamics and interaction of landscapes. Landscape ecology focuses on spatial relationship of landscape elements and ecosystems, functional and structural features of the land mosaic and change that is emerged over time (Dramstad *et al.* 1995).

Landscape ecology has been emerged since 1980 that is useful and important for land-use planners and landscape architects. By this time, the concept of landscape ecology is seen in other disciplines. After 1980, important study areas of landscape ecology was started to be publish (Dramstad *et al.* 1995). The last decade has seen a growth in the number of studies and variety of topics that fall under the broad banner of landscape ecology (Farina 2010).

Landscape ecology investigates (emphasizes) the interaction between spatial pattern and ecological process, that is, the causes and consequences of spatial heterogeneity across a range of scales (Turner *et al.* 2001). The discipline of Landscape Ecology is rapidly emerging as a motive force, both in the domain of theoretical ecology, and in applied fields (Sanderson and Harris 2000).

Landscape ecology recognizes that ecological units (systems) are arrayed in space in response to gradients of topography, temperature, moisture, and soils. Additional pattern is imposed by disturbances, biotic interactions, and human use of the land. Spatial arrangement, in turn, influences many ecological processes, such as the movement patterns of organisms, the spread of disturbances, and the movement of matter or energy. Landscape ecology, focusing on spatial pattern and the ecological responses to this pattern, leads to a new set of principles, distinct from the principles that govern ecosystem and population dynamics at finer scales (Turner *et al.* 2001).

Technological developments have also contributed to the emergence of landscape ecology. These developments include rapid advances in desktop computing power, availability of remotely sensed data such as satellite images, and development of powerful computer software packages called geographic information systems (GIS) for storing, manipulating, and displaying spatial data. New research techniques are required in landscape ecology because of the focus on spatial pattern and Dynamics and on large areas that simply cannot be thoroughly sampled or easily manipulated. For example, laboratory and plot experiments are appropriate at fine scales, but broad-scale experiments are logistically difficult, and replication is often impossible. Landscape ecologists have needed to incorporate new sources of data into their studies and creatively study natural experiments. The availability of remote imagery has made it possible to study spatial pattern over large areas and its change through time, opening new horizons for landscape analysis (Turner *et al.* 2001).

Landscape ecology focuses on three characteristics of the landscape (Forman and Godron 1986).

Structure: The spatial relationships among the distinctive ecosystems or elements.

Function: The interactions among the spatial features.

Change: The alteration in the structure and function of the ecological mosaic over time.

3. Landscape structure

Assessing landscape function and landscape change, landscape structure must be known. Connectivity and fragmentation are known with understanding landscape structure.

Landscape structure expresses the spatial pattern of landscape elements and the connections between the different ecosystems or landscape elements. Landscape structure assesses relationship between ecosystems as measure, number, size and shape (Forman and Godron 1986; Gergel and Turner 2002).

Landscape structure has two qualities. These are composition and configuration (Farina 2000).

Landscape composition: Attribute of composition is not spatial, and can't be measured. It defines the quality of the landscape patches, scattered in landscape. The composition is not a precise identification of the mosaic structure of the landscape. But, It is a good indicator for living environment suitability of some species (appropriate patch type for species) (Farina 2000).

Landscape configuration: Configuration refers to the spatial characteristics. It refers to spatial characteristics same as the spatial distribution of land cover (Farina 2000).

Landscape ecologists use four basic terms to define spatial structure (FISGRW 1998)

Patch: A nonlinear area (polygon) which is less abundant. It is different from the matrix.

Corridor: A special type of patch which links other patches in the matrix. Typically, a corridor is linear or elongated in shape, such as a stream corridor.

Matrix: the land cover that is dominant and interconnected over the majority of the land surface. Often the matrix is forest or agriculture, but theoretically it can be any land cover type.

Mosaic: a collection of patches, none of which are dominant enough to be interconnected throughout the landscape.

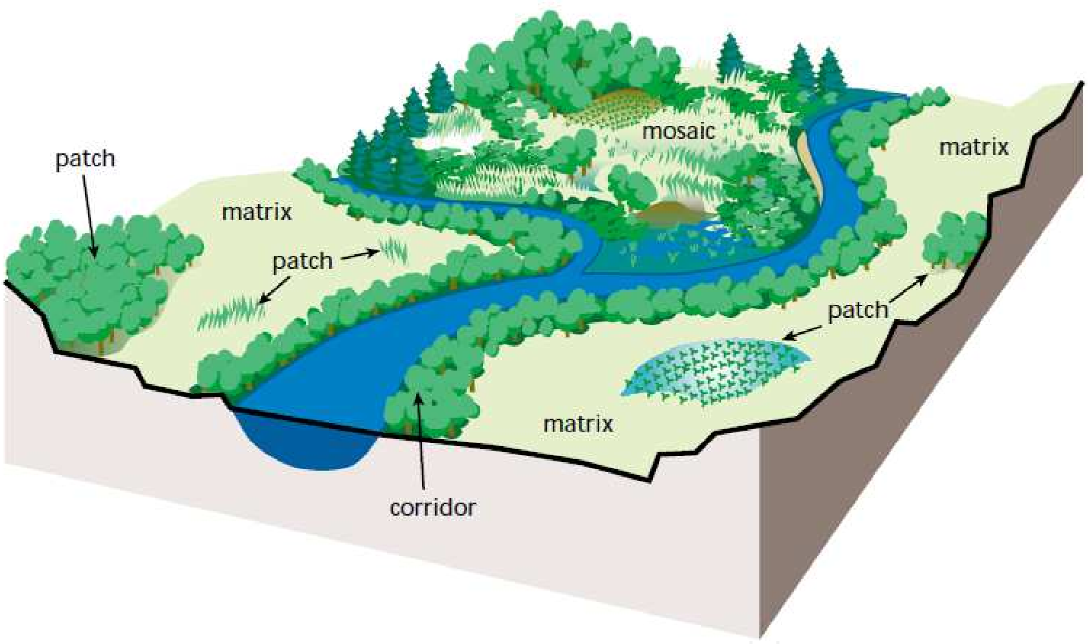

Figure 1. Basic terms to define landscape ecology (FISGRW 1998)

4. Landscape function

Landscape function involves flows of animals, plants, energy, mineral nutrients and interactions among these elements. The primary structural characteristics for landscape function are corridors, hedgerows, matrix and networks (Forman and Godron 1986).

Corridors have four important functions. These are; a habitat for certain type of species, movement area for species, a barrier or filter area, a source of environmental and biotic effects. All these functions involve flows of animals and plants; the last two functions also include flows of energy and mineral nutrients (Forman and Godron 1986).

Corridors serve as conduits and as filters for much of the movement of animals, plants, materials, and water across the landscape. Network and matrix characteristics affect transactions in contrasting ways, depending on whether the objects cross corridors or use corridors as conduits. Landscape functioning integrates flows both between adjacent ecosystems and across a landscape (Forman and Godron 1986).

Strip corridors have an interior environment and interior species. Stream corridors are most effective in controlling water and mineral nutrient flows from upland to stream when they cover both flood plain and banks, when they are wide enough above a bank to enhance the movement of upland interior species along the corridor. Networks contain alternative pathways for species movement, have differing types of intersections, enclose landscape elements, and exhibit varying mesh sizes (Forman and Godron 1986). Hedgerows are constructed to protect areas from animals. Animals damage crop in a cropland. Hedgerows network effects wind and water stream.

Various birds and mammals appear to move effectively along hedgerows. In winter (rainy season) stream flow was lower in the hedgerow landscape than in the open landscape. In the hedgerow landscape stream flow is less variable through the year (Forman and Godron 1986).

Networks are composed of corridors and notes, and trunk lines handle high-volume flows. A network is done for the movement of people it is important for other ecological features in landscape planning and management. Movement through a matrix depends on its connectivity. Species move along a connected matrix (Forman and Godron 1986).

In the landscape flows dependent on the orientation of the structure (Forman and Godron 1986). Connectivity is very important for landscape function. Sometimes landscapes have fragmented structure.

Habitat fragmentation severely threatens biodiversity and ecosystem functioning wherever humans dominated landscape. Land use planners play a significant role in determining whether and how landscapes and ecosystems are fragmented or maintain natural connectivity (ELI 2003).

5. Landscape change

The landscapes of today have been shaped by powerful. Ever-present forces are seen in space and time by anthropogenic activities (Sanderson and Harris, 2000). Landscapes are not static. Landscapes are impressed by Climate changes, land-use changes and human activities. It can be changed mosaic structure, shape and size of patches in a landscape. All these changes could be seen different spatial sizes and frequencies (Farina 2000).

A change can be defined as any modification occurring in a system state (from individual to biosphere) produced by a broad variety of abiotic and/or biotic factors that introduce or subtract energy and information to the system (Farina 2010).

Changes can be considered modifications in the availability of an expected resource or pattern and the temporary or permanent impossibility for species, populations, communities, ecosystems, and land mosaics to incorporate the new conditions (Farina 2010).

To assess the current conditions of the landscape, historical process must be known. Depending on the natural and cultural influences the changes are seen over time in the landscape structure. In this case, landscape structure and relationship between ecosystems are changed. As a result of change studies, functions and conditions in the mosaic of different sized and shaped patches can be revealed (Wu and Hobbs 2000).

Changes can be integrated with the abiotic-biotic processes, and basic components of each ecosystem. Health of the system can be revealed to analyze rate, frequency, and intensity of change. Change may be occurred at different levels. Small scale systems have a higher change level from large-scale systems. It is more useful to assessment of the change at large scales (Farina 2000).

There are two main factors of landscape change. These are natural processes and human activities (especially nowadays). Both natural conditions and human needs are changed over time. Complex changes can be emerged in the landscape structure related to natural conditions and human needs (Antrop 1998; Farina 2000).

Defining change depends upon the temporal resolution of consecutive observations and data sets. Also, these differences must be observable or measurable in magnitude and this depends on the degree of detail and accuracy of the data used. Frequent and multiple observations enhance the knowledge of the dynamics of landscape processes, but became only available with the technology of remote sensing and the setting up of monitoring programs (Antrop 2005).

Landscape change can be revealed to analyze of aerial photography, land maps and satellite images through different techniques. There are some challenges related to landscape change studies. Data for previous years are different type and quality. It is difficult to get qualified data (Farina 2000).

Landscapes change 'naturally' as they are the expression of the interaction between the natural environment and man's activities. Both the natural conditions and the human needs change in time and are controlled by different but interactive factors (Antrop 1998).

Change can be expressed to made comparison of at least two different time statuses. Landscapes are mixture of the different qualifications in consists of peculiar dynamics. Depending on these dynamics, change can be emerged in different speed and scale (Antrop 1998).

Five main compelling powers are effective in the landscape change. These are listed below (Farina 2000; Bürgi *et al.* 2004; Antrop 2005):

- Socio-economic forces: Urbanization, industry, industrial activities.
- Political forces: Incorrect applications.
- Technological forces: Car roads, infrastructure facilities

- Natural forces: Avalanche, landslide, flood,
- Cultural forces: Accessibility, human intervention, fire.

Accessibility is most important within the forces. Whenever people arrived in a field, they quickly start to change this field (Antrop 2005).

The nature of change also demands new thinking. Actual changes are so complex and fast it becomes hard to keep track of them. Comprehensive and integrated methods for fast inventorying and monitoring and assessment at a landscape scale are urgently needed (Antrop 2005).

6. Landscape metrics

Landscape metric tools were used in landscape ecology as supporting Landscape planning and landscape management decisions. Landscape metrics were used to measure the landscape structure and the complexity of this structure. The complexity of the structure of landscape structure, landscape metrics used for measuring and Mosaic structure and related information can be obtained. Thus, the characteristics of the landscape easily perceived (Farina 2000; Letiao and Ahern 2002; Wu 2004).

Calculation of the landscape structure (Jaeger 2000):

- To put forward the development of the landscape,
- To assess fragility, emerging over time.
- It was required for determining the relations among structural features, landscape function and landscape change.

Landscape metrics help to calculation composition and configuration, which have two characteristics of landscape structure. We learn knowledge on ecological processes, to use calculations related to composition and configuration (Mc Garical *et al.* 2002).

To perceive of Landscape composition and configuration with landscape metrics, different approaches are available. To perceive composition, metrics are used to with regard to the importance of each patch type. It was determined characteristics such as rate, richness (patch richness), regularity, dominance and diversity (patch number) with metrics related composition. It was defined physical distribution of patches in mosaic structure with landscape configuration. Metrics are size and shape, neighborhood (the distance to the nearest neighborhood) and distribution related configuration, (Farina 2000; Letiao and Ahern 2002).

Landscape metrics help us to understand changes in landscape from different perspectives (Visual, ecological, cultural). Landscape metrics have been provided contributions to the Landscape ecology studies. These contributions are listed below (Letiao and Ahern 2002; Miller *et al.* 2005).

- It is understood relationship between landscape structure and landscape function with Landscape metrics. Otherwise, using landscape metrics, It is estimated the effects of planning activities on ecological systems.

- Quantifying of structural characteristics is necessary for sustainable planning. In this way, ecological processes are understood, various modeling studies are done and contributions are made to the monitoring studies in the area.
- At the same time, landscape metrics are made, to determine the changes in the landscape over time.

Landscape metrics are used in conjunction with geographic information systems (GIS). GIS has made a major contribution to the study of the landscape metrics (Johnston 1998). GIS and related technologies are used for a long time in studies related to the ecology. It offers a lot of possibilities to the users. To use landscape metrics and digital data adapted with GIS have been made contributes to the landscape planning studies (Karadeniz and Gökyer 2005). To quantify the Landscape metrics, computer programs have been developed same as Fragstats (Mc Garical and Marks 1994; Mc Garical *et al.* 2002), and Patch Analyst (Elkie *et al.* 1999).

Determination of landscape structure, Quantifying changes in this structure and determination of the structure of the landscape, with regard to the evaluation of these enhanced measures (Landscaping measures). These metrics are listed below (Elkie *et al.* 1999; Mc Garical and Marks 1994; Mc Garical *et al.* 2002):

- Area/Density/Edge metrics
- Shape metrics
- Core area metrics
- Isolation/Proximity metrics
- Diversity metrics
- Evenness metrics
- Connectivitiy metrics
- Dominance metrics

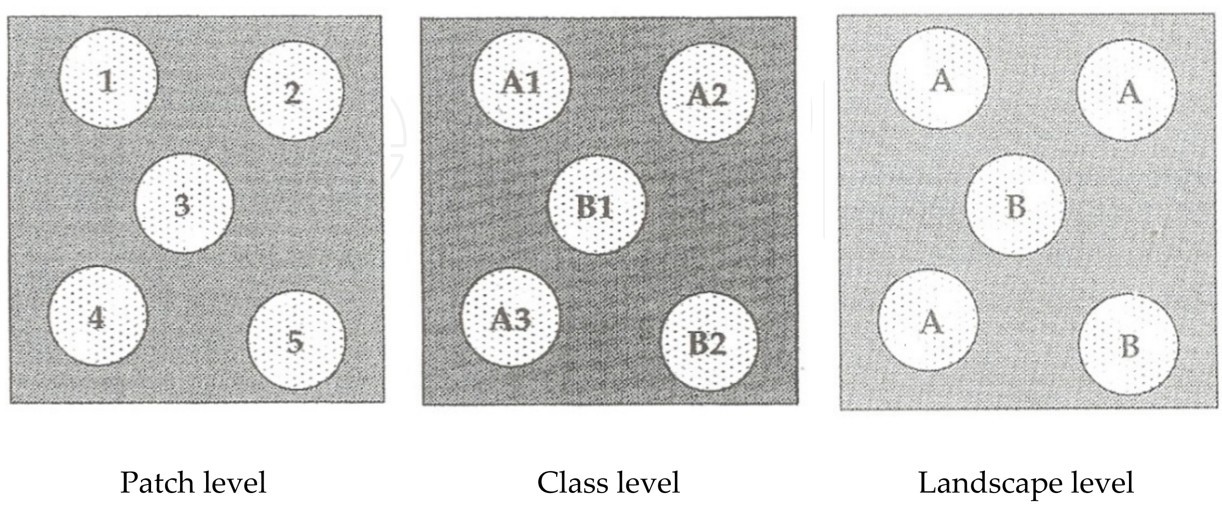

Figure 2. Calculation levels of landscape metrics (Farina 2000).

Landscape metrics could be calculated to three categories (Figure 2) (Mc Garical *et al.* 2002; Farina 2000):

1. Patch level: To calculation ever patch type in a mosaic.
2. Class level: To calculation ever patch type class.
3. Landscape level: All of the mosaic is calculated.

7. Case study

In this study, Case study area is Bartın province in North part of Turkey (Figure 3). Central part of the Bartın was selected to analyze (Figure 4).

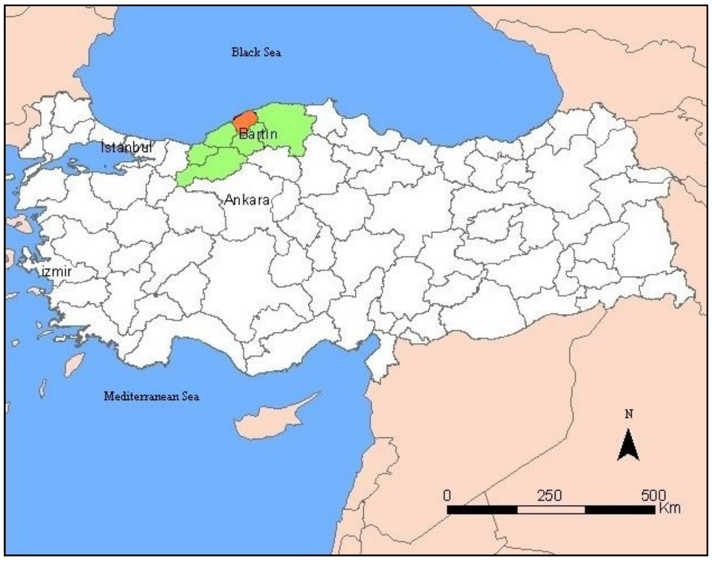

Figure 3. Bartın province in Turkey

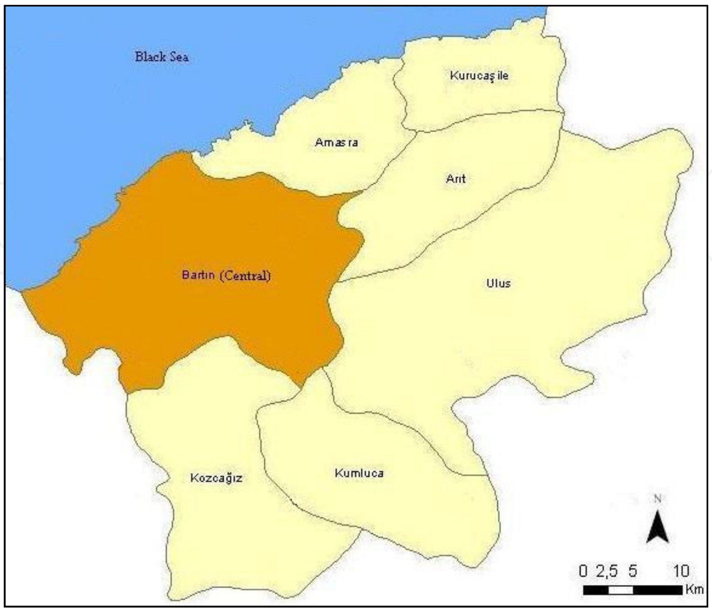

Figure 4. Case study area in Bartın province

In this study, Land cover maps were developed using Landsat satellite images obtained in 2000 (Landsat 7 ETM) and 2010 (Landsat 5 TM). Images were formed by supervised classification method using ERDAS IMAGINE 8.4. Five land cover types are identified and used in this study. Classified maps were analyzed with neighborhood functions (3x3 moving window). Land cover types are forest, agriculture, residential, water (river), sand (sandy areas). Classified maps (landcover maps) can be seen in figure 5-6.

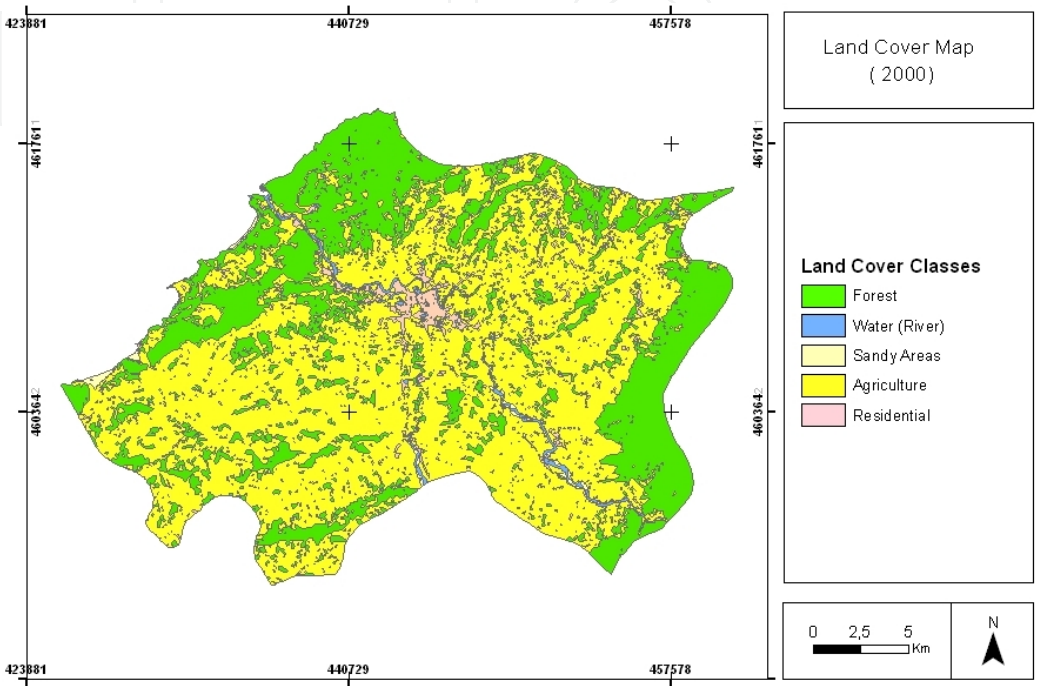

Figure 5. Land cover map for the year of 2000.

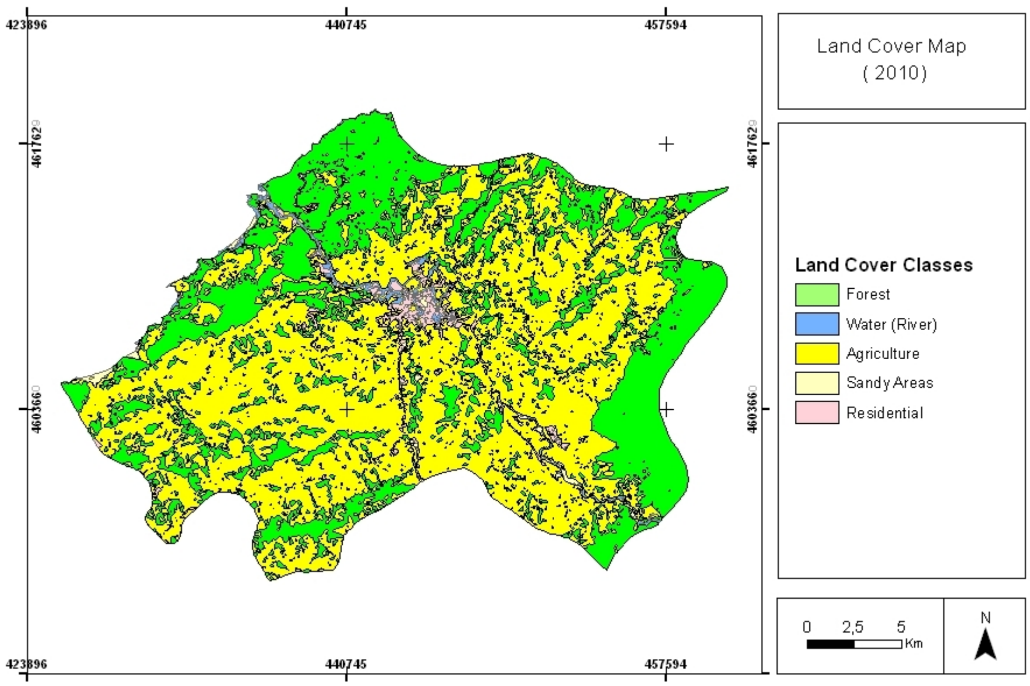

Figure 6. Land cover map for the year of 2010.

In the study, the overall Accuracy and Kappa analysis were used to perform a classification accuracy based on error matrix analysis. For the 2000 dated image, overall classification accuracy was established as 87.12% and Kappa coefficient was computed 0.7524. For the 2010 dated image, overall classification accuracy was established as 90.27% and Kappa coefficient was computed 0.8092. Results of the accuracy analysis can be seen in the table1-2.

Class Name	Reference Totals	Classified Totals	Numbers Correct	Producers Accuracy	Users Accuracy
Forest	39	43	37	94.87%	86.05%
River	2	2	2	100%	100%
Sandy Areas	1	1	1	100%	100%
Agriculture	81	82	73	90.12%	89.02%
Resident	9	4	2	22.22%	50.00%
Total	132	132	115		

Overall Accuracy 87.12 %, Overall Kappa Statisics 0.7524

Table 1. Accuracy analysis results for land cover map (2000)

Class Name	Reference Totals	Classified Totals	Numbers Correct	Producers Accuracy	Users Accuracy
Forest	47	38	38	80.85 %	100 %
River	1	2	1	100 %	50 %
Sandy Areas	1	1	1	100 %	100 %
Agriculture	62	72	62	100 %	86.11 %
Resident	2	1	1	50 %	100 %
Total	113	113	102		

Overall Accuracy 90.27 %, Overall Kappa Statisics 0.8092

Table 2. Accuracy analysis results for land cover map (2010)

Landscape metrics were calculated using the fragstats program (Rempel *et al.* 2012). Results can be seen in the table 3-4.

CalculationLevel	**Calculated Parameters**							
Class Level	**CA (ha)**	**TLA (ha)**	**NUMP**	**MPS (ha)**	**TE(m)**	**MSI**	**SEI**	**SDI**
Resident	1382	-	1180	1.1	440837	1.3	-	-
Agriculture	32834	-	570	57.6	1779556	1.4	-	-
Forest	17690	-	1169	15	1368308	1.4	-	-
Water (River)	550	-	318	1.7	171174	1.3	-	-
Sandy Areas	244	-	155	1.6	64093	1.2	-	-
Landscape Level	52703	52703	3392	15.5	3823970	1.3	0.8	0.5

CA: Class Area, TLA: Total Landscape Area, NUMP: Patch Number, TE: Total Edge, MPS: Mean Patch Size, MSI: Mean Shape Index, SEI: Shannon Evenness Index, SDI: Shannon Diversity Index, ha: hectare, m: meter

Table 3. Calculation results for landscape metrics by the year 2000 land cover map

Calculation Level	Calculated Parameters							
Class Level	**CA (ha)**	**TLA (ha)**	**NUMP**	**MPS (ha)**	**TE (m)**	**MSI**	**SEI**	**SDI**
Resident	1034	-	731	1.4	316104	1.3	-	-
Agriculture	31429	-	666	47	1843999	1.4	-	-
Forest	19031	-	1240	15	1543806	1.4	-	-
Water (River)	847	-	722	1.2	299287	1.3	-	-
Sandy Areas	362	-	279	1.2	109238	1.3	-	-
Landscape Level	52703	52703	3638	14.5	4112437	1.4	0.9	0.5

CA: Class Area, TLA: Total Landscape Area, NUMP: Patch Number, TE: Total Edge, MPS: Mean Patch Size, MSI: Mean Shape Index, SEI: Shannon Evenness Index, SDI: Shannon Diversity Index, ha: hectare, m: meter

Table 4. Calculation results for landscape metrics by the year 2010 land cover map

Class Area (CA): Changes can be identified over time with CA.

Number of The Patches (NUMP): Patch number can be evaluated over time with NUMP. If NUMP value increases it is understood fragmentation increases in the field. If NUMP value decreases it is understood fragmentation decreases in the field.

Mean Patch Size (MPS): MPS can be used to evaluate fragmentation. If MPS value increases it is understood fragmentation increases in the field. If MPS value decreases it is understood fragmentation decreases in the field.

Total Edge (TE): TE can be used to determine important areas for wild life. Agriculture, forestry and water are seen as important areas for wildlife in the study area. If TE is high valued these areas are suitable for edge species. TE value is used to determine suitable habitats for edge species.

Shannon Evenness Index (SEI): SEI identifies to distribution (regular or irregular) of patches in the area. If SEI value approaches 1 it is understood patches distribution are regular in the field.

Shannon Diversity Index (SDI): SDI refers to diversity of patches in the area. If SDI value is zero it is understood area consist of single patch. Distribution of patches can be identified in each other and field.

8. Conclusions

In the case study area landscape metrics were calculated by the year 2000 land cover and by the year 2010 land cover. In the study area;

- It is seen increase in forest areas and decrease in agricultural areas.
- Patches distribution is regular in the area.
- The distribution of the patches does not change over time in the field.
- Mean patch size is decreased over time. That describes, fragmentation is increased.
- Total edge value for forest, agriculture and river is high. So these areas are appropriate for edge species.

In the study area, increasing to the forest areas are extremely important for wild life. Habitats and transaction fields are increased. Increasing to the fragmentation is negative for living species in the area. Because their habitats and transaction areas is restricted.

In the study area, Bartın River as corridor is important controlling water and mineral nutrient flows. Area is separated into two parts along the river. Various birds and mammals appear to move effectively along the River.

Using landscape metrics provide many facilities in landscape ecology studies. We can obtain objective results on landscape structure with the calculation of landscape metrics. Numerical results can be obtained on landscape mosaic.

Landscape structure can be analyzed over time using these results. With calculating landscape metrics, human effects can be detected on landscapes over time. Landscape health can be determined.

As a result Landscape metrics are important for landscape ecology. Metrics provide numerical data on landscape. Landscape structure and landscape change can be analyzed. Information can be obtained about landscape function using metrics.

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