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# A Research on the Determination of the Ecological Effects of Road Networks: The Example of Hendek, Turkey

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**Abstract:** The number of road networks increase day by day. This brings about many problems. The aim of the study is to determine the effects of road networks on landscape structure with the landscape ecology-based approaches. In the study, to carry out landscape ecology based evaluations, 7 patch classes belonging to forest matrix were determined by firstly examining forest cover type map. The effects of roads were evaluated in the context of fragmentation situation. Fragmentation was analyzed with Patch Analysis, which was performed under ArcGIS program. At the end of the analysis, patch size and number, patch form, patch edge and core areas values concerning the patch classes were determined. These values were relatively scored out of 5 points, provided that the areas with less fragmentation were considered to have conservation priority. The total score of every patch class was found and the patch classes were divided into classes between each other according to their conservation priority degrees. The results of the study showed that the study area where road networks existed and intensified had much more fragmentation. The fragmentation in the patch classes increased in the direction of "mixed leafy, leafy- mixed forest, open area in forestry, coniferous-grassland, mixed coniferous". In the evaluation in which less-fragmentation areas considered to have conservation priority, it was found that 16.14% of the study area had a very high, 24.63% of it had a high, 12.78% of it had a moderate, 0.05% of it a low and 0.1% of it very low conservation degree.

**Key words:** Road networks, landscape change, landscape fragmentation, landscape ecology, patch analysis

## INTRODUCTION

Roads are a critical component of civilization and modern life (Lugo and Gucinski, 2000). Roads provide safe and efficient mobility. However fragmentation is influenced by the existence and extension of road networks (Baker, 1989; Farina, 2000; Mander and Antrop, 2003; Burel and Baudry, 2003; Forman, 2005). Fragmentation changes landscape structure (Serfis, 1994; Spellerberg, 1998; Lugo and Gucinski, 2000; Riitters *et al.*, 2004; Forman *et al.*, 2003; Hawbaker *et al.*, 2006). Fragmentation has two negative effects in landscape: "smaller more isolated remaining habitat patches and loss of total habitat area" (Esbah, 2001). Fragmentation is when the landscape elements that show sustainability or an area usage that makes up landscape matrix become isolated parts. If this process goes on, these parts get even smaller and the distance among them will get further. In time, rest of the parts will gradually vanish. At the end of this stage, a new matrix comes into being (Forman *et al.*, 2003; Selman, 2006).

Landscape ecology provides understanding of landscape fragmentation (Forman, 1995; Uzun, 2003; Ivits *et al.*, 2005; Forman, 2009). Landscape ecology focuses on landscape structure and change (Clark, 2010; Turner *et al.*, 2001). Landscape structure is determined by composition and configuration of patches, corridors and matrix. The properties of patch enable to evaluate fragmentation. The properties of patch are determined by patch size, patch number, patch shape, patch edge and core area (Forman, 1995; Dramstad *et al.*, 1996; Uzun, 2003; Ivits *et al.*, 2005). Below, the basic information of each element in the patch classes is summarized:

- As the size of the patch grows the fragility of the landscape increases. Similarly, the increase in the number of big patch indicates the decrease in the level of fragmentation and the increase in the number of small patches indicates the increase in the level of fragmentation. In this scope, the increase in the number of patch is interpreted as a result of fragmentation. The increase in the number of patches will increase fragility in this situation. The state of fragmentation is put forward by evaluating the patch size and patch number together (Forman, 1995; Uzun *et al.*, 2012)

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- Patch shape is important as it affects the dynamics and the flows (energy, nutrition, etc.) in the landscape. Patch shape is evaluated in the frame of 3 basic principles. *Compact forms* are effective in protection and protects the inner resources against the harmful influences around. *Curvy forms* increases the interaction with the environment. *Web form* enables the action in the system. Patch shape is evaluated with "Mean Shape Index (MSI), Mean Perimeter Area (Mpar), Mean Patch Fractal Dimension (MPFD)" concerning the patch classes. When MPAR value is low and MPFD value is close to 1, it shows that the patches are more pressed and more circular. The fact that the patch form is circular and pressed means less fragmentation. Patch edge density's being low, namely less edge, means more internal kind habitat. When core area density value decreases, internal kind habitat diminishes. The analyses that were made with vectorial data took the circle form as a base (Forman and Godron, 1986; Forman, 1995; Uzun, 2003)
- Patch edge is the exterior part of a patch. Patch edges form the areas where mutual relationships between different animals are dense and these areas are neighbour to the transition zones, which are called ecotone (Uzun *et al.*, 2012; Turner *et al.*, 2001). The form of the edges affects the flow of nutrition, water and energy in the patch. In the evaluations concerning the patch Edges, Total Edge (TE), Edge Density (ED) and Medium Patch Edge (MPE) are examined. In the ex-post evaluation, especially ED was interpreted. The fact that the density is low shows that the patch class edge is low. This situation means that more interior habitats live. The fact that interior type is less shows that fragmentation increases. This situation, however, is not a situation of primary protection (Uzun *et al.*, 2012)
- Core areas are defined as the biggest circle area that can fit into the inside of the patch and in the evaluation, the unweathered part of the patch is focused. Ecologically the core area generally shows the center of a patch. The presence of core areas in the patch is related to the interior habitat beings that will live there. The presence of a core area having enough width in the patch is important for the life of living beings (Forman, 1995; Dramstad *et al.*, 1996; McGarigal *et al.*, 2009; Uzun *et al.*, 2011). In this situation, the presence of core areas means that there is less fragmentation and there will be high protection. In the evaluations concerning the core areas, a 100-meter buffer zone, mentioned in Uzun *et al.* (2012), concerning the patch class was formed and subjected to patch analysis and "Total Core Area (TCA), Core Area Density (CAD) and total core area index (TCAI)" were obtained. In the ex-post evaluation, especially CAD value was interpreted. The fact that density is high means that more interior type habitats live. This situation, as stated before, shows that fragmentation is less

The purpose of the study was to determine the effects of road networks on landscape structure with the landscape ecology-based approaches.

## MATERIALS AND METHODS

**Study area:** The study was carried out in the urban area of Hendek Country of Sakarya province located in Catalca-Kocaeli part of Marmara Region (Fig. 1). The study area is located in 5525300.00-573900.00 east longitude and 4512880.00-4526967.00 north latitudes in ED50/UTM zone 36 N. It covers approximately 264.5 $km^2$ (Fig. 2) (Anonymous, 2009). The study case has forest (53.37%), agricultural (40.48%), settlement (6.04%), meadow (0.05%) and water body (0.046%) (Anonymous, 2004a).

When the natural landscape elements of the study area was analysed, it was seen that the geological structure was formed by the rock succession of "alluvial quaterner, pebble-sandstone pliocene, rock-andesite-basalt sub eocene-mid eocene, sandstone sub ordovician, argillaceous limestone ordovician-sub devonian, sandstone-mudstone sub eocene-mid eocene". The area is situated on the first-degree seismic zone (Anonymous, 2004b).

There are I, II, III, IV, VI and VIIsoil classes (land capability class). VII soil classes constitute the 49.32% of the study case. The study areas is covered by 72.94% non-calcareous brown forest soil and 19.86% colluvial soil (Anonymous, 2004c). The height in the study area changes mostly between 22-253 m and the height in the area-wide is 180 m. While the 56.37% of the area has a slope of 0-10, the 29.26% of the area has a slope of 11-21%. Additionally, 48.76% of the study area is exposed to south (south, southeast, southwest), 22.31% is exposed to north (north, northeast, northwest) and 17.84% is exposed to west (Anonymous, 2009). Due to its geographical position, the study area is located on the transition area of the Continental Mediterranean climate Region and West Black sea climate Region. When the climactic data is evaluated, it is seen that the mean yearly temperature is 14.1°C, the coldest month is January by 5.7°C and the hottest month is July by 22.8°C. The number of rainy day is approximately 119 and the amount of rainfall is 804 mm. Rainfall is seen mostly in winter and in

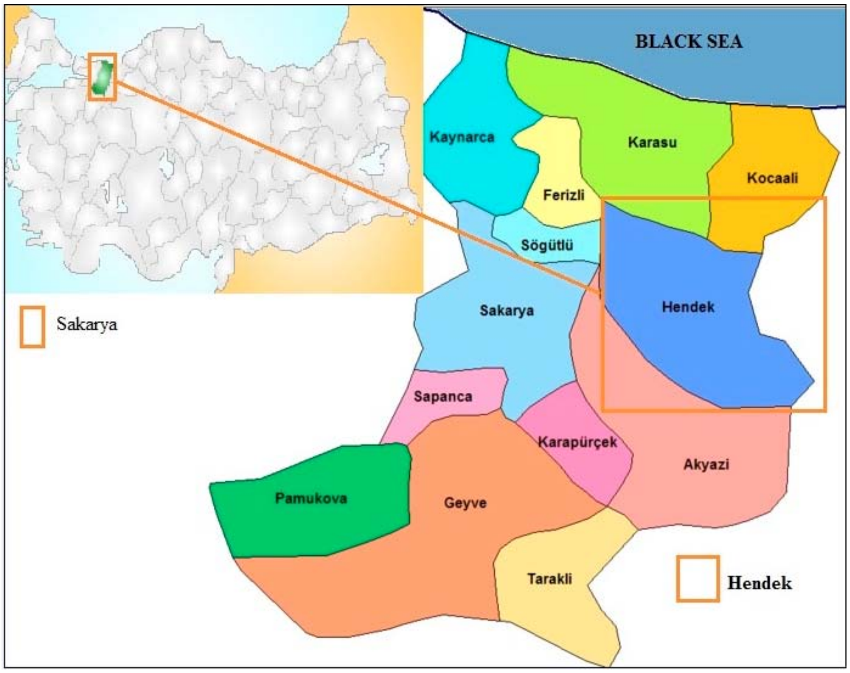


Fig. 1: Location of the study area in Turkey

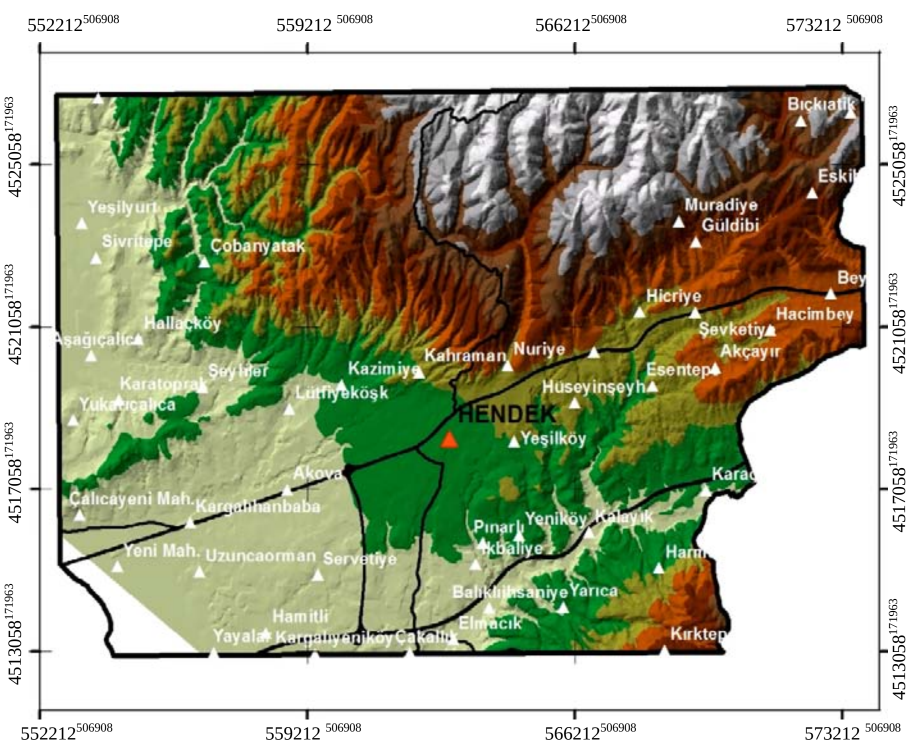


Fig. 2: Study area

December (12.5%). The most droughty month is August (4.5%). The number of snowy days is approximately 7 and the highest snow depth has been measured as 48 cm. The number of clear weather is 55, cloudy weather is 190, overcast weather is 120.

The winds generally blow from northeast (northeaster) and northwest (northwester) and sometimes from south (southwester) (Anonymous, 2011a). In the study area, there is a forestland of 141.17 $km^2$ in total, 43.05% of which is leafy, 30.25% is mixed leafy, 4.62% is coniferous, 0.18% is mixed coniferous, 3.1% is mixed and 18.8% is open area. The common tree species of the forestland are *Quercus* sp. (25.92%) and *Fagus orientalis* (13.13%) (Anonymous, 2004a).

When the cultural landscape elements concerning the study area are examined, it is seen that there are 1 central municipality, which has 20 district, 2 towns and 45 villages in the administrative structure (Anonymous, 2012). In the study area, 61825 people in total live in Hendek County by 72.27% and in towns and villages by 27.73% according to the results of 2011 general census. The population density in the study area is 234 person $km^{-2}$ (Anonymous, 2011b). The economy in the study area depends on agriculture and 60% of the active workforce deals with agriculture. Especially hazelnut is grown in this area. The fact that meadows take a small space in the area enabled livestock farming to develop to meet the needs (Colfaoglu, 2006). The industry in the area accelerated its development with the Organized Industrial Site (Anonymous, 2013), which was established in 1997 on an area of 3.5 $km^2$ and with the stimulation of industry, which was given by the state after the earthquake of 1999. Also, the fact that the area is close to big cities (Ankara, Bursa, Istanbul, Izmit) supports that development (Hayir, 2005). The study area is located on the D-100 Highway and its distance to Istanbul is 170 km, to Ankara is 275 km, to Adapazari is 30 km and to Bursa is 205 km (Colfaoglu, 2006). When the road network is analysed, it is detected that there are 80.68 km highway and 28.3 km motorway between the cities; and 225.9 km vehicle road in the intercity. There are also 124.85 km forest road and 162.72 km village road (Anonymous, 2012).

**Determination and evaluation of patch classes:** The effect of the road networks was expressed with landscape fragmentation in this study. In the evaluation of the fragmentation, the statistical values concerning the patch classes were used. In this context, the method is composed of four stages.

In the first stage of the method, basic patch classes were determined by analyzing the digital forest cover type maps. Then, to build up the polygons belonging to the patch classes, the 1:25000 scaled digital forest cover type maps which are still used today and developed by The Ministry of Forestry and Water (Anonymous, 2004a) and the digital road network map developed by Sakarya Governorship (Anonymous, 2012) were overlaid. For the overlay, the overlay analysis, which was performed under ArcGIS 10 program, was used. However, by taking the influence spheres of the roads into consideration, a buffer zone being 4m and used by Uzun *et al.* (2012) was built. To determine the buffer zone, the buffer analysis being performed under ArcGIS 10 program, was used (Booth, 2000).

In the second stage of the method, the statistical data to be used in evaluating the patch classes were determined. Also, 4 criteria were used in evaluating the patch classes: patch size and number, patch shape, patch edge and core areas. The Patch Analysis module was used to gain evaluation data. The Patch Analysis-5.1, which was performed under ArcGIS 10 program, was used in the study. The Patch Analysis was created by Rempel. The statistical data concerning "patch size and number, patch shape, patch edge" are gained by analysing the patch classes, which are predetermined by the Patch Analysis, in the level of class. To gain data concerning the core area, a core area is formed primarily. For this, a buffer zone of 100 m is formed in the patch classes (Uzun *et al.,* 2012). The obtained core area map is analysed with Patch Analysis and total core area, core area density and total core area index are obtained.

In the third stage, the values concerning patch size and number, patch shape, patch edge and core area were considered in the frame of fragmentation. While considering these values, the patches with less fragmentation were considered as "conservation priority". The patch classes were relatively scored out of 5 points (1: Very high 2: High 3: Moderate 4: Low 5: Very low) according to the conservation priority. In this scope, in scoring the patch size and number, an evaluation was carried out from "patch classes of less fragmentation" to "patch classes of more fragmentation" and the scores were given from 5 to 1. In scoring the patch shape, an evaluation was carried out from "straight, round and pressed" to "folded, lobed and long" and scores were given from 5 to 1. In scoring the patch edge, an evaluation was carried out from "less density for patch edge" to "more density for patch edge" and scores were given from 5 to 1. In scoring the core area, an evaluation was carried out from "more density for core areas" to "less density for core areas" and scores were given from 5 to 1. Then, the total score which was given to each patch class was calculated. The total scores were evaluated relatively among each other again. The results were transferred to the map. In the evaluation of and scoring the fragmentation process, works of "Forman and Godron (1986), Forman (1995), Uzun (2003), Forman (2009), Uzun *et al.* (2011) and Uzun *et al.* (2012)" were used.

Lastly, landscape ecology based suggestions concerning the process of planning the highways were developed by putting forward patch classes, which were to be protected in the process of planning the highways.

## RESULTS AND DISCUSSION

The ten patch classes were acquired by analyzing the forest cover types in the study area. These patch classes are: "mixed coniferous, coniferous, leafy, mixed leafy, mixed forest, grassland, open area in forestry, water resource, agriculture, settlement". In the study, only the forest matrix, which has mixed coniferous, coniferous, leafy, mixed leafy, mixed forest, grassland, open area in forestry was evaluated to clearly put the effects of highways forward and agriculture, settlement areas weren't included in the evaluation. Then, the patch classes taking place in the forest matrix were formed by overlaying the forest cover type and road network maps. As a result of the overlay analysis, 4175 polygons for eight patch classes have been defined.

As a result of the evaluation of the whole patch classes with patch analysis, "patch size and number, patch form, patch edge and core areas" values concerning the area were found (Table 1). As the statistical values of water resources were low, they were not included in the evaluation. When the patch class area values were analysed, it was seen that leafy had the most patch area (6077.05 ha) and Grassland had the least patch area (13,699 ha). When the patch number values were considered, on the other hand, it was seen that leafy had the highest number of patches (225) and Grassland had the lowest number (3). When the patch size values were considered, it was seen that leafy had the highest mean patch size (12.20). However, to analyse the situations of the patch classes according to each other within the context of the study, the patch numbers in a 100 ha area were determined. In this situation, in 100 ha, there were 59.10 patches in mixed coniferous, 44.93 patches in open area forestry, 34.5 patches in coniferous, 21.91 patches in grassland, 10.05 patches in mixed forest, 9.33 patches in leafy and 8.20 patches in mixed leafy. This was interpreted as an increase in the patch number as a result of fragmentation. Most of the fragmentation happened in mixed coniferous patch class. To analyses patch form, especially mean perimeter area ratio and mean patch fractal dimension values were examined. The values showed that patch form gradually deviated from being circular in the direction of "grassland (1122-1.48), open area in forestry (2195-1.47), mixed forest (4066-1.55), mixed coniferous (4159-1.59), mixed leafy (422-1.60), leafy (6075-1.56) and coniferous (8613-1.51)" and became a longer and complex structure. That was interpreted as deviation of patch form from being circular as a result of fragmentation. Coniferous patch form had the most of the fragmentation. When the patch edge density values were considered, it was seen that patch edges gradually diminished in the direction of "leafy (32.11), mixed leafy (21.33), coniferous (7.53), mixed forest (2.67), open area in forestry (2.59), mixed coniferous (0.27) and grassland (0.19)". That was interpreted as increase in the density or length of edges. Leafy patch class had the most of the fragmentation. When the core area density values were considered, it was seen that density gradually decreased in the direction of "leafy (0.59), mixed leafy (0.35), open area in forestry (0.21), coniferous (0.11), mixed forest (0.06) and mixed coniferous (0.01)". That was interpreted as

Table 1: Patch analysis results

| Parameters | I | II | III | IV | V | VI | VII |
|---|---|---|---|---|---|---|---|
| Class area (ha) | 651.91 | 25.38 | 6077.05 | 4270.00 | 437.67 | 204.75 | 13.69 |
| Total landscape area (ha) | 23997.74 | 23997.74 | 23997.74 | 23997.74 | 23997.74 | 23997.74 | 23997.74 |
| Number of patches | 225.00 | 15.00 | 567.00 | 350.00 | 44.00 | 92.00 | 3.00 |
| Mean patch size | 2.90 | 1.69 | 10.72 | 12.20 | 9.95 | 2.23 | 4.56 |
| Median patch size | 0.38 | 0.09 | 0.20 | 0.13 | 0.37 | 0.41 | 1.98 |
| Patch size coefficient of variance | 287.81 | 224.44 | 426.54 | 459.76 | 363.10 | 206.07 | 104.02 |
| Patch size standard deviation | 8.34 | 3.80 | 45.72 | 56.09 | 36.12 | 4.59 | 4.75 |
| Total edge | 180767.55 | 6581.97 | 770553.12 | 511752.75 | 64168.34 | 62146.31 | 4510.63 |
| Edge density | 7.53 | 0.27 | 32.11 | 21.33 | 2.67 | 2.59 | 0.19 |
| Mean patch edge | 803.41 | 438.80 | 1359.00 | 1462.15 | 1458.37 | 675.50 | 1503.54 |
| Mean shape index | 2.22 | 1.90 | 2.48 | 2.65 | 2.44 | 2.08 | 3.09 |
| Area weighted mean shape index | 2.17 | 1.53 | 2.85 | 3.00 | 2.92 | 1.69 | 1.92 |
| Mean perimeter area ratio | 8612.65 | 4158.51 | 6074.87 | 4227.09 | 4066.46 | 2195.03 | 1122.13 |
| Mean patch fractal dimension | 1.51 | 1.59 | 1.56 | 1.60 | 1.55 | 1.47 | 1.48 |
| Area weighted mean patch fractal dimension | 1.34 | 1.30 | 1.33 | 1.32 | 1.34 | 1.32 | 1.34 |
| Total core area | 7500.45 | 7500.45 | 7500.45 | 7500.45 | 7500.45 | 7500.45 | 0 |
| Total core area index | 13.19 | 15.76 | 35.21 | 40.75 | 32.38 | 6.33 | 0 |
| Core area density | 0.11 | 0.01 | 0.59 | 0.35 | 0.06 | 0.21 | 0 |

I: Coniferous II: Mixed coniferous III: Leafy IV: Mixed leafy V: Mixed forest VI: Open area in forestry VII: Grassland decrease in the core area density as a result of fragmentation. Mixed coniferous patch class had the most of the fragmentation (Table 1).

Patch size and number, patch form, patch edge and core areas value concerning the seven patch classes in the study area were relatively scored out of 5 inversely proportional to fragmentation situation and the total score concerning each patch class was found. The scores were evaluated between each other and the patch classes were divided into five according to conservation priority. When the scores were evaluated, mixed leafy had a very high conservation degree with 18 points; leafy and mixed forest had a high conservation degree with 17 points; open area in forestry had a moderate conservation degree with 15 points; coniferous and grassland had a low conservation degree with 14 points; mixed coniferous had a very low conservation degree with 12 points (Table 2).

The results reached according to conservation status were transferred to the map on the Fig. 3. On the map, the

Table 2: The evaluation of patch classes in terms of conservation degree

| Parameters | I | II | III | IV | V | VI | VII |
|---|---|---|---|---|---|---|---|
| Patch size and number | 3 | 1 | 5 | 5 | 5 | 2 | 4 |
| Patch form | 4 | 5 | 4 | 5 | 5 | 5 | 5 |
| Patch edge | 5 | 5 | 3 | 4 | 5 | 5 | 5 |
| Core area | 2 | 1 | 5 | 4 | 2 | 3 | 0 |
| Total | 14 | 12 | 17 | 18 | 17 | 15 | 14 |

I: Coniferous II: Mixed coniferous III: Leafy IV: Mixed leafy V: Mixed forest VI: Open area in forestry VII: Grassland

conservation degree is very low in the areas where road networks exist and intensify. This situation shows that roads lead to fragmentation. Additionally these results are parallel to the studies of Lugo and Gucinsk (2000), Forman *et al.* (2003), Riitters *et al.* (2004), Ivits *et al.* (2005) and Hawbaker *et al.* (2006) that emphasised on the fragmentation effect of the highways. When the study area was examined according to conservation degrees, 24.63% of the area had a high conservation degree, 12.78% of it had a moderate conservation degree, 0.1% of it had a very low conservation degree and 0.05% of it had a low conservation degree. Additionally, the water body, agriculture, settlement, etc. constitute 46.3% of the study area.

Forman (1995) and Tuncay *et al.* (2009) stated that the elements (patches, etc.) displaying sustainability in the structure of landscape would firstly be isolated and then would gradually vanish in time by getting smaller. This process plays a deterministic role on the ecological operation and the quality of the landscape. This process also isn't a desired situation for present landscapes as it will lead to habitat loses, decrease in bio-diversity, change in ecological balance, etc. when the results of the study was examined, it was seen that there was less fragmentation in the south and the southeast of the study area. A protection map was formed after fragmentation situation was analysed. The map revealed the priority of the areas to be protected in the process of developing the

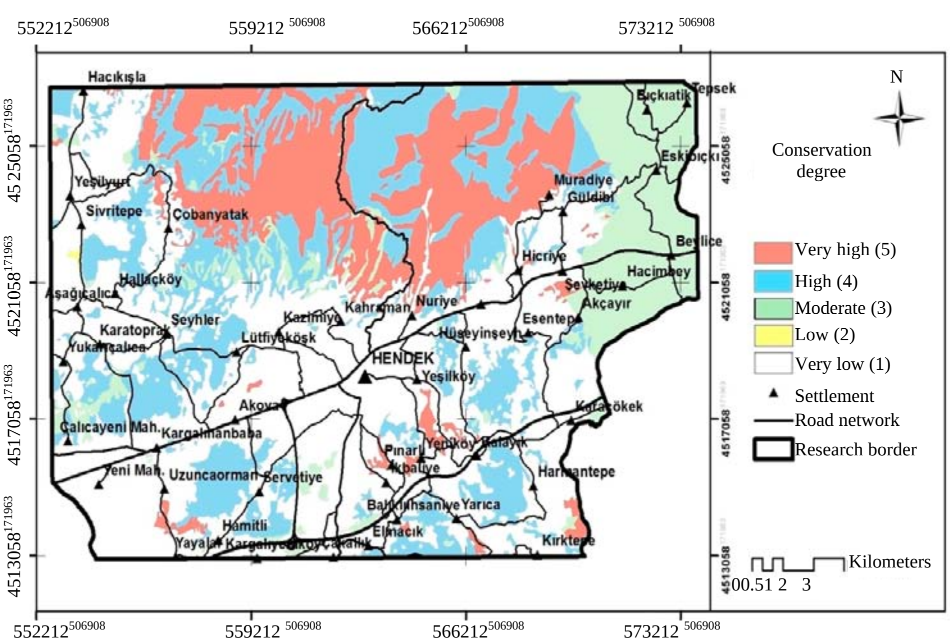


Fig. 3: Conservation area in Hendek

road networks. In this situation, the south and the southeast of the study area have protection priority and dense road network system must be avoided. More detailed evaluations on the level of patch are needed for the road routes to be determined. The fragmentation will be able to be diminished by evaluating area and road routes concerning road networks interactively.

To decrease or prevent the fragmentations that are caused by road networks, putting the structure of landscape is important. Some statistical data are used to evaluate the situation of fragmentation. Forman *et al.* (2003), Uzun (2003), Forman (2008) and Tuncay *et al.* (2009) state that these statistical data enable evaluations concerning landscape structure to be made and more effective plan-execution decisions to be developed. Additionally, the data is also the handle for land use planning, since spatial pattern strongly controls dynamics, flows and changes of both natural systems and people. These data concerning the structure of the landscape are obtained by various methods. In the study, the data concerning patch classes were evaluated. To obtain data, Patch Analysis-5.1 module, which was performed under ArcGIS 10, was used. Patch analysis is an effective module in obtaining easy and fast data concerning patch classes.

## CONCLUSION

Fragmentation increased and landscape structure changed in the areas where roads existed and road networks intensified in Hendek County. The patch classes of forest matrix were very important data in showing the fragmentation caused by road networks. Patch Analysis-5.1 module, which was performed under ArcGIS 10 and used in the analysis of fragmentation status, is an effective tool. The values of patch size and number, patch shape, patch edge and core areas belonging to patch classes, which were acquired as a result of patch analysis, enabled fragmentation situation to be determined. These values were interpreted with landscape ecology based approaches. Conservation degrees, namely the areas having conservation priority, in the study area were determined after fragmentation situations were evaluated. Transferring the areas of conservation priority into the map provided the process of planning and designing of highways with an important base map. This base map is an inventory for preserving the habitats and biodiversity at the same time. As a result, the road networks that can be developed with landscape ecology based approaches will provide important contributions for the spatial planning that carries conservation and sustainable use goals.

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