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Analyzing Landscape Change Through Landscape Structure Indices: Case of the City of Aydin, Turkey

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Abstract: This study analysis the spatial pattern change with regards to landscape connectivity in Aydin by using landscape structure indices and GIS technology. Rectified black and white aerial protographs from 1977 and pan sharpened Ikonos images from 2002 are used in the analysis. A set of class level landscape structure indices are employed: percentage of landscape; patch number; mean patch size; area weighted mean patch size; mean shape index and connectance index. The findings indicate a decrease in the proportion, patch number, mean patch size and connectance of the crop fields, fruit groves and natural areas and an increase of these attributes for open spaces, vacant lots and urban built up areas. The recommendations to improve the spatial structure in relation to landscape connectivity include: increasing the amount of natural patches by restoring the natural attributes of the open space patches; mitigating the conversion of open spaces to urban built up areas by allocating suitable areas as parks and open space corridors for a city wide ecological network; making agricultural patches as main components of the local and regional ecological networks; encouraging ecologically sound agricultural practices for an effective network structure; preserving riparian corridors and improving structure by applying ecologically sound design principles and encouraging finger-like development pattern to implement green wedges penetrating into the urban core areas.

Key words: Landscape pattern, landscape indices, GIS, landscape change, City of Aydin

INTRODUCTION

Urbanization is one of the major reasons for habitat loss and fragmentation. When urban areas extend, they transform the original landscape into a number of smaller patches of smaller areas, isolated from each other. Typical phases of fragmentation include perforation, incision, dissection, dissipation, shrinkage and attrition (Jaeger, 2000; Forman, 1997). Any of these may occur simultaneously and fast paced in urban areas, hence, a dramatic change in the function and structure (spatial pattern) of the landscape. Species differ in their sensitivity to these changes (Bierwagen, 2007). For instance, habitat generalists survive better in a changing matrix than habitat specialist species (Jules and Shahani, 2003).

Connectivity is an important concept in fragmented landscapes (Taylor *et al*., 1993). Merriam (1984) has introduced the concept of connectivity to emphasize the interaction between landscape structure and the species behavior. Lindenmayer and Fischer (2006) emphasized the distinction between three types of connectivity: ecological connectivity, habitat connectivity and landscape connectivity. Ecological connectivity is the connectedness of ecological processes across multiple scales such as disturbance process, hydroecological flows. Habitat connectivity is the connectedness between patches of suitable habitat for an individual species. Landscape connectivity is the human perspective of the connectedness of pattern of a land cover in a given landscape. According to Forman and Godron (1986), landscape connectivity deals with the mapable spatial arrangements of different land cover types in the landscape and is measured by analyzing landscape pattern independent of the any attributes of the organisms of interest (Collinge and Forman, 1998; Tischendorf and Fahrig, 2000; Bennett, 2003). Landscape connectivity affects the source-sink or foraging area relationship and acts as a filter that consequently governs the ability of many species to move into different areas (Forman, 1995; Young and Jarvis, 2000).

Quantification of landscape pattern is a key element for studying the implications of landscape fragmentation (Turner *et al*., 2001; Forman and Godron, 1986). Metrics to characterize such pattern are termed landscape structure indices (Lindenmayer and Fischer, 2006; Forman, 1997). Landscape structure indices attempt to provide descriptions of landscape composition, configuration and connectivity. They can be used to assess the ecological integrity of landscapes or as variables for models that support planning actions (Yang and Liu, 1995). Typical phases of fragmentation such as shrinkage and attrition (disappearance) can easily be detected by landscape structure indices. Caution should be exercised in their utilization. For instance, a small set of indices that are not redundant but can capture the major properties of a landscape should be preferred (Leitao and Ahern, 2002), because the choices of indices are quite rich and some of them may be correlated with each other (Leitao *et al*., 2006). Choice of appropriate spatial observational units is another critical issue because landscape structure indices are sensitive to the extent over which they are calculated (Yang and Liu, 1995).

The present study attempts to analyze the spatial pattern change in the City of Aydin, Turkey from 1977 to 2002 by using landscape structure indices. More specifically, the objective is to quantify the impacts of urbanization on the spatial pattern and landscape connectivity of its surrounding landscape.

MATERIALS AND METHODS

Study area: The study area, City of Aydin, is located in Aydin Province, region of Aegean in Turkey. It is bounded by 27°47'40" and 27°53' 52" East and 37°52' 2" and 37°48'51" North coordinates and covers a 2450 ha area. Aydin urban area is located between the Southern skirts of the Aydin Mountains and Northern section of the Big Meander Valley. Big Meander River runs from East to West direction approximately 5 km away from the city. Tabakhane Stream, running North to South direction in the city, traverses the plain and reaches to the river (Fig. 1).

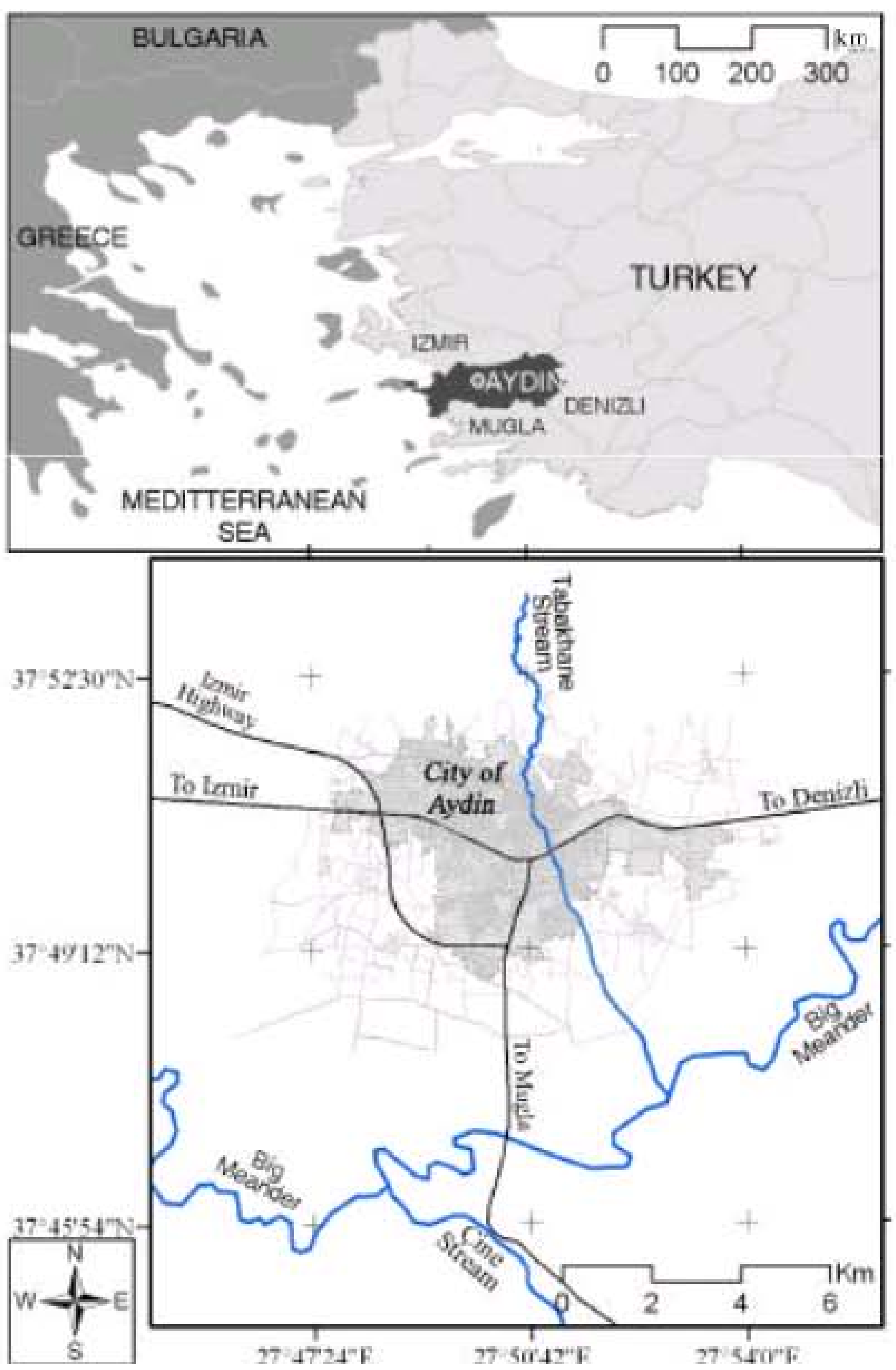

Fig. 1: Study area

Stretching in the East-West direction along the major road connecting two major industrial cities, Izmir and Denizli, Aydin is the fifth fastest growing city in Turkey (Deniz *et al*., 2008). The social and economic structure of Aydin is mainly shaped by agriculture: olive, fig and cotton productions have significant impact on local economy. The second important economic activity is commerce, which is based on the processing of agricultural goods. However, the agriculture's role in the local economy is changing since 1980s due to national industrialization policy.

The urban population of Aydin has grown continuously during the last four decades. Between 1960 and 2000, urban population increased 4.03 times and reached to 143,267 in 2000. Population density increased from 111 to 332 person km^{-2} in this period. The City of Aydin's population density is higher than the provincial, regional and national average (121 person km^{-2} in the province, 96 person km^{-2} in Aegean region and 87 person km^{-2} in Turkey according to 2000 census). Area wise, the city grew 7.2 times in this period. Open space opportunities are very limited in the urban matrix. Even though the City of Aydin puts a great deal of effort in meeting the varying outdoor needs of the society, their effort is undermined by the unsustainable planning, design and management of Aydin's open spaces (Esbah and Deniz, 2007).

Images and GIS procedures: The primary research materials included rectified 1:35,000 scale black and white aerial photographs from 1977 and the pan sharpened and rectified Ikonos images from 2002 with 1 m resolution. First, the materials were visually studied and based on this, seven land cover categories are defined: crop fields (areas of mainly cotton, corn and wheat production), fruit groves (areas of olive and fig plantations), natural areas, open spaces (areas with altered natural attributes such as topography, vegetation, soil etc.), riparian (drainage corridors, washes and creeks), urban (built-up areas), vacant (areas with signs of construction foundations). Second, the polygons of different land covers were created in ArcGIS 9.2 environment by on screen digitization for each study period and a change matrix is generated by calculating the land cover transformations through the intersect function of the software. And then, the 1977 and 2002 land cover maps were used as the primary data for computing selected landscape indices: Percentage of land (PLAND), Patch Number (PN), Mean Patch Size (MPS), Area Weighted Mean Patch Size (AWMPS), Mean Shape Index (MSI) and connectance index (CONNECT).

The ArcGIS software has several imbedded functions that support the measurements of utilized metrics. The software automatically calculates polygon area and perimeter length and adds such information to the attribute table of each map. New columns for shape index and area weighted patch size were added to the attribute tables and the field calculator function was utilized to generate the values for each patch. Information pertaining to the first five indices were calculated by utilizing the summarize function of the software. Connectance index was calculated by using Fragstats (version 3) software. Fragstats was also utilized in verifying the values obtained from the analyses in ArcGIS9.2.

Landscape structure metrics: In this study, we utilized six class level landscape structure indices (Table 1). These metrics, either individually or in conjunction reveal a

Table 1: Metric equations

Metrics equations	Description	References
$PLAND_i = \frac{\sum_{j=1}^{n} a_{ij}}{A} \times 100$	$PLAND_i$ = Class area percentage for the ith land cover class, a_{ij} = Area of patch j for the ith land cover class and A = Total landscape area	Leitao *et al*. (2006)
$PN = \sum_{i=1}^{n} P_i$	PN = Patch number and P_i = Patch of the ith land cover class	Leitao *et al*. (2006)
$MPS = \frac{\sum_{j=1}^{n} a_{ij}}{n_i}$	MPS = Mean patch size, a_{ij} = Area of patch j for the ith land cover class and n_i = No. of patches in the ith land cover class	Leitao *et al*. (2006)
$AWMPS = \sum_{j=1}^{n} \left[a_{ij} \left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}} \right) \right]$	AWMPS = Area weighted mean patch size, a_{ij} = Area of patch j for the ith land cover class	Leitao *et al*. (2006)
$MSI = \frac{\sum_{j=1}^{n} \frac{p_{ij}}{2\sqrt{\pi \times a_{ij}}}}{n_i}$	MSI = Mean shape index, p_{ij} = Perimeters of patch j for the ith land cover class, a_{ij} = Area of patch j for the ith land cover class, n_i = No. of patches of the ith land cover class	Mc Garigal and Marks (1995)
$CONNECT = \left[\frac{\sum_{j=k}^{n} c_{ijk}}{\frac{n_i(n_i-1)}{2}} \right](100)$	c_{ijk} = Joining between patch j and k of the corresponding patch type (i), n_i = No. of patches of the ith land cover class	McGarigal *et al*. (2002)

distinct but complementary aspect of complex processes such as fragmentation and shrinkage in a particular land cover class.

PLAND measures the percentage of the landscape comprised of a particular land cover class. It allows to quantify the extent of each land cover class and thereby discern the presence of a matrix, identify poorly represented land cover classes and characterize the overall evenness (or its complement, dominance) of the landscape (Forman and Godron, 1986; Leitao *et al*., 2006). PLAND approaches zero when the corresponding land cover class becomes increasingly rare in the landscape and equals 100 when the entire landscape consists of a single patch of the corresponding land cover type.

PN represents the number of discrete patches of a particular land cover class. PN is simply the total number of patches within a specified land cover class. Landscape processes such as fragmentation divide large contiguous patches into smaller remnant patches. PN reveals this subdivision aspect of fragmentation, which is listed as one of the greatest threats to biodiversity (Forman, 1997; Groom *et al*., 2005).

According to McGarigal and Marks (1995), patch size is the single most important and useful piece of information, as patch size affects biomass, primary productivity, nutrient storage per unit area, as well as species composition and diversity (Forman and Godron, 1986). MPS measures the size of discrete patches summarized across all patches of a particular land cover class. AWMPS weighs each patch on the basis of its size relative to the total class area. AWMPS is insensitive to the omission or addition of very small patches and weighs larger patches more heavily than smaller patches. This metric is particularly relevant when one or more large patches may be dominant in the particular land cover (e.g., urban-built up areas), despite the presence of numerous small patches (Leitao *et al*., 2006). MPS or AWMPS can serve as a fragmentation index if it is used with PN.

MSI measures the average patch shape for a particular land cover class. Patch size and shape strongly influences the magnitude and nature of the interaction of a patch with its surrounding neighborhood, principally via., edge effects and cross-boundary processes. MSI deals explicitly with the geometric complexity of a patch: higher patch complexity yields higher MSI values. Linear patches and corridors have greater MSI than compact, rounded patches. And complex, convoluted patch shapes have greater MSI than simple patch shapes (Forman and Godron, 1986).

As a measurement of landscape connectivity, CONNECT refers to the physical continuity of a patch type (or a land cover class) across the landscape. Connectance is defined on the number of functional joining between patches of the corresponding patch type and reported as a percentage of the maximum possible connectance given the number of patches (McGarigal and Marks, 2002). The index ranges between 0 when either the focal class consists of a single patch or none of the patches of the focal class are connected and 100 when every patch of the focal class is connected (McGarigal *et al*., 2002). Greater details of these landscape structure indices are available in McGarigal Marks (1995), McGarigal *et al*. (2002), Leitao *et al*. (2006) and Forman (1997).

RESULTS

As being the leading land cover type, crop fields covered 56.36% of the study area and displayed a highly connected structure in 1977 (Table 2). By 2002, the proportion, patch number and mean patch size of crop fields decreased along with their landscape connectivity. This means that the crop fields not only declined in quantity but also in quality. Primary implications of this decline may include lower rates of production, diminishing opportunities for species dispersal between agricultural patches and diminishing pollination. The shape of the crop fields have become slightly less complex due to their interaction with urban land covers (Table 2). Increasing interaction of this cover with the urban areas is also supported by the type of land cover transformations: Crop fields have been converted primarily to built-up areas and secondarily to open spaces (Table 3). Some crop fields have been converted to fruit groves, however, fruit groves have benefited more from this reciprocal shift (Table 3).

Fruit groves has experienced a similar but relatively less change compared to crop fields (Table 2). Decreasing proportion, patch number and mean patch size values indicate that fruit groves are in the attrition stage of the land transformation. The results also show that the connections between the fruit groves have diminished 25%. As urbanization has taken over the groves, new fruit grove patches with more complex shapes have emerged by converting the peripheral natural areas to olive plantations by removing the rest of the maqui vegetation (Table 3). The outcome of such a conversion could be declining biodiversity and overall ecological integrity in Aydin.

The proportion and number of natural patches has declined in the study area (Table 2). The remnant natural patches have become smaller and less connected. This means that the habitat quality of the remnant natural areas may decline due to increasing edge effects and decreasing

Table 2: Percentage of landscape (PLAND), patch number (PN), mean patch size (MPS), area weighted mean patch size (AWMPS), mean shape index (MSI) and connectance index (CONNECT) results (1977-2002)

Parameter	Pland (%)	PN	MPS (m^2)	AWMPS (m^2)	MSI ($m\ m^{-2}$)	Connect (%)
1977						
Crop fields	56.37	724	19078.14	48.60	1.33	95.76
Fruit groves	10.71	121	21683.61	433.29	1.31	50.93
Natural	4.25	35	29778.63	2228.01	1.65	63.52
Open space	7.65	111	16884.55	894.05	1.44	25.22
Riparian	0.71	3	57975.85	23559.56	4.19	33.33
Urban	20.07	138	35650.32	2346.33	1.37	18.86
Vacant	0.25	6	10115.04	2565.59	1.23	0.00
2002						
Crop fields	20.41	357	14007.80	70.63	1.29	70.57
Fruit groves	7.64	100	18734.08	456.66	1.37	38.20
Natural	1.18	20	14507.39	1852.92	1.54	47.89
Open space	16.30	262	15250.44	435.06	1.36	34.08
Riparian	0.51	6	21016.72	4091.70	2.97	20.00
Urban	50.24	138	89217.41	4631.07	1.45	54.49
Vacant	3.71	32	28407.24	2879.14	1.39	11.09

Table 3: Land cover transformations (ha) in the study area (1977-2002)

Land use (ha)	Crop fields	Fruit groves	Natural	Open space	Riparian	Urban	Vacant	2002 total
Crop fields	460.37	19.33	11.93	5.82	0.00	2.63	0.00	500.08
Fruit groves	62.66	97.29	24.42	2.59	0.23	0.16	0.00	187.34
Natural	0.31	1.09	27.16	0.07	0.18	0.20	0.00	29.01
Open space	286.69	24.65	22.40	56.13	0.14	9.54	0.00	399.56
Riparian	0.00	0.00	0.00	0.00	12.61	0.00	0.00	12.61
Urban	519.89	116.69	7.29	102.75	4.23	478.94	1.41	1231.20
Vacant	51.66	3.29	11.02	19.86	0.00	0.41	4.66	90.90
1977 total	1381.57	262.34	104.23	187.23	17.39	491.88	6.07	2450.71
Class change	921.20	165.06	77.06	131.09	4.78	12.95	1.41	
Image difference	-881.49	-262.34	-104.23	-187.23	-17.39	-491.84	-6.07	

opportunities for species depending on the ecologically important core area of natural patches. Natural areas have been primarily converted to fruit groves and open spaces and secondarily, to crop fields and vacant lots (Table 3). Conversion of natural cover to urban land cover has been relatively low until 2002, but this may increase in the future. The transformation of natural lands to open spaces and vacant lots points the areas of the future urban encroachment (Fig. 2).

Open spaces have increased mainly at the expense of agricultural lands (Table 3). New open space patches have emerged at the peripheral areas of urban development where the agricultural activities were abandoned with the anticipation of forthcoming urban development. The open space structure has become more fragmented as indicated by increasing patch number and decreasing mean patch size of the open space cover. The form of the open spaces has displayed less convoluted shapes. This makes them more suitable and easy to convert to urban uses. Nevertheless, a 35.13% increase in their landscape connectivity may improve the ecological quality in the urban matrix, if the open spaces were utilized for creating a city wide ecological network.

Urban developments have expanded 150.26% mainly at the expense of crop fields. Even though the number of urban patches hasn't changed, the average size of these patches has grown significantly: the area weighted mean patch size has displayed a 97.37% increase (Table 2). This indicates the concentric expansion of Aydin. The increase in the connectance index indicates that the city has grown in continuous blocks. Mean shape index results show that the form of the development is 5.38% more complex. The rate of urban development could be escalating as indicated by a significant increase in the magnitude of the vacant lots. Present results showed that vacant lots expanded at the expense of crop fields, open spaces and natural areas (Table 3).

As a result of urbanization, the riparian corridors of Aydin have decreased 27.50% between 1977 and 2002 (Table 3). Tabakhane stream has been the major riparian element in the study area (Fig. 2). It was crossing the natural and cultural landscapes of the study area with almost no disruption in 1977. However, the stream corridor has gone through a major habitat alteration: it was canalized and dissected by roads and sidewalks, hence becoming narrower and less connected and complex in shape. Moreover, the wash, in the northeast, has been dominated by building blocks. These changes in the structure of riparian corridors may have various ecological, social and physical implications such as altered flow pattern, increasing flood hazard, decreasing opportunities for species dispersal, diminishing recreational potential and visual qualities.

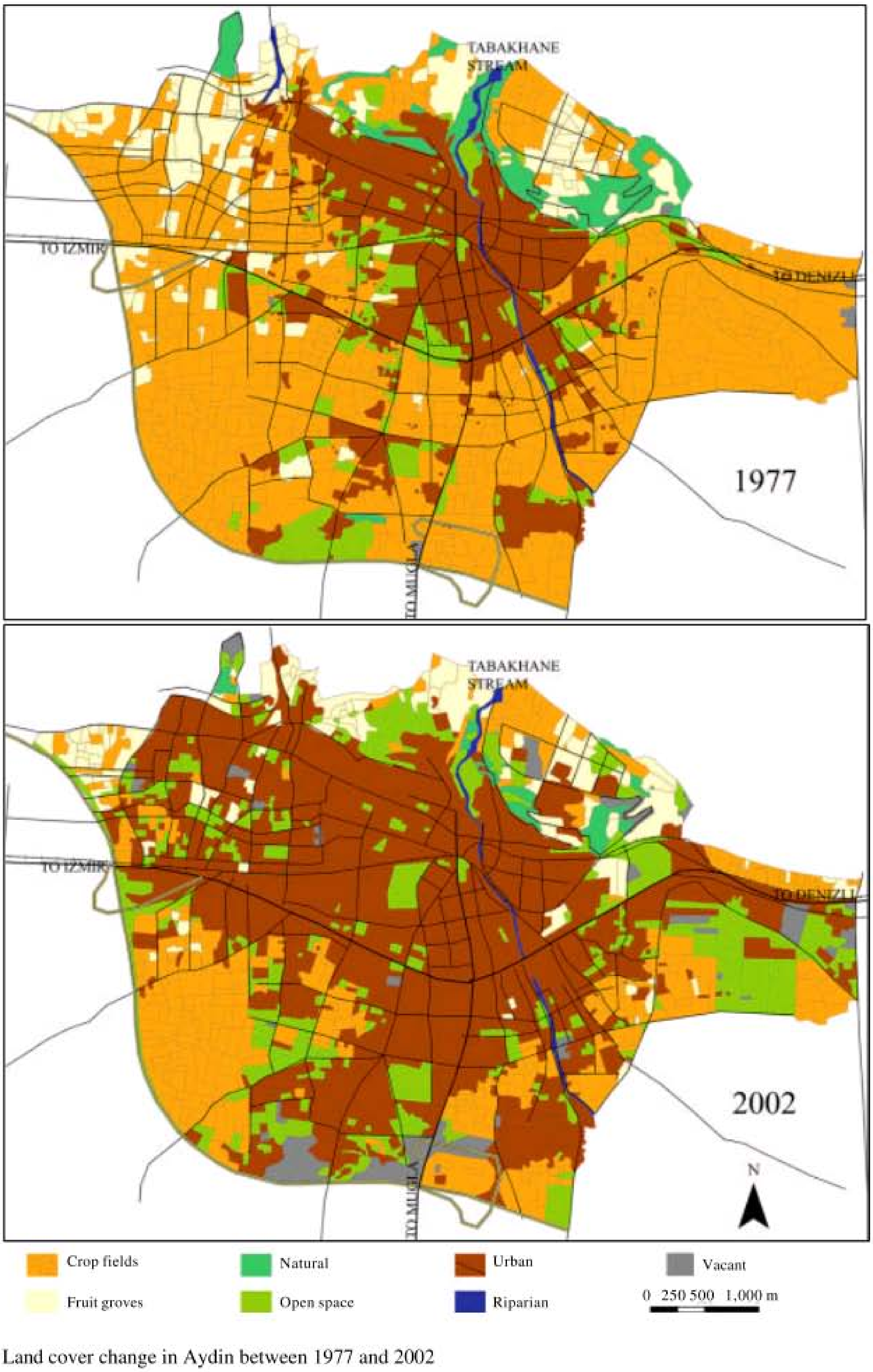

Fig. 2: Land cover change in Aydin between 1977 and 2002

DISCUSSION

This study analyzes the urbanization driven changes in the landscape pattern through landscape structure indices in the City of Aydın. Even though the application of landscape indices to relatively pristine rural areas are abundant, the utility of such indices in urban planning is scarce due to the resulting confusion about the selection and interpretation of these metrics (Leitao *et al*., 2006) and also due to the redundancy and overlap among them (Tischendorf, 2001). However, articles by Cook (2002), Bierwagen (2007) and Leitao and Ahern (2002) demonstrate the utility of landscape structure indices in urban planning practices.

This study is the first example of using landscape structure indices for monitoring and planning of an urban environment in Turkey. Leitao and Ahern (2002) suggest using several indices in conjunction, each revealing a distinct but complementary aspect of fragmentation. The method proposed in this study has followed their suggestion and allowed for a quick inquiry and could be applicable to regional and metropolitan land use planning in Turkey and other international cases. Because the study is based on quantitative landscape ecology, it can be adjusted to local conditions, allowing further refinements when new relevant information appears.

Existing studies on landscape connectivity either deals with more natural systems at regional scale (Soulé, 1991), or focuses on metropolitan areas with substantial amount of ecological corridors and habitat areas as in Barcelona (Marulli and Mallarach, 2005), or urban preserves as in Phoenix (Cook, 2002). The investigation of landscape connectivity in smaller, denser and more compact urban environments as in the case of Aydin is rare. But, the issue deserves attention, because the land use planning and management techniques indigenous to aforementioned areas may not be practical due to different dynamics involving in the development of dense urban areas. For instance, as in the examples from some European and Asian cities, high density development mode often lacks natural green spaces (Jim and Chen, 2003). Therefore, policies should be developed to modify the future urban growth pattern to include substantial amount of high quality open spaces. Bierwagen (2007) states that highly aggregated landscapes are likely to experience rapid, ecologically significant decreases in connectivity and opportunities to protect or restore connectivity disappear quickly as growth continues. The findings of this study confirm this fact, in that the landscape connectivity of natural and agricultural systems has declined considerably.

In line with the findings of Esbah and Deniz (2007) and Esbah (2007), the present study has demonstrated that the Aydin's landscape matrix was an aggregated agricultural matrix at the beginning; however the priorities in land utilization have shifted from agriculture to urban. In fact, this is the case in many other urban areas in Turkey (Alphan and Yilmaz, 2005; Kurucu and Chiristina, 2008). The findings of this study are significant in terms of detecting the attrition (disappearance) stage of the land transformation in the agricultural and natural areas and demonstrating the magnitude of fragmentation in open space system. This study also confirms the research by Tuncay and Esbah (2006), in that the urbanization of Aydin has negatively affected the structure of the riparian corridors.

CONCLUSIONS AND RECOMMENDATIONS

This study has quantified the impacts of urbanization on the spatial pattern of its surrounding landscape and landscape connectivity in the City of Aydin. Subsequently, the study has tested the performance of a set of landscape indices (percentage of landscape, patch number; mean patch size; area weighted mean patch size; mean shape index and connectance index). The selected indices of this study have effectively captured the impact of urbanization on the spatial pattern of the surrounding landscape and therefore, can be used in the forthcoming monitoring and planning activities for the study area as well as for other urban cases with similar landscape structure.

The findings of this research have indicated that urbanization has most negatively affected crop fields, fruit groves, natural areas and riparian corridors through fragmentation process. In fact, these land covers have been in attrition (disappearance) stage of the landscape transformation. Open spaces has increased in the study area, but the open space system has presented a highly fragmented structure with vast numbers of smaller patches. Establishing an ecological network in the area is necessary and timely to maintain urban ecological integrity.

This study recommends the following planning strategies to improve the spatial structure in relation to landscape connectivity in the City of Aydin: (1) increase the amount of natural patches by restoring the natural attributes (e.g., vegetation, soil) of the open space patches; (2) reduce the conversion of open spaces to urban built up areas by allocating these areas as parks and open space corridors for a city wide ecological network; (3) stop the degradation of agricultural areas by means of zoning, subsidies, acquisition, law enforcements and so forth and see them as main components of the local and regional ecological networks; (4) encourage ecologically sound agricultural practices for an effective network structure; (5) develop strategies to preserve riparian corridors and improve their contribution to ecological network of the city by developing ecologically sound and sustainable design applications and (6) encourage finger-like development pattern to implement green wedges penetrating into the urban core areas.

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REFERENCES

Alphan, H. and T.K. Yilmaz, 2005. Monitoring environmental changes in the Mediterranean coastal landscape: The case of Cukurova, Turkey. Environ. Manage., 35: 607-619.

Bennett, F.B., 2003. Linkages in the Landscape the Role of Corridors and Connectivity in Wildlife Conservation. Gland, Switzerland.

Bierwagen, B., 2007. Connectivity in urbanizing landscapes: The importance of habitat configuration, urban area size and dispersal. Urban Ecosyst., 10: 29-42.

Collinge, S.K. and T.T. Forman, 1998. A conceptional model of land conversion process-predictions and evidence from a microlandscape experiment with grassland insects. Oikos, 82: 66-84.

Cook, E.A., 2002. Landscape structure indices for assessing urban ecological networks. Lands. Urban Plann., 58: 269-280.

Deniz, B., H. Esbah, E.V. Kücükerbas and U. Sirin, 2008. Analysis of vegetation structure in urban land uses: Case of the City of Aydin. Ekoloji, 17: 55-64.

Esbah, H., 2007. Land use trends during rapid urbanization of the City of Aydin, Turkey. Environ. Manage., 39: 443-459.

Esbah, H. and B. Deniz, 2007. Effects of land use development on urban open spaces. J. Applied Sci., 7: 1138-1144.

Forman, R.T.T. and M. Godron, 1986. Landscape Ecology. John Wiley and Sons, New York.

Forman, R.T.T., 1995. Some general principles of landscape and regional ecology. Land Scape Ecol., 10: 133-142.

Forman, R.T.T., 1997. Land Mosaics. Cambridge University Press, Cambridge, UK.

Groom, M.J., G.K. Meffe and R.C. Carroll, 2005. Principles of Conservation Biology. 3rd Edn., Sinauer Assoc. Inc., New York.

Jaeger, J.A.G., 2000. Landscape division, splitting index and effective mesh size: New measures of landscape fragmentation. Landscape Ecol., 15: 115-130.

Jim, C.Y. and S.S. Chen, 2003. Comprehensive green space planning based on landscape ecology principles in compact Nanjing City, China. Lands. Urban Plann., 65: 95-116.

Jules, E.S. and P. Shahani, 2003. A broader ecological context to habitat fragmentation: Why matrix habitat is more important than we thought. J. Veg. Sci., 14: 459-464.

Kurucu, Y. and N.K. Chiristina, 2008. Monitoring the impacts of urbanization and industrialization on the agricultural land and environment of the Torbali, Izmir region, Turkey. Environ. Monit. Assess., 136: 289-297.

Leitao, B.A. and J. Ahern, 2002. Applying landscape ecological concepts and metrics in sustainable landscape planning. Lands. Urban Plann., 59: 65-93.

Leitao, A.B., J. Miller, J. Ahern and K. McGarigal, 2006. Measuring Landscapes: A Planner's Handbook. Island Press, New York.

Lindenmayer, D. and J. Fischer, 2006. Habitat Fragmentation and Landscape Change: An Ecological and Conservation Synthesis. Island Press, New York.

Marulli, J. and J.M. Mallarach, 2005. A GIS methodology for assessing ecological connectivity: Application to the Barcelona metropolitan area. Lands. Urban. Plann., 71: 243-262.

McGarigal, K. and B.J. Marks, 1995. FRAGSTATS: Spatial Analysis Program for Quantifying Landscape Structure. US. Department of Agriculture, Portland.

McGarigal, K., S.A. Cushman, M.C. Neel and E. Ene, 2002. FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps. University of Massachusetts, Amherst, MA.

Merriam, G., 1984. Connectivity: A Fundamental Ecological Characteristic of Landscape Pattern. In: Methodology in Landscape Ecological Research and Planning, Brandt, J. and P. Agger (Eds.). Roskilde University, Denmark, pp: 5-15.

Soulé, M.E., 1991. Land use planning and wildlife maintenance: Guidelines for conserving wildlife in an urban landscape. Am. Plann. Assoc. J., 57: 313-332.

Taylor, P.D., L. Fahrig, K. Henein and G. Merriam, 1993. Connectivity is a vital element of landscape structure. Oikos, 68: 571-573.

Tischendorf, L. and L. Fahrig, 2000. On the usage and measurement of landscape connectivity. Oikos, 90: 7-19.

Tischendorf, F., 2001. Can landscape indices predict ecological process consistently? Lands. Ecol., 16: 235-254.

Tuncay, A.A. and H. Esbah, 2006. Understanding the effects of historic land use pattern on an urbanized stream corridor. J. Applied Sci., 6: 1873-1881.

Turner, M.G., R.H. Gardner and R.V. O'Neill, 2001. Landscape Ecology in Theory and Practice: Pattern and Process. Springer-Verlag, New York.

Yang, X. and Z. Liu, 1995. Quantifying landscape pattern and its change in an estuarine watershed using satellite images and landscape metrics. Int. J. Remote Sens., 16: 3585-3594.

Young, C.H. and P.J. Jarvis, 2000. Measuring urban habitat fragmentation: An example from the Black Country. Lands. Ecol., 16: 643-658.