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Cellular automata-Markov chain and landscape metrics for landscape planning

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Abstract:
Landscape monitoring and modeling enable effective and comprehensive understanding of land use change. This, in turn, helps planners in gaining insight about the complex relationships involving in the planning process. This study aims to model land use/cover in the western Aydin Province for 2025 by using Cellular automata-Markov Chain and landscape metrics. Spot 2X (1994) and Aster (2005) images were utilized along with digital elevation model and population information. Modeling parameters included Elevation, Slope, Aspect, Population, and a set of Distance maps. Fuzzy logic and multi criteria approaches were pursued for model development, and then a core set of landscape metrics were applied. The results show that while urbanization would be changing landscape characteristics significantly in the study area, coniferous forest and salt marshes will increase due to management efforts in the legally protected parks; and that Maqui and Garique cover would continuously decrease by 2025 as a result of anthropogenic pressures. Recommendations include protecting large habitat patches and establishing an ecological network; developing buffer zone typologies and strategies for ecologically important areas; preserving stepping stone habitats; improving river, hedgerow, and road and canal corridors; and promoting soft landscape matrix as a landscape management strategy in rapidly urbanizing areas.

Keywords: *Landscape planning, land use change, modeling, landscape metrics*

Introduction

Forecasting future urban development has important implications for sustainability of species and protection of ecosystems. Changes in land use pattern and current development trends are important inputs in modeling upcoming urban growth (DeFries et al. 2004). These models and land use change maps can help planners, decision makers and public to generate strategies for mitigating adverse effects of unsustainable development. The goal of the urban modeling is to understand the dynamics of an urban system and to analyze its effects on environment. A range of analytical techniques are generated based on different urban theories. Urban form, urban size and economy are some of the approaches urban theories are constructed upon.

The initial efforts of urban modeling can be seen in the work of Alonso (1970). Later, with the progress of computer technology, the advance inquiries made possible: Gravity models (Lowry 1964) and probabilistic models are two examples to these efforts (Dökmeci 2005). Because the modeling of complicated urban or ecological systems mostly involve spatial and temporal processes, these static models is being challenged by explicitly more dynamic models.

One of the most commonly used stochastic models is Cellular Automata (CA) - Markov Chain. CA models are dynamic spatial models in which the basic unit is the cell, which can take on various states and is influenced by what is happening in other cells in their immediate neighborhood. (Batty 2005). CA models can easily be incorporated into GIS or can be used in developed software (Torrens, 2000; Yang ve Lo, 2003; Torrens, 2006). Markov analysis can be used three different ways: 1- for ex-post impact assessment of projects and policies, 2- for projecting the equilibrium land use vector, and 3- for projecting future land use changes given at initial transition probability matrix. Markovian analysis uses matrices that represent all the multi-directional land-use changes between all the mutually exclusive land-use categories (Weng, 2002; Xiaoying et al. 2004). Because it is flexible and practical, the application of CA_Markov model to many urban cases are common such as Atlanta (Yang and Lo,2003), Lizbon and Porto (Silva and Clarke, 2002), Desokata (Sui and Zeng, 2001), and Dongguan (Li and Yeh, 2000).

Landscape metrics enable effective and comprehensive evaluation of modeling results. They can be used to assess the ecological integrity of landscapes or as variables for models (Yang and Liu 1995). Land use transformation stages (Forman 2008) such as fragmentation, shrinkage and attrition (disappearance) can easily be detected by landscape metrics. Therefore, the combination of CA-Markov Chain and landscape metrics could be an important method for sustainable landscape planning.

This study aims to model land use/cover in the western Aydin Province for 2025 by using Cellular automata-Markov Chain and landscape metrics. Specifically, the objectives are to elaborate the drivers and magnitude of the long term land use/cover changes in the study area, to display the outcomes of the future land use/cover transformations, and to provide recommendations for the sustainable landscape planning in the study area. The significance of the study comes in the form of combining landscape metrics with CA-Markov analysis to explain the spatial and temporal changes in the study area, and hence elaborating the utility of CA- Markov and landscape metrics in supporting landscape planning actions.

Study area

Covering a total of 16650 ha., the study area is located along the Aegean coast of Aydın Province. It includes lands from Aydın's Kusadasi, Soke and Didim towns (Figure 1). Kusadasi is one of the prominent touristic and agricultural areas of Turkey. Kusadasi has grown significantly for over 50 years. Its population went up from almost 7000 people in 1960 to 47000 in 2000 and 56001 in 2008. Population density is approximately 582 person/square kilometers in Kusadasi, while the average density for the Province is 121 (Esbah et al. 2009). This is contributed mostly by domestic immigration and tourism. As a result urban sprawl occurred in the form of summer houses and touristic establishments. Currently, the town is merged with the neighboring other two towns on the south, Guzelcamli and Davutlar. The development not only impinges on agricultural areas, but also it pressures natural systems.

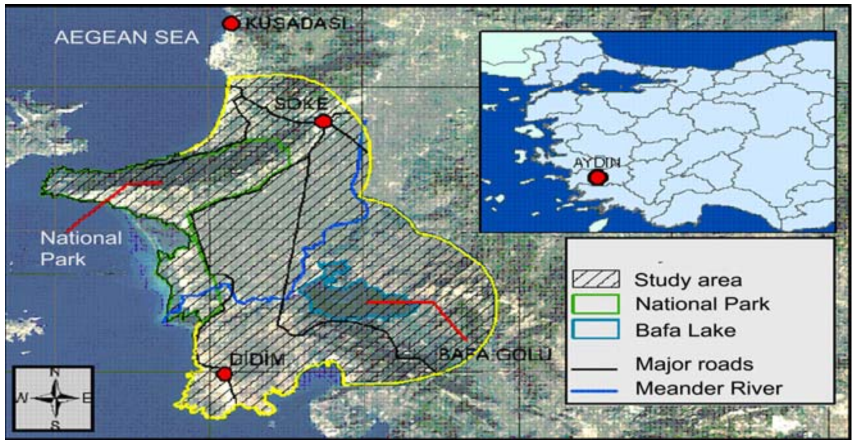

Figure 1. *Location of study area*

Guzelcamli borders with one of Turkey's oldest and ecologically important national parks, Dilek Peninsula-Big Meander Delta National Park. Dilek Peninsula part of the national park (10985 ha.) was declared in 1966 and Big Meander Delta (16690 ha.), south of the peninsula, was added later in 1994. The Peninsula is a "Flora Biogenetic Reserve" based on the European Council's European Biogenetic Reserve classification, and the Delta is an "A Class Wetland".

Figure 2. *Views from Kuşadasi; Kuşadasi harbor and business district (upper left), summer house developments on agricultural land (upper right), illegal waste dumping of Guzelcamli into the adjacent national park (lower left), and increasing pressure to natural patches and corridors by urban and agricultural uses (lower right).*

The national park borders with agricultural settlements of Tuzburgazi, Batiköy, Balat and Akköy. Doganbey, the only settlement in the park, is located at the transition zone from the peninsula to the delta. Despite its conservation status, the park faces significant challenges such as fire, water pollution, over grazing and hunting, exceeding visitor capacity during summer months, and thus the management actions focus on the interior dynamics. However, a greater threat is generated by the anthropogenic factors in the landscape context in which the parks are embedded (Figure 2). In a larger landscape scale, the interaction between the Kusadasi urban area and natural systems could be critical for the successful management of the resources.

The national park, specifically the Big Meander Delta section, also neighbors with Didim on the south. In addition to this, Didim is surrounded by other sensitive ecosystems such as the Aegean shoreline to the west and south, and the Bafa Lake Nature Park to the northeast. The town is the fastest-growing urban area in the Aydin Province of Turkey. The population density in Didim is approximately 507 person/square kilometer. For a long time, Didim was a small village whose economy relied on agriculture conducted in the peninsula's relatively infertile soils. Since 1990, when Didim was discovered by tourists seeking a modest vacation in an area with a nice climate and attractive beaches, the economy has changed significantly. Also, the landscape characteristics of Didim have changed rapidly by housing developments (Figure 3). The first-class Altinkum beach, various ancient historical sites such as the Temple and Oracle of Apollo, and a comfortable climate that is especially soothing for asthma patients, have been major reasons why Didim became an attractive tourist destination.

Figure 3. *Views from Didim area; a typical summer housing project in Didim (upper left), new developments fragmenting landscape towards Bafa (upper right), edge effects created by summer houses in Akbuk (lower left), decaying of never utilized summer houses.*

On January 6, 2005, Didim was registered as a ‘‘cultural and tourism protection and development region’’ by the Ministry of Culture and Tourism (MCT), which means that the Turkish government has designated it as a major investment area (MCT 2005). The MCT was given primary authority to generate macroscale development plans for the area and to oversee all investments and microscale planning. The resulting 1 : 25,000 scale general plan, effective as of 28 January 2006, encourages upscale, high-impact tourism development with planned construction of a fully operational marina, golf courses, sports centers, and five-star holiday villages. This is anticipated to substantially change the social, ecological, and economic characteristics of the town. Subsequently, unsustainable development would place severe pressure on the surrounding ecologically important ecosystems.

Even though, the proximity to the national park is not a constraining factor in terms of population dynamics in the major settlement areas such as Didim and Kusadasi, it is negatively effecting population in the small village like settlements. Because development activity is restricted in the borders of the national park, this is leading people to move other areas for finding jobs, hence leading population decrease. Batıköy, Balat, Akköy, Kapıkırı are some examples in hand. In general, the farther an area is from the national park and the closer it is to the major settlements (Didim, Kuşadası), the lower the rate and amount of population decline.

BLNP covers 12281 ha, of which 6721.5 ha is the Bafa Lake (Figure 1). Bafa Lake was one of the busiest bays of the Aegean Sea (Gulf of Lade) in the 7th century B.C. The sediments brought by the Big Meander River slowly separated the bay from the Aegean sea by the 1st century A.C. The altitude of the lake is 2m above sea level, and its maximum depth is 25m. The lake is primarily fed by the floods from the Big Meander River.

Despite its protection status and rich biological content, the environmental quality of the lake has been declining. The dynamics of the aquatic systems of BLNP has been altered significantly by the construction of a levee, canal and regulators since 1985. Pollution in the lake has been caused by the unregulated disposal of both domestic and industrial waste (Esbah et al. 2008). Moreover, residuals from agricultural fertilizers and pesticides upstream in the Soke Plains are threatening the fish and bird populations (Koc 2008). In 2009, the General Directorate of State Hydraulic Works (GDSHW) has initiated a project titled “Protecting the Natural Life and Ecological Balance of Lake Bafa” (Figure 4). Some encouraging improvements with regards to the quality of the lake water are already emerging from the project such as increasing water level and decreasing salinity due to adequate water input to the lake (Koc 2008).

Soke urban area is located on the east of the study area. Its population and urban growth is relatively slower, however the population density is much higher (c.a. 1348 person/square kilometer). Unlike Kusadasi and Didim, Soke is an agricultural community: finance, management and coordination center of agricultural activities in the Soke Plain. Soke plain is an important agricultural production area of Turkey especially for, cotton, wheat, corn and sunflower production. Soke is also an industrial town whose main production is based on agricultural goods.

Figure 4. *Views from Bafa Lake; traditional village living (upper left), ruins of ancient city of Heraklia (upper right), pollution in the lake (lower left), a regulator structure to control water flow to Bafa, GDSHW's solution for environmental recovery of Bafa.*

Material and method

Material

This study utilized ortho-rectified SPOT 2X (dated March 03, 1994) and ASTER Terra (dated April 27, 2005) images along with already rectified QuickBird satellite images (dated March 05, 2006). Additionally, 1:25000 scale topographical maps, existing GIS coverage and reports obtained from the municipalities, and local public institutions, and population reports are used for the analyses. Data collected by hand held Global Positioning System (GPS), and notes generated during our field studies are also used in the analysis as ground truth data.

Method

The analytical steps of the study are five fold: generating initial land use/cover maps; defining factors and constraints; weighting factors and assigning class suitability; CA-Markov chain process, and applying landscape metrics.

Generating initial land use/cover maps

Landuse/land cover maps of 1994 and 2005 are generated through an object based classification of Spot 2X and Aster images. Object based approach produces a thematic map composed of geographical entities labeled with actual land cover classes. This allows obtaining meaningful objects of ground features for analyzing landscape pattern with landscape metrics, describing the spatial complexity of the objects, and better utilizing complicated GIS functions in analyzing the data (Esbah et al., 2010). This study utilized already existing land use/cover maps from Esbah et al. (2009).

Due to the extend and context of the study and also hardware and software capacities, the 16 classes of the initial maps were reclassified into 8 categories: Agriculture, Coniferous forest, Garrique cover, Maqui cover, Water surfaces, Salt marshes, Rock surfaces, and Settlement areas. The cloud cover was masked in both classifications to reduce modeling flaws. The resolution of the material is re-sampled to 20 m.

Defining factors and constraints
At this stage of the study, the constraints, limiting change, were defined as legal boundaries of protected areas, and factors were defined as elevation, slope, aspect, distances to sea, roads and settlements, and population potential. Factors, which are affecting the direction and magnitude of the change, are mapped in GIS by using high resolution satellite images and aerials, topographical maps, digital elevation model (DEM), and population information. Among these factors; elevation, slope and aspect were generated from DEM by using 3D extension of the ArcGIS 9.3. Information regarding coastal line (sea), roads, and settlements were digitized from the satellite images and topographical maps. And then, Distance maps for each of these three landscape elements were produced based on Euclidian distances.

Population potential approach was employed for displaying the effects of population. The population potential of a target settlement is sum of the population of the surrounding settlements over their distance to the target settlement (Dökmeci, 2005). Reverse Distance Weighting interpolation was used to generate continuous population maps for 54 settlement areas (including both villages and major settlements). And then, a fuzzy approach is applied to each data set. This way, the values in each factor is assigned to a common scale (e.g.0-255 for 8 bit) for standard evaluation.

Defining class suitability
Multi criteria (MC) analysis was employed for generating suitability maps for each of the 8 land use/cover classes. MC facilitates the integration of multiple criteria during decision making process. For each suitability maps not only the weighting of the factors but also the direction of the interaction plays an important role. An expert choice approach was pursued when assigning weights.

CA-Markov chain process
Markovian process involves modeling future condition of a system based on its previous state. Markov chain analyzes spatial changes from one period to another in the past, and uses this information to make projections for future. A sub-product of this procedure is called transition probability matrix in which the probability of the transition of each land use/cover to other categories are presented. In this matrix, the columns represent the new categories while the lines represent initial land use/cover categories. In this study, the matrix is obtained in GIS by using 1994 and 2005 land use/cover maps. Finally, a set of three basic information were used as inputs to create the land use/cover map for 2025: a) 2005 land use/cover map as a baseline map, b) a final suitability map created by overlapping all the suitability maps, and c) transition probability matrix.

Landscape metrics
The quantification of landscape pattern through landscape metrics is a key element for studying landscape function and change (Turner et al 2001;

Forman and Godron 1986). After obtaining land use/cover maps for 1994, 2005 and 2025 a core set of landscape metrics were applied. First, these maps were converted from raster to vector format because the raster model has an inherent bias in how boundaries are represented (Leitao et al. 2006). And then, five class level landscape structure metrics namely percentage of landscape (PLAND), patch number (PN), mean patch size (MPS), and mean shape index (MSI), and patch density (PD) were utilized in the ArcGIS 9.3 environment (Table 1).

Table 1. *Core set of metrics used in the study and their explanation*

Metric	Formula	Explanation
Percentage of Landscape	$PLAND_i = \frac{\sum_{j=1}^{n} a_{ij}}{A} \times 100$	Quantifies the extent of each land cover class and thereby discerns the presence of a matrix, identifies poorly represented land cover classes, and characterizes the overall evenness (or its complement, dominance) of the landscape
Patch Number	$PN = \sum_{i=1}^{n} P_i$	Represents the number of discrete patches of a particular land cover class. reveals the subdivision aspect of fragmentation, more patches mean more boundaries between different land cover types, and new intervening land cover classes that may pose barriers to movement
Mean Patch Size	$MPS = \frac{\sum_{j=1}^{n} a_{ij}}{n_i}$	Patch size affects biomass, primary productivity, nutrient storage per unit area as well as species composition and diversity, therefore serves as rough indicators of landscape function, also serves as a fragmentation index (when used with PN)
Mean Shape Index	$MSI = \frac{\sum_{j=1}^{n} \frac{p_{ij}}{2\sqrt{\pi \times a_{ij}}}}{n_i}$	Deals with the geometric complexity of a patch. Linear and complex or convoluted patch shapes have greater amounts of boundary than round and, compact patch shapes. more boundary means higher possibility of edge effects
Patch Density	$PD = \frac{PN}{A} x100$	Displays the magnitude of the presence of similar patches in the landscape, indicates isolation if PD decreases. Isolation restrains energy and material exchange hence resulting species decline.

a_{ij}= the area of patch j for the i th land cover class, *A*=the total landscape area. P_i =patch of type i, n=number of patches in the i th land cover class, p_{ij}= the perimeter of patch j for the i th land cover class

ArcGIS 9.3 software has several imbedded functions that support the measurements of PLAND, PN, MPS, and MSI. PD was calculated in Microsoft Excel. The utilized metrics either individually or in conjunction, reveal a distinct but complementary aspect of complex processes such as fragmentation and shrinkage in a particular land cover class. Greater details of these metrics are available in (McGarigal and Marks 1995; Forman 1997; Leitao et al. 2006; Esbah et al. 2010).

Results

Between 1994 and 2005, agricultural lands increased (Table 2). However, their average patch size decreased, while their patch number increased (Table 3). This indicates a fragmented structure prevailing in the agricultural landscape. Agriculture remained to be the most dominant land use in 2005. Transition probability matrix showed that agricultural lands are most likely to be transformed into salt marshes, settlement, and garrigue cover (Table 4). Transformation from agricultural uses to salt marshes is the indicator of the effective monitoring efforts in the protection of Big Meander Delta. As it is the common case, the settlement areas grove as a detriment of their adjacent agricultural lands. The reasons of transformations from agricultural to garrigue can be explained as the abandonment of agricultural practices in some locations (e.g. lands between Didim and Bafa Lake) with the anticipation of imminent urban development.

Simulated 2025 map displayed even more fragmented agricultural landscape indicated by higher patch number and significantly lower mean patch size. This means smaller agricultural plots would prevail in the agricultural landscape as an outcome of two driving factors: inheritance dynamics and agricultural politics. The decline in the size could also be a function of agricultural land opening in the garrigue and maqui areas; because, when converting the landscape, farmers start with inconspicuously removing the small pieces of natural vegetation cover to make their illegal action less noticeable.

Table 2. *Percentage of landscape of land use/cover classes*

Land use/ cover (%)	1994	2005	2025
Agriculture	27,14	27,56	26,37
Conifer	7,12	7,72	8,01
Garrigue	19,42	17,49	17,42
Maqui	25,46	24,53	23,40
Water surfaces	12,64	13,01	12,41
Salt marshes	3,01	3,09	3,96
Rock	3,33	3,61	3,93
Settlements	1,88	2,98	4,51

Conifer cover increased 8,41% between 1994 and 2005. The model simulation indicated their continuous increase. Coniferous forests usually take place on higher elevations and in the protected areas. The increase in this cover indicates the effectiveness of the protection efforts. However, the fragmentation of the coniferous cover needs to be monitored, and special actions should be taken to improve the mean patch size and patch shape to support formation of core area for habitat specialist species (Table 3). Conifer cover most likely transforms into maqui cover as a result of timber harvesting: this is attributable to the forest management exercises at the higher altitudes and also to edge effects of small forest villages. Here, the timber activities generate a fragmented pattern. On the other hand, there are improvements of the coniferous cover especially at the northern sections of the national park and inside Bafa Lake Nature Park. Reforestation activities of these sites have been contributing to increases in forest cover and forest patch density, hence decreasing isolation in this cover (Table 3).

Table 3. *Patch number, mean patch size and mean shape index (1994-2025)*

	PN (n)			MPS (ha)			MSI (m/m2)			PD (n/100ha)		
	1994	2005	2025	1994	2005	2025	1994	2005	2025	1994	2005	2025
Agricult.	534	884	2273	84,65	51,92	19,32	1,84	1,68	1,40	0,32	0,53	1,36
Conifer	482	892	2213	24,61	14,42	6,03	1,73	1,70	1,36	0,29	0,54	1,33
Garrigue	1181	1822	2184	27,39	15,99	13,28	1,92	1,77	1,38	0,71	1,09	1,31
Maqui	765	1506	2870	55,42	27,12	13,58	1,91	1,78	1,36	0,46	0,90	1,72
Water	115	225	812	182,00	96,28	25,45	3,03	2,27	1,44	0,07	0,14	0,49
S. marsh	237	545	487	21,13	9,45	13,54	1,76	1,79	1,31	0,14	0,33	0,29
Rock	610	830	1366	9,09	7,24	4,79	1,76	1,73	1,38	0,37	0,50	0,82
Settlemnt	198	450	442	15,79	11,03	16,99	1,73	1,80	1,40	0,12	0,27	0,27

Table 4. *Transition probability matrix*

Probability (%)		1994							
		Agri.	Conifer	Garrigue	Maqui	Water	S. marsh	Rock	Settlem.
2005	Agriculture	65.10	0.96	8.90	10.76	4.26	4.55	0.62	4.86
	Conifer	2.79	25.41	20.61	37.35	0.31	0.33	12.20	1.00
	Garrigue	14.53	8.33	25.05	38.67	1.85	1.88	5.25	4.44
	Maqui	9.12	16.30	28.82	35.75	0.74	1.16	5.89	2.23
	Water	13.32	0.33	1.17	1.78	76.14	6.38	0.37	0.51
	S. marshes	24.76	0.82	6.89	8.94	20.31	34.73	0.65	2.92
	Rock	12.65	6.47	30.77	31.93	2.16	1.50	8.70	5.81
	Settlements	15.95	1.03	15.06	11.45	2.61	4.13	2.56	47.22

Overall, garrigue cover experienced the most spatial deterioration compared to other land use/cover classes: 9.94% decline occurred in the size of garrigue cover from 1994 to 2005. Forming a more fragmented pattern, the number of patches and the mean patch size also changed considerably. Even though the patch density and mean shape index is displaying a slightly enhanced condition, this is typical misleading point at the beginning of the fragmentation stage where a big patch is divided into several ones with small distances among them. If measures are not taken these smaller patches may diminish, subsequently patch density would decrease. However, the employed scenario in the simulation generated minor improvements in the conditions: subsequently, the rate of fragmentation seems to be slowing down by 2025 (Table 3).

Similarly, the maqui cover continued to deteriorate (Figure 5). Maquis experienced 3,65 % decrease in their size from 1994 to 2005, and this is projected to be 4,60% from 2005 to 2025 (Table 2). There was a widespread fragmentation of maqui and garrigue cover. MSI and PD revealed somewhat illusive results as in garrigue class. There are two major processes in the landscape: generation of denser and higher maqui cover to form a forest like cover, and transformation from a dense and vigorous vegetation cover to a less dense garrigue cover. These two processes almost balance each other: nevertheless the probability of the latter is higher (Table 4). In addition, agricultural and settlement related pressures work as a detriment of maqui cover in the form of various edge effects (e.g. land clearing for agricultural purposes and housing development, destruction of species, introduction of exotics, pollution, vandalism etc.)

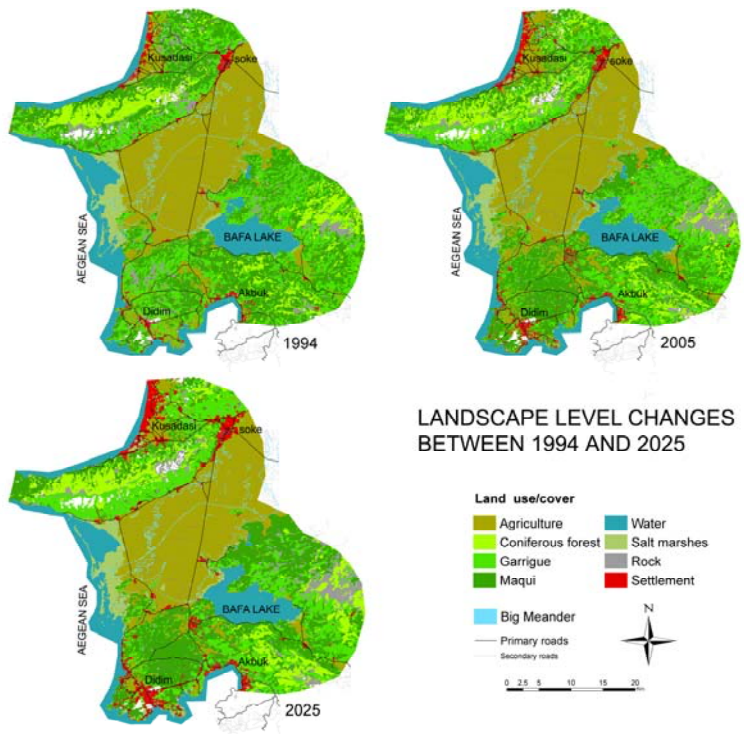

Figure 5. *Land use/cover maps (1994- 2005) and simulation map (2025)*

Salt marshes are important ecosystems; increasing in size by 2.82%, they mostly correspond to the protected landscapes of the study area. However, some agricultural activities are conducted without permission in these areas. This explains 4.55% transition probability from salt marshes to agricultural cover. Also some parts of salt marshes especially around Bafa Lake and Didim were converted into settlements. Therefore, the transition probability matrix suggested 4.13% expansion of settlements on salt marshes. These conversions resulted in a more fragmented character in the marsh environments (Table 3). Some farmers try to cultivate crops in these highly salty and sandy soils; subsequently, the practice is not economically and ecologically viable. Moreover, some developers build summer houses on these habitats, hence generating impairment of structural integrity and public safety. Due to all these negative consequences, not only those marshes which have protection status but also all other wetland like environments should be protected from settlement development and agriculture. Based on this notion, the 28.03% increase in this cover was anticipated between 2005 and 2025 along with decreasing patch number; increasing mean patch size; and less complex patch shape: all of which indicates the improving ecological integrity of salt marshes.

The results showed that settlement areas covered very small portion of the study area, and that the settlements would most probably to continue expanding on garigue, maqui and agricultural cover. Increasing patch number and decreasing mean patch size indicated more scattered urban development pattern. New developments have caused perforations on the landscape, however the settlement pattern became slightly more compact (Table 3). The dissection of landscape for the provision of roads and utility lines will take study area to other stages of land cover transformation that of green space fragmentation and shrinkage in and around the urban matrices.

As the settlements expanded, their edge effect also increased. A study by Kor et al. (2010) illustrated increasing edge effects on the national park. The matrix utility index yielded 6% increase of edge related pressures on the boundary of the national park between 1993 and 2006. Moreover, they stated that the current city plan would generate 41% more edge effect.. Another study by Esbah et al. (2009) showed that the pressures generated by urban edge can be even higher, if a larger zone is scrutinized rather than solely focusing on the boundary. These eye opening results emphasizes the importance of urban form and peri-urban context for protection efforts.

Conclussion

In order for fully understanding landscape dynamics and also for sustainable landscape management, a holistic approach, reciprocally evaluating both landscape quality and quantity, is essential. Also, the assessment of both landscape composition and configuration is crucial. Recent advances in remote sensing, GIS and computer sciences offer variety of tools in this endeavor. The comprehensive approach of utilizing remote sensing and modeling can help planners gaining knowledge about the characteristics of current and anticipated landscape change, this in turn help in promoting sustainable planning practices. Integrated with landscape ecology knowledge, the landscape metrics approach of this study is a novel way of moving towards attaining more ecologically and economically viable landscapes. Proliferation of this approach is critical for strengthening ties between ecology and planning principles. This study showed the utilization of CA-Markov chain modeling and landscape metrics in explaining the complex spatial processes. It also elaborated the role of remote sensing, modeling and landscape metrics to generate objective planning and management suggestions.

Holistic assessment of the study area revealed two distinct processes occurring in the study area: the transformation of natural vegetation into a more vigorous cover, and the transformation from a dense vegetation cover to a less dense cover. Major drivers of the landscape change included urbanization, agriculture, grazing, fire, and clearing of original vegetation for heating and timber. Subsequently, all of the natural and semi-natural land use/ cover classes has displayed the spatial dimensions of ongoing fragmentation process in the landscape. The results explicitly showed that while urbanization and agriculture would be changing landscape characteristics in the study area, coniferous forest and salt marshes would increase due to management efforts in the legally protected parks; and that Maqui and Garique cover would continuously decrease as a result of anthropogenic pressures by 2025.

Considering the pressures already caused by the utilization of land by humans, the following suggestions are proposed for sustainable landscape planning in the study area:

- Large natural patches with high structural integrity are important in mitigating negative effects of anthropogenic pressures. Therefore, the protection of these areas by laws and management strategies should be supported. These large patches should be utilized to form a green network in the larger landscape scale. While these large patches could act as core areas, smaller patches could serve to strengthen the network circuitry. Network management strategies should be generated to ensure greater protection. Additionally, the restoration of some patches is essential. Two restoration approaches can facilitate better landscape structure: First, focusing on those areas where the vegetation is turning into less dense cover (reforestation with native species, changing grazing and harvesting habits etc.), and, second, restoring old natural patches whose attributes are totally deteriorated, hence gaining new natural patches.

- Maintaining a natural structure as much as possible is crucial for maintaining ecological integrity. This type of landscape is called soft matrix. Soft matrix is doable at least by using native species and decreasing impervious surfaces. Because this type of matrix allow material and energy flow, the dependency on corridors is minimized and connectivity is increased. Soft matrix is also an efficient strategy to decrease edge effects. In short, the soft matrix should be promoted in highly dense and rapidly urbanizing areas such as Kuşadası and Didim as a land management strategy.

- Creating buffer zones at the urban- rural (or developed- natural) interface could be another strategy for sustainable landscape and urban planning. Buffers can mitigate the effects of urban uses hence contributing to the ecological integrity. There could be different buffer typologies and widths depending on the surrounding factors. For example, a 50m. buffer is suggested to prevent the mixing of pesticides to rivers. Whilst, a 60 to 200 m. wide buffer is suggested in forests for the livability of different birds. Besides, there could be more than one buffer zone to form different management zones.

- Connectivity in fragmented landscapes such as the study area is an important notion for maintaining ecological integrity of urban systems and could be established either by corridors or stepping stones. The protection and preservation of existing connections is more viable and easier than establishing new ones. Therefore, the detection of these corridors and stepping stones before they are taken over by urban developments are important task, which should be conducted before any planning efforts. In the study area, there exist four types of corridors: river corridors, agricultural hedgerows, road corridors and canal corridors, each of which contributes to sustainability different ways and levels, and therefore deserves special attention in terms of their planning, design and management. Because corridors and stepping stone patches could be refuges for habitat generalist species, even a small vegetation patch can contribute to the system. Therefore, their monitoring is necessary. There are many small habitats that could work as stepping stones in the north of the national park, between Kusadasi and Soke urban area, and also in Didim peninsula. The habitat qualities of these patches should be surveyed, and measures should be taken to improve their qualities.

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Peyzaj planlamasında hücresel özişleme-Markov zinciri ve peyzaj metrikleri

Peyzaj planlama çalışmalarında konuma bağlı tahmin modellerinin kullanımı giderek artmaktadır. Konumsal modellerin kullanımı ile peyzajdaki karmaşık süreçlerin anlaşılması ve temel ekolojik yapıya ait bilgilerin derlenmesi mümkün olduğundan, bu tür modellerin doğa koruma ve peyzaj planlama alanında kullanılmaları sürdürülebilir kaynak yönetimini de mümkün kılmaktadır. Bu çalışmada, Aydın ilinin Ege Denizine kıyı olan en batı kısmında yer alan Kusadası, Soke ve Didim ilçelerinin arazi kullanımı/arazi örtüsünün 2025 yılı için modellenmesi amaçlanmıştır. Çalışma alanının geçirdiği alan kullanımı/arazi örtüsü değişikliklerinin boyutunun ve nedenlerinin ortaya konulması, peyzajın ileride alabileceği kompozisyon ve konfigürasyonun tarif edilmesi ve bunları baz alarak sürdürülebilir peyzaj planlaması için önerilerin geliştirilmesi hedeflenmiştir.

Yaklaşık 16650 hektar büyüklüğündeki çalışma alanı ülkemizin eski milli parklarından biri olan Dilek Yarımadası- Büyük Menderes Deltası Milli Parkı, ekolojik açıdan özellikle kuşlar açısından önemli Bafa Gölü Tabiat Parkı ve buna ek olarak Büyük Menderes Nehri ve bağlantılı habitatlarını barındırmaktadır. Çalışma alanı ayrıca ülkemizin ekonomik açıdan önemli tarım faaliyetlerinin yer aldığı Söke ovasını ve çeşitli maden ocaklarını, turizm ve kültürel miras açısından önemli pek çok eseri içermektedir. Bu coğrafyada deniz turizmi açısından ön plana çıkan Kuşadası ve Didim yerleşimleri hızlı bir şekilde yayılmaktadır. Çalışma alanının zengin ekolojik, ekonomik ve sosyo-kültürel içeriği bu peyzajın sürdürülebilir bir şekilde planlanmasını gerektirmektedir.

Uzaktan algılama, GIS ve modelleme teknolojileri bu amaca hizmet edecek önemli araçlardır. Bu çalışmada Hücresel Özişleme-ve Markov Zinciri modelleri bir arada kullanılmıştır. Hücresel Özişleme (CA) modeli dikdörtgen gridler oluşturan sürekli ve bitişik hücrelerin sahip olduğu koşullar doğrultusunda tekrarlanan uygulamalarla karakter ve özniteliklerine göre durumlarını değiştirmelerine dayalı olarak çalışmaktadır. Bir hücrenin sahip olduğu durumun başka bir duruma geçiş koşulları, büyüme veya küçülmenin üreticileri olarak tahmin edilmektedir. CA hücrelerin bitişik komşu hücrelerinde neler olduğunu hesaba katan bir fonksiyonu temel alarak çalışmaktadır. Markov Chain analizi ise peyzajdaki süreçler ve değişimlerin tanımlanmasının güç olduğu durumlarda alan kullanım değişiminin modellenmesinde yararlı bir araçtır. Markov Chain analizi, bir periyottan diğer periyoda olan alan kullanımı değişimini tespit edebilir ve bu işlemden elde edilen sonuçları gelecek değişimlerin projeksiyonlarının yapılmasında kullanır. Markov Chain ve CA kombinasyonunda, giriş verisi olarak detaylı bir alan kullanımı/arazi örtüsü haritası ve değişim matrisi kullanılmaktadır.

Bu haritaların oluşturulmasında Spot 2X (1994) ve Aster (2005) uydu görüntüleri kullanılmıştır. Çalışma alanında değişimin yönünü ve şiddetini etkileyen faktörlerden yükseklik, eğim, bakı, yollardan, denizden ve yerleşimden uzaklık ile ilgili veriler GIS teknikleri kullanılarak oluşturulmuştur. Nüfus faktörü için nüfus potansiyeli yaklaşımı kullanılmıştır. Her yerleşim merkezi için hesaplanan nüfus potansiyeli Ters Uzaklık Ağırlıklandırma interpolasyon yöntemi kullanılarak sürekli yüzeye sahip görüntüye çevrilmiştir. Faktörlerin ağırlıklandırılmasında Bulanık Mantık kullanılmıştır. Değişim faktörlerinin bir araya gelmesiyle her arazi sınıfı için uygunluk görüntülerinin oluşturulmasında Çoklu Kriterli Analiz yöntemi uygulanmıştır. CA-Markov modeli dahilinde CBS ortamında hazırlanan: temel sınıflama görüntüsü olan 2005 yılı sınıflaması, çoklu kriter analizi ile hazırlanmış sınıflara ait uygunluk görüntüleri ve alansal geçiş olasılık matrisi verilerinin girdi olarak kullanılmasıyla 2025 yılı arazi örtüsü haritası elde edilmiştir. Peyzaj metrikleri yardımıyla peyzajdaki ekolojik kalitenin göstergesi olabilecek parçalanma ve kenar etkilerinin boyutları ve peyzaj kompozisyonundaki değişim ortaya konulmuştur.

Çalışma alanındaki dokunun değişimine sebep olan ana aktiviteler; kentleşme, tarım, hayvan otlatma, yangın, kereste ve yakacak temini için doğal örtünün tahrip edilmesidir. Bu etkinin sonucunda 1994-2005 yılları arasında garik ve maki örtüsü azalmış, yerleşim alanlarının kapladığı alan yaklaşık %50 artmıştır. Artış yüzdesi yerleşimler kadar bariz olmasa da tarım, su yüzeyleri, kıyı vejetasyonu ve konifer ormanlarında bir artış yaşanmıştır. Geçiş olasılık matrisine göre tarımsal arazilerin en fazla kıyı vejetasyonu, yerleşim ve garik örtüye dönüşüm olasılığı görülmektedir. Koniferler en fazla makiye dönüşme eğilimindedir. Bu daha çok orman alanının kesilerek kaldırıldığı alanlarda gözlenen bir sonuçtur ve doğal alanlardaki insan baskısının bir göstergesidir. Garik ise en fazla kayalığa dönüşme eğiliminde olup bu da bitki dokusu fakir olan garik alanlarındaki toprağın aşınarak uzaklaşmakta olduğunu göstermektedir Makiler en çok garik örtüye dönüşmektedir. Bu da alanda devam eden tarım alanı açma faaliyetleri ve küresel ısınmanın bir sonucu olarak vejetasyon dokusunun cılızlaşması şeklinde yorumlanmıştır. Yerleşim ise çok düşük oranlarda olmakla birlikte daha çok kayalık, tarım ve garik alanlarına dönüşmektedir. Bu durum çalışma alanındaki bazı köy yerleşimlerinde nüfusun küçülmesi ile bağlantılıdır.

Yapılan 2025 yılı tahminine göre 2005 yılı esas alındığında tarım arazilerinin artışının durarak 2005'den sonra bu alanlarda bir azalma olacağı görülmektedir. Maki alanlarındaki azalma da aynı hızla devam edecektir. Su yüzeylerinde alansal olarak azalma vardır. Bununla birlikte yerleşim, konifer, kıyı vejetasyonu ve kayalık sınıflarında ise artma görüleceği belirlenmiştir. Tahmin edilen en büyük değişim % 60'ı geçen bir büyüme oranıyla yerleşim alanlarındadır. Koniferdeki artış daha çok milli park sınırı içinde görülmektedir, bu da koruma faaliyetlerinin başarısını göstermektedir.

Peyzaj metrikleri ile yapılan değerlendirmeler doğal vejetasyon örtüsünde (Konifer, Maki, Garik ve Kıyı vejetasyonu) parçalanmanın olduğunu. Parçalanmanın maki ve garik gibi azalmakta olan arazi örtülerinin habitat kalitelerini çok daha olumsuz etkilediğini ortaya koymuştur. Parçalanma ve insan kullanımlarının yoğunluğunun artmasından dolayı koruma alanlarında kenar etkisinin artacağı dile getirilmektedir.

Çalışma alanının peyzajlarının sürdürülebilir planlaması için geliştirilen öneriler listelenmiştir. Bu kapsamda, büyük ve yüksek kaliteli doğal alanların mümkün olduğu kadar etkili bir şekilde (yasa ve yönetmeliklerle) korunması ve peyzajın genelinin bir doğal alanlar ağı mantığı ile ele alınmasında fayda vardır. Doğal alanların çevresinde onlarla uyumlu alan kullanımlarının ağırlıklı olarak yer almaları sağlanmalıdır. Bu amaçla tampon bölge tipolojileri geliştirilmelidir. Peyzajdaki bağlantılılığı artırmak için adım taşı niteliğindeki habitatlar ve ayrıca doğal koridorlar korunmalıdır. Çalışma alanında mevcut koridor sisteminin iyileştirilmesi için özellikle dikkat edilmesi gereken 4 peyzaj elemanı vardır: nehir koridorları, tarımsal arazi koridorları, yol ve kanal koridorları. Bu koridorların ekolojik işlevlerini yerine getirmelerini kolaylaştıracak şekilde kesitlerinin yeniden ele alınması, ayrıca uygun materyaller ve tasarımlarla ekolojik işlevlerinin artırılması sağlanmalıdır. Peyzaj matrisinde doğala yakın bir doku oluşturmak (yumuşak matris) ekolojik açıdan oldukça önemlidir. Bu sebeple yumuşak matrisin özellikle Didim ve Kuşadası gibi kentsel yoğunluğun arttığı yerlerde bir arazi planlama ve yönetim stratejisi olarak ele alınması düşünülmelidir.