A Portrayal of Uncertainty: Revealing Problems and Opportunities of Landscape Change via Sleuth Cellular Automata Model

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Abstract: Urban growth models and cellular automata (CA) become a new representation technique of contemporary sustainable planning, and work almost as an artificial intelligence in urban landscape studies. At this study, SLEUTH cellular automata model is used as a guidance to blend these information techniques with geography and landscape to develop wiser growth decisions. These information techniques almost work as an artificial intelligence in landscape architecture and may lead designers when implemented into a geodesign process. In this research, this notion is elaborated on a case study on the town of Sarıyer, Istanbul, Turkey, which is a unique town with its cultural and environmental values. Three growth scenarios are developed to portrait the problems and opportunities of different growth strategies within a creative, flexible development approach.

Keywords: Geodesign, cellular automata, urban growth models, SLEUTH model, landscape change

1 Introduction

As a response to rapid urban growth, a devastating stress on natural environment and landscape loss occur in urban and peri-urban areas. Therefore, analysis of urban growth and landscape change became vital in monitoring cities' sustainability. In addition, predicting the outcomes of future growth became essential for developing growth strategies, and master plans. In the meantime, Geographical Information Systems (GIS) brought great opportunities for analysing landscape structure and complex urban environments in terms of data collection, preparation and spatial analysis. Therefore, GIS technology is essential through the whole process of design and modelling of heterogeneous systems as cities, and environments (CLARKE, PARKS & CRANE 2000). This relation between GIS – Landscape and Urban Design has been reinterpreted as Geodesign system which emphasizes the association of physical and social environments in a design concept (MCELVANEY 2012). Steinitz defines this process as a technology based methodology to develop a better understanding of natural systems and geographical information (STEINITZ 2012). Geography, as a fundamental discipline, scrutinizes human and nature through an interval and spatial process, and the correlation of GIS technology and modeling has provided outstanding amenities and resources. At this study, Sleuth cellular automata model is used with a scenario development process reflecting different approaches to urban landscapes. Subsequently, the model works as a guidance to blend these information techniques with geography and landscape to develop wiser growth decisions for the town.

Especially during the last decades, urban growth modelling and simulation studies have become essential tools to analyse the dynamic structure of complex cities and landscape mosaics (BATTY & LONGLEY 1994; CLARKE & HOPPEN 1997; MCGARIGAL, CUSHMAN & ENE

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2012). Thus, cellular automata models (CA) work almost as an artificial intelligence in contemporary sustainable planning, and urban landscape studies. They are capable of reading problematic and complex systems such as cities and urban landscapes while considering variety of parameters effecting each other (DIETZEL & CLARKE 2006). The paper specifically focuses on SLEUTH model, a popular cellular automata, which is used for predicting possible urban growth and land use change based on user-defined scenarios (CLARKE & HOPPEN 1997). Even though, the model works autonomously, it still provides opportunities for user modification and management. Scenario development is one of these crucial sections of model calibration, and it reflects different future predictions based on different development interests. In this endeavour, three growth scenarios are developed and calibrated with the model to portrait the uncertainty of the urban growth and reveal the problems and opportunities of different growth strategies.

This research elaborates these information techniques on a case study on the town of Sarıyer, Istanbul Turkey to understand the effects of land use decision. Sarıyer has very rich natural and cultural landscape quality, however, the ecological and cultural values of the town are about to change due to new growth decisions. The research question at hand is “what will be the spatial outcome of the new investments in the town of Sarıyer, and how will it affect the natural and semi-natural landscapes of the town”.

2 Study Area

Town of Sarıyer in Istanbul-Turkey, is chosen as the study area to analyze landscape changes and land use/land cover change. Sarıyer, is located in the north of Istanbul between 410° North Latitude and 290° Eastern Longitude. It is surrounded by the Black Sea on the north, Besiktas, and Sisli towns on the south, the Eyup town on the west, and the Bosporus on east (Figure 1). It covers 151 km^2 land with population of 335,598 in 2013 (TUIK). Sarıyer has experienced a significant population growth between 2007 and 2013. Currently, 10% of this population lives in the rural areas.

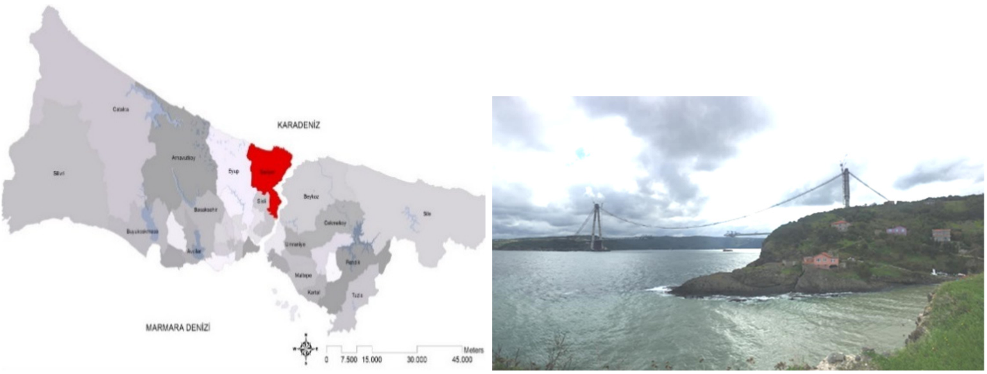

Fig. 1: Sarıyer District is located in the European side of Istanbul and locates in the route of new bridge connecting Asia and Europe

Sarıyer houses good quality water resources in the city, and these water resources are located on the hills. Most of the slopes are 6-15 % in more natural areas. The common slope for the settlement areas is 0-5 % (SARIYER REHBERI 1998, AYASLIGIL 2011). Forest land covers 17.5 % of the whole area (26,470 km^2). Along with semi natural land uses such as agricultural lands, natural forest and semi natural covers constitute the major land use types in the town, followed by artificial surfaces (TOKUS 2012).

Sarıyer contains a considerable part of the northern forests of Istanbul. It has a strategic location as it is at the entry to Bosporus from north. Subsequently, this area is famous with not only with its natural landscape attributes, but also with its cultural landscapes, historical monuments, and countryside fisherman villages (Figure 1).

However, new transportation projects, such as the third bridge over the Bosporus, may affect variety of ecological and cultural dynamics in the city. The route of the new Bosporus Bridge is passing through the town of Sarıyer, and connecting very high volumes of commercial traffic from Middle East, Asia, and Turkey to Europe. Along this new route, big investments are on the way such as a major Airport, and new urban and suburban developments. Therefore, analysing the possible effects of these major changes is crucial for developing foresights, and recommendations to safeguard the ecologic and cultural values in the town.

3 Methodology

The analytic approach of this study is based on GIS analysis (data preparation), scenario development, and SLEUTH model calibration. Even though the model is capable of solving this unpredictable structure automatously, the scenario development section is crucial to test the effects of growth decisions. At this point, different scenarios can illuminate designers and can help Geodesign process to test potential design solutions.

Besides, the success of the model calibration relies on the accuracy of input data. Therefore, before stepping into the prediction stage, a detailed examination is completed to understand how urbanization of the study area has been shaped through history.

The paper embraces the research in four main phases; 1- understanding the existing landscape structure and urban pattern in Sarıyer, 2- developing alternative growth scenarios based on three different management approaches, 3- utilizing SLEUTH model to simulate the implications of the growth scenarios for 2045, 4- Interpretation of results.

3.1 Data Gathering and Analysis of Existing Structure of Landscape and Urban Pattern

Current urban pattern of the study area is analysed under three main topics: 1- land use /land cover (LULC) change, 2- transportation expansion (especially for understanding the major effects of the third bridge), 3- urban extension.

Bosporus bridges are one of the major drivers of urban growth in Istanbul, construction period of existing two bridges (1973 and 1988) are considered as important thresholds for growth. Therefore, urban and transportation expansion data are extracted from 1984, 1992, 2005, 2013 dated LANDSAT images and 1966, 1982 dated aerial photos by using on screen digitization technique. Urban boundary expansion and road extension outputs constructed the inputs for the modeling of the future landscape composition of urban landscape.

Then, 2005 dated IKONOS image, and 2013 dated SPOT5 image are classified for analysing land use change (WELCH 1982). "Supervised classification" tool under the ArcGIS program was used to display the land use/land cover change in 2005 and 2013 in the study area. Then, five main CORINE land cover classes were adopted to determine the change in land use classification: (1) artificial surfaces, (2) forest and semi natural areas, (3) agricultural areas, (4) wetlands, and (5) water bodies. Then an accuracy assessment was applied to understand the reliability of the results.

3.2 Developing Alternative Growth Scenarios Based on Three Different Management Approaches

The present paper supports the decision-making process by revealing the impact of different growth scenarios on landscape structure. In this study, SLEUTH CA model is used to simulate future landscape change in Sarıyer for the year 2045. In this endeavour, three main scenarios are calibrated to reveal the impact of different management objectives in the town. Scenarios combine offensive (aggressive) growth and defensive growth, and conservation strategies. Based on the growth interest, the growth rules of the model (limitations, and potentials) are defined. The main objective of scenario development is to figure out the most effective and appropriate growth strategy which considers human and nature as a whole. In this scope, the growth rules in the model are defined based on the scenario strategies.

Aggressive Growth Scenario (AG): The main objective of AG scenario is reflecting an aggressive growth attitude based on an un-restricted urban growth strategy. At this point only the physical restrictions as water surfaces, geologically unsuitable areas, military lands, and sanctuary preservation areas are excluded from urbanisation. This scenario is prepared to see the natural urban growth without any human interaction.

Current Trends Scenario (CT): The main objective of CT scenario is revealing future growth simulation based on current development plans, policy and legislations. This scenario is an important representative of urbanization trends based on current planning acts and codes. In this scope water surfaces, geologically unsuitable areas, military lands, sanctuary preservation areas, protection forests, wild life protection areas, seed production areas, national parks, agricultural lands under sanctuary preservation, and first degree protected sites are excluded from urbanisation. Briefly, this scenario shows if the laws and legislations are capable of protect urban landscape.

Protective Growth Scenario (PG): The PG scenario represents the ecological growth approach in urban structure. This scenario is developed according to patch-corridor-matrix model in landscape ecology. In this scope, the priority components of landscape mosaic in current situation are pointed out based on their land use classes, sizes and neighbouring relations. In addition, water surfaces, geologically unsuitable areas, military lands, sanctuary preservation areas are excluded from urbanization. By giving priority to important landscape components, this scenario reveals an important alternative with a nature oriented growth approach.

3.3 Utilizing CA Based SLEUTH Model to Simulate the Implications of the Growth Scenarios for 2045

Following the analysis of current situation of Sarıyer, CA based SLEUTH model is used to predict the future changes in Sarıyer. SLEUTH is an Urban Growth Model (UGM) which is a C program running under UNIX, and it is an acronym of initials of its input data: Slope, land use, excluded areas, urban areas, transportation network, and hillshade. The model has three main stages: test, calibration and prediction, and five coefficient values to control the calibration phase (diffusion, breed, spread, slope, and road gravity) (CLARKE 2002). Each coefficient changes after each phase, and best fit values are defined according to calibration results. Accuracy of the model output is assessed through the metrics embedded in the model. Besides, the model is specifically sensitive for the changes in the road network, therefore is more suitable to use in Sarıyer case in which the negative implications of building road infrastructure is highly speculated.

3.4 Interpretation of Results

The model results reflected the possible LULC change and urbanization for 2045 based on three scenarios. At this point, the study proposes flexible growth alternatives considering geographical, social and institutional drivers of urbanization. Finally, the spatial outcome of the new investments in the town of Sarıyer, and how they will affect the natural and semi-natural landscapes of the town will be revealed.

4 Research Results

4.1 Implications of Land Use | Land Cover Change in Sarıyer

According to 2005 and 2013 land use classifications, forest and semi-natural areas are the dominant land use classes in Sarıyer's landscape, followed by artificial surfaces (urban areas) which has tendency to increase. In 2005 the forests are mostly distributed around northern parts of the study area whereas urban areas are usually located in the southern parts.

Overall, urban areas (mainly artificial surfaces) increased 3 %, and forest cover increased 5 % within an eight-year period in Sarıyer. This development worked as a detriment of forest areas, as most of the new development took place at the edge of the forest cover. Some urbanization occurred on the fertile agricultural areas, where the farmers abandon their practice with the anticipation of eminent urban development. This change worked against other land use classes. As a result, agricultural lands, and wetlands experiences 3 % and 2 % decrease respectively (Table 1).

Table 1: Area proportions of land use classes for 2005 and 2013

Land Use Classes	2005	2013
Urban	18 %	21 %
Forest	44 %	49 %
Agricultural Lands	6 %	3 %
Wetlands	11 %	9 %
Water Bodies	19 %	18 %

Within eight years period, new urbanization emerged in the south and south west due to the transformation of agricultural lands. This transformation of arable lands into new settlement areas can be defined as a typical edge effect of urban uses on agricultural lands (ESBAH 2009). Decline of wetlands undermines the efforts to protect water resources and their surroundings in the area. Since Sarıyer hosts many important wetlands that provide habitat for variety of wildlife species, the future change should be monitored carefully. In addition, new strategies should be developed to protect productive landscapes such as agricultural lands.

4.2 Implications of Transportation Expansion in Sarıyer

The results display 64 % road expansion between 1966 and 2015. Specifically, 13 % increase in the road system occurred after the construction of the first Bosporus Bridge (between 1972 and 1988). New roads emerged especially in the southern parts of the area, closer to the bridge. These roads worked as disturbance to forests and natural areas. Especially in the southern parts of the area, roads divided large forest patches into smaller pieces, which resulted in vegetation loss while attracting new settlements. Thus, these results show that roads are the main drivers of urbanization in Sarıyer.

4.3 Implications of Urban Extension in Sarıyer

Subsequently, the increase in the transportation network encouraged rapid urban extension in Sarıyer. In order to detect this expansion, urban boundary of 1966, 1987, 2005, 2013 were delineated from the satellite images. The results showed that urban growth was slow until 1987, but after 1987 the growth rate went up. Subsequently, Sarıyer experienced a rapid sprawl until 2013. After the construction of the first bridge between 1972-1988 (16 years) 13 % of increase in the urban growth occurred while 199 % (almost three times) urbanization is detected in 2005, after the establishment of the second bridge (1988). This critical urbanization jump is due to the second bridge. New roads emerged spreading from the main artery, and 30,4 % transportation expansion was detected in the same period. This considerable increase in urbanization resulted in a strong pressure on forest areas, hence gradual shrinkage. This rapid urbanization demonstrates the growth attitude of the city in case of a major transportation change.

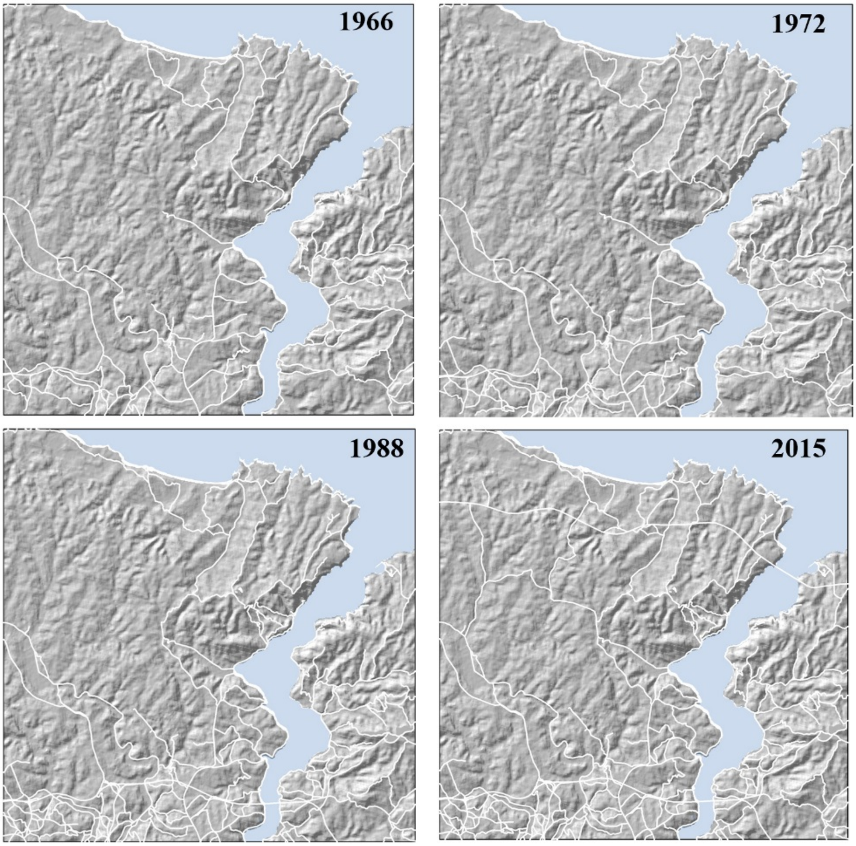

Fig. 2: Transportation Expansion in Sarıyer between 1966-2015

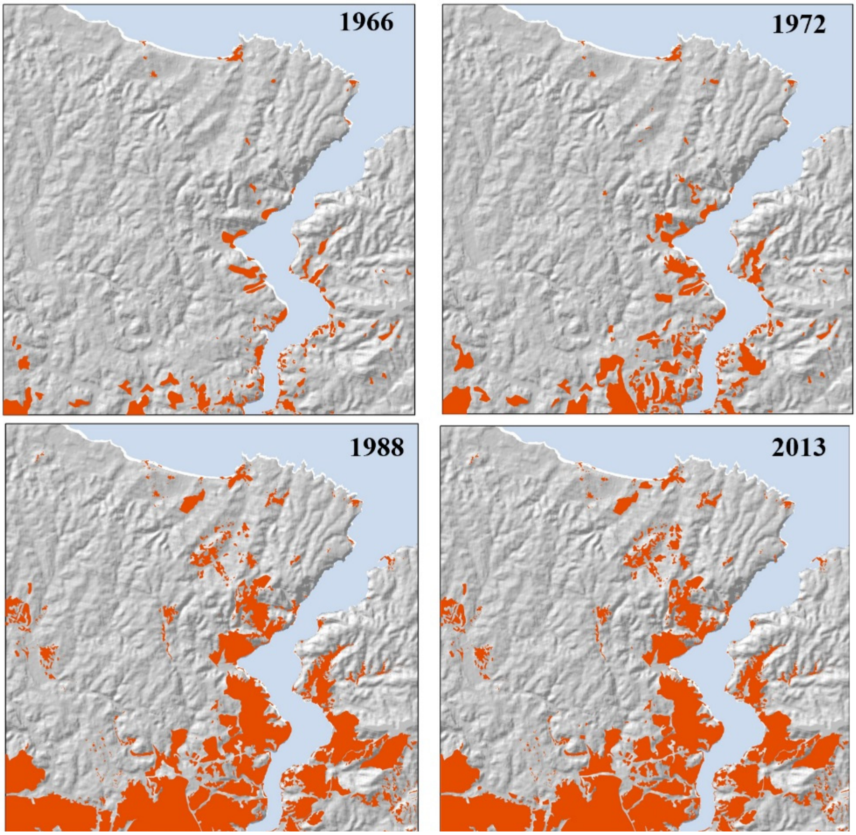

Fig. 3: Urban Extension in Sarıyer between 1966-2013

4.4 Revealing Uncertainty in Sarıyer for 2045 via Sleuth Model

An exhaustive calibration process revealed the best fit values, which were then utilized to develop the prediction scenarios within SLEUTH model. Five main coefficient values controlled urbanization; 1-diffusion, 2-breed, 3-spread, 4- slope, and 5-road weight (Table 2). These coefficients represent the spatial distribution preference of each scenario.

Table 2: Best Fit values of growth parameters for three growth scenarios (AG, CT, PG)

Growth Scenarios	Diffusion	Breed	Spread	Slope	Road Gravity
Aggressive Growth	100	85	2	1	70
Current Trends	100	90	1	2	9
Protective Scenario	54	2	100	1	94

SLEUTH model simulated a realistic reproduction of the study area with three different growth approaches (Figure 4). Specifically, in the case of Aggressive Growth Scenario, diffusion, breed, and road gravity coefficients showed an increasing behaviour. This attitude encourages the creation of road oriented new urban centers separately from existing urban structure. This is a critical thread for surrounding landscape habitat, which may lead to fragmentation.

In the Current Trends scenario, high diffusion and breed values indicated an organic growth towards new urban centers. This change resulted as new emerging urban nodes independent from existing urban structure towards north in the natural vegetation cover dividing the landscape structure into smaller pieces. These findings highlight the possible effects of third Bosporus Bridge in the urbanization behaviour, which may lead to considerable landscape loss in Sarıyer in 2045.

On the other hand, Protective Growth scenario revealed a higher spread parameter with lower diffusion and breed parameters respectively. This change in the parameters points to a more compact growth attitude while preserving the existing natural patches, and corridors of landscape. These parameters give more rational interpretations when combined with land use class proportions (Table 3). So that it is possible to read the possible landscape change in 2045 compositionally and configurationally.

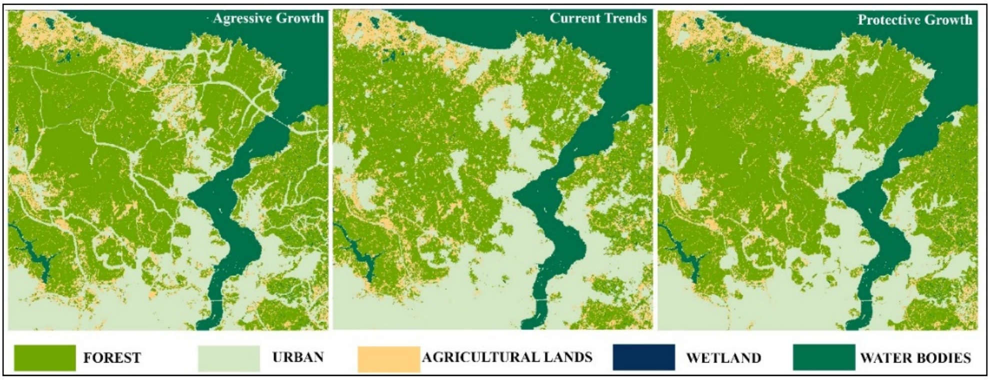

Fig. 4: Land Use Simulations for 2045 based on three growth scenarios

According to the comparison of land use maps (2005-2045), AG scenario will lead to a considerable landscape loss with 7 % decrease in forest areas while urbanization will show 9 % increase. Urbanization is to spread through the new transportation route in the north of the study area. This growth behavior causes further pressure on the northern forests and wetlands. As a result, wetlands show 8 % decrease. This decrease in valuable landscape habitats mostly transformed into urban lands and agricultural lands, and agricultural areas show 2 % increase.

On the other hand, CT scenario predicted 13 % increase in urban areas where forests showed a 5 % decrease between 2005-2045. Besides, forests would lose their compactness and most of the large patches would turn into smaller forest lands. These spatial and proportional changes remark a critical transition in the territorial landscape mosaic where forest lands are losing their dominancy. Besides, this scenario simulates a similar decrease in agricultural lands, and wetlands tough, inspects less urbanization than AG scenario. Most of the wetlands will lose their landscape value, and experience a critical decline of 9 %.

PG scenario promises less forest loss, and encourages a compact growth from the urban edges. Even tough, this scenario simulates 9 % increase in urban areas it promises the smallest increase between three scenarios. Besides this is the only scenario, which predicts and increase in forests. PG scenario not only protects landscape components spatially but also encourage important land use class areas proportionally (Table 3).

Table 3: Land use class proportions based on three different SLEUTH Model simulations

Land use classes	2005	2013	AG 2045	CT 2045	PG 2045
Urban	19 %	21 %	34 %	32 %	28 %
Forest land	44 %	49 %	37 %	39 %	45 %
Agricultural lands	6 %	3 %	8 %	8 %	7 %
Wetlands	11 %	9 %	3 %	2 %	2 %
Water bodies	18 %	18 %	18 %	18 %	18 %

5 Discussion and Conclusion

Scenarios show that urbanization in Istanbul is inevitable tough, protective approach scenario displays a defensive growth strategy toward natural resources in Sarıyer while aggressive growth scenario and current trends scenario lead to an offensive urbanization in the town. Geodesign gets on the stage by defining key issues and concerns to meet multiple management objectives (MCELVANEY 2012). The SLEUTH model and scenario development process revealed a good example of how CA can help Geodesign during decision-making process when utilized at an urban landscape scale. Scenarios can combine artificial intelligence of models and management objectives. From this case study, it's clear that CA models can be an effective and appropriate environment to test variety of design solutions while considering geographical values and different growth interests of actors in planning.

The three scenarios revealed different land use simulations for 2045. This flexible approach is good way to predict any type of landscape change. In this study, the decision making process (scenario development) is a unique addition in terms of integrating landscape ecology approach to the model. Landscape structure may lead to perforation, dissection, shrinkage, fragmentation, and attrition due to their configurational and compositional changes by time (Forman & Godron, 1986). This study shows that the Current Trends (CT) scenario encourages an organic growth and may lead to fragmentation of important forest habitats in Sarıyer. Besides, protective growth scenario (PG) is based on the landscape metric analysis, and patch-corridor-matrix model. Therefore, PG scenario is stricter on preserving the existing habitat patches, corridors and encourages urbanization through the edges of already existing urban areas. Protective growth scenario is based on the landscape metric analysis, and patch-corridor-matrix model, and primarily aimed to enhance the structure and function of valuable water resources, valleys, green corridors, and patches in the landscape mosaic. Briefly, PG scenario underlines the "importance" of landscape values instead of "suitability" of land use classes.

Another critical outcome of the simulations is the decline in wetlands in Sarıyer. The wetlands are mostly located towards the northern and western parts of the town adjacent to water resources, and they are mostly neighbouring forest and natural lands. Therefore, their sustainability mostly relies on the quality of their surrounding environments. Tough, results show that the northern forests are mostly disturbed by urbanization pressure approaching from south (Figure 4). The decline in the environmental quality and vegetation loss is more rapid and dramatic in Aggressive Growth scenario.

Results of simulations created a valuable guide for designers to see geographical, and environmental threats, and opportunities in the town of Sarıyer. The research implemented in the case of Sarıyer helps in exploring uncertainties that the landscapes will be facing in the future, and thus is applicable to other rapidly growing urban areas in Turkey as well as other countries with similar context.

6 Lessons Learned

- Spatial detection of landscape change and predictions can be very effective and reveal useful outputs when combined with urban growth models such as SLEUTH CA model.
- Multiple scenario alternatives will enrich the precaution mechanism of urban planning and design process.
- CA growth scenarios can detect the impacts of planning decisions and they can automatically simulate future landscapes. CA models, and these constructed landscapes can guide designers and form an effective environment to test potential design solutions.

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