Quantitative spatial assessment of the impact of urban growth on the landscape network of Türkiye's coastal cities

Merve Yılmaz · **Fatih Terzi**

Abstract This study aims to evaluate the impact of urban spatial expansion on the landscape patterns of coastal cities in Türkiye through the use of spatio-temporal indices. To this end, temporal samples covering a period of approximately 30 years (1986–2000 and 2000–2015) were analyzed for six selected coastal cities in Türkiye. The urban spatial growth patterns in these cities were characterized using 17 geospatial indices, and Pearson's correlation coefficient and principal component analysis were employed to assess the quantitative relationships between urban spatial development and the fragmentation of landscape networks. The results of the study demonstrated that the patterns of landscape fragmentation caused by the spatial growth patterns of the selected coastal cities can be divided into two categories: disconnected landscape connections and perforated landscape patterns. Leapfrog development was identified as a major factor in the fragmentation of landscape continuity, leading to the formation of perforated green structures. The findings of this research can serve as spatial guidelines for addressing disconnected landscapes, a crucial factor in enhancing urban sustainability in Türkiye's coastal cities. Furthermore, the outcomes of this study may be useful for informing the national well-being strategy for urban planning and natural mitigating policies in Türkiye's coastal regions.

Keywords Urban spatial growth · Landscape connectivity · Landscape fragmentation · Coastal city

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Introduction and literature review

Coastal regions, which encompass natural terrestrial ecosystems, social ecological systems, and geographic regions, are attractive locations for settlement and living (Burke et al., 2000; Tett et al., 2011; Wilkinson, 2012). Cities in these regions reflect the history of urbanization in coastal areas. It is well established that a significant proportion of the global urban population resides in coastal regions (Balk et al., 2009; Burke et al., 2000; McGranahan et al., 2005; UN-Habitat, 2008). Coastal cities also serve as hubs for economic, social, and environmental activities around the world (Hoyle, 2000; Pelling & Blackburn, 2013; Timmerman et al., 1997). The increase in human use and the transformation of natural areas in coastal regions demonstrate the dynamic pressures of urbanization on these areas (Hassan & Nazem, 2016; Salvati et al., 2013; Tett et al., 2011).

Coastal cities often experience growth both along the coast and inward from the coast due to their

topographic structure (Forman, 2010; Yılmaz & Terzi, 2021). This growth can pose problems for the natural environment and lead to environmental degradation in the ecosystem services associated with land and sea resources (Agardy et al., 2005; Arnold & Gibbons, 1996; Forman, 2014; Millennium Ecosystem Assessment, 2005; Tett et al., 2011). Local-scale stressors, such as habitat destruction, water contamination, and coastal erosion, can have larger impacts on the Earth system, including ocean contamination and greenhouse effects (Carter, 1991; Dihkan et al., 2015; Post & Lundin, 1996; Sekovski et al., 2012).

It is essential to note that the transformation of natural areas into built-up areas and the increase in human activities in these areas contribute to the degradation of ecosystems. The landscape network consists of patches, corridors, and matrix concepts, which represent gradients, networks, and hierarchies at various scales ranging from regional to local. This concept has been widely utilized for scientific analysis (Alberti, 2008; Forman, 1991; Henein & Merriam, 1990). Landscape corridors are a critical component of land cover, and land use plays a crucial role in the sustainability of the concept (Bennett, 2003; Forman, 2014; Forman & Godron, 1981; Guneroglu et al., 2013; Peng et al., 2017a, b). Corridors influence the hydrology, ecology, and climate of urbanized areas, which are crucial to ecosystems (Guneroglu et al., 2013; Jeong et al., 2021).

Coastal zones around the globe are facing increasing stress, as demonstrated by numerous studies (Tett et al., 2011). These stresses are often the result of increased demand for the natural resources of rapidly expanding cities, which can pose a threat to the associated ecosystems located in the land-sea interface (Agardy et al., 2005; Batty & Longley, 1988; Chettry & Surawar, 2021; Dasgupta et al., 2009; Forman, 2008; McGranahan et al., 2005; Merkens et al., 2016; Neumann et al., 2015; Peterson & Lubchenco, 1997; Wong et al., 2015). To sustain coastal resilience, landscape connectivity, and habitat life in urbanized coastal areas, it is necessary to implement spatial policies. However, simply restricting urban spatial growth may not necessarily be a sustainable policy solution. Instead, it is important to consider the manner and location of spatial growth in order to ensure the sustainability of natural areas. In this context, the implementation of appropriate spatial policies

is critical for preserving the long-term viability of coastal ecosystems.

Landscape networks that promote sustainable spatial growth in coastal cities are a key factor in the maintenance of ecosystem functioning processes, which involve the relationship between the city and nature (Alberti, 2008; Bennett, 2003; Cantwelp & Forman, 1993; Carlier & Moran, 2019; Guneroglu et al., 2013; Henein & Merriam, 1990; Peng et al., 2017a, b). The connectivity and infrastructure of these networks can also play a role in reducing the vulnerability of coastal cities to natural disasters and climate change risks, thereby enhancing coastal resilience (Jeong et al., 2021; Kim et al., 2021; Vollmer et al., 2015). Therefore, landscape networks that support sustainable spatial growth in coastal cities are essential for maintaining the health and functionality of these ecosystems.

In the land-sea interaction zone, the spatial pattern of coastal urbanization is critical for the maintenance of coastal ecosystems and the wetland and water-related structures that are integral to these ecosystems (Forman, 2016; Paul & Meyer, 2008). These structures include valleys that connect to the coast, riparian regions that connect to the coast, and ecological corridors that provide habitat for both urban and natural areas. It is important to prioritize ecology when considering the combination of coastal ecosystems and built-up areas (Jahani & Barghjelveh, 2021; Timmerman et al., 1997), as urban spatial growth is a major driver of habitat loss and change (Bolund & Hunhammar, 1999; Mcdonald et al., 2008). Therefore, it is crucial to analyze and evaluate past urban spatial development in order to effectively plan for future urban management, especially in developing countries, and to implement appropriate urban policies.

Geospatial techniques and methods have been demonstrated to provide a more nuanced understanding of urban growth through modelling and analysis, which can inform planning decisions both in the present and future. Urban growth is influenced by a range of factors, including topographical features, such as those found in coastal (Yılmaz & Terzi, 2021), desert (Mansour et al., 2022), and mountainous regions (Mansour et al., 2020). The use of GIS-based algorithms for analyzing urban growth in both developed and developing countries is also prevalent as a tool for guiding spatial planning policies (Hassan

& Nazem, 2016; Huang et al., 2007; Mansour et al., 2020).

Landscape fragmentation refers to the division of a contiguous landscape into smaller, disconnected pieces, which can be caused by the construction of infrastructure such as roads and buildings, or by natural processes like erosion or landslides. There is a significant body of research on landscape distribution (Alberti, 2005; Forman & Collinge, 1997; Henein & Merriam, 1990; Robinson et al., 2005; Zhou et al., 2014), but less attention has been paid to the structural properties of landscape connections, which are essential for maintaining connectivity (Bennett, 2003; Guneroglu et al., 2013; Hysa & Başkaya, 2018; Tischendorf & Fahrig, 2000; Tzoulas et al., 2007). While the impact of urbanization on landscape structure has been widely studied in the context of built-up expansion (Crawford, 2007; Man et al., 2019; Pili et al., 2017; Wu et al., 2016; Zhou et al., 2014), the effects of different types of urban spatial growth on landscape structure at various spatial scales have been poorly monitored (Kirtland et al., 1994; Peng et al., 2017a, b; Wilson et al., 2003; Yılmaz & Terzi, 2018). It is well established that urban spatial growth primarily consumes natural areas, leading to landscape degradation.

Coastal cities tend to expand along the coast unless their growth is constrained by natural boundaries. As a result, the landscape between land and sea is continually threatened by fragmentation and conversion into fully built-up areas (Yılmaz & Terzi, 2021). As a developing country, Türkiye is experiencing high rates of population growth in its coastal regions rather than in its inland regions. This rapid growth trend in Türkiye coastal cities, which have fragile natural structures, makes this area of particular interest for examining the tension between urban spatial growth pressures and the conservation of natural connectivity. These coastal cities in Türkiye have undergone rapid urbanization in recent years, resulting in the expansion of urban settlements. While there is a considerable amount of research on land cover and land use change in these cities, there is a lack of understanding about the quantifiable effects of landscape disconnectivity on coastal cities. Previous studies have mainly focused on land cover changes in Türkiye's coastal cities (Atay Kaya & Kut Görgün, 2020; Güler et al., 2007; Kesgin & Nurlu, 2009; Kilic et al., 2006; Kuleli & Bayazıt, 2022), but

there has been limited investigation into the overall impact of urban growth on landscape fragmentation in these cities (Yılmaz & Terzi, 2019). This study aims to address this gap in the literature by examining how spatial growth patterns in urban settlements located in coastal areas can lead to landscape fragmentation. Understanding this relationship is crucial because it is important to carefully consider the potential impacts of urban growth on the surrounding landscape and to develop strategies to mitigate any negative effects. Therefore, the research question of this paper is: how do different urban spatial growth patterns impact the landscape pattern in coastal cities? Based on this research question, the aim of this paper is to examine the relationships between the components of urban spatial growth and changes in landscape connectivity to evaluate landscape degradation in coastal regions. Landscape deterioration is influenced by both structural and functional structures. Landscape structure involves the spatial and temporal quantification of landscape patterns (Esbah et al., 2010; Hysa & Başkaya, 2018; Mcgarigal et al., 2009), while landscape function examines the relationships between the populations of species in habitat patches (Forman, 1997; Forman & Collinge, 1997). In this study, we have assessed the landscape structure of Türkiye's coastal cities in terms of the spatial and temporal distribution of landscape structure, rather than functional properties. The methodology utilized in this study is outlined in the "Methodology" section, which describes the study areas, the data sets and their definitions, the indicators employed to assess landscape fragmentation, and the range of statistical analyses conducted. The "Results" section features the fragmentation patterns of the landscape network, and an overview of the statistical relationships observed. The "Discussion" section contains general findings and comparisons with relevant literature, as well as a discussion of the implications of the research for national policy. The final conclusions are presented in the "Conclusion" section.

Methodology

The following subsections outline an approach for determining the effects of urban spatial growth on landscape fragmentation, including the main stages involved.

Study areas

The six coastal cities in Türkiye chosen as the sample area exhibit a range of spatial sizes and socio-economic levels at various levels. According to Yılmaz and Terzi (2021), İzmir, Kocaeli, and Antalya are coastal cities that rank among the highest in terms of socio-economic development levels, while Samsun, Tekirdağ, and Mersin are classified as middle-level cities (for further information, see Yılmaz & Terzi, 2021). The central districts along the seafront were selected as study areas: İzmir on the Aegean Sea coast, Antalya, and Mersin on the Mediterranean coast, Kocaeli and Tekirdağ on the Marmara Sea coast, and Samsun on the Black Sea coast (Fig. 1). The selected coastal cities exhibit diverse coastal geomorphologic structures, including coasts of gulfs, straight sea coastlines, shores of narrow straits, and narrow areas. Upon examination of the geomorphological characteristics and population sizes of the sample area, Samsun is located parallel to the highly sloped mountains and the sea, and has a population of 700,000 and an area of 630 km^2. Located in the south and west of the country, İzmir, Kocaeli, Antalya, Mersin, and Tekirdağ have geographically flat areas towards the interior. Their population sizes are, respectively, İzmir around 3 million and an area of 750 km^2, Kocaeli 1 million and an area of 810 km^2, Antalya 1.2 million and an area of 850 km^2, Mersin 1 million and an area of

545 km^2, and Tekirdağ 200,000 and an area of 509 km^2 (Fig. 2).

As the altitudes of the coastal regions fall from the inland region towards the sea, valleys and riparian regions become connected to the sea. Simultaneously, the intersection of land and sea possesses unique qualities in terms of landscape ecology (Forman, 2016), which significantly influences the formation of the pattern of landscape connectivity of the coasts. The fragmentation of the landscape connectivity pattern can be studied in the selected coastal cities because they have experienced rapid spatial growth. According to the 2015–2016 city census, the latest available data on the spatial distribution of the sample cities, these areas represent approximately 45% of the population of Türkiye's coastal cities and one-third of all cities. Istanbul is not included in this assessment because it is the largest coastal city in Türkiye and a global city (Table 1).

Data collection

The present study employed a temporal sampling approach that utilized three distinct time periods—1986, 2000, and 2015—in order to comprehensively examine the processes and patterns of urban growth and landscape connectivity in six coastal cities located in Türkiye: İzmir, Kocaeli, Antalya, Mersin, Samsun, and Tekirdağ. The aim of this sampling strategy was to cover a period of approximately 30 years, in order to track changes and trends in urbanization over time, and to identify any
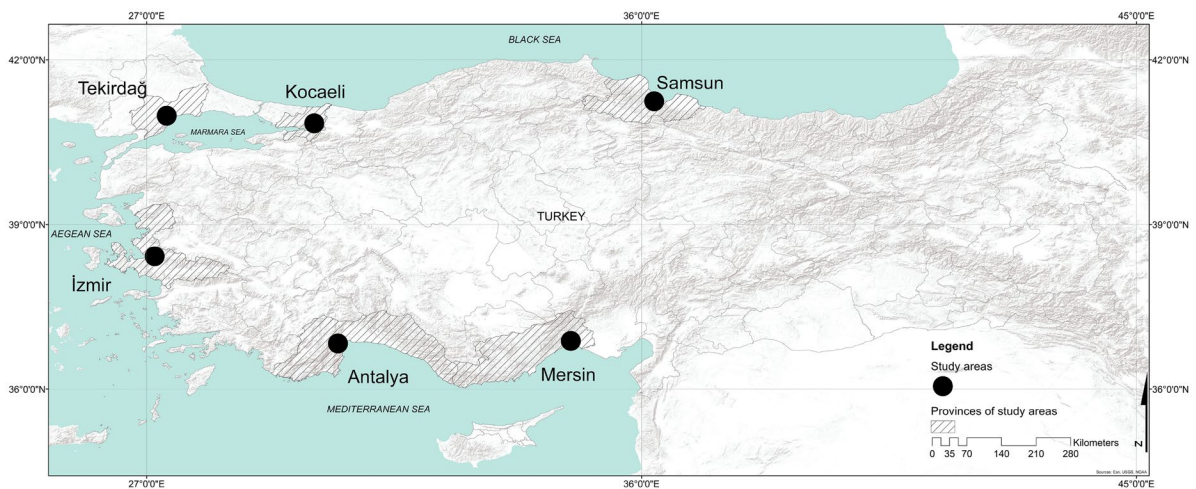

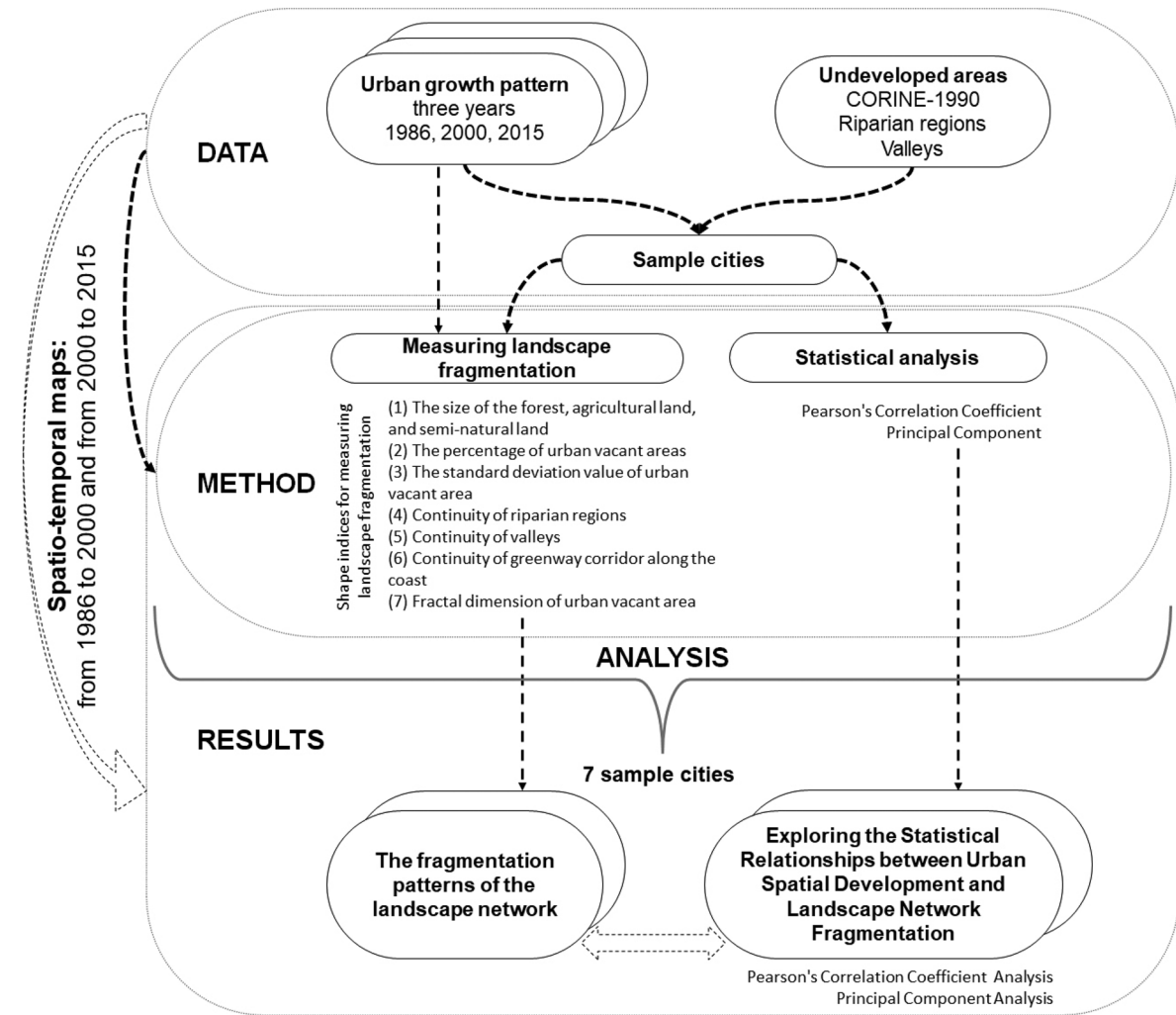**Fig. 1** Geographic location of the study areas (prepared by authors)

Fig. 2 Illustrative flowchart of the methodological framework utilized in the study (prepared by authors)

notable landscape fragmentation that may have emerged. In the present study, sample cities were defined by a grid of cells, each of which covered an area of one hectare

(Yılmaz, 2019). This cell-based approach allowed for the systematic and uniform examination of the spatial patterns and processes of urbanization within the sample

Table 1 Data definition and source of the components of landscape connectivity utilized in this study

Components	Definition	Source
(i) Forest (ii) Agriculture land (iii) Semi-natural areas	These components were classified by the 1990 CORINE Land Cover. The data, representing the largest change class (level 1) in CORINE, was utilized to investigate regions where the natural structure underwent transformation	(EEA, 2019)
Riparian regions	The data were sourced from the European Environment Agency within the context of the EU Copernicus program. Statistical techniques were applied to the analysis of these transitional areas, located between land and freshwater ecosystems, in order to identify potential riparian zones that may have undergone transformation into built-up areas	(EEA, 2017a)
Valley	The component was derived from a Digital Elevation Model (DEM) using ArcGIS software (Esri)	(EEA, 2017b)

cities. The size of the cells, which were defined as one hectare in size, was chosen in order to provide a sufficient level of detail and resolution for the analysis, while also allowing for the aggregation of data at larger spatial scales if necessary. The number of cells within each city varied, and was determined by the size and spatial extent of the urban area. Accordingly, the number of cells (N) within each sample city was as follows: 75,000 cells in İzmir, 81,000 cells in Kocaeli, 85,000 cells in Antalya, 54,500 cells in Mersin, 63,000 cells in Samsun, and 50,900 cells in Tekirdağ (Fig. 3).

Two main components were utilized in the study: *urban spatial growth* and *undeveloped areas* (natural areas) *for landscape connectivity*. The former was determined using a methodology developed by Yılmaz and Terzi (2021), which allowed for the systematic and quantitative analysis of the spatial expansion of urban areas over time. The latter component, *undeveloped areas*, was included in order to assess the impact of landscape connectivity on the urbanization process. Firstly, the data definitions and sources of the components of landscape connectivity utilized in this study are detailed in
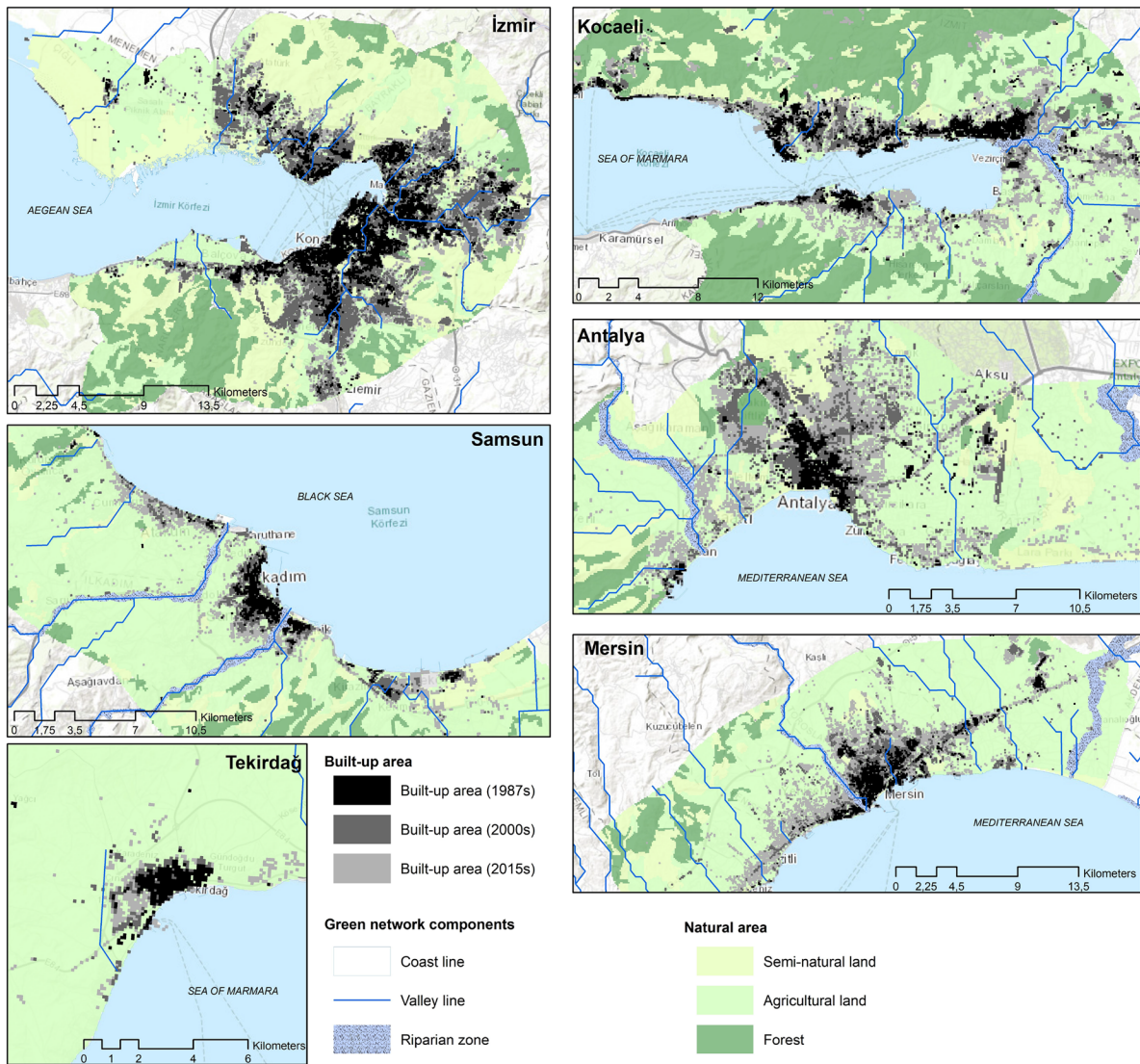

Fig. 3 Built up area (Yılmaz & Terzi, 2021), green network components, and natural area of sample areas (prepared by authors)

Table 2. Secondarily, the indices of urban spatial growth encompass both centrifugal and centripetal dimensions, as well as the fractal dimension of the urban area, linearity along the coast, and linearity along the road as components of urban spatial geometry (shape). Additionally, the components of urban spatial growth types (size) include urban expansion, infill development, leapfrog development, and population density (Yılmaz & Terzi, 2021). The methodological approach is illustrated in a flowchart format in Fig. 2.

Measuring the landscape fragmentation

In this study, we employed a geographic information system to calculate indices of landscape fragmentation resulting from urban spatial growth on a 100×100 m grid. These indices were calculated for the purpose of analyzing undeveloped areas, which have been identified as significant indicators of landscape fragmentation from the perspective of the landscape shape index (Forman, 2008; Guneroglu et al.,

2013). The components of these indices included the size of natural areas, urban vacant areas, continuity of riparian regions, valleys, and greenway corridors along the coast, as well as the fractal dimension of urban vacant areas, which served as a measure of shape. The indices are presented below:

1. *The size of the forest, agricultural land, and semi-natural land* — They were evaluated as indicators of the rate at which these areas were transformed into different land uses (such as forest, agricultural land, and semi natural land) in the surrounding built-up area. A decrease in the values of these variables corresponded to a decrease in the size of these areas.

2. *The percentage of urban vacant areas* — This metric assesses the proportion of undeveloped land (such as parks, playgrounds, and vacant lands) within the built-up area, serving as a measure of the rate of transformation of the built-up area over time. As the value of this variable decreases, the amount of undeveloped land

Table 2 Descriptive statistics of change of indices used for 1986s, 2000s, and 2015s

Codes for indices	Indices	1986–2000				2000–2015			
		Median	Std. dev	Min	Max	Median	Std. dev	Min	Max
BLT_CENTRAL	Centrifugal and centripetal dimension	−0.886	1.90	−2.70	−2.79	−1.095	1.10	−3.14	0.12
BLT_FRACTAL	Fractal dimension of urban area	0.092	0.09	−0.05	0.24	0.117	0.05	0.00	0.14
BLT_LINE_COAST	Linearity along the coast	−0.072	0,13	−0.26	0.15	0.012	0.19	−0.54	0.11
BLT_LINE_ROAD	Linearity along the road	0.612	2.99	−2.66	6.47	0.245	8.57	−7.47	18.28
BLT_EXPANSION	Urban expansion	125.156	70.29	6.65	253.91	101.399	70.93	31.48	240.59
BLT_INFILL	Infill development	13.841	5.61	1.89	20.14	11.766	5.67	2.88	22.61
BLT_LEAPFR	Leapfrog development	0.67	0.76	0.25	2.71	0.591	0.35	0.26	1.32
BLT_DENSTY	Population density	−67.8	97.07	−274.52	36.59	−27.16	58.63	−86.35	79.68
NTR_FOREST	The size of forest	0.077	0.23	0.00	0.54	0.498	0.72	0.00	1.85
NTR_AGCULT	The size of agriculture land	3.219	10.66	0.06	32.78	5.867	7.72	0.44	20.36
NTR_SEMI	The size of semi natural land	0.867	3.08	0.00	9.21	5.333	4.89	−0.10	14.45
NTR_VACANT	The rate of urban vacant area	−4.847	7.44	−18.16	7.39	−2.663	11.12	−11.34	24.39
NTR_SD	The standard deviation value of urban vacant area	−0.35	4.70	−5.90	9.11	0.44	12.97	−9.42	36.30
NTR_RIPARIAN	Continuity of riparian regions	1.55	2.86	0.00	9.13	3.57	5.82	0.00	14.68
NTR_VALLEY	Continuity of valleys	0.59	3.45	0.00	10.76	2	4.33	0.00	10.35
NTR_CSTCRR	Continuity of greenway corridor along the coast	8.64	5.73	−0.49	13.92	9.58	9.02	1.04	25.04
NTR_FRACTAL	Fractal dimension of urban vacant area	0.057	0.07	−0.02	0.21	0.082	0.08	−0.02	0.20

within the built-up area also decreases, while an increase in the value corresponds to a higher rate of vacant land within the built-up area. The calculation of this metric is performed using the following Eq. (1):

$$= \frac{\sum urban\ vacant\ area\ (ha)}{\sum built-up\ area\ (ha)} x100 \qquad (1)$$

3. *The standard deviation value of urban vacant area* — The vacant area within the built-in region exhibits a degree of similarity or divergence in size. The sustainability and continuity of ecological systems are dependent on the size of urban vacant areas, natural areas, parks, and green corridors. The size of urban vacant areas becomes increasingly similar as the value of the variable decreases, and becomes increasingly divergent as the value increases. The value is determined through the use of the following Eq. (2):

$$= \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (x_i - \bar{x})^2} \qquad (2)$$

N represents the number of urban vacant regions, and $\{x_i, ..., x_n\}$ denotes the sizes of the distribution of urban vacant land.

4. *Continuity of riparian regions* — This metric indicates the proportion of built-up areas within the riparian region (EEA, 2017a). An increase in this rate results in a degradation and disconnection of the green network system. A decrease in the value of the variable preserves the continuity of the riparian region, while an increase in the value leads to a decrease in the continuity of the riparian region.

5. *Continuity of valleys* — This metric quantifies the proportion of built-up area within a 100-m radius of the valley. An increase in the value of the variable reduces the representation of valleys within the green network system and results in a degradation of connections. A decrease in the value of the variable ensures the continuity of valleys, while an increase in the value leads to a decrease in continuity.

6. *Continuity of greenway corridor along the coast* — This metric evaluates the proportion of undeveloped areas within a 500-m radius of the coast relative to the inland region. An increase in this rate decreases coastal use and weakens the con-

nection between natural areas. A decrease in the value of the variable preserves the continuity of these areas, while an increase in the value leads to a decrease in continuity.

7. *Fractal dimension of urban vacant area* — The complexity of the shape of the vacant areas is represented by the fractal dimension. A value closer to 1 indicates a simpler shape, while a value closer to 2 indicates a more complex shape. The calculation of this value is performed using the following Eq. (3):

$$= \frac{\log N\left(2^{-(k+1)}\right) - \log N\left(2^{-k}\right)}{\log 2^{k+1} + \ln 2^k} = \log \frac{N\left(2^{-(k+1)}\right)}{N2^{-k}} \qquad (3)$$

k represents the iteration number, taking on values of "0, 1, 2, …" and N represents the number of cells or grid points in the analysis.

Statistical analysis

The study endeavors to assess the influence of various urban spatial growth patterns on landscape connectivity and fragmentation in a sample of coastal cities over the time periods of 1986–2000 and 2000–2015. To achieve this objective, we employ a combination of GIS-based analysis and statistical modelling methods to quantitatively evaluate changes in the spatial distribution of land cover and land use within the study regions. In order to ensure the reliability and robustness of our analysis, we utilize Cronbach's alpha to assess the internal consistency of the components being synthesized into a set of elements, and apply descriptive statistics and the Pearson's correlation coefficient (PCC) to examine changes in the data. The PCC is a statistical measure that reflects the strength and direction of the linear relationship between two variables, and can range from -1 to $+1$, with negative values indicating an inverse relationship, positive values indicating a direct relationship, and values approaching 0 indicating a weak or non-linear relationship.

The use of these methods allows for a comprehensive examination of the research question at hand and adds robustness to the findings of the study. Additionally, these methods enable a robust and reliable analysis of the data, enabling us to draw nuanced and informed conclusions about the impact of urban

spatial growth types on landscape connectivity and fragmentation in the sample of coastal cities. The PCC value indicates the magnitude of the relationship between two variables, with higher values indicating a stronger relationship. This value varies between −1 and + 1, with negative values indicating a relationship in the opposite direction, and positive values indicating a relationship in the same direction. The closer the value is to −1 or + 1, the weaker the relationship, as it approaches 0 when expressing a strong linear relationship. The following Formula (4) can be used to calculate the PCC between x and y, which are values of observation ranked by rank (Plata, 2006):

$$r(x, y) = \frac{\left(\frac{1}{n}\sum_{i=1}^{n} x_i y_i\right) - \overline{x.y}}{\sqrt{\left(\frac{1}{n}\sum_{i=1}^{n} x_i^2\right) - (\overline{x})^2} \cdot \sqrt{\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) - (\overline{y})^2}} \tag{4}$$

where x and y are the values of the observations ranked by rank, and $\overline{x}$ and $\overline{y}$ represent the mean values of x and y, respectively. This formula allows for the quantification of the degree to which the values of x and y are correlated, enabling researchers to determine the extent to which changes in one variable are associated with changes in the other.

Following the analysis of the Pearson's correlation coefficient (PCC), we employ principal component analysis (PCA) to reduce the dimensionality of the dataset and identify the underlying principal components. PCA is a statistical technique that aims to transform a large number of correlated variables into a smaller number of uncorrelated variables, known as principal components, which capture the most important information in the data (Anderson, 2003; Jolliffe, 2002). By utilizing PCA, we can gain a more sophisticated understanding of the relationships between the variables of interest and derive informed conclusions about the data.

Results

This study analyzed the statistical relationships between multiple patterns and computational variables. In particular, the patterns of built-up and undeveloped or natural areas were examined in relation to landscape connectivity. Given the focus on the continuity of landscape connectivity, the study examined urban spatial growth patterns that disrupt or disconnect the landscape network and their highly correlated associations. The analysis is presented in two subsections: the "Fragmentation patterns of the landscape network" and the "Statistical relationships between the effects of urban spatial development and the fragmentation of the landscape network".

The fragmentation patterns of the landscape network

The landscape network is a system of interconnected natural areas. As such, the transformation of natural areas into built areas can trigger landscape fragmentation. In this study, we examine the impacts of these transformations on landscape connectivity. The transformation of natural areas into built areas, as depicted in Fig. 4, has been examined for both time periods of 1986–2000 and 2000–2015. These natural areas are categorized as agricultural, forest, and semi-natural areas. The results of the study reveal that the conversion of agricultural land to built-up areas during the 2000–2015 period is more extensive than in the preceding time frame. Among the selected locations, İzmir is the only city that experienced a greater transformation of agricultural land to built-up areas during the 1986–2000 period compared to the subsequent time period. When the conversion of forests into built-up areas is evaluated, Kocaeli exhibits the highest level of transformation. Additionally, a higher rate of land consumption occurred during the 2000–2015 period. The second time period, 2000–2015, is also observed to dominate in the rate of conversion of semi-natural areas into built areas, with İzmir demonstrating the most significant area consumption. Antalya and Kocaeli also display significant consumption of semi-natural areas during the 2000–2015 period.

The fragmentation patterns of the landscape network in the sample cities are characterized by changes in the built-up area, natural area, urban vacant area, and built-up area, as illustrated in Fig. 5. Descriptive statistics of the change in indices for the years 1986, 2000, and 2015 are presented in Table 2. The analysis shows that the majority of land conversions resulting from built-up areas in all sample cities were from agricultural land. The increase in built-up area during the 1986–2000 and 2000–2015 periods indicates that more transformation occurred during the earlier period (Table 1). In particular, Antalya and Izmir
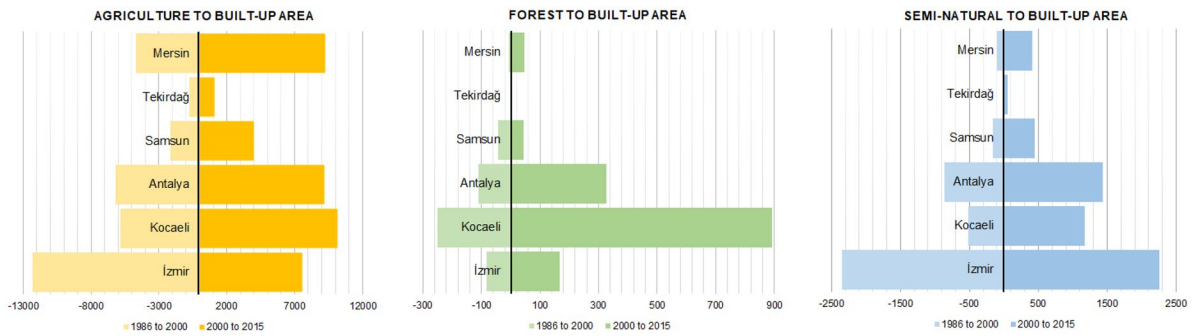
Fig. 4 Transformation sizes of natural area classes into built areas (hectares) for the periods 1986–2000 and 2000–2015 (prepared by authors)

experienced the greatest increase (Fig. 5). These trends have contributed to the fragmentation patterns shown in Fig. 5. Additionally, the analysis reveals that the rate of urban vacant area displayed high values in both periods, indicating a significant presence of such areas in the sample cities.

Exploring the statistical relationships between urban spatial development and landscape network fragmentation

The statistical relationships between the effects of urban spatial development and the fragmentation of the landscape network were quantitatively analyzed using Pearson's correlation coefficient and principal component analysis. Cronbach's alpha was used to assess the reliability of the indices and ensure internal consistency. A higher result approaching 1 indicates higher internal consistency. The Cronbach's alpha reliability of the 17 indices used in the study was found to be 78.7% for the period 1986–2000 and 73.3% for the period 2000–2015. These values are considered sufficient for statistical analysis (Cohen et al., 2007). The results of these analyses are presented and interpreted in the following sections.

Pearson's correlation coefficient analysis

Pearson's correlation coefficient (PCC) was used to examine the statistical relationships between variables, as illustrated in Fig. 6, which was generated using RStudio, a programming language for statistical computing and graphing, with spatial data generated

using ArcGIS. According to Fig. 6, a significant positive or negative relationship exists between variables when the significance level is less than $p = 0.05$. In the 1986–2000 period, the indices of landscape areas (undeveloped areas) that show a correlation with other indices include: the fractal dimension of the urban vacant area with linearity along the coast ($r = .87$); the continuity of the greenway corridor along the coast with linear growth along the road ($r = .87$); infill development ($r = .97$); the standard deviation value of the urban vacant area ($r = 0.89$); and the continuity of riparian regions ($r = 0.88$) with leapfrog development. Linear growth along the road is also correlated with population density ($r = -0.82$), indicating that it affects the continuity of the greenway corridor along the coast and population density.

In terms of relationships between the indices of landscape areas, the size of agriculture land and the size of semi-natural land ($r = .97$), the size of agriculture land and continuity of valleys ($r = .94$), the size of semi-natural land and continuity of valleys ($r = .94$), and the rate of urban vacant area and the standard deviation value of urban vacant area ($r = .95$) are correlated (Fig. 6).

In the 2000–2015 period, the indices of landscape areas (undeveloped areas) with correlations include the standard deviation value of urban vacant areas ($r = -.94$) and the rate of urban vacant areas ($r = -.88$) with linearity along the coast. Linear growth along the road correlates with several landscape areas, including the size of forest ($r = .88$), the size of agricultural land ($r = .88$), and the continuity of the greenway corridor along the coast ($r = .84$). The continuity of greenway corridors along the coast is correlated

with urban expansion (*r*=.87). Infill development correlates with the continuity of the greenway corridor along the coast (*r*=.83) and the size of semi-natural land (*r*=.97). Linear growth along the road is also correlated with urban expansion (*r*=.85), indicating that the size of agricultural land, the size of forest, and the continuity of the greenway corridor along the coast affect urban expansion. Furthermore, relationships between the indices of landscape areas include: the size of agriculture land and the size of forest (*r*=.97), the size of agriculture land and continuity of valleys (*r*=.85), the rate of urban vacant area and the standard deviation value of urban vacant area (*r*=.96), and the continuity of the greenway corridor along the coast and the continuity of riparian regions (*r*=.93) (Fig. 6).

The analysis of the two periods revealed that the indices of centrifugal and centripetal dimension and fractal dimension did not show a correlation with the other indices. As a result, the principal component analysis was conducted using 15 indices.

Principal component analysis

The results of the principal component analysis (PCA) using 13 indices are shown in Table 3. No correlation was found for the variables BLT_CENTRAL, BLT_FRACTAL, BLT_EXPANSION, and NTR_FOREST in the 1986–2000 period and BLT_CENTRAL, BLT_FRACTAL, BLT_LEAPFR, and BLT_DENSTY in the 2000–2015 period. The results of the PCA were interpreted using direct oblimin rotation, with the study periods oriented from negative to positive scores. These findings provide empirical evidence of the spatial patterns described in the "Fragmentation patterns of the landscape network" section.

The loadings of the indices on the components for each period are shown in Table 3. Indices with highly positive loadings on components greater than 0.65 are highlighted. In the 1986–2000 period, BLT_LINE_COAST in PC3 is negatively involved in PC2. This result may have led to an increase in the component loading of NTR_VACANT in the 2000–2015 period. NTR_RIPARIAN was affected by the decline in the loading of NTR_VACANT in the 1986–2000 period, but began to be influenced by urban spatial growth in the 2000–2015 period. Additionally, negative loading indices in the 1986–2000 period turned into positive loadings in the 2000–2015 period.

In the periods 1986–2000 and 2000–2015, three PCs axes were found to be significant. For the 1986–2000 period, these three axes explained 97.1% of the variance: 52.9%, 29.6%, and 14.6% for axes 1, 2, and 3, respectively. For the 2000–2015 period, the three axes explained 89.6% of the variance: 48.0%, 26.6%, and 15.0% for axes 1, 2, and 3, respectively. The PC axes in Fig. 7 illustrate the group of indices associated with each axis. In the 1986–2000 period, PC2 and PC3 have positive values, while PC1 has both positive and negative values. In the 2000–2015 period, PC1, PC2 (with the exception of BLT_LINE_COAST), and PC3 have positive values.

The PC axes appear to strongly associate indices within the landscape network with NTR_. The indices of built-up areas that contribute to the fragmentation of the landscape network show strong positive correlations with BLT_LINE_COAST, BLT_LINE_ROAD, BLT_INFILL, BLT_LEAPFR, and BLT_EXPANSION, and a negative correlation with BLT_DENSITY DENSITY (Table 3 and Fig. 7). Based on the PCs for the two periods, BLT_LINE_COAST, NTR_FRACTAL, and BLT_DENSITY display outlier properties. Therefore, PC1 and PC2 are dominant components. In component 1, BLT_LINE_ROAD, NTR_CSTCRR, and NTR_VALLEY are indices that affect the landscape connectivity network. In component 2, NTR_SD and NTR_VACANT are indices related to the formation of perforated urban patterns. At the same time, BLT_LEAPFR in the first period is the built-up factor that affects this pattern. Consequently, the indices that affect the linear connections of the landscape network are clustered in PC1, while the indices that fragment the landscape continuity by forming a perforated structure are clustered in PC2 (Fig. 7).

The results of the principal components regression analysis for the sample cities are presented in Table 4. In the periods 1986–2000 and 2000–2015, the dominant cities for each factor are determined based on the regression results. For the 1986–2000 period, İzmir has the highest value for factor 1 (1.777), while Tekirdağ has the highest value for factor 1 in the 2000–2015 period−1.459). For factor 2, Kocaeli has the highest value in the 1986–2000 period (1.953), while Antalya has the highest value in the 2000–2015 period (1.942). For factor 3, Samsun has the highest value in both periods, with –1.480 in 1986–2000 and 1.531 in 2000–2015 (These values are expressed in bold font in Table 4).
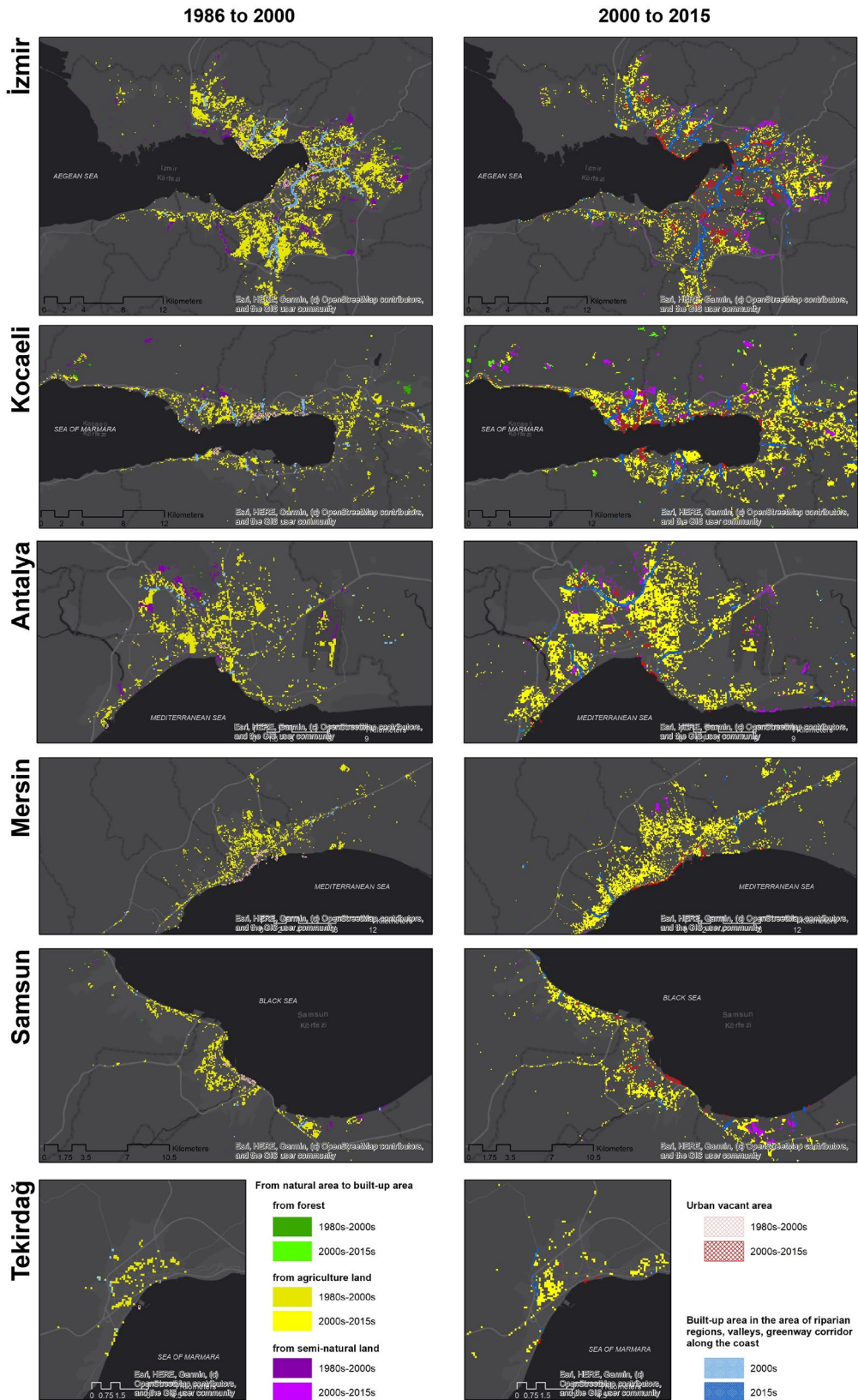
◀**Fig. 5** Built up area, natural area, urban vacant area, and built-up area in landscape network patterns of the sample cities (1986 to 2000 and 2000 to 2015) (prepared by authors)

Discussion

The research question addressed in this article is "How do different urban spatial growth patterns impact the landscape pattern in coastal cities?" The study investigates the relationship between components of urban spatial growth and changes in landscape connectivity in order to evaluate landscape degradation in coastal regions. In this context, if a comprehensive discussion is conducted, coastal cities often experience urban development and land transformation as a result of various spatial forces, including economic, social, and environmental drivers (Atay Kaya & Kut Görgün, 2020; Kuleli & Bayazıt, 2022; Merkens et al., 2016; Todd et al., 2019; Yılmaz & Terzi, 2021). Economic drivers, such as the availability of employment, transportation infrastructure, and proximity to central business districts, can significantly impact the patterns of urbanization in these cities. Social factors, such as desired lifestyles and the presence of amenities and services, also play a role in shaping the spatial development of coastal cities. Additionally, the availability of land for development, regulatory frameworks, and the physical constraints of the natural environment can all influence the pattern of urban development and land transformation in coastal cities. It is worth noting that these drivers are often interconnected and can interact in complex ways, contributing to the multifaceted nature of urban development and land transformation in coastal cities. According to Yılmaz and Terzi (2021), the sample cities in this study exhibit various social, economic, and environmental driving forces. It is noted that Izmir, Kocaeli, and Antalya possess a higher socio-economic status compared to the other sample cities. However, the cities of Izmir and Kocaeli, situated in bay settlements, exhibit an urban growth trend along the gulf. As a result, the influence of the landscape corridor on these cities is more complex in comparison to cities such as Samsun and Tekirdağ, which display a more linear spatial growth pattern.

Coastal cities worldwide, many of which are located along coastlines, have the potential to significantly impact the natural environment. Coastal degradation and vulnerability are increasing globally, including in Europe, North and South America, and Asia (Tett et al., 2011). These increasing stresses on coastal zones and their ecosystems are due to population growth, urbanization, and increasing demand for natural resources (Vargas et al., 2021). In light of these challenges, it is important for rapidly emerging cities to implement spatial policies that promote coastal resilience, landscape connectivity, and habitat conservation.

Landscape connectivity, which involves creating corridors that facilitate movement and interactions between different ecosystems, is crucial for reducing the vulnerability of coastal cities to natural disasters (Vollmer et al., 2015). Previous research has proposed various methods for characterizing landscape connectivity, including a guide developed by Carlier and Moran (2019) and a qualitative decision model proposed by Scolozzi and Geneletti (2012a, b) to assess local ecological values and minimize the impacts of fragmentation. These recommendations can help to protect ecosystem networks and enhance the resilience of coastal cities. Additionally, riparian regions, which are areas adjacent to rivers, streams, or other bodies of water, are important for mitigating some of the risks associated with climate change in cities (Vollmer et al., 2015). However, the conversion of these areas into built-up areas can negatively impact the resilience of coastal cities. One of the objectives of this research is to evaluate the changing landscape fragmentation in the spatial–temporal scope of the Türkiye sample and to reveal the relationship between the growth patterns of coastal cities and landscape degradation. This evaluation provides the opportunity to show the types and sizes of degradation caused by the need to protect landscape corridors in the spatial context.

Landscape corridors are dynamic and change over time and space (Bennett, 2003). Previous studies have investigated how landscape corridors may change in response to various factors (Cantwelp & Forman, 1993; Carlier & Moran, 2019; Guneroglu et al., 2013; Henein & Merriam, 1990; Peng et al., 2017a, b). Additionally, research has shown that landscape connectivity increases as habitat fragmentation increases (Tischendorf & Fahrig, 2000). The negative impacts of fragmentation on coastal cities, as highlighted in previous research, are also evident in the present study. The results of this study show that in Izmir and Kocaeli, two gulf settlements with urban growth
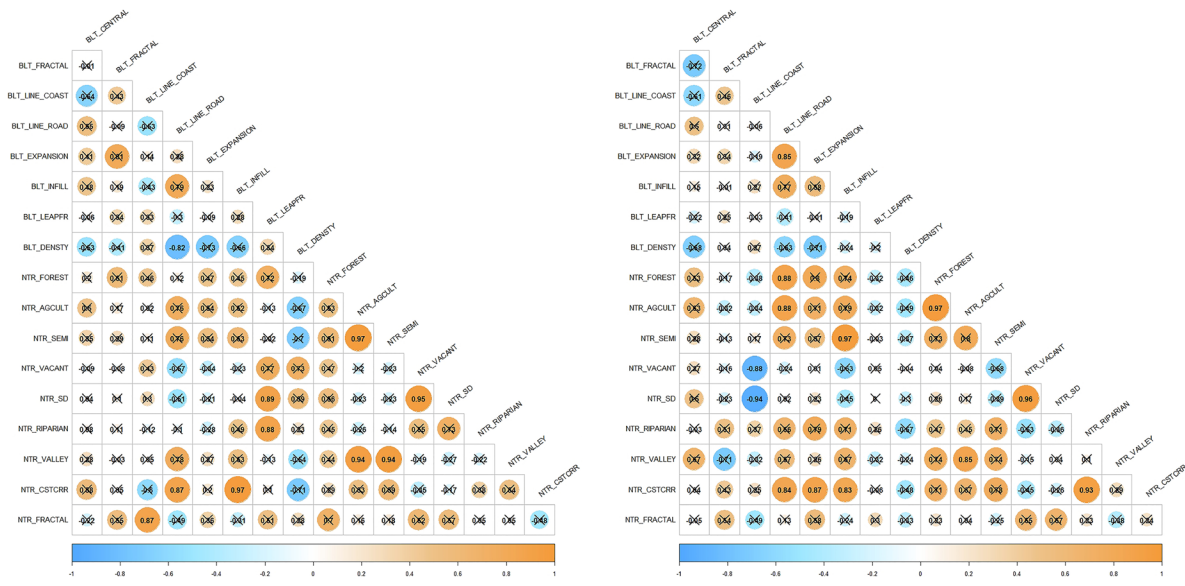
Fig. 6 Pearson's correlation coefficient of the indices in the periods 1986–2000 and 2000–2015 (correlation statistically significant at the $p < 0.005$ level (two-tailed); prepared by authors)

patterns both along the coast and along the road, landscape patches disappear in fully built-up areas rather than experiencing fragmentation. This fragmentation is largely due to the transformation of urban vacant areas, the continuation of riparian regions and valleys. In Mersin and Antalya, which have experienced urban growth along the coast and the road, the continuity of the greenway corridor along the coast has

partially disappeared. Tekirdağ exhibits a more compact form of spatial growth and has experienced partial landscape fragmentation.

The results of this study indicate that the patterns of landscape fragmentation in the sample coastal cities can be divided into two categories: (i) disconnected landscape connections and (ii) perforated landscape patterns. These patterns of fragmentation

Table 3 Results of principal component analysis for the periods 1986–2000 and 2000–2015

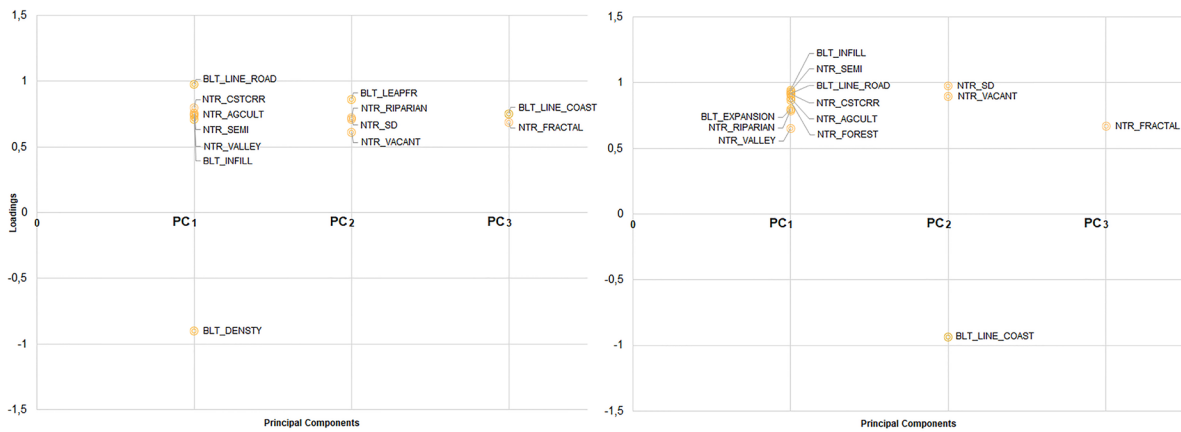| Indices	1986–2000				2000–2015		
	PC1	PC2	PC3		PC1	PC2	PC3
BLT_LINE_COAST			0.751	BLT_LINE_COAST		−0.938	
BLT_LINE_ROAD	0.976			BLT_LINE_ROAD	0.915		
BLT_INFILL	0.71			BLT_EXPANSION	0.799		
BLT_LEAPFR		0.86		BLT_INFILL	0.942		
BLT_DENSTY	−0.9			NTR_FOREST	0.865		
NTR_AGCULT	0.745			NTR_AGCULT	0.885		
NTR_SEMI	0.753			NTR_SEMI	0.931		
NTR_VACANT	−0.71	0.612		NTR_VACANT		0.897	
NTR_SD	−0.653	0.71		NTR_SD		0.974	
NTR_RIPARIAN		0.723		NTR_RIPARIAN	0.787		
NTR_VALLEY	0.735			NTR_VALLEY	0.65		
NTR_CSTCRR	0.796			NTR_CSTCRR	0.913		
NTR_FRACTAL			0.684	NTR_FRACTAL		0.724	0.669

PC principal component

Fig. 7 Principal component loadings: the periods of 1986–2000 by 3 PC (left) and 2000–2015 by 3 PC (right) (prepared by authors)

are the result of the spatial growth patterns of the coastal cities and can be attributed to four types of urban spatial growth: linear growth (along the coast and along the road), infill growth, urban expansion, and leapfrog development. These findings highlight the importance of considering the impacts of different types of urban growth on landscape connectivity and the potential consequences for the resilience of coastal cities.

Leapfrog development, which refers to the skipping over of undeveloped areas in favor of development in more distant locations, is a major contributor to the fragmentation of landscape continuity through the creation of perforated green structures. The most fragmented types of landscape corridors are those that involve the continuity of the greenway corridor along the coast, the continuity of valleys, and the rate of urban vacant area. Both spatial (Fig. 5) and quantitative (Fig. 6) results demonstrate that the corridor pattern has fragmented due to the deterioration of the coastal region and valley linearity, which have

previously been identified as important components of the landscape corridor (Forman, 2014; Jahani & Barghjelveh, 2021). The rate of urban vacant area, which reflects the potential for urban expansion, has also been shown to be a significant factor in landscape fragmentation. However, the degradation of this pattern, as indicated by the transformation of these corridors into built-up areas, suggests that landscape connectivity may be compromised in these areas. However, it is not feasible to maintain the integrity of the landscape corridor without degradation within built-up areas. Nevertheless, preserving the sustainability of this corridor at a regional scale to the greatest extent possible will contribute to the conservation of the natural structure and the sustainable growth pattern of the built environment. This is due to the fact that, the landscape connectivity within urban areas varies according to physical geography, with each coastal city exhibiting its own unique landscape network pattern. As demonstrated by the spatial changes observed in the sample coastal cities over

Table 4 Regression results in PC: the periods of 1986–2000 and 2000–2015

Cities	1986–2000			2000–2015		
	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3
Antalya	0.121	–0.081	1.115	0.351	**1.942**	–0.271
İzmir	**1.777**	–0.705	–0.232	–0.856	–0.408	–1.266
Kocaeli	0.035	**1.953**	0.114	1.136	–0.975	–0.733
Mersin	–0.574	–0.001	–0.589	0.852	–0.255	0.080
Samsun	–0.143	–0.596	**–1.480**	–0.024	–0.147	**1.531**
Tekirdağ	–1.216	–0.571	1.073	**–1.459**	–0.157	0.659

the past three decades (the "Data collection" section) and the fragmentation of landscape corridors (the "Fragmentation patterns of the landscape network" section), rapidly growing coastal cities often experience growth at the expense of the integrity of their landscape network patterns. In fact, the spatial dimensions of cities intersect with both landscape planning and spatial planning (Antrop, 2001). As the sample coastal cities in this study are among the rapidly developing coastal cities in Türkiye and have the priority of being directly targeted by central government spatial policies, they have the opportunity to receive more budget allocation. However, in developing countries, landscape network planning may be classified as a lower priority due to cost considerations (Vollmer et al., 2015).

From the perspective of national coastal spatial strategies and policies, landscape fragmentation is a significant consideration in various national strategy policies in coastal cities (Alphan et al., 2022; Bazant-Fabre et al., 2022; Fu et al., 2022; Lagarias & Stratigea, 2022). For example, in terms of environmental conservation and sustainability, coastal cities frequently harbor high levels of biodiversity and ecological value, and landscape fragmentation can have detrimental effects on the integrity and functioning of these ecosystems (Hao et al., 2022; Lu et al., 2022; Yang et al., 2022). In terms of coastal zone management and flood protection, landscape fragmentation can affect the ability of coastal areas to absorb and buffer against the impacts of storms and flooding (Dissanayaka et al., 2022; Peng et al., 2023). In terms of tourism and recreation, landscape fragmentation can affect the aesthetic and recreational value of coastal areas, as well as the attractiveness of these areas for tourism and recreation (Martin et al., 2016; Wang et al., 2022). In terms of economic development and land use planning, landscape fragmentation can affect the efficiency and productivity of land use, as well as the attractiveness of an area for investment and development (Liang et al., 2022; Woodruff et al., 2022). In general, landscape fragmentation is a vital consideration in a wide range of national strategy policies in coastal cities that impact the natural environment, flood protection, tourism and recreation, and economic development.

In the context of sample areas, urban disaster risk management in coastal areas in Türkiye primarily focuses on integrated coastal area management and planning, adopting a strategic approach that accounts for the specific characteristics of coastal and transitional areas rather than landscape connectivity in coastal cities. However, it is crucial to consider both the natural areas and coastal cities in conjunction with inland regions when implementing risk management strategies. Landscape networking, which involves creating corridors that facilitate movement and interactions between different ecosystems, is a crucial element of sustainable development in accordance with physical geography, rather than merely focusing on the amount of green space per capita within cities.

A quantitative analysis of the impacts of urban growth on landscape fragmentation in coastal cities may be subject to certain limitations and challenges. For instance, the scale of the data used in the study may affect the ability to capture the spatial resolution of the processes under examination. Additionally, the specificity of the physical geography of the study area may limit the generalizability of the findings to other coastal regions with different socio-economic, cultural, and environmental characteristics. While the adaptability of the research methodology to other locations may provide some insight, the results may not be fully transferable due to the complexity of the system and the potential for variation in the drivers and impacts of urbanization at different scales.

Conclusions

The pattern of urban spatial growth along coasts varies according to the coastal typologies, geographical features, and socio-economic activity patterns. This spatial growth pattern also impacts the landscape network. Measuring urban spatial patterns can assist urban planners in understanding the dynamics of urban growth and ensuring sustainability through tools such as land use planning, environmental impact assessment, and tax imposition, which facilitate sustainable spatial growth in coastal cities. This paper assesses the disconnection of landscape connectivity and loss of natural areas that result from spatial growth in coastal cities using spatiotemporal indices.

Managing urban spatial growth along coasts involves the challenge of creating cities that are both economically and environmentally sustainable. Within the context of landscape fragmentation in coastal cities, urban planning and urban spatial policies involve complex planning issues. Therefore, it is essential to describe, understand, evaluate, and

monitor urban spatial growth over time in order to take a holistic approach that can improve landscape connectivity conditions in coastal cities by mitigating the effects of fragmentation.

Effective spatial use decisions for landscape corridors are critical for implementing land use decisions made by local government planning actors in coastal cities. This research demonstrates that the context of how spatial growth is shaped, including the role of physical geography, is important for the sustainability of natural areas and landscape connectivity. Ultimately, the findings of this investigation will provide valuable insights for policymakers and planners seeking to manage the impacts of urbanization on the environment and to promote sustainable urban development.

Declarations

Consent of human participants Not applicable.

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