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Original Research

Landscape Changes and Their Socio-Economic Driving Factors in Coastal Zone

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Abstract

The coastal zone is not only the most active natural area on the Earth's surface but also the area with the most superior resources and environmental conditions. The sustainable development of the coastal ecological environment is closely related to the survival and development of human beings. In recent centuries, the coastal landscape has undergone tremendous changes with a massive increase in human population in the coastal areas. Therefore, it is urgent to identify the specific driving factors that affect coastal landscape changes to achieve sustainable management of coastal landscapes. In this paper, the Ningde Coastal Zone in China is selected as a case study. The study focuses on the impact of socio-economic and policy factors on coastal landscape changes and identifies the differences in the impact of various socio-economic factors on coastal landscape changes based on remote sensing data and statistical data. The results show that population, economy, consumption, and technology are the main driving factors affecting coastal landscape changes. The ranking of the impact of these factors on the coastal zone follows the order population>economy>consumption>technology. The influence of these driving factors on coastal landscapes continues to increase. In addition to socio-economic driving factors, policies are also one of the driving factors affecting coastal landscape changes.

Keywords: land use, principal component analysis, Fujian Province, Ningde City

Introduction

The coastal zone experiences the strongest interactions between land and sea and is also considered the most important ecological interlock zone in the world. "Agenda 21" adopted by the United Nations in 1992 states that more than 50% of the global population resides within 60 km of coastline [1]; in 2020, this proportion increased to 75%. It is estimated that by 2030, 50% of the global population will live in areas 100 km from the coast [2]. China has a coastline of 18,000 km and an island coastline of 14,000 km, where 60% of the population is concentrated within 60 km of the coastline [3]. Although coastal areas only account for 13% of the total land area in China, more than 50% of its large cities, 40% of the small and medium-sized cities, and more than 40% of the population is concentrated in coastal zones. These zones also contribute to approximately 70% of the gross domestic product in China [4-5].

Coastal ecosystems provide a variety of services. They do not only provide food, and habitats and

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nurseries for 80% to 90% of the marine fish and shellfish worldwide; they also regulate water quality, alleviate climate change, and reduce sea level rise and geological disasters [2]. The study of coastal ecosystems can be vital to social and economic development because coastal zones host abundant resources and can provide ecosystem services. However, the rapid increase in coastal populations in recent centuries has seriously reduced the resilience of coastal ecosystems and affected their normal output of ecosystem services. More seriously, recent human activity driven by high-speed global urbanization has increasingly damaged coastal zones [6]. These zones face severe environmental problems, including water, oil, and solid waste pollution; destruction of biological habitats; invasion of alien species; loss of biodiversity; reduction of fisheries; sea level rise; coastal erosion; seawater intrusion; and land salinization from global warming [7-10]. Therefore, the ecological security and sustainable development of coastal areas are under significant threat, which means that research on the sustainable development of coastal zones is high priority in coastal planning and landscape sustainability.

A landscape pattern is a combination of landscapes of different shapes and sizes embedded in the land surface; it is the product of interactions between humans and nature [11]. Landscape changes refer to the changes in the spatial structure and function of landscape over time [12]. The changes in landscape patterns have become an important indicator of the relationship between human society and natural ecosystems [13, 14]. In coastal zones, the landscape pattern is undergoing increasing levels of disturbance and becoming highly fragmented. Landscape changes are becoming more complex with the ongoing development of human society, and hence, the ecological issues of coastal zones are becoming increasingly prominent. In this context, there is a critical need for research on the changes in coastal landscape patterns and the underpinning driving mechanisms. This research contributes to the sustainable development of coastal zones and the alleviation of pressure on natural ecosystems as a result of the changes in coastal landscape patterns [15-16].

Research on the dynamic changes in coastal landscape patterns and the mechanisms driving these has been conducted in many countries to date. Parcerisas et al. [17] used landscape indicators to study the changes in the landscape pattern of the Spanish Mediterranean coast from 1850 to 2005 and the socio-economic forces driving this. Their results showed that the environment in the study area deteriorated rapidly over the past 150 years, with urban expansion and agricultural abandonment being the main causes of landscape degradation. Rivis et al. [18] analyzed the trends in land cover and landscape development in the coastal zone of Estonia under the effect of both social and natural factors and revealed that the diversity of seabed landforms a key factor affecting the speed and magnitude of landscape changes. Most changes to the coastal landscape caused by natural processes occurred near the coastline, while the impact of human activity on the coastal landscape increased with distance therefrom. Petrisor et al. [2] studied the evolution of the landscape in coastal areas of Vietnam and Algeria and found that urban expansion and the rapid development of tourism were the main reasons for changes in the landscape along the coast of Vietnam while urbanization and agricultural development were the main causes of landscape degradation along the coast of Algeria, and explosive growths in population, the migration of rural populations, and urban dwellers have exacerbated the degradation of the landscape in the coast of Algeria. Ou et al. [19] studied the characteristics of changes in the landscape pattern and the mechanisms driving these in the coastal zone of Yancheng, northern Jiangsu, China. Their results showed that economic development and population growth have led to the transformation of natural coastal landscape patterns into artificial landscape patterns, reductions in the heterogeneity of natural landscapes, and increases in the heterogeneity of artificial landscapes. Ding [20] used using the landscape index method to analyze the process by which landscape in the Bohai Rim region evolved from 1980 to 2010 and noted that agriculture, fisheries, and human economic activities were the driving forces behind the changes in the pattern of that landscape. Xu et al. [21] interpreted three-phase remote sensing images and combined this field investigations, sampling analysis, the landscape pattern index method, and a transfer matrix to study the spatiotemporal dynamics of the landscape pattern of the Rizhao coastal zone in China. Their results showed that the evolution of regional landscape patterns was closely related to changes in natural conditions and human activities.

The mechanisms that drive the evolution of coastal landscape patterns include both natural and human factors. However, the former are relatively stable over a short time scale; therefore, at this scale, human activities are the main factors driving changes in coastal landscape patterns [22]. Different scholars have different understandings of the latter. Ehrich and Daily [23] state that the human factor should include population, wealth, and technology while Turner et al. [22] state that it should include population, income, technology, policy, economy, and culture. The International Human Dimensions Programme on Global Environmental Change (IHDP) divides the socio-economic factors that affect terrestrial landscape changes into direct and indirect factors. Indirect factors include population change, technological developments, economic growth, political and economic policies, and wealth and value orientation. Of these six factors, the impact of population on changes in terrestrial landscape patterns has always been an important part of research on the mechanisms driving the former. Therefore, this study assumed that population was one of the main factors driving the evolution of the coastal landscape pattern of the Ningde coastal zone.

China underwent tremendous social, economic, and cultural changes at the beginning of the 21^{st} century and these changes were reflected clearly in changes to the terrestrial landscape. Since 2010, the Fujian Provincial Government has enacted a series of strategic arrangements to develop the economy of coastal areas and accelerate the development of the marine economy. The development and utilization of land in the coastal area of Ningde has led to an unprecedented climax. Ningde is not just the coastal city with the longest coastline in Fujian Province; it is also home to two national forest parks, a global geological park, and a national wetland park. Therefore, changes in the landscape pattern of Ningde will inevitably have a profound impact on local biodiversity and ecology. Owing to its unique characteristics, the Ningde coastal zone has always been a key site for various studies. It has attracted a lot of attention from scholars and experts, and it was the focus of a series of studies [24-27]; however, these focus mainly on the vulnerability of the models used to evaluate of erosion, town planning and resource development, aquaculture water quality status, and the ecological risk from invasive plants in coastal wetlands. There have been no studies on the evolution of landscape patterns in the Ningde coastal zone, and there has been no work on quantitative identification of the contribution of factors driving coastal landscape change. Therefore, this study uses the evolution of coastal landscape patterns in Ningde as the research object and seeks to quantify the changes in landscape and the associated drivers using landscape indices, and principal component analysis (PCA) to analyze and summarize the characteristics of changes in the landscape pattern in coastal areas and the driving mechanism behind this under the background of rapid economic development. This study both identified the driving factors affecting the Ningde coastal zone and ranked them according to their influence on the changes in the landscape. The outcomes from this study are of important practical significance and provide a reference for the accurate prediction of changes to coastal landscape patterns, the appropriate planning of coastal lands, and the sustainable development of the coastal zone.

Material and Methods

Selection and Overview of Study Area

The Ningde coastal zone is located northeast of Fujian Province (Fig. 1). The coastline is 878.16 km in length, accounting for one third of the Fujian Province coastline. The area of sea is 44,500 km^2, constituting one third of the total area of sea for Fujian Province. It provides the largest breeding grounds for the large yellow croaker and is the only harbor providing around the clock berthing for half a million ton ships in China [28].

The total population in the coastal zone increased from 2.08 million to 2.35 million from 2000 to 2019, respectively; this represents an increase of 0.27 million. By the end of 2019, residents in the coastal zone accounted for 66% of residents in Ningde. The population density increased from 332 people/km^2 in 2000 to 375 people/km^2 in 2019 [29]. The coastal zone has four administrative districts; Fuding, Fu'an, Xiapu, and Jiaocheng. Fuding has the highest population density at 392 people/km^2, while Xiapu has the lowest population density at 322 people/km^2 [29-32]. The zone experiences a typical mid-subtropical monsoon climate as it is located in the mid and low latitudes and is affected by solar radiation, mountain topography, and monsoons. The average annual temperature is between 18.5 and 19.3ºC, and the extreme maximum temperature is 43.2ºC, whereas the extreme minimum temperature is

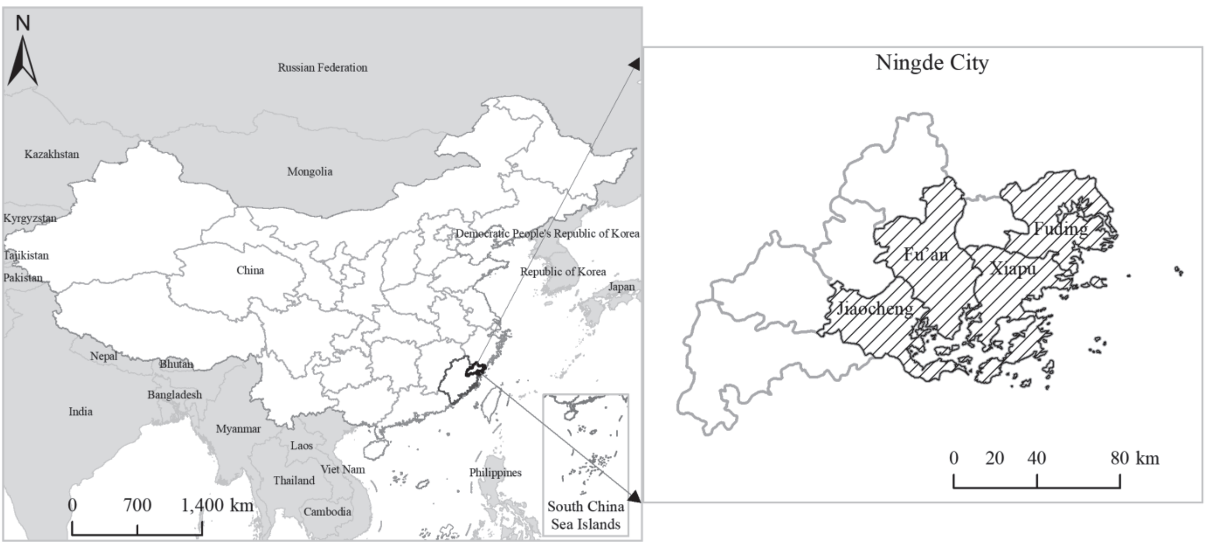

Fig. 1. Map of study area.

between 0 and 3.9ºC.

Based on landform type and soil combination characteristics, land resources may be divided into three categories: mountain soil, plain agricultural soil, and tidal flats. Mountain and hilly areas account for 73.3% of the entire coastal zone, followed by tidal flats. The cities of Fu'an, Xiapu, Fuding, and Jiaocheng are 1810, 1708, 1542, and 1505 km^2, respectively [29-32]. A large amount of freshwater flows into the Ningde coastal zone, introducing large quantities of organic matter and inorganic salt into the sea. The annual average temperature of the sea is between 11 and 29ºC, and salinity is between 26 and 29 ‰.

Remote Sensing Data

The remote sensing data, including Landsat-5 Thematic Mapper (TM) (2000 and 2009) and the Landsat-8 Operational Land Imager (OLI) (2014), were obtained from the Geospatial Data Cloud (http://www.gscloud.cn/). The cloud coverage of this imagery was less than 10%. Four scenes were required to cover the entire study area; their track numbers were 119/42, 119/41, 118/41, and 118/42. Data on the socio-economic drivers of Ningde City from 2000 to 2014 were obtained from the statistical yearbook of the Ningde Municipal Statistical Bureau [30-32], and the administrative zoning maps were obtained by the Geographical Information Monitoring Cloud Platform (http://www.dsac.cn/).

These remote sensing imageries were level 1T data. These data were subjected to digital elevation model terrain and the correction of ground control point geometry prior to downloading. Color synthesis, mosaic, clip, and object-oriented classification were constructed using the Environment for Visualizing Images (ENVI) 5.2 tool. The selected land-use types were unused land, dry land, paddy fields, rivers, forest and grassland (combined), construction land, lakes, aquaculture, and reservoirs. The remote sensing imagery from the Landsat-5 TM and Landsat-8 OLI were processed using 4, 3, 2 bands and 5, 4, 3 bands for color synthesis, respectively. In total, 250 samples for each land-use type were selected to obtain better classification results. Interactive verification using Google Earth and field investigations were carried out. The final classification accuracy of the remote sensing images of 2000, 2009 and 2014 was 89.30%, 94.50%, and 92.50% respectively, meeting the requirements of this study.

Landscape Indices

The following section describes the selected landscape indices, which clearly express landscape changes in the study area [33-34]:

(1) Total landscape Area (TA): This is the total area of a study region. This index determines the scope of the landscape and the largest scale of research and is the basis for calculating other indicators. In the design of nature reserves, the landscape area is one of the most important indicators to protect dominant, rare, and endangered species. It is expressed as follows:

$$TA = A \tag{1}$$

...where TA is the total area of the study area (ha), and the value is always greater than 0.

(2) Patch richness (PR): This is the number of patch types. PR has an impact on many ecological processes and is one of the key indicators representing landscape composition and spatial heterogeneity. There is a strong positive correlation between PR and species richness. It is particularly important for organisms requiring multiple habitat conditions. PR is expressed as follows:

$$PR = m \tag{2}$$

...where PR is the richness of the landscape patch, which is greater than or equal to 1; and m is the total number of patch types.

(30) Fractal dimension of the perimeter area (PAFRAC): This index represents the complexity of patch shape, which may be expressed as follows:

$$PAFRAC = \frac{\dfrac{2}{\left[N\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\ln p_{ij}\ln a_{ij}\right)\right]-\left[\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}\right)\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln a_{ij}\right)\right]}}{\left[N\sum_{i=1}^{m}\sum_{j=1}^{n}\ln\left(p_{ij}\right)^{2}\right]-\left[\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}\right]^{2}} \tag{3}$$

...where $PAFRAC$ is the fractal dimension of the perimeter area; a_{ij} is the area of patch, ij; p_{ij} is the perimeter; and N is the total number of patches. The PAFRAC is between 1 and 2. When the PAFRAC is close to 1, this signifies a simpler patch shape, whereas a value close to 2 indicates that the shape is more complex.

(4) Number of patches (NP): This refers the total number of patches of a specific landscape type. It is positively correlated with the fragmentation of a landscape type. NP has an impact on many ecological processes including the determination of the spatial distribution of various species and their secondary species in a landscape and changes in the stability of interactions among species. Moreover, NP has an important influence on the spread of various disturbances in a landscape. NP may be expressed as follows:

$$NP_1 = n \tag{4}$$

$$NP_2 = n_i \tag{5}$$

...where NP_1 and n are the number of patches at the landscape level and the total number of each patch type, respectively; NP_2 and n_i are the number of patches at the level of patch types and the number of patches of patch type, i, respectively. The NP is greater than or equal to 1; an NP of 1, signifies that there is only one patch in the entire landscape.

(5) Patch density (PD): This signifies the number of patches per unit area in a landscape. This reflects the fragmentation of entire landscape patches and may be described as follows:

$$PD = \frac{n}{A} \times 100 \tag{6}$$

...where *PD* is expressed in n/100 ha and is greater than 0; *n* is the total number of specific patches in a landscape; and *A* is the total area of the study region.

(6) Largest patch index (LPI): This is the proportion of the largest patch area to the entire landscape area. This index determines the dominant type of landscape, and its value reflects the abundance of dominant and other species. The changes in the LPI are indicative of the change in the intensity and frequency of interference. The LPI may be expressed as follows:

$$LPI = \frac{max_{j=1}^{n}(a_{ij})}{A} \times 100 \tag{7}$$

...where *LPI* is expressed in %, ranging between 0 and 100; and a_{ij} is the area of patch, *ij*; *A* is the total area of the study region.

(7) Shannon's diversity index (SHDI): This index represents the richness and complexity of landscape types. The SHDI range is greater than or equal to 0. When the SHDI is equal to 0, it indicates that there is only one type of patch in a landscape. Thus, an increase in the SHDI signifies an increase in the number of patch types, reflecting the heterogeneity of the landscape. It is particularly sensitive to the uneven distribution of patch types in a landscape. The SHDI may be expressed as follows:

$$SHDI = -\sum_{i=1}^{m}[P_i \ln P_i] \tag{8}$$

...where P_i is the existence probability of patch type, *i*, in a landscape; and *m* is the total number of patch types.

(8) Patch cohesion index (COHESION): This refers to the natural connectivity of patch types. In a closed area, a higher COHESION indicates better connectivity and lower landscape fragmentation. COHESION may be expressed as follows:

$$COHESION = \left[1 - \frac{\sum_{j=2}^{n} p_{ij}}{\sum_{j=2}^{n} p_{ij}\sqrt{a_{ij}}}\right]\left[1 - \frac{1}{\sqrt{A}}\right]^{-1} \tag{9}$$

...where *COHESION* ranges between 0% and 100%; *a* is the area of patch, *ij*; and *P* is the circumference.

(9) Contagion index (CONTAG): This indicates the agglomeration of different patch types in a landscape. As this index contains spatial information, it is one of the most important indices to describe landscape patterns, which is expressed as follows:

$$CONTAG = \left[1 + \frac{\sum_{i=1}^{m}\sum_{k=1}^{m}\left(P_i \frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\ln\left(P\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)}{2\ln m}\right] \times 100 \tag{10}$$

...where *CONTAG* is the aggregation index (%), ranging between 0% and 100%; P_i is the ratio of patch type, *I*, to the total landscape area; and g_{ik} is the number of adjacent grid cells among patch types. A greater CONTAG indicates that a certain dominant patch type in a landscape has better connectivity, whereas a lower CONTAG indicates higher fragmentation of patches.

(10) Percentage of landscape (PLAND): This is the proportion of a specific landscape type in the entire study area. It may be used to determine the dominant patches, biodiversity, and dominant species in a landscape, which is expressed as follows:

$$PLAND = p_i = \frac{\sum_{i=1}^{n} a_{ij}}{A} \times 100 \tag{11}$$

...where *PLAND* ranges between 0% to 100%; a_{ij} is the area of patch, *ij*; and p_i is the proportion of patch type, *I*, in the entire landscape.

(11) Interspersion juxtaposition index (*IJI*): This reflects the distribution of various patch types. It is one of the most important indicators to describe the spatial pattern of landscapes. It is a significant indicator of the distribution characteristics of ecosystems severely restricted by certain natural conditions. For example, various ecosystems in mountainous areas have a circular distribution due to the vertical zonality, generating a low *IJI*. In contrast, many transitional vegetation types in arid areas are affected by the distribution of water, generating a high *IJI*. The *IJI* may be expressed as follows:

$$IJI = -\frac{\sum_{i=1}^{m}\sum_{k=i+1}^{m}\left[\left(\frac{E_{ik}}{\sum_{k=1}^{m} E_{ik}}\right)\ln\left(\frac{E_{ik}}{\sum_{k=1}^{m} E_{ik}}\right)\right]}{\ln\frac{1}{2}m(m-1)} \times 100 \tag{12}$$

$$IJI_i = -\frac{\sum_{k=1}^{m}\left[\left(\frac{E_{ik}}{\sum_{k=1}^{m} E_{ik}}\right) ln\left(\frac{E_{ik}}{\sum_{k=1}^{m} E_{ik}}\right)\right]}{ln(m-1)} \times 100 \tag{13}$$

...where E_{ik} is the side length of patch type, *I*, adjacent to various patch types; IJI_i represents the *IJI* of patch type, *i*. The *IJI* ranges from 0% to 100%; when it is close to 0%, this indicates that a specific type is distinct from other types, whereas an *IJI* close to 100% indicates the presence of more patches of a specific type that are adjacent to other types.

Principal Component Analysis

PCA is a multivariate statistical method that examines the correlation between multiple variables [35-37]. It is a multivariate statistical method to extract a subset of variables from the original suite of variables to express additional information using the least variables [38]. PCA was used to understand the influence of socio-economic drivers on landscape changes. Natural drivers of change were not examined as the relatively short period (14 years) of this study was considered insufficient to clearly detect the influence of such drivers on landscape changes. In contrast, socio-economic drivers have a significant impact on landscape changes in the short-term [39-40]. The Ningde coastal zone is located in the middle of the Yangtze River Delta, Pearl River Delta, and Taiwan. The socio-economic drivers relating to the economy, population, and urbanization have had a greater impact on landscape changes.

The suitability of utilizing the PCA was assessed in four systematic steps. First, the statistical yearbook was reviewed to determine the socio-economic drivers that can be quantified and are clearly connected to landscape. Second, data from these selected drivers were intact for the years 2000, 2009, and 2014. Third, data was processed in a non-dimensional manner using Statistical Product and Service Solutions (SPSS) due to the different units of each driver. Finally, Bartlett and the Kaiser-Meyer-Olkin (KMO) test were used to determine the suitability of these drivers for PCA, and then, the principal components were obtained using SPSS.

After the implementation of these PCA screening steps, a total of 18 drivers were identified. These drivers were categorized into specific types including population, economy, technology, consumption, and social awareness (Table 1). Normalized data were processed using the Bartlett and KMO test, and the significance (correlation probability) from the Bartlett test was 0.000; this was less than the significance level of 0.05. The KMO was 0.825, indicating that there was a linear correlation among these drivers; consequently, it was deemed suitable to process these factors using PCA.

Results and Discussion

Landscape Changes in the Ningde Coastal Zone on Landscape Level

Landscape indices (i.e., *TA*, *PR*, *PAFRAC*, *NP*, *PD*, *LPI*, *SHDI, COHESION,* and *CONTAG*) were used to quantify the landscape changes of the entire study area. Table 2 shows that during the study period, the *TA* increased from 6102 to 6253 ha, exhibiting an increasing trend in landscape area. The *PR* stayed the same over this time, indicating that the patch types of

Table 1. Code, name, unit, and types of the selected socio-economic drivers.

Code	Name	Unit	Types of drivers
X_1	Household registration	Household	Population
X_2	Total population	People	
X_3	Urban population	People	
X_4	Population density	People/km^2	
X_5	Rural population	People	
X_6	Gross domestic product	Billion USD	Economy
X_7	Primary industry	Billion USD	
X_8	Secondary industry	Billion USD	
X_9	Tertiary Industry	Billion USD	
X_{10}	Industrial output	Billion USD	
X_{11}	Gross agricultural output value	Billion USD	
X_{12}	Local fiscal revenue	Billion USD	
X_{13}	Local fiscal expenditure	Billion USD	
X_{14}	Total investment in fixed assets	Billion USD	Technology
X_{15}	Total retail sales of social consumer goods	Billion USD	Consumption
X_{16}	Urban and rural residents' savings balance	Billion USD	
X_{17}	Average annual salary of all employees	USD	
X_{18}	Natural population growth rate	‰	Social awareness

Table 2. Changes in the landscape indices of the Ningde coastal zone.

Landscape indices (unit)	2000	2009	2014
TA (ha)	6102	6115	6253
PR (N/A)	9	9	9
PAFRAC (N/A)	1.346	1.355	1.362
NP (N/A)	13790	14064	13381
PD (n/100 ha)	2.264	2.304	2.149
LPI (%)	63.76	47.30	46.87
SHDI (N/A)	1.171	1.151	1.142
COHESION (%)	99.52	99.60	99.64
CONTAG (%)	70.97	71.50	71.57

the landscape did not change. The *PAFRAC* increased from 1.346 in 2000 to 1.362 in 2014, indicating that patch shapes had a tendency toward greater complexity. The *NP* rose from 13790 in 2000 to 14064 in 2009, and then dropped to 13381 in 2014, indicating that landscape fragmentation had initially increased and then decreased. *PD* increased from 2.264 in 2000 to 2.304 in 2009, and then declined to 2.149 in 2014, indicating that the trajectory in the number of patches per unit area had changed from increasing to decreasing. This was because prior to 2009, the massive increase in population and the lack of coordination of economy and environment had caused chaos in the coastal zone, where fragmentation and the density of landscape patches had rapidly increased. After 2009, urbanization had advanced significantly with continuous economic development. Therefore, the landscape showed an increase in the aggregation of coastal patches and a decrease in NP, PD, and landscape fragmentation.

The *LPI* had reduced from 63.76% in 2000 to 46.87% in 2014, indicating that the advantage of dominant patches has gradually weakened. *SHDI* decreased from 1.171 in 2000 to 1.142 in 2014, signifying a decrease in the types of patches and landscape heterogeneity of over time. *COHESION* had risen from 99.52% in 2000 to 99.64%, indicating that the natural connectivity in the landscape had gradually increased, whereas fragmentation had decreased. *CONTAG* had increased from 70.97% in 2000 to 71.57% in 2014, indicating that the landscape patches were gradually aggregating.

Landscape Changes in Cities within the Ningde Coastal Zone on a Landscape Level

The landscape indices (*NP, PD, CONTAG, PAFRAC,* and *SHDI*) were used to investigate the landscape changes in the cities. Fig. 2a) shows that during the study period, the *NP* of Xiapu increased from 3095 in 2000 to 4354 in 2014; this meant that the number of patches had continued to rise, indicating that landscape heterogeneity and fragmentation of Xiapu had increased. This ultimately means that the landscape of Xiapu has been greatly affected by external disturbances. The *NP* of Fu'an and Fuding decreased from 4300 and 3742 in 2000 to 3318 and 2824 in 2014, respectively. This shows that their landscape heterogeneity and fragmentation had decreased. The *NP* of Jiaocheng had only increased by 231 in 14 years, indicating that its landscape heterogeneity and fragmentation had not changed substantially.

Fig. 2b) shows that the number of patches per unit area of Xiapu continued to increase from 1.677 in 2000 to 2.384 in 2014. In contrast, PD of Fu'an and Fuding continued to decline; Fu'an had the largest decrease in PD of 0.596, whereas there was only marginal change in the *PD* of Jiaocheng.

Fig. 2c) shows that the average *CONTAG* in Fuding over the past 14 years was 76.81%; this was significantly higher than that of other cities. This indicates that Fuding had the lowest level of landscape fragmentation. The average *CONTAG* in Fu'an was only 65.92%, which was significantly lower than that of other cities. Therefore, Fu'an experienced the highest level of landscape fragmentation. However, the *CONTAG* for Fu'an continued to rise from 64.47% in 2000 to 67.49% in 2014. This indicates that landscape fragmentation in Fu'an had gradually decreased. The *CONTAG* of Jiaocheng and Xiapu showed a downward trend, indicating that landscape fragmentation in these cities had gradually increased.

Fig. 2d) illustrates that the *PAFRAC* for these cities showed an upward trend, indicating that the patch shape of the Ningde coastal zone was increasing in complexity from 2000 to 2014. The *PAFRAC* of Jiaocheng experienced the greatest increase from 1.345 in 2000 to 1.377 in 2014. The *PAFRAC* for Xiapu had initially risen from 1.326 in 2000 to 1.354 in 2009, and then declined to 1.341 in 2014. This indicates that patch shape in Xiapu was initially complex and then became simple. There was little change in patch shape for Fu'an and Fuding; however, the average *PAFRAC* in Fu'an was 1.370. This is the highest value, indicating that the patch shape of Fu'an was the most complex.

Fig. 2e) shows that Fu'an had the largest average *SHDI* of 1.361, indicating that its patch composition was the most complex. In contrast, the average *SHDI* of Fuding was the smallest, at only 0.945, indicating that the patch composition of Fuding was the simplest. However, both the *SHDI* values in these cities was decreasing. The *SHDI* of Jiaocheng and Xiapu showed a slight upward trend, indicating a more diversified patch composition; however, their values had not changed considerably.

Landscape Changes in the Ningde Coastal Zone in Terms of Patch Types

Landscape indices (*PLAND, NP, IJI,* and *PAFRAC*) were used to quantify landscape changes in terms of

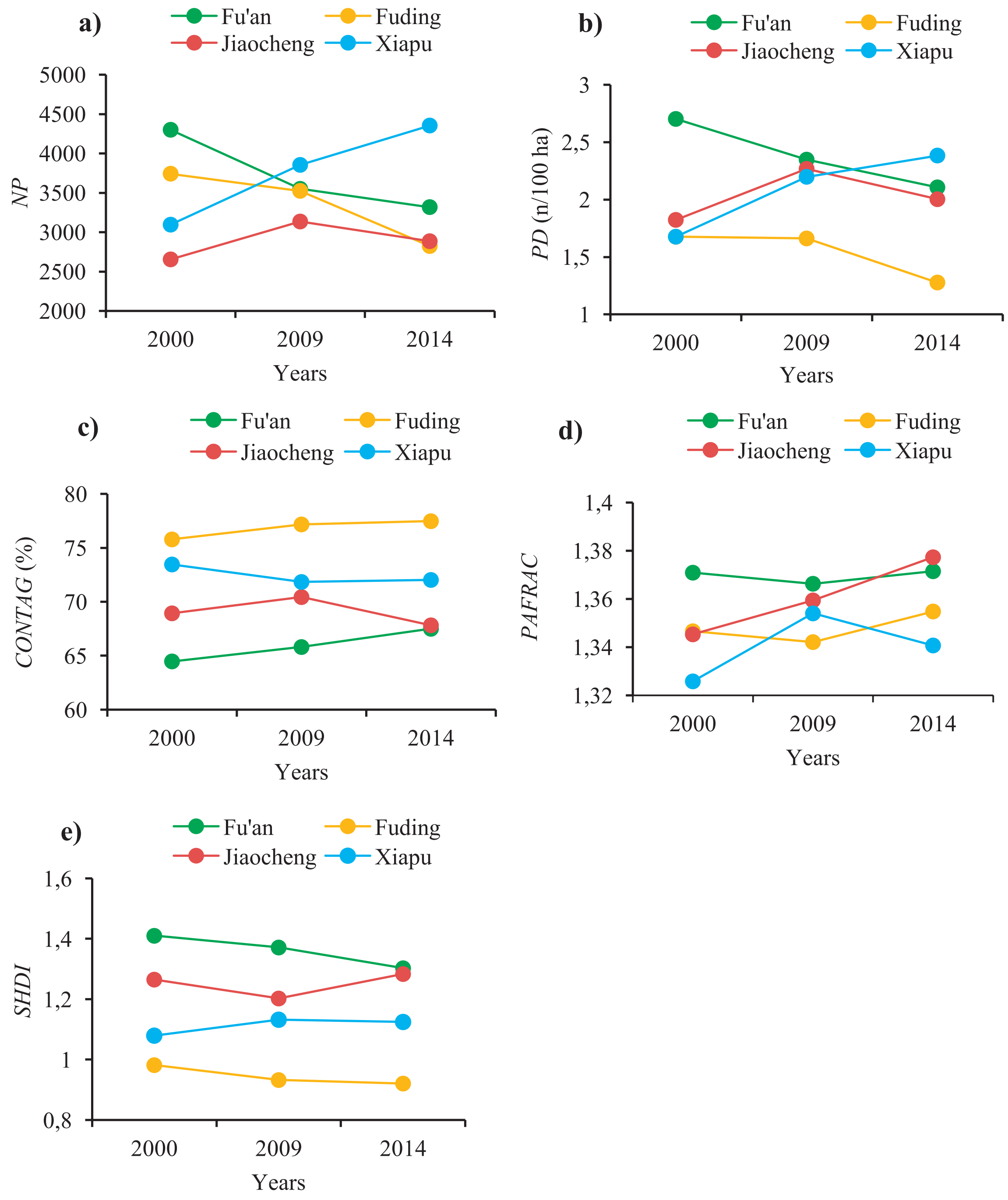

Fig. 2. Changes in the landscape indices for cities within the Ningde coastal zone.

patch types. Fig. 3 shows that dry land, paddy fields, forest, and grassland were the main landscape types. The area of paddy fields and dry land had gradually decreased from 25.41% and 36.83% in 2000 to 16.95% and 29.93% in 2014, respectively, signifying an 8.46% and 6.90% decrease over the 14 years. The area of forest and grassland has gradually increased from 26.72% in 2000 to 43.47% in 2014, with an increase of 16.75%.

Fig. 4 shows that the number of patches in dry land, paddy fields, and rivers was significantly higher than that of other landscape types; this means that these landscape types were more fragmented. However, the average *NP* in forests and grasslands with larger areas was only 1623, indicating a more concentrated distribution. For construction land, the number of patches had reduced from 1764 in 2000 to 710 in 2014, with a decrease of 1054 over the 14 years. Furthermore, the area of construction land had essentially remained the same, suggesting that the distribution of construction land was concentrated. In addition, there was low fragmentation of other landscape types due to the small number of patches and area.

Fig. 5 shows that the *IJI* of dry land, paddy fields, forest, and grassland were lower than 65%. This indicates that these landscape types had less contact with surrounding landscape types. However, the

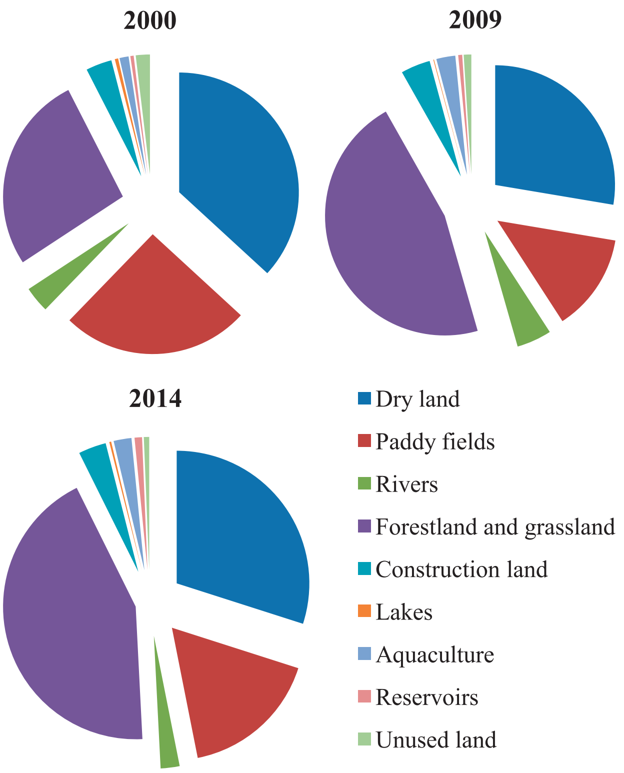

Fig. 3. Changes in the *PLAND* for the landscape types within the Ningde coastal zone (%).

average *IJI* of rivers, construction land, and unused land was 74.28%, indicating that these landscape types were concentrated, particularly in lakes, aquaculture, and

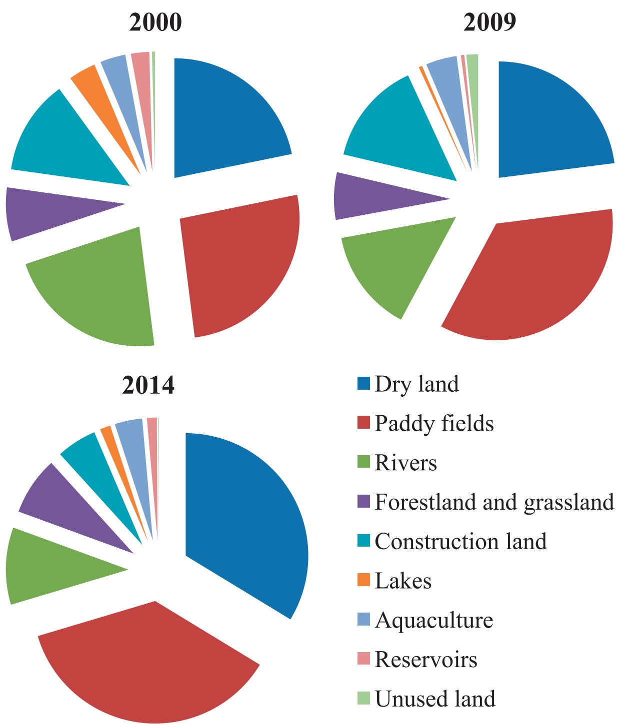

Fig. 4. Changes in the *NP* for the landscape types within the Ningde coastal zone.

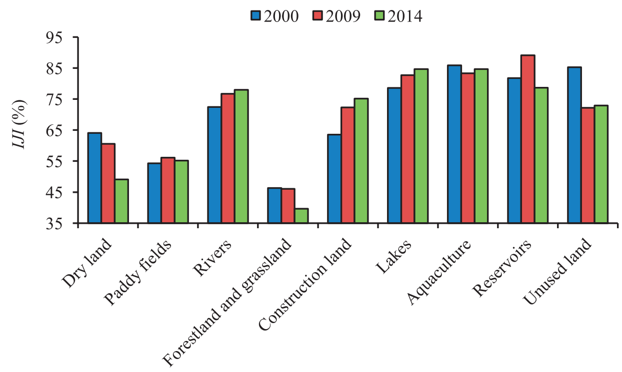

Fig. 5. *IJI* of landscape types within the Ningde coastal zone in 2000. 2009, and 2014.

reservoirs. Their average *IJI* was above 80%, and the *IJI* of rivers, construction land, and lakes had shown an annual increase. This suggests that they were in closer contact with the surrounding landscape types over time. In contrast, the *IJI* for dry land, forest, and grassland had decreased each year, suggesting that they had gradually become isolated in the landscape over time.

Fig. 6 shows that the average *PAFRAC* for dry land, paddy fields, rivers, forest, grassland, and construction land were 1.362, indicating a more complex shape. In contrast, the average *PAFRAC* of lakes, aquaculture, reservoirs, and unused land was 1.258, representing a more regular shape. From 2000 to 2014, the *PAFRAC* of dry land, lakes, and unused land have been increasing, particularly in forests and grasslands. This indicates that their shapes tend to become more complex. The *PAFRAC* of paddy fields had been declining over time, signifying a tendency toward a regular shape.

Socio-Economic Driving Factors in the Coastal Zone

Following PCA, two principal components were obtained as their initial feature value was greater than 1 and the accumulation value was greater than 85% (Table 3). The accumulation value of the initial two principal components was 85.97%; this means that these two principal components represented 85.97% of

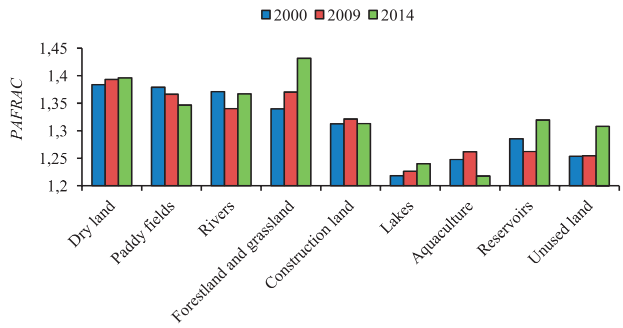

Fig. 6. *PAFRAC* of landscape types within the Ningde coastal zone in 2000. 2009, and 2014.

Table 3. Initial feature values of the principal components.

Principal components	Total	Variance (%)	Accumulation (%)
1	13.75	76.38	76.38
2	1.73	9.59	85.97

the total information. Therefore, these two principal components represented the 18 drivers of landscape change.

The load matrix of these drivers (Table 4) was rotated using the maximum variance to more efficiently explain the principal component; the results are shown in Table 5. These results show that the correlation coefficient between the first principal component and demographic factors excluding population density exceeded 0.900. This indicates that population was the main driver of landscape change in the Ningde coastal zone. The correlation coefficient between the first principal component and the primary industry, tertiary industry, gross agricultural output, and average annual salary of all employees exceeded 0.800, suggesting that economy and consumption produced landscape change in the coastal zone. The correlation coefficient between the second principal component and total investment in fixed assets was 0.769, indicating that technology was also one of the drivers influencing landscape change.

The population of the Ningde coastal zone increased from 2.08 million in 2000 to 2.30 million in 2014 with an increase of 0.22 million in 14 years. This large population increase has triggered a daily increase in the demand for agricultural products. However, the implementation of policies to return farmland to forests has led to a significant reduction in the area of cultivated land. Therefore, the only solution is to improve the productivity of the cultivated land by exploring agricultural technology. There have been improvements to land quality and food yield, suggesting that technology is one of the influencing factors affecting landscape changes in the Ningde coastal zone.

The loading matrix data (Table 4) were input into the Data Editor window of SPSS software, and the eigenvector was calculated using data conversion. The expression of two principal components was obtained using the eigenvector and standardized data to determine the changes to the impact of these drivers on the Ningde coastal zone landscape over time (Equations 14 and 15):

Table 4. Loading matrix of the selected socio-economic drivers.

Code	Name of driver	Component 1	Component 2
ZX_1	Household registration	0.891	-0.421
ZX_2	Total population	0.858	-0.460
ZX_3	Urban population	0.791	-0.520
ZX_4	Population density	0.312	0.459
ZX_5	Rural population	0.937	-0.298
ZX_6	Gross domestic product	0.985	0.145
ZX_7	Primary industry	0.941	-0.178
ZX_8	Secondary industry	0.927	0.029
ZX_9	Tertiary Industry	0.946	-0.096
ZX_{10}	Industrial output	0.914	0.327
ZX_{11}	Gross agricultural output value	0.974	0.015
ZX_{12}	Local fiscal revenue	0.916	0.309
ZX_{13}	Local fiscal expenditure	0.954	0.240
ZX_{14}	Total investment in fixed assets	0.871	0.356
ZX_{15}	Total retail sales of social consumer goods	0.983	0.075
ZX_{16}	Urban and rural residents' savings balance	0.964	0.198
ZX_{17}	Average annual salary of all em-ployees	0.867	-0.143
ZX_{18}	Natural population growth rate	0.258	0.502

Table 5. Rotated loading matrix of selected socio-economic drivers.

Code	Name of driver	Component 1	Component 2	Type of driver
ZX_1	Household registration	0.977	0.125	Population
ZX_2	Total population	0.971	0.074	
ZX_3	Urban population	0.947	-0.013	
ZX_4	Population density	0.015	0.555	
ZX_5	Rural population	0.950	0.253	
ZX_6	Gross domestic product	0.752	0.653	Economy
ZX_7	Primary industry	0.889	0.357	
ZX_8	Secondary industry	0.766	0.524	
ZX_9	Tertiary Industry	0.849	0.429	
ZX_{10}	Industrial output	0.594	0.767	
ZX_{11}	Gross agricultural output value	0.813	0.537	
ZX_{12}	Local fiscal revenue	0.606	0.754	
ZX_{13}	Local fiscal expenditure	0.675	0.716	
ZX_{14}	Total investment in fixed assets	0.542	0.769	Technology
ZX_{15}	Total retail sales of social consumer goods	0.788	0.593	Consumption
ZX_{16}	Urban and rural residents' savings balance	0.705	0.686	
ZX_{17}	Average annual salary of all employees	0.808	0.346	
ZX_{18}	Natural population growth rate	-0.053	0.562	Social awareness

$$F_1 = 0.2403ZX_1 + 0.2314ZX_2 +V0.2133ZX_3 + 0.0841ZX_4 + 0.2527ZX_5 + 0.2657ZX_6 + 0.2538ZX_7 + 0.25ZX_8 + 0.2551ZX_9 + 0.2465ZX_{10} + 0.2627ZX_{11} + 0.2470ZX_{12} + 0.2573ZX_{13} + 0.2349ZX_{14} + 0.2651ZX_{15} + 0.2600ZX_{16} + 0.2338ZX_{17} + 0.0696ZX_{18} \quad (14)$$

$$F = 0.178ZX_1 + 0.167ZX_2 + 0.145ZX_3 + 0.114ZX_4 + 0.199ZX_5 + 0.248ZX_6 + 0.210ZX_7 + 0.225ZX_8 + 0.219ZX_9 + 0.247X_{10} + 0.235ZX_{11} + 0.246ZX_{12} + 0.249ZX_{13} + 0.239ZX_{14} + 0.242ZX_{15} + 0.248ZX_{16} + 0.196ZX_{17} + 0.104ZX_{18} \quad (15)$$

The covariance matrix of the principal component scores was obtained using PCA (Table 6). This was a unit matrix, indicating that the extracted principal components F_1 had no relationship with F_2; therefore, the integrated model, F, was achieved (Equation 16). F was determined using Formulas 14, 15, and 16:

$$F = \frac{\lambda_1}{\lambda_1 + \lambda_2} F_1 + \frac{\lambda_2}{\lambda_1 + \lambda_2} F_2 \quad (16)$$

$$F = 0.178ZX_1 + 0.167ZX_2 + 0.145ZX_3 + 0.114ZX_4 + 0.199ZX_5 + 0.248ZX_6 + 0.210ZX_7 + 0.225ZX_8 + 0.219ZX_9 + 0.247X_{10} + 0.235ZX_{11} + 0.246ZX_{12} + 0.249ZX_{13} + 0.239ZX_{14} + 0.242ZX_{15} + 0.248ZX_{16} + 0.196ZX_{17} + 0.104ZX_{18} \quad (17)$$

From Fig. 7, the total score of the socio-economic drivers influencing the Ningde coastal zone continued to rise from 2000 to 2014. The value increased from -0.186 in 2000 to 3.808 in 2009 and continued to rise to 9.719 in 2014. This indicates that the impact of these drivers on the Ningde coastal zone landscape has consistently increased. Fig. 8 also shows that the scores of the socio-economic drivers of these cities also continued to rise. However, most of these scores were negative during the study period. Only the values for Fuding and Fu'an in 2014 were positive, being 0.492 and 0.636, respectively. This showed that the influence of the socio-economic drivers on landscape changes in Xiapu and Jiaocheng was weak. Fu'an and Xiapu had the highest and lowest average scores, with values of -0.955 and -1.985, respectively. This indicates that landscape changes in

Table 6. Covariance matrix of principal component scores.

Component	1	2
1	1.000	.000
2	.000	1.000

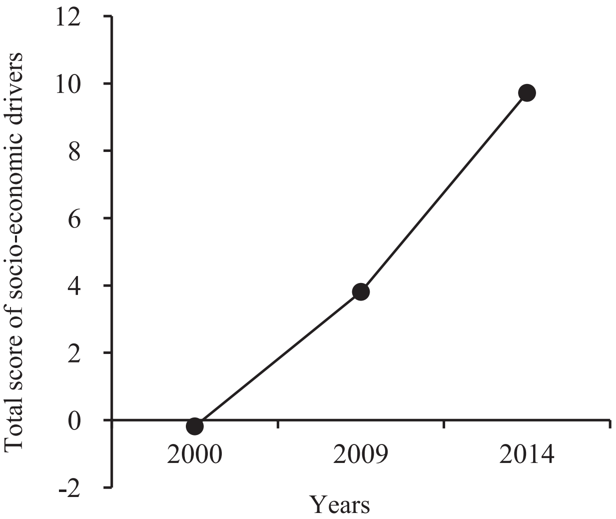

Fig. 7. Total score of socio-economic drivers influencing landscape changes in the Ningde coastal zone.

Fu'an and Xiapu were the most and least affected by socio-economic drivers.

In addition to these influential drivers, policy was also a factor that affected landscape changes in the Ningde coastal zone. As policy could not be quantified in this study, only a qualitative assessment of the impact of policy was possible. Land policies and regulations have had a significant impact on landscape changes in the coastal zone. For example, the Chinese central government issued a number of opinions on pilot studies where farmland (dry land and paddy fields) were rehabilitated back to forest and grassland in 2002. Therefore, over the 14 years of the study, the area of forestland and grassland has increased significantly to 1047.240 km^2, whereas the area of dry land and paddy fields has significantly reduced to 959.450 km^2 in total. These impacts emphasize that policy was also a key driver in influencing landscape changes in the Ningde coastal zone.

This study analyzed remote sensing data on the Ningde coastal zone, taken over 14 years, using GIS, RS, and Fragstats software. It used the landscape pattern index and principal component analysis methods to study the dynamic changes in the landscape pattern of the Ningde coastal zone from 2000 to 2014 and mechanisms driving that change. This research has a certain theoretical value and great significance in terms of providing strong practical guidance to promote the coordinated and sustainable development of the economy, society, and ecological environment of the Ningde coastal zone.

This study found that the driving factors affecting the evolution of the landscape pattern of the Ningde coastal zone included the population level, technology, and consumption, as well as economic and policy concerns. Parcerisas et al. [17] stated that urban expansion and agricultural abandonment were the main reasons

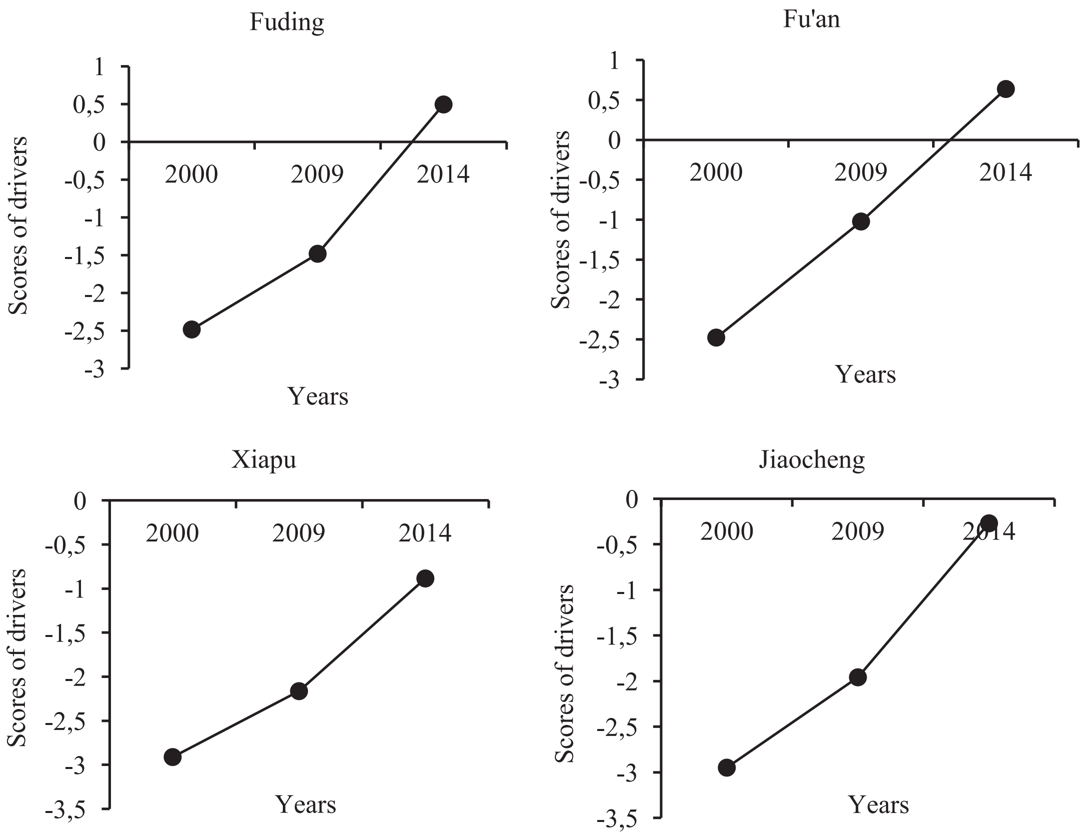

Fig. 8. Scores of drivers influencing the landscape changes on the cities within the Ningde coastal zone.

for the degradation of the landscape of the Spanish Mediterranean coast. Petrisor et al. [2] found that urban expansion and the development of tourism were the main reasons for changes in the landscape in the coastal areas of Vietnam. Urbanization, the development of agricultural, and population growth and migration have led to the degradation of the landscape in the coastal areas of Algeria. Urbanization or urban expansion, the development of agriculture, the development of tourism, and population growth and migration in the above studies correspond, respectively, to the economy, technology, consumption, and population factors in this study. Therefore, this study produced results similar to those of the above studies. Although the factors influencing changes in the landscape pattern in different coastal areas were different, they generally included population, technology, economy, and consumption factors.

However, this study still has some shortcomings, although it has in general enriched the body of case studies on changes in the evolution of coastal landscape patterns and the mechanisms driving these and effectively ranked the factors driving these changes in terms of their influence.

(1) This study paid close attention to dynamic changes in the landscape pattern of terrestrial areas but did not consider the interaction between the land and the sea. It is well known that ecological processes along coastal landscapes differ from those of other terrestrial landscapes because the former involves many factors related to the aquatic environment. Therefore, future research could examine how to integrate marine environmental factors into research on coastal terrestrial landscape ecology and how to couple the mechanisms that cause changes in coastal terrestrial landscape patterns and marine processes.

(2) Research on dynamic changes in coastal landscape patterns should be combined with that on coastal ecosystem service functions. Assessing the service functions of coastal ecosystems and predicting the trends in their future development will suggest a way to manage coastal ecosystems such that they continue to services useful to humans.

Conclusions

During the study period, the total area of the Ningde coastal zone has continued to increase, whereas the patch types remained unchanged and patch shapes increased in complexity. The number and density of patches decreased, and the influence of dominant patches had gradually weakened. The heterogeneity and fragmentation of patches had decreased, whereas the natural connectivity of the patches had increased, and patches were tending toward increased aggregation.

NP, PD, and fragmentation of the landscape in Xiapu were on the rise. The patch shape and patch composition tended to be more complex. The number and density of patches and landscape fragmentation in Fu'an showed a downward trend. Patch shape and composition were the most complicated. In Fuding, NP and PD showed a downward trend, whereas landscape fragmentation showed an upward trend. The shape of patches tended to be complex, although patch composition was the simplest. In Jiaocheng, NP, PD, and fragmentation increased, and the shape and composition of the patches was increasing in complexity.

The landscape was dominated by dry land, paddy fields, and forest and grassland with increasingly complex shapes. These landscape types were isolated from the landscape; the dry land and paddy fields were more fragmented, whereas the forest land and grassland had become increasingly concentrated. Despite the lower area of construction land and rivers, these landscape types were more scattered and were in close contact with lakes, aquaculture, reservoirs, and unused land.

Population, economy, consumption, and technology were the drivers influencing landscape changes in the Ningde coastal zone. The influence of these drivers on the landscape changes followed the order of population > economy > consumption > technology; the implementation of recent policy was also a driver that influenced the landscape changes in the Ningde coastal zone. The socio-economic drivers influencing landscape changes in the Ningde coastal zone had continued to increase during the study period.

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Conflict of Interest

No conflict of interest exits in the submission of this manuscript, and manuscript is approved by all authors for publication.

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