The Forest Pattern and Its Variation Characteristics in Economic Zone on the Western Coast of the Taiwan Straits

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Abstract Taking Economic Zone on the Western Coast of the Taiwan Straits as the study area, we use GIS, remote sensing, mathematical statistics and other methods, to analyze the forest pattern and its variation characteristics in Economic Zone on the Western Coast of the Taiwan Straits during the period 1992 – 2008; use canonical correspondence analysis (CCA) to examine the effects of environmental factors on changes in forest pattern. The results show that the forest resources are rich in Economic Zone on the Western Coast of the Taiwan Straits, accounting for 61.40% of the total area, but the geographical distribution is very uneven, with obvious regional and elevation gradient difference; since 1992, the forest has been dwindling in Economic Zone on the Western Coast of the Taiwan Straits, from 89 300 km^2 in 1992 to 88 300 km^2 in 2008; in terms of changes in region and elevation gradient, there is obvious difference in the forest, and the central and western forest of Wuyi Mountain tends to decline obviously; the main environmental factors influencing changes in forest pattern in Economic Zone on the Western Coast of the Taiwan Straits include temperature, sunshine hours, GDP per capita and precipitation; evaporation, evaporation and population density have weak effects on changes in forest pattern.

Key words Economic Zone on the Western Coast of the Taiwan Straits, Forest pattern, CCA, Driving force

Forest, the basis for sustainable social and economic development and important barrier for regional ecological security, is of great significance to water conservation, climate regulation, biodiversity conservation and soil conservation[1–2]. The pattern of forest plays an important role for the structure and function of ecosystem within a region, thus affecting the stability of the entire regional ecosystem. Its formation and changes are closely related to the natural environment and human interference[3–5]. With population growth and economic development, a lot of forest resources are destructed, and the forest pattern is changed, thereby endangering the survival and development of human beings. Researching the forest pattern and its dynamic spatio-temporal changes, exploring the change results, and revealing its process of change, is an important aspect for the study of forest ecology, which can provide a good scientific theoretical basis for the rational use of forest resources, management and maintenance of the ecological balance of the region[6–8].

Economic Zone on the Western Coast of the Taiwan Straits is one of the areas in China with the highest degree forest coverage. It has superior ecological environment quality, and high biodiversity, occupying an important position in the national ecological security pattern. In recent years, with rapid economic development and intensified human disturbance activities in Economic Zone on the Western Coast of the Taiwan Straits, the forests are destructed and the pattern is changed, exerting a serious impact on the ecological safety of Economic Zone on the Western Coast of the Taiwan Straits and the surrounding areas.

In this paper, taking Economic Zone on the Western Coast of the Taiwan Straits as the study object, we use the theories and methods of landscape ecology, land ecology and quantitative ecology, combined with remote sensing and GIS technology, to analyze the overall characteristics and evolution of forest pattern in Economic Zone on the Western Coast of the Taiwan Straits, in order to provide scientific basis for the industrial development planning and ecological environmental protection in Economic Zone on the Western Coast of the Taiwan Straits, and to achieve the economic and ecological sustainability in Economic Zone on the Western Coast of the Taiwan Straits.

1 Overview of the study area

According to the definition by the National Bureau of Statistics, the Economic Zone on the Western Coast of the Taiwan Straits refers to the area with Fujian as the main body, covering some areas of Zhejiang, Guangdong, and Jiangxi. This paper determines the study scope of Economic Zone on the Western Coast of the Taiwan Straits as follows: nine prefecture-level cities in Fujian Province; Shantou City, Chaozhou City and Jieyang City in Guangdong Province; land portion of Wenzhou City in Zhejiang Province. Economic Zone on the Western Coast of the Taiwan Straits (22°53′ – 28°36′N, 115°36′ – 121°18′E), is connected with the Pearl River Delta, Yangtze River Delta, with Fujian as the main body. Its area reaches 144 500 km^2, with eastern part facing China Taiwan and western part across the Wuyi Mountain. Terrain tilts from the inland to the coastal region, with many hills but few plains. The coastline is long and tortuous, and various harbors are interspersed along the coast. Economic Zone on the Western Coast of the Taiwan Straits has a marine subtropical monsoon climate,

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with distinct seasonal changes. The soil within the area mainly consists of red soil, yellow soil and mountain meadow soil.

2 Research data and methods

2.1 Data sources and image preprocessing The data used in this paper include 1:250 000 topographic map and DEM; Landsat TM/ETM + remote sensing image with the spatial resolution of 30 m in 1992 and 2008; field survey statistics. The image is stitched after geometrical correction, and then the image is supervised and classified using computer for automatic identification and manual interpretation. The maximum likelihood method is adopted, and the classification principle is to calculate the attribution probability of each pixel corresponding to each type, and assign the pixel to the type with the greatest attribution probability[9]. The classification accuracy is 85%. Then in the ArcGIS environment, the forest information is extracted. According to Technical Regulations on Land Use Survey promulgated by National Agricultural Zoning Commission, the forest in Economic Zone on the Western Coast of the Taiwan Straits is divided into four categories: closed forest land, shrub forest land, open forest land, other woodland.

2.2 Building of elevation grading and distribution index In terms of altitude, the study area is divided into five types: <200 m, 200 – 500 m, 500 – 1 000 m, 1 000 – 1 500 m, >1 500 m. The DEM data are graded, to generate the vector data of elevation grading. Then in ArcGIS environment, the forest vector data and elevation grading vector data are overlaid for analysis; different elevation levels of forest distribution data are summarized.

In data processing, the raster and vector conversion, the cutting operation between the two, and the vectorization in the beginning of the data preparation, cause the area error[10]. In order to eliminate the impact of area error, the distribution index P is introduced, to compare different vegetation types on the elevation gradient.

$$P = (S_{ie}/S_i) \times (S/S_e) \quad (1)$$

where P is distribution index; S_{ie} is the area of forest i in the terrain range e; S_i is the total area of forest i in the study area; S_e is the total area of topographical range e in the study area; S is the area of the entire study area. The greater the P value, the higher the frequency of occurrence of one certain forest type; the interval of $P>1$ is the superior terrain interval of forest distribution[11-12].

2.3 Driving forces We select 13 cities in the Economic Zone on the Western Coast of the Taiwan Straits as the spatial analysis samples; four forest types in each city (closed forest land, shrub forest land, open forest land and other woodland) as the species variables; temperature, evaporation, precipitation, sunshine hours, population density and GDP per capita in Economic Zone on the Western Coast of the Taiwan Straits as the environment variables. The absolute value normalization is conducted on changes in the area of the four forest types during the period 1992 – 2008 and the corresponding changes in the value of six environmental indicators. And the species and environmental factor data matrices are established, respectively. Using internationally accepted analysis software CANOCO 4.5, the canonical correspondence analysis (CCA analysis) is conducted[13-14].

3 Results and analysis

In this study, we take the forest pattern of Economic Zone on the Western Coast of the Taiwan Straits in 2008 as the status quo to conduct characteristic analysis, and take the period 1992 – 2008 as the dynamic evolution data for analysis.

3.1 Forest type and distribution The forest ecosystem area of Economic Zone on the Western Coast of the Taiwan Straits is 88 300 km^2, accounting for 61.40% of the total land area, occupying the vast majority of the total land area of Economic Zone on the Western Coast of the Taiwan Straits, so the forest ecosystem is the superior ecosystem in Economic Zone on the Western Coast of the Taiwan Straits. The forest ecosystem in Economic Zone on the Western Coast of the Taiwan Straits is mainly composed of temperate coniferous forest, subtropical coniferous forest, tropical deciduous forest, subtropical evergreen broadleaf forest, bamboo forest and bamboo grove, accounting for 0.12%, 79.49%, 0.01%, 14.16%, 6.22% of the forest ecosystem, respectively. The forest of Economic Zone on the Western Coast of the Taiwan Straits is mainly distributed in the Wuyi Mountain area and the central mountain belt, where the subtropical coniferous forests is widely distributed, especially in Fujian Province (Fig. 1).

3.2 Forest distribution characteristics in different areas Fig. 1b and Table 1 show that the forest coverage is overall high in Economic Zone on the Western Coast of the Taiwan Straits, but there are significant differences in various areas (high coverage in the central and western cities, low coverage in the eastern coastal areas). The forest coverage in Longyan is the highest (74.87%), while the forest coverage in Shantou is the lowest (only 25.79%). In the eastern coastal areas with low forest coverage, there are also significant differences. Wenzhou, Fuzhou and Ningde in the north have relatively high forest coverage; the eastern coastal city group in Fujian, and Shantou City, Jieyang City and Chaozhou City, have low forest coverage.

It indicates that the majority of forests in Economic Zone on the Western Coast of the Taiwan Straits are distributed in the economically underdeveloped inland mountainous areas, where the forest is well preserved; for the eastern coastal areas, and especially in estuary plains, the cities are burgeoning in full swing, where human disturbance is strong and forest is less distributed.

There is difference in the relative number of the same forest type in various areas (Table 1). Closed forest land is the main forest type in Economic Zone on the Western Coast of the Taiwan Straits, with the largest proportion in various regions; open forest land also has a large share, more than 10%; shrub forest and other woodland are the forest types with small share in various regions, and there are great differences in the share between the regions, indicating that there are obvious regional difference in shrub forest and other woodland in Economic Zone on the Western Coast of the Taiwan Straits. The forest fragmentation in the regions varies (Fig. 3). The forest fragmentation is the greatest in Wenzhou, reaching 0.009 9 while the forest fragmentation is the smallest in Sanming, only 0.003 2. It indicates that the human activities are frequent in Wenzhou, thus the breadth and depth of forest use are greater than that of other regions; the forest is well preserved in Sanming, with intact structure.

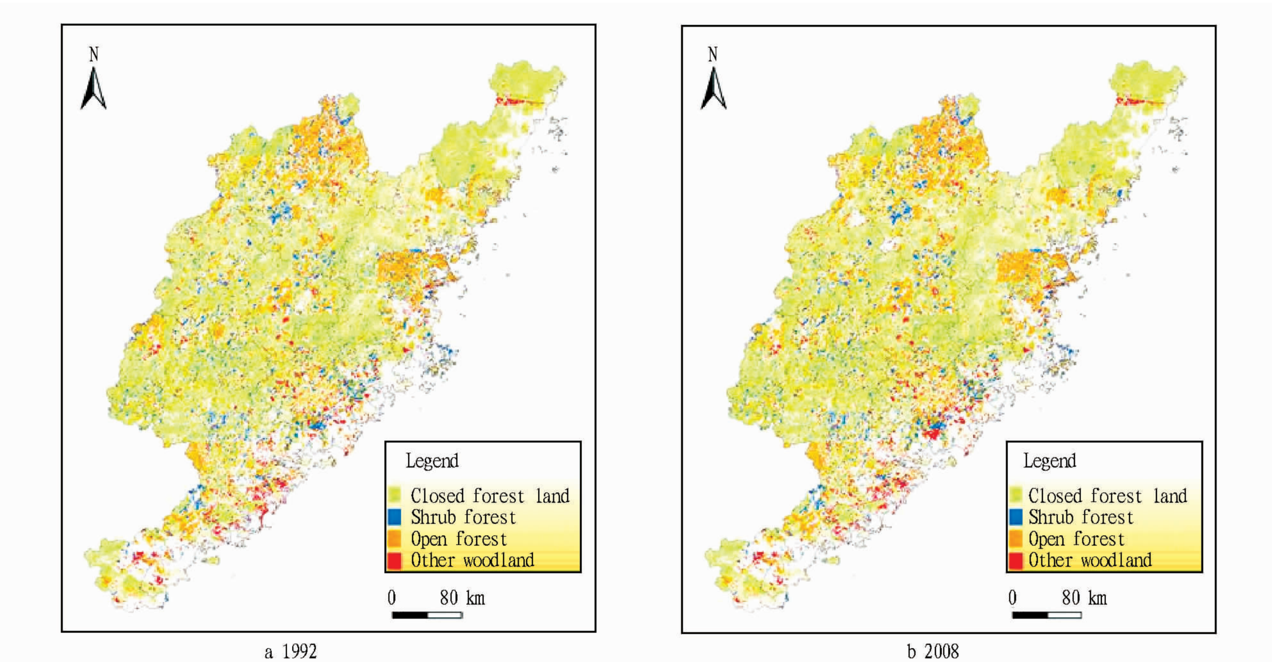

Fig. 1 The forest pattern of Economic Zone on the Western Coast of the Taiwan Straits in 1992 and 2008

Table 1 Forest distribution characteristics in different areas

Region	Closed forest land		Shrub forest		Open forest land		Other woodland		Coverage // %
	Area hm^2	Proportion // %	Area hm^2	Proportion // %	Area hm^2	Proportion // %	Area hm^2	Proportion // %	
Zhangzhou	340 555.68	55.09	58 233.63	9.42	128950.92	20.86	90 467.18	14.63	49.41
Xiamen	28 299.24	42.85	12 384.30	18.75	10932.64	16.55	14 432.69	21.85	43.53
Wenzhou	451 624.04	72.57	60 070.96	9.65	91473.35	14.70	19 125.45	3.07	54.44
Chaozhou	63 987.48	43.01	19 806.42	13.31	60571.87	40.71	4 414.55	2.97	47.94
Fuzhou	384 458.91	55.98	52 593.26	7.66	226590.06	32.99	23 173.26	3.37	59.33
Jieyang	171 289.76	73.59	6 940.57	2.98	36742.26	15.79	17 791.44	7.64	44.42
Longyan	1 067 667.17	74.87	96 702.99	6.78	232503.55	16.30	29 240.46	2.05	74.87
Nanping	1 028 869.42	58.96	130 199.72	7.46	514 660.98	29.49	71 388.20	4.09	66.29
Ningde	542 156.16	72.05	18 378.72	2.44	180 735.90	24.02	11 216.78	1.49	57.80
Putian	115 206.90	60.76	28 753.55	15.16	33 779.01	17.81	11 872.39	6.26	49.48
Quanzhou	367 075.38	58.10	60 349.67	9.55	137 573.12	21.78	66 793.24	10.57	57.04
Sanming	1 217 763.20	73.65	101 271.90	6.12	285 457.54	17.26	48 962.82	2.96	72.01
Shantou	30 491.54	54.93	1 008.63	1.82	14 692.52	26.47	9313.32	16.78	25.79

3.3 The distribution characteristics of forest in elevation gradient Table 2 shows that the forest coverage tends to increase in elevation gradient (coverage of 30.25% in areas below 200 m, coverage of 75.08% in areas above 1 500 m). It indicates that with increasing altitude, more human productive and life activities are limited, thereby reducing the interference with forests and increasing forest resources.

There are different natural conditions in different elevations, so the distribution of various forest types is also affected. Table 2 shows that the proportion of closed forest land rises with increase in the elevation, while the proportion of shrub forest and open forest land diminishes with increase in the elevation, indicating that these three forest types are restricted significantly by elevation. As can be seen from Fig. 4, in the interval <200 m, there is no forest type showing dominant distribution, and the dominance of other woodland is relatively large; in the interval 200 – 500 m, all forest types show dominant distribution, and the dominance of other woodland is large; in the interval 500 – 1 000 m and 1 000 – 1 500 m, closed forest land, shrub forest, and open forest land show dominant distribution, and the dominance of closed forest land is relatively large; in the interval >1 500 m, closed forest land and other woodland show dominant distribution, and the dominance of other woodland is large. Fig. 4 also shows that other woodland is more selective about elevation, and has its dominant distribution range, while other forest types can well adapt to elevation differences.

Table 2 The distribution characteristics of forest in elevation gradient

Elevation//m	Closed forest land		Shrub forest		Open forest land		Other woodland		Coverage//%
	Area hm^2	Proportion//%	Area hm^2	Proportion//%	Area hm^2	Proportion//%	Area hm^2	Proportion//%	
<200	621299.73	58.45	82 062.94	7.72	287 575.97	27.06	71 972.50	6.77	30.25
200 – 500	2 351 020.96	68.47	226 855.36	6.61	716 742.64	20.87	139 008.29	4.05	68.87
500 – 1000	2 718 189.19	71.23	237 206.12	6.22	781 167.30	20.47	79 423.77	2.08	74.71
1 000 – 1 500	373 437.44	74.53	29 903.31	5.97	90 667.01	18.10	7 022.26	1.40	73.07
>1 500	13 120.55	84.98	545.84	3.54	1 076.65	6.97	696.82	4.51	75.08

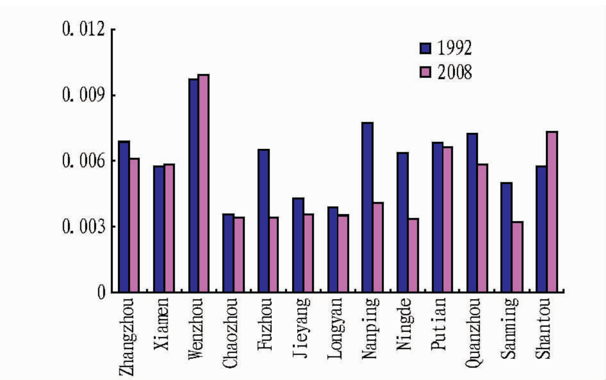

Fig. 2 The forest fragmentation in different regions in 1992 and 2008

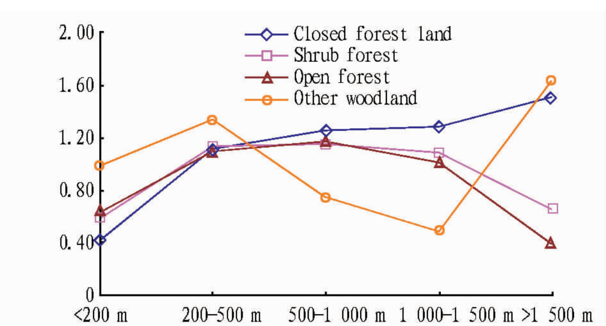

Fig. 3 The elevation index distribution of different forest types

From the vegetation fragmentation in different elevation interval (Fig. 5), in the interval <200 m and >1 500 m, the forest fragmentation is high; in the interval 200 – 500 m, 500 – 1 000 m and 1 000 – 1 500 m, the forest fragmentation is low. In the interval <200 m, affected by intense interference of human production and living activities, the forest is divided into many small areas; in the interval >1 500 m, restricted by topography, climate, hydrology and other natural factors, the forest assumes small range distribution, resulting in high degree of forest fragmentation in these areas.

3.4 Temporal and spatial changes of forest pattern Based on the interpretation results of remote sensing image of Economic Zone on the Western Coast of the Taiwan Straits, the forest area declined from 1992 in Economic Zone on the Western Coast of the Taiwan Straits, from 89300 km^2 in 1992 to 88300 km^2 in 2008, but the forest structure is still stable, with little change (Fig. 2).

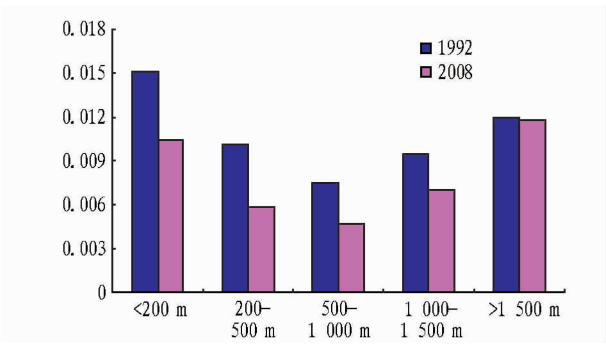

Fig. 4 The forest fragmentation at different altitudes in 1992 and 2008

As can be seen from Table 3, since 1992, in Economic Zone on the Western Coast of the Taiwan Straits, the forest area of Ningde, Wenzhou, Putian, Chaozhou and Shantou has dwindled (the largest reduction in Ningde and Wenzhou, reaching 19.62% and 13.73%, respectively); the forest area of the remaining cities has increased (the largest increase in Xiamen and Zhangzhou, reaching 15.15% and 14.98%, respectively).

From the point of view of the forest types, the reduction of closed forest land area mainly happens in Wenzhou, reducing by 107 460.46 hm^2, and the increase of closed forest land area mainly happens in Fuzhou, Ningde, Nanping, Sanming and Longyan; the reduction of shrub forest area mainly happens in Ningde, reducing by 202 934.05 hm^2, Nanping and Fuzhou also share the same situation, and the increase of shrub forest area only happens in Wenzhou and Xiamen (increase of 12 839.22 hm^2 in Wenzhou, 360.66 hm^2 in Xiamen); the reduction of open forest land area mainly happens in Longyan, a decrease of 18 448.44 hm^2, and the increase in area only happens in Fuzhou and Shantou, 3 793.85 hm^2 and 236.86 hm^2, respectively; the reduction of other woodland area mainly happens in Ningde, Wenzhou, Chaozhou, Fuzhou, Jieyang and Shantou (the largest reduction in Ningde, 1 126.3 hm^2), and the increase in area mainly happens in Zhangzhou, Xiamen, Longyan, Nanping, Sanming and Quanzhou (the largest increase in Zhangzhou, 90 364.22 hm^2).

As can be seen from Table 4, in the interval <200 m and 500 – 1 000 m, the forest area is reduced, and there is the largest reduction in the interval <200 m (10.99%); the area in other altitudes is increased slightly. The area of closed forest land is increased in the regions with different elevations. In the regions with elevation <1 000 m, the area is increased along with increase in elevation, and in the regions within elevation >1 000 m, the increased area is reduced along with increase in elevation. The area distribution law of shrub forest is contrary to that of closed forest land. It is reduced in the regions with various elevations. In the regions with elevation <1 000 m, the reduced area is increased along with increase in elevation, and in the regions with elevation >1 000 m, the reduced area is decreased along with increase in elevation. In the regions with elevation <1 500 m, the area of open forest land is reduced in different degrees, and in the regions with elevation >1 500 m, the area is increased slightly. In the regions with elevation <200 m, the area of other woodland is reduced substantially, and in the regions with elevation >200 m, the increased area is reduced along with increase in elevation.

Table 3 Forest area changes in different regions during the period 1992 –2008 Unit: hm^2

Region	Closed forest land	Shrub forest	Open forest land	Other woodland
Zhangzhou	−3 555.90	−838.76	−5 423.90	90 364.22
Xiamen	1 505.12	360.66	−860.14	7 684.17
Wenzhou	−107 460.46	12 839.22	−3 721.05	−605.60
Chaozhou	−1 029.49	−263.79	−438.54	−119.42
Fuzhou	25 380.51	−17 966.25	3 793.85	−714.78
Jieyang	2 710.72	−225.07	−861.64	−726.55
Longyan	21 816.75	−3 375.13	−18 448.44	4 683.31
Nanping	39 082.16	−31 469.69	−820.33	16 241.86
Ningde	24 543.25	−20 2934.05	−4 200.85	−1 126.43
Putian	−142.62	−762.86	−193.86	−454.51
Quanzhou	513.75	−5 164.01	−760.14	7 397.14
Sanming	64 267.42	−8 261.09	−8 365.43	10 279.81
Shantou	−260.90	−9.36	236.86	−817.39

Table 4 Forest area changes in different elevations during the period 1992 –2008 Unit: hm^2

Elevations // m	Closed forest land	Shrub forest	Open forest land	Other woodland
<200	23 165.97	−2 427.52	−33 994.62	−118 090.49
200 –500	52 405.24	−35 389.03	−11 771.01	23 395.22
500 –1 000	58 195.43	−57 524.01	−19 684.01	16 688.85
1 000 –1 500	12 495.33	−5 512.46	−1 651.55	738.09
>1 500	298.90	−30.97	6.05	8.95

3.5 Driving force for changes in forest pattern CCA analysis shows that the total eigenvalues of ordination axes are 0.927, indicating that ordination axes are significantly correlated with changes in forest pattern and environmental factors. The cumulative percentage of eigenvalues of the first two ordination axes is 73.89%, putting together the majority of the correlation reflected by total ordination axes, so CCA can reflect the impact of environmental factors on changes in forest pattern.

In Fig. 5, the dots represent the 13 administrative units in Economic Zone on the Western Coast of the Taiwan Straits, and the distance between the dots represents the similarity of forest pattern changes in the administrative units; the triangles represent changes in four kinds of forest types in Economic Zone on the Western Coast of the Taiwan Straits, and the distance between the triangles represents the similarity of forest pattern changes; the arrow vector represents the environmental factor, and the direction of the arrow indicates the change trend of the environmental factors; the length of the arrow indicates the influence of environmental factors on sorting, and the longer the arrow, the greater the influence of environmental factors on changes in forest pattern; the angle between arrows and ordination axes represents the size of the correlation between the environmental factors and ordination axes, and the angle between arrows represents the correlation between two environmental factors[15–16]. As can be seen from Fig. 5, the major environmental factors influencing changes in the forest pattern of Economic Zone on the Western Coast of the Taiwan Straits include temperature, sunshine hours, GDP per capita and precipitation; evaporation and population density have relatively weak impact on changes in forest pattern.

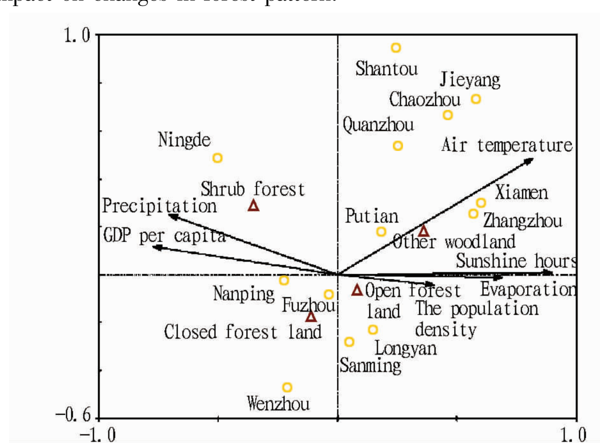

Fig. 5 CCA ordination diagram of the environmental factors and forest

Affected by different environmental factors, there differences in changes in various forest types. It can be seen from Fig. 5 that in terms of the optimum value, various forest types in the temperature axis are sequenced as follows: other woodland > open forest land > shrub forest > closed forest land; in terms of the optimum value, various forest types in the sunshine hours, evaporation and population density axis are sequenced as follows: other woodland > open forest land > closed forest land > shrub forest; in terms of the optimum value, various forest types in the precipitation and GDP per capita axis are sequenced as follows: shrub forest > closed forest land > open forest land > other woodland. There are also spatial differences in the regional forest pattern changes in Economic Zone on the Western Coast of the Taiwan Straits. It can be seen from the figure that the spatial distribution of changes in forest pattern is divided into three groups, each with similar driving factors for changes. Shantou, Quanzhou, Chaozhou, Jieyang, Putian, Xiamen and Zhangzhou in the first quadrant are taken as a group; Ningde is separately as a group, in the second quadrant;

the remaining five administrative units are taken as a group, near the ordination axes in the third and fourth quadrant.

4 Conclusions and discussions

The forest coverage in Economic Zone on the Western Coast of the Taiwan Straits is high, including closed forest land, shrub forest land, open forest land, immature forest land, and non-forest land suitable for afforestation. The closed forest land is the main type of forest in Economic Zone on the Western Coast of the Taiwan Straits, accounting for 65.80 % of total forest area. Forest is of great significance to water conservation, climate regulation, biodiversity conservation and soil conservation. The widespread forest resources provide a fundamental guarantee for good terrestrial ecological environment quality, rich biodiversity and regional ecological security in Economic Zone on the Western Coast of the Taiwan Straits. But the geographical distribution of forest resources in Economic Zone on the Western Coast of the Taiwan Straits is uneven, with significant regional differences and elevation gradient differences. Forests are mainly distributed in the Wuyi Mountain area, rarely in the plain and river network in the southeast coastal areas.

Since 1992, the forest in Economic Zone on the Western Coast of the Taiwan Straits has been declining, and there are differences in the regional and elevation gradient changes. The forest in central and western Wuyi Mountain is reduced obviously, including the Futunxi valley, Shaxi valley, and Tingjiang valley; in the regions with elevation <200 m, the forest area is also reduced obviously, but in the regions with elevation >1 000 m, the forest area is increased slightly. Within the implementation of afforestation, forest protection and ecological construction projects in recent years, the area of forest plantation and its proportion is increased dramatically in Economic Zone on the Western Coast of the Taiwan Straits, and the area of natural forest and its proportion is reduced constantly. The increasing plantations also lead to young age structure of forests in Economic Zone on the Western Coast of the Taiwan Straits. Meanwhile, the plantations are mostly conifers, leading to the ceaseless reduction of proportion of broadleaf forest within the area. It can be predicted that with the constant reduction of forest in Economic Zone on the Western Coast of the Taiwan Straits, the declining proportion of natural forests and plantations will lead to the prominent phenomenon of young forests, thereby making the ecosystem in Economic Zone on the Western Coast of the Taiwan Straits tend to be simplified, affecting the stability of forest ecosystem, and leading to declining ecological functions.

CCA analysis shows that the main environmental factors influencing changes in forest pattern in Economic Zone on the Western Coast of the Taiwan Straits include temperature, sunshine hours, GDP per capita and precipitation; evaporation, evaporation and population density have weak effects on changes in forest pattern. There are differences in the optimum value of various forest types in the axis of different environmental factors, and there are also differences in forest pattern changes in Economic Zone on the Western Coast of the Taiwan Straits. In this study, CCA analysis method is applied to the analysis of changes in forest pattern, and the sequencing diagram can basically reflect the information about changes in forest pattern and the environmental factors, which plays a guiding role for the protection and rational utilization of forest resources in Economic Zone on the Western Coast of the Taiwan Straits. However, due to the lack of additional information on environmental factors, we can not make further analysis of the driving forces for changes in forest pattern. It will be further explored in the future studies.

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