Evaluation on Land Ecological Security in Hainan Island，China

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Abstract　Based on the introduction of Hainan island and the special feature of its geographical environment，land ecological pressure，land ecological status and land ecological response are taken as the subsystems with in all 18 indices selected according to the 1999 – 2008 *Hainan Statistical Yearbook*，1999 – 2008 *Hainan Yearbook*，and 2000 – 2004 *Hainan Ecological Construction Yearbook*，as well as the principles of science，representativeness，comprehensiveness，simplicity，operability and applicability. Land ecological security assessment index system is established based on the "P – S – R" conceptual framework model. Land ecological security evaluation model is set up by using Comprehensive Evaluation Method and Analytical Hierarchy Process Theory，which can be used to evaluate and analyze the land ecological security in the years 2000 – 2007. According to the evaluation result，specific countermeasures and suggestions are put forward in order to promote the sustainable use of land resources and to maintain the ecological security. Result shows that land ecological security of Hainan Island is at the sensitive level（early-warning state）in the years 2000 – 2007 and at good level（relatively security state）in the year 2007. Land ecological security as a whole shows an increasing trend year by year. Factors restricting the level of land ecological security of Hainan Island are mainly the natural population growth rate，grain production per unit sown area，urbanization level，per capita cultivated land，reserve resources rate of land resources，growth rate of total fixed asset investment，per capita net income of rural residents and so on.

Key words　Land ecology；Security evaluation；Index system；Hainan island；China

As human activity and land use intensity increase，land ecological environment becomes more and more seriously damaged. Area of land desertification，as well as soil and land erosion，rapidly expands. All these increasingly prominent ecological problems directly threat the ecological security of China's land resources. Therefore，land ecological security becomes an important issue of current sustainable use of land resources[1]；and land safety assessment is an important research content of land ecological security，offering an effective method to scientifically evaluate and measure the impact of certain activity on land and the ecological effects，as well as an important way to realize the sustainable use of land resources[2].

1　Overview of the research area，data sources and research method

1.1　Overview of the research area　Hainan Island（18°10′ – 20°10′ N，108°37′ – 111°03′ E）is situated in the southern end of China，the main land of Hainan Province with the total area of 33.9 thousand square kilometers. It is high in the center and low and flat in its peripheral areas with 1 867 meters altitude and the highest mountain Wuzhi. There are hilly basins in mountainous region and hilly is mainly distributed in the inland island and the northwest and southwest areas. Coastal plain is all around the island. Hainan Island has the characteristics of significant cascade structure and annular step-like landform composed of mountain，hills，plateaus and plains with Wuzhi Mountain and Yingge Ridge as the core[3]. Hainan Island is located in the tropical area，belonging to the tropical monsoon climate. It is the most distinctive region of tropical marine climate，with warm and hot all the year around，obvious wet and dry season，big constant wind，severe tropical storm，frequent typhoon and rich climate resources. Affected by the landform，differentiation of biological climatic conditions is caused，and soil distribution shows distinct vertical zonality and regionalism.

1.2　Data source　Research data are from the 1999 – 2008 *Hainan Statistical Yearbook*，the 1999 – 2008 *Hainan Yearbook*，the 2000 – 2004 *Ecological Province Construction Yearbook of Hainan*，the *Hainan Encyclopedia*，the 2000 – 2008 *Report on* the *State of Environment in Hainan Province*，the *Construction Theory and Practice of Ecological Province of Hainan*，and so on.

1.3　Research method　At present，there are many methods for comprehensive evaluation on land security. And we select Comprehensive Index Method and Analsis Hierarchy Process according to the advantages and disadvantages of various methods.

2　Construction of land ecological security evaluation system

2.1　Construction of evaluation index system　The key of land ecological security assessment is to establish a scientific evaluation index system and to determine the weight of index[4]. At present，evaluation index system of land ecological

safety is still at the exploratory stage and construction of index system remains to be the difficulty in research. Selection of evaluation index not only considers the environment condition, but also reflects the impact of human activity and important factors affecting ecological security. Besides, the operability of method and the availability of ecological security index data should also be considered, as well as the complex relationship of evaluation factors of regional land ecological security, level of land ecological security and relevant research results in China[5]. Based on the principles of representativeness, compre-

hensiveness, simplicity, operability, applicability and scientific nature, as well as the "Pressure – State – Response" (P – S – R) conceptual framework model, a total of 18 indices are selected according to the particular geographical features of Hainan Island. Taking Land ecological pressure, land of ecological state and land ecological response as the subsystems, evaluation index system of ecological security is constructed (Fig. 1). This index system includes target layer (A), criterion layer (B) and index layer (C).
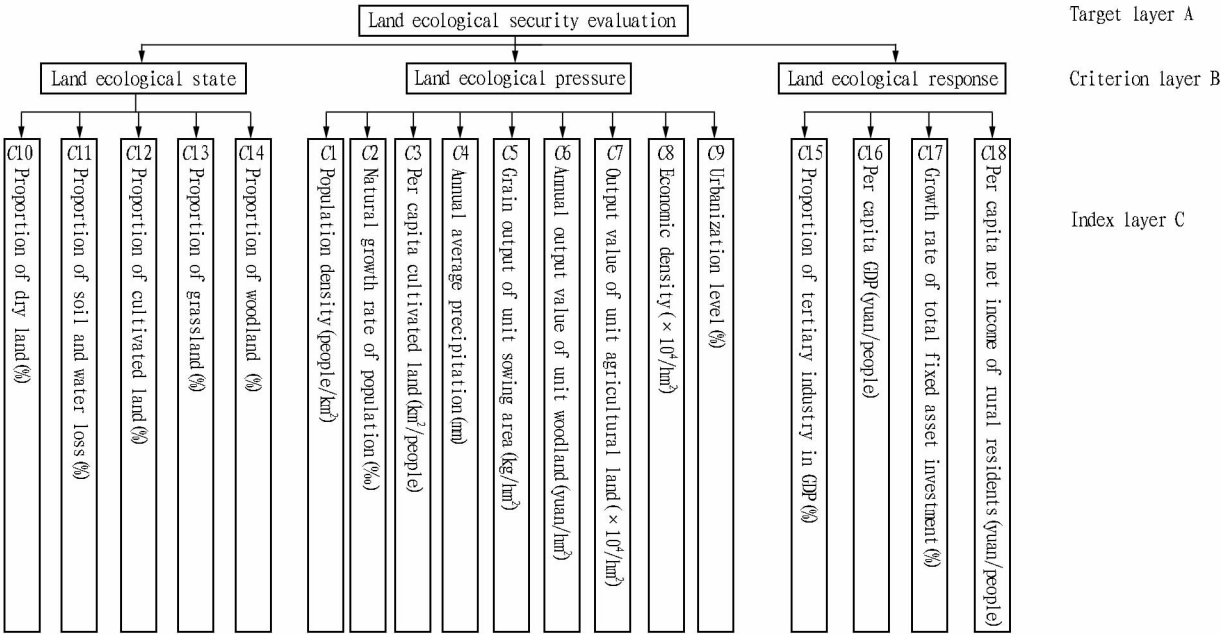

Fig. 1　Index system of land ecological security in Hainan Island, China

2.2　Determination of index weight and reference value of ecological security evaluation　In the evaluation of ecological security, reference value of evaluation index mainly cones from the international accepted value, the world average value, the various standards all over the world, and the standards promulgated by local governments. Meanwhile, considering the characteristics of land ecological environment and the actual situation of Hainan Island, part of the index reference values choose the national average according to the reference literatures.

　　Weight is the information representing the index factor variables and the relative importance to the factor at the upper grade. This research adopts the Analytic Hierarchy Process method (AHP method) and determines the index weight according to the experience of experts[4]. Firstly, according to the relationship of each level index, the hierarchical structure model is constructed. Then, experts compare and judge the relative importance of index. Based on the evaluation result of experts, weighted method is calculated and the land ecological security index of Hainan Island is obtained (Table 1).

2.3　Standardization of evaluation index　Standardization treatment of index is conducted by range method. And different indices have different standardization equations.

　　When the evaluation index is positive, we have $p_i = (x_i - $

$x_{min})/(x_{max} - x_{min})$; and when the evaluation index is negative, we have $p_i = (x_{max} - x_i)/(x_{max} - x_{min})$, where x_i is the actual observed value of a given index, x_{max} and x_{min} are the maximum and minimum values of the index within time series, and p_i is the actual evaluation value of the index after standardization.

　　After the standardization treatment of evaluation index, the value is between 0 and 1. And 0 represents the worst state of a given index in a given year within time series, compared with the same index in the other year. 1 means the best state of a given index in a given year within time series, compared with the same index in the other year[10].

Table 1　Index weight of land ecological security in Hainan Island

Index	Weight	Safety trend	Index	Weight	Safety trend
C_1	0.03	–	C_{10}	0.04	–
C_2	0.05	–	C_{11}	0.08	+
C_3	0.05	+	C_{12}	0.05	–
C_4	0.03	+	C_{13}	0.06	+
C_5	0.02	+	C_{14}	0.08	+
C_6	0.08	+	C_{15}	0.03	+
C_7	0.08	+	C_{16}	0.06	+
C_8	0.08	+	C_{17}	0.05	+
C_9	0.08	+	C_{18}	0.05	+

3 Result and analysis

3.1 Calculation of the safety value of evaluation index

According to the correlation between evaluation index and land ecological security，index can be divided into positive and negative indices. Positive index includes the annual output value of unit agricultural land，economic density，urbanization level，proportion of tertiary industry in GDP，per capita GDP，growth rate of total fixed asset investment，and per capita net income of rural residents[8-9]. And negative index refers to population density，natural growth rate of population，proportion of dry land，and proportion of soil and water loss. As for the index having the characteristic of greater security due to bigger positive index，its reference value is the lower limit of security and the value is unsafe if it is lower than the limit. As for the index having the characteristic of greater security caused by smaller positive index，its reference value is the upper limit of security and the value becomes unsafe if it is greater than the limit[7-10].

Equation of positive index is

$$Y_i = \begin{cases} 1 & X_i \geqslant S_i \\ X_i/S_i \times 100\% & X_i < S_i \end{cases},$$

while equation of negative index is

$$Y_i = \begin{cases} 1 & X_i \leqslant S_i \\ S_i/X_i \times 100\% & X_i > S_i \end{cases},$$

Hence，the security value of single index is

$$I = Y_i \times W_i,$$

where X_i is the actual value of index，S_i is the reference value of index，Y_i is the security index of index，I is the security index of single index，and W_i is the index weight.

According to the above calculation method，security value of single index of land ecological security evaluation in Hainan Island in the years 2000 – 2007 is obtained（Table 2）.

Table 2 Ecological security value of land ecological security evaluation index in Hainan Island，China

Year	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}
2000	0.018 0	0.007 0	0.050 0	0.030 0	0.015 7	0.061 1	0.065 3	0.080 0	0.032 0	0.040 0	0.038 8	0.031 5	0.000 7	0.080 0	0.030 0	0.043 5	0.005 3	0.044 0
2001	0.018 0	0.006 8	0.050 0	0.030 0	0.015 9	0.064 5	0.068 1	0.080 0	0.030 7	0.040 0	0.038 8	0.031 5	0.000 58	0.080 0	0.030 0	0.047 2	0.019 7	0.045 0
2002	0.017 5	0.007 0	0.050 0	0.030 0	0.015 7	0.076 3	0.075 5	0.080 0	0.031 2	0.040 0	0.038 5	0.031 5	0.000 58	0.080 0	0.030 0	0.051 8	0.027 7	0.047 79
2003	0.017 3	0.007 3	0.050 0	0.030 0	0.015 9	0.080 0	0.078 5	0.080 0	0.031 8	0.040 0	0.035 4	0.032 6	0.000 6	0.080 0	0.030 0	0.056 7	0.050 0	0.050 0
2004	0.016 95	0.007 4	0.048 87	0.030 0	0.016 4	0.080 0	0.080 0	0.080 0	0.044 1	0.040 0	0.035 35	0.032 73	0.000 7	0.080 0	0.030 0	0.060 0	0.041 0	0.050 0
2005	0.016 68	0.007 5	0.047 93	0.030 0	0.014 5	0.080 0	0.080 0	0.080 0	0.044 7	0.040 0	0.036 59	0.032 89	0.000 7	0.080 0	0.030 0	0.060 0	0.048 8	0.050 0
2006	0.016 4	0.007 5	0.047 1	0.030 0	0.016 9	0.080 0	0.080 0	0.080 0	0.045 0	0.040 0	0.036 5	0.032 9	0.000 6	0.080 0	0.030 0	0.060 0	0.027 7	0.050 0
2007	0.016 1	0.007 5	0.046 2	0.030 0	0.017 8	0.080 0	0.080 0	0.080 0	0.045 0	0.040 0	0.036 5	0.032 9	0.000 7	0.080 0	0.030 0	0.060 0	0.050 0	0.050 0

3.2 Calculation of the integrated value of land security

Although security value of single index can reflect the status of land ecological security in Hainan Island from various aspects，it can only reflect a certain aspect of land ecological security system. In order to fully reflect the status of land ecological security in Hainan Island，security value of single index should be synthesized into comprehensive value. Therefore，we select the index sum method to calculate the integrated value of land ecological security，that is

$$T = \sum_{i=1}^{n} (Y_i \times W_i),$$

where T is the integrated value of land ecological security，Y_i is the security index of the ith index，W_i is the weight of the ith index，and n is the total number of indices[11-13].

Thus，the integrated values of land ecological security in the years 2000 – 2007 are 0. 675 44，0. 701 2，0. 735 6，0. 770 6，0. 779 8，0. 785 9，0. 775 0 and 0.801 2，respectively.

3.3 Evaluation standard of land ecological security

Since the integrated value of land ecological security is between 0 and 1，it is difficult to evaluate the status of land ecological security by direct observation. According to the integrated security value calculated，relevant literatures have set up the integrated evaluation standard of land ecological security in Hainan Island（Table 3）. Range of integrated security value（0 – 1）is classified into 5 security grades by non-equidistance method. The greater the integrated security value is，the better the land ecological security becomes，and *vice versa*. Moreover，system characteristics of the corresponding 5 grades are described[13-14].

Table 3 System standard and grading of land ecological security

Grade	Security value	System state	System characteristics
I	(0,0.4]	Adverse grade	Extremely adverse land ecological environment，incomplete structure of land ecological system，severely degraded service function，and difficult reconstruction of ecological restoration
II	(0.4,0.6]	Risk grade	Adverse land ecological environment，greatly damaged structure of land ecological system，severely degraded service function of land ecology，incomplete system function，difficult recovery after external disturbance，prone to ecological disasters
III	(0.6,0.8]	Sensitive grade	Relatively poor land ecological environment，damaged structure of land ecological system，degraded service function of land ecology，which is able to maintain its basic functions，deterioration after disturbance，relatively easy occurrence of ecological disasters
IV	(0.8,0.9]	Good grade	Good land ecological environment，relatively complete structure of land ecological system，almost completed function of land ecological service function，relatively good system function，easy recovery after external disturbance，relatively little possibility of ecological disasters
V	(0.9,1.0)	Safe grade	Good land ecological environment，complete structure of land ecological system，completed function of land ecological service function，good system function，recovery after external disturbance，little possibility of ecological disasters

3. 4   Analysis of evaluation result   Result of evaluation shows that land ecological security of Hainan Island is at sensitive grade (pre warning status) in the years 2000 – 2006, and at good grade (relatively security status) in the year 2007. Moreover, land ecological security shows an increasing trend year by year in general.

(1) According to the evaluation standard, land ecological security in Hainan Island belongs to grade Ⅲ from the year 2000 to 2006, and to grade Ⅳ in the year 2007. This is because that the natural condition is better in Hainan Island. In recent years, Hainan has implemented the strategy of sustainable development in order to improve the level of ecological security. At the same time, proportions of woodland and per capita cultivated land in Hainan Island are both higher than those of the national average. But the proportion of cultivated in Hainan Island is relatively small and the economic density is relatively high. Proportion of tertiary industry in GDP is above 40% and the urbanization level is also improved rapidly from 26% in the year 2000 to 39% in 2007. However, the growing population density, the high growth rate of population, and the low per capita net income of rural residents and reserve rate of land resources have restricted the further improvement of land ecological security in Hainan Island.

(2) Fig. 2 illustrates that both land ecology and security level of Hainan Island have increased gradually, indicating that the security level has the condition for transformation. In the years 2000 – 2006, comprehensive evaluation value of land ecological security is between 0. 67 and 0. 78, indicating that the ecological security is under continuous improvement. Since the ecological province construction of Hainan Province in the year 1998, the ecological environment of land has been improved, function of land ecosystem has been recovered through the closed forest, the conversion of cropland to forest, the restoration of coastal protective forest, the effective improvement of cultivated area, the acceleration of soil erosion and desertification control, the enhancement of growth rate of total fixed asset investment and the per capita net income of rural residents. All these measures have further promoted the land ecological security level of Hainan Island. Fig. 2 indicates that land ecological security of Hainan Island in the year 2007 is significantly higher than that in the years 2000 – 2006, showing that the ecological construction of Hainan Island has achieved initial success.

(3) Research shows that restrictive factors of land ecological security level of Hainan Island are mainly the natural population growth rate, the grain production of unit sowing area, urbanization level, per capita cultivated land area, reserve rate of land resources, growth rate of total fixed asset investment, per capita net income of rural residents and so on. Although Hainan Island has been committed to reducing population growth rate, it still maintains at a rate of 8. 9% at present due to the cultural differences and low educational level. At the same time, growth rate of total fixed asset investment of Hainan Island is significantly lower (9. 4%) in the year 2006. And per capita cultivated land is decreasing, which is neither conducive to the development of modern agriculture nor to the optimization of industrial structure. Therefore, we should protect the limited cultivated
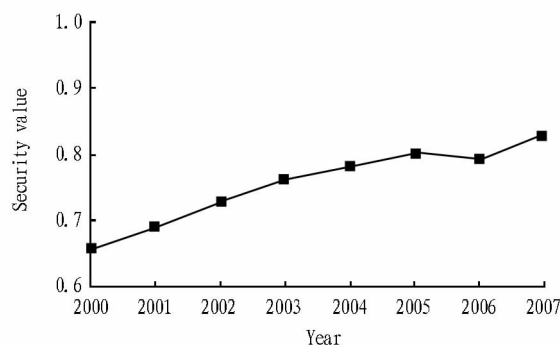

Fig. 2   Variation trend of land ecological security value in Hainan Island

land resources, and rationally develop the precious land resources.

4   Countermeasures

According to the result of evaluation, suggestions from 4 aspects are put forward in order to strengthen the construction of land ecological security and to further improve the land ecological security of Hainan Island based on the land ecological problems at present.

(1) Implement the ecological construction plan of Hainan Island, and organically combine the economic and social development with the ecological protection and construction. With the development of economy and the expansion of urban scale, there is a growing demand for land resources, which also threatens the security of land ecological environment. Thus, protection and development of land not only promotes the regional development, but also is the need to maintain ecological security. In recent years, Hainan Island has implemented the closed forest and has strengthened the construction policy of natural protection[5]. All the slope land above 250 should conduct the policy of returning cultivated land to forest, and canopy density of tropical natural forest should be gradually increased.

(2) Strengthen the protection of farmland, adhere to the regulation system of land use based on the planning, establish a strict farmland protection system, and set up a scientific and feasible protection index of cultivated land. According to the reserve resources of cultivated land, appropriate land development should be carried out by taking land consolidation and reclamation as the major measures in order to increase the effective cultivated land and to improve the quality of cultivated land[15 – 16].

(3) Pay attention to the improvement of land ecological environment, prevent land degradation, and control the land ecological environment construction and land pollution, integrating prevention and treatment together. At the same time, apply fertilizers and pesticides rationally in order to reduce the pollution of land. When utilizing and developing resources orderly and appropriately, we should focus on enhancing the resource utilization rate and resource saving, and adopt the development mode of resource-saving type. Moreover, we should also make the overall land use planning, utilize land rationally, and ensure land use for each industry. Due to the imperfect land market of Hainan Island, a great number of land transfers are not fully in

accordance with the mechanisms of market economy laws and there is too much human intervention. Therefore，we should establish a new mechanism for land use as soon as possible to perfect the land market[16-17].

（4）Ecological environment is the lifeline of human existence and economic development，as well as the key for sustainable land use. Therefore，the concept of ecological security should be firmly established. Since Hainan has relatively large population density，and prominent contradiction human and land，we should make population planning and policy compatible with the natural capacity，control population growth and ease the contradiction between people and land.

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海南岛土地生态安全评价

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摘要 　以海南岛为研究区,在介绍研究区概况的基础上,依据 1999 ～2008 年《海南统计年鉴》、1999 ～2008 年《海南年鉴》、2000 ～2004 年《海南生态省建设年鉴》等数据,依据科学性、代表性、综合性、简明性、可操作性、适用性等原则,结合海南岛这个特殊的地理环境特点,基于"压力－状态－响应"（P－S－R）概念框架模型,以土地生态压力、土地生态状态、土地生态响应为子系统,共选取 18 项指标,构建了土地生态安全评价指标体系。运用层次分析原理和综合评价法建立了土地生态安全评价模型,利用此模型对 2000 ～2007 年海南岛的土地生态安全状况进行评价和分析,根据评价结果从促进土地资源可持续利用和维护生态安全的角度提出了具体的对策与建议。结果表明,2000 ～2007 年海南岛土地生态安全处于敏感级(预警状态),2007 年处于良好级(较安全状态),并且土地生态安全水平整体上呈逐年增加的趋势;制约海南岛土地生态安全水平的因素主要是人口自然增长率、单位播种面积粮食产量、城市化水平、人均耕地面积、土地资源后备资源率、全社会固定资产投资增长率、农村居民人均纯收入等。

关键词 　土地生态;安全评价;指标体系;海南岛