The functional assessment of agricultural ecosystems in Hubei Province, China

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Received 27 February 2003; received in revised form 12 August 2004; accepted 28 September 2004
Available online 2 March 2005

Abstract

Located in Central China and the middle reaches of Yangtze River, Hubei Province is distributed in a transitional belt where physical conditions and landscapes are on the transition from north to south and from east to west. It is one of the regions possessing most energetic and greatest potential in both today and future socio-economic development in Central China. Well known as “a land of rice and fish”, the region enjoys some of the favorable physical conditions, with a diversity of natural resources and the suitability for growing various crops. According to analytic hierarchy process (AHP) the indicators’ weights of the agricultural systems function system in Hubei Province are worked out. According to Multiple Hierarchies, Targets-Fuzzy Comprehensive Measurement Model, Triangle Evaluation Model, the economic function, eco-environmental function and the social function in Hubei Province are all calculated, then the whole agricultural systems function is worked out and the regional differentiation regularity of agricultural systems function is summed up. It is considered that the difference of the agricultural systems function in each county in Hubei Province is great while the regional differentiation of agricultural systems function is regular. According to the difference seven agricultural systems function regions in Hubei Province (Wuhan-Ezhou-Huanggang (I), Northeast of Hubei (II), Southeast of Hubei (III), Jianghan (IV), North of Hubei (V), Northwest of Hubei (VI), and Southwest of Hubei (VII)) are distinguished, their function are identified and studied. Based on the analysis the problems of each of the regions are found out, solutions that can maximize integrated benefits economically, socially and ecologically by enhancing the management of ecosystems and optimizing systematic capability are sought out.

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Keywords: Ecological construction; Agricultural systems function; Comprehensive measurement; Regional differentiation regularity; Hubei Province

1. Introduction

Over the past three decades, there has been a surge of interest and study on ecosystem management.
in the world. Many countries, both developed and developing, have taken it very seriously in their environmental policy-making. From then on, many people have been focusing on studying ecological risk assessment, which is seen as an integral component of ecosystem management (Gentile et al., 2001). It has also been widely accepted that ecosystem management provides not only a framework for achieving a sustainable society but also spatial and intergenerational time scales by which the interactions between human and natural systems can be observed and studied (Gumbine, 1994; US MAB, 1994; Harwell et al., 1996).

Being the result of human and nature reciprocity, agricultural ecosystems stands high place in the development of regions. In order to assess the function of agricultural ecosystems, many researchers have been searching for new concepts, modeling and methodologies (Gertsev and Gertseva, 2004; Olden et al., 2004; Yang and Li, 1998; Chen and Wang, 1998; Gao et al., 1997; Agrell et al., 2004; Park and van de Giesen, 2004; Münier et al., 2004; Gentile and Harwell, 1998). All of them made different modeling to assess ecological systems, while few of them have found a satisfactory model to assess the main components of agricultural ecosystems, namely their economical, ecological and social aspects.

Using the principles of Human Ecology and Ecological economics, and taking Hubei Province as an example, this paper is an attempt to address the issue through a functional assessment of agricultural ecosystems. The study aims to integrate the economic, social and ecological components of agricultural systems in a specific region, with the goal of promoting sustainable agricultural development in areas that have a variety of physical conditions, resource structures and land-use patterns.

In this paper, the first section is a brief introduction to principles of comprehensive functional assessment of agricultural systems, which can be seen as general guidelines governing the procedure of the assessment project. The second part aims to establish an index system and to discuss how these indexes are selected and determined. The third part focuses on the evaluation of integrated function on the evaluation of integrated functions on each of the agricultural systems in Hubei Province in Central China. Finally, some are drawn from the research project.

2. Conceptual models

2.1. Principles of comprehensive assessment

The functional assessment of an agricultural ecosystem is a comprehensive evaluation of the economy, society and ecology of a given region, which is usually carried out by choosing several major indexes, classifying regional ecosystems, establishing mathematical models and carefully examining each agricultural systems. The project focuses on a systemic assessment of the sustainability of each ecosystem. Building on the findings derived from the evaluation procedure, lessons can be inferred, policies can be formulated and measures can be taken to strengthen the organization, management and protection of these agricultural ecosystems. The methodology employed and the indexes selected for the assessment are determined by the level of economic development and regional characteristics of a given region. Generally speaking, three main guidelines or principles should be taken into account in the assessment process.

1. The integrity of systemic capacity. The agricultural systems is a complex system consisting of interrelated economic, social and ecological components. In fact, it is the interaction of the different components that determines the characteristics and performance of an agricultural systems, and so all its aspects must be taken into account.

2. Within an agricultural ecosystem, human activities have a significant impact. Furthermore, the management of an agricultural systems is related to a number of factors, such as the educational level population and its capacity to absorb scientific techniques. Certain indexes that play an important role in the interaction between people and the ecosystem need to be included.

3. When selecting the index variables for the assessment, the existing statistical database must be taken into consideration so that data can be effectively integrated. At the same time, the calculation methods used in the assessment should be relatively simply so that ordinary technicians can utilize these methods in their management and monitoring work after a short period of training.
Table 1

<table>
<thead>
<tr>
<th>B_1</th>
<th>B_2</th>
<th>B_3</th>
<th>Weight (w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1/2</td>
<td>2</td>
<td>0.2857</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>4</td>
<td>0.5714</td>
</tr>
<tr>
<td>1/2</td>
<td>1/4</td>
<td>1</td>
<td>0.1429</td>
</tr>
</tbody>
</table>

w = B_i / \sum B_i

2.2. Indexes of comprehensive functional assessment of agricultural ecosystem

2.2.1. Objective levels

The ultimate objective of studying agricultural ecosystems is how to maximize sustainable integrated benefits of the ecosystems. Utilizing the AHP method of multi-objective decision-making, the ultimate objective can be broken down into several levels, as Table 1 shows. The first level is the integrated function of an agricultural ecosystem. The second level is composed of ecologic, economic and social components, while the third level consists of the various factors which affecting the integrity of the environment, economy and society.

In ecologic benefit level, farmland efficiency, expressed by the percentage of the actual output against the climate potential, can reflect the fundamental ecologic characteristics of farmland in a given region. The coverage of forest can be seen as one of the most important indexes indicating the environmental situation of the agricultural systems in a region. Soil fertility is denoted by the percentage of the soil area containing ≥2% of soil organic matter to the total area of the ecosystem as a whole. Potential of water resources is represented by using current agricultural water consumption as a basis to calculate the percentage of potential of usable precipitation. Soil erosion is an important index reflecting the stability of the agricultural systems, which is measured by erosion modulus t/km^2.a.

In economic benefit level, the ratio of output to input is a comprehensive index describing an agricultural systems function, and denoted by the ratio of output value to input value. The commodity rate of agriculture is expressed by the percentage of the total agricultural product output against the total sales of agricultural product. Land productivity is a comprehensive index mainly reflecting economic benefit, and expressed by GNP per unit of land (10^4 yuan/km^2). Per capita income, a reflection of the bearing of a system, is denoted by net value of per capita output (yuan per capita). And per capita grain is expressed by grain per person annually.

In social benefit level, the index of rural energy (%) is represented by the availability of rural living energy in a region. The educational index, which is used to demonstrate the educational level of a population in a region, is expressed by the ratio of the population who has attained junior high middle school and above against the total population who is 6 years old and above. The percentage of the labor being engaged in the secondary and tertiary sectors is one of the valuable indexes reflecting the degree of regional development.

2.2.2. Weights of indexes

In order to establish a perfect system in which the comprehensive function for a single agricultural systems can be effectively monitored, determining the weight of each index in the index system is as important as establishing the index system itself for the assessment. The reason lies in that the performance of a system is a result of interactive of various factors but every factor plays its own role and makes different contribution to the system as a whole. In determining the weight of each of the indexes, AHP will be employed to calculate the contributions of the lower level to the upper level.

(1) Contributions of the second level to the first level.

In a developing country like China, the first priority should be given to economic development, especially it should be recognized that China is still at its primary stage of economic development. From the experience of development derived from both developed and developing countries, it is also particularly true that the level of social development and environmental protection relies on the degree of economic development to a great extent. Therefore, in the study, we will place more emphasis on the economic benefit level, and then take both the social benefit and economic benefit into consideration. In other words, the economic benefit is the
fundamental goal we are pursuing while the social benefit and ecological benefit can be seen as a supporting and security system that plays an important role in safeguarding the stability and sustainability of the agricultural systems as a whole. Building upon the assumption, the first order judgment matrix is set up as follows, and the calculation results are presented in Table 1.

\[ CI = \frac{\lambda_{\text{max}} - n}{n-1} \]
\[ CR = \frac{CI}{RI} \]

In the formulas, CI denotes the consistency index; \( \lambda_{\text{max}} \), the maximum eigenvalue; \( n \), the order of the judgment matrix; RI, the average random consistency index; CR, the value of consistency check. When CR < 0.1, the matrix has satisfying consistency, otherwise it should be adjusted. The results of the first order matrix are:

\( \lambda_{\text{max}} = 3.0092 \), \( CI = 0.0046 \), \( RI = 0.58 \), \( CR = 0.0079 < 0.1 \)

Therefore, the results have satisfactory consistency.

(2) Contribution of the third level to the second level.

Based on the same principle, the contributions of every factor \( C_i \) in the third level to \( B_1 \), \( B_2 \) and \( B_3 \) can be worked out, respectively and pass the consistency check, as Table 2 shows.

### Table 2

The order of hierarchy C to hierarchy B and A

<table>
<thead>
<tr>
<th>Hierarchy</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecological factors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farmland efficiency ( C_1 )</td>
<td>0.0972</td>
<td>0.0809</td>
<td>–</td>
<td>0.0725</td>
</tr>
<tr>
<td>Forest coverage ( C_2 )</td>
<td>0.1901</td>
<td>0.0288</td>
<td>–</td>
<td>0.0720</td>
</tr>
<tr>
<td>Soil fertility ( C_3 )</td>
<td>0.0570</td>
<td>0.0499</td>
<td>–</td>
<td>0.0438</td>
</tr>
<tr>
<td>Potential of water resources ( C_4 )</td>
<td>0.0355</td>
<td>0.0309</td>
<td>0.0706</td>
<td>0.0436</td>
</tr>
<tr>
<td>Soil erosion ( C_5 )</td>
<td>0.1803</td>
<td>0.0450</td>
<td>0.1166</td>
<td>0.1020</td>
</tr>
<tr>
<td>Ratio of agricultural output to input ( C_6 )</td>
<td>–</td>
<td>0.1538</td>
<td>0.1100</td>
<td>0.1051</td>
</tr>
<tr>
<td>Production ( C_7 )</td>
<td>–</td>
<td>0.1416</td>
<td>0.1100</td>
<td>0.1051</td>
</tr>
<tr>
<td>Economic factors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income per person ( C_8 )</td>
<td>0.0417</td>
<td>0.0999</td>
<td>0.0711</td>
<td>0.0782</td>
</tr>
<tr>
<td>Grain per person ( C_9 )</td>
<td>0.0674</td>
<td>0.0784</td>
<td>0.0784</td>
<td>0.0763</td>
</tr>
<tr>
<td>Land productivity ( C_{10} )</td>
<td>0.0626</td>
<td>0.0828</td>
<td>0.0603</td>
<td>0.0731</td>
</tr>
<tr>
<td>Rural energy ( C_{11} )</td>
<td>0.1102</td>
<td>0.0364</td>
<td>0.1151</td>
<td>0.0712</td>
</tr>
<tr>
<td>Social factors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Culture and education ( C_{12} )</td>
<td>0.0355</td>
<td>0.0604</td>
<td>0.1277</td>
<td>0.0551</td>
</tr>
<tr>
<td>Labor transferring ( C_{13} )</td>
<td>0.0392</td>
<td>0.0202</td>
<td>0.1023</td>
<td>0.0354</td>
</tr>
<tr>
<td>Birth rate ( C_{14} )</td>
<td>0.1052</td>
<td>0.0624</td>
<td>0.1440</td>
<td>0.0885</td>
</tr>
</tbody>
</table>

2.2.3. Hierarchies ranking

Based on the previous principles and formulas, the contributions of the third level (C) to the first level (A) can be calculated, which is called hierarchy ranking. The calculation results can be seen as the comparative contributions of all factors in level C to level A. The values of all indexes in level C need normalizing because the numbers of indexes that are chosen to represent different benefit in level B and level C are gained by comparing with each upper level.

The normalization formula is:

\[ x_i = \frac{y_i}{\sum_{i=1}^{n} y_i} \]

In the formula, \( x_i \) denotes the contributions (weights) of factor \( i \) in level C to the regional integrate benefits. \( y_i \) denotes the comparative contributions of factor \( i \). The result of calculation can be found in Table 3 (Fig. 1).
3. A case study in Hubei Province

Located in Central China and the middle reaches of the Changjiang (Yangtze) River, Hubei Province is distributed in a transitional belt where physical conditions and landscapes are on the transition from north to south and from east to west (Fig. 2). Thus, Hubei Province is well known as “a land of rice and fish” since the region enjoys some of the favorable physical conditions, with a diversity of in natural resources and the suitability for growing various crops. At the same time, however, there are also some restrictive factors for developing agriculture such as a tight man–land relation between, a constant degradation of natural resources and a growing population pressure on land resource reserve. Despite cherishing a burning desire to promote their standard of living, people living in the area are frustrated because they have no ability to enhance their power to accelerate economic development because of a dramatic decline in quantity and quality of natural resources and a deteriorating environment.

Based on the distinctness and differences in environment and natural resources, Hubei Province can be roughly divided into seven agroecological regions (Fig. 3) (Agriculture Rationalization Commission of Hubei Province, 1993; Hu, 1997).

3.1. Weights of all indexes in agroecological region

In the seven agroecological regions, according to the integrated evaluation indexes, the corresponding element values of all indexes (expressed by the relative values, such as average per capita, density, percentage, etc.) are counted, ranked and marked accordingly. For instance, farmland efficiency is ordered as number 1, 2, 3, . . . and 10, and then marked as 10, 9, 8, . . . and 1, respectively (Tan, 1990). The procedure is required to be repeated for each of the element values. The next step is to multiply each mark of each of the element values with its corresponding weight that is given in Table 4. Then the results can be used to calculate the values for each benefit type within each of the seven agroecological regions, respectively. Finally, the total benefit weights can be obtained by summing these values according to each of the three categories and each of the seven regions in Hubei Province as can be seen Table 4.
3.2. Assessments of comprehensive functions in agroecological regions

If putting the three benefit weights for those regions into a coordinate graph and linking these points with lines, the whole picture looks like a diagram formed by several triangles with different shapes and statuses (Fig. 4). Each of the triangles delivers very important information about the advantage and disadvantage of the three benefits in different agroecological

<table>
<thead>
<tr>
<th>Benefit type</th>
<th>Region I</th>
<th>Region II</th>
<th>Region III</th>
<th>Region IV</th>
<th>Region V</th>
<th>Region VI</th>
<th>Region VII</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecological benefit</td>
<td>4.92</td>
<td>5.31</td>
<td>4.56</td>
<td>5.06</td>
<td>4.76</td>
<td>3.76</td>
<td>4.00</td>
<td>31.85</td>
</tr>
<tr>
<td>Economic benefit</td>
<td>6.45</td>
<td>5.04</td>
<td>3.92</td>
<td>6.59</td>
<td>5.59</td>
<td>2.12</td>
<td>2.11</td>
<td>31.82</td>
</tr>
<tr>
<td>Social benefit</td>
<td>5.70</td>
<td>4.12</td>
<td>4.58</td>
<td>3.85</td>
<td>3.91</td>
<td>3.34</td>
<td>4.44</td>
<td>29.94</td>
</tr>
<tr>
<td>Total</td>
<td>16.97</td>
<td>14.47</td>
<td>13.86</td>
<td>15.44</td>
<td>14.26</td>
<td>8.84</td>
<td>10.55</td>
<td>93.59</td>
</tr>
</tbody>
</table>

Source: Hubei Province Statistical Bureau, 2002.
regions and the macro-combination state of regional comprehensive functions. Based on the above analysis, the specific category representing comprehensive functions in each of the different regions can be further grouped with respect to the quality and characteristics imposed with each of the triangles. As we have discussed above, since the priority is placed on the economic benefit in the study, the agroecological regions can be divided into two groups based on their performance in the economic benefit: one group is called “front-triangle” (angle $b$ upward) while another is called “back-triangle” (angle $b$ downward).

On the basis of the two groups, a group of subtype can be further divided in terms of social benefit level in order to promote regional sustainable development. This is because it is people equipped with advanced knowledge and skills who are responsible for organizing productive activities in the development of regional economy and construction of eco-environment. Therefore, the two basic groups can be further classified into two subtypes: A (angle $c$ is higher than angle $a$), and B (angle $c$ is lower than angle $a$). Furthermore, the subcategories can be classified again as 1, 2, 3, ... based on the benefit weights. From Fig. 3, it can be seen that: the region of Wuhan-Ezhou-Huanggang (I) falls into the subtype A$_1$ of “front-triangle”; Northeast of Hubei (II) belongs to the subtype B$_1$ of “front-triangle”; Southeast of Hubei (III) is classified as the subtype A$_1$ of “back-triangle”; Jianghan Region (IV) belongs to the subtype B$_2$ of “front-triangle”; North of Hubei (V) falls into the subtype B$_3$ of “front-triangle”; Northwest of Hubei (VI) is in the subtype B$_2$ of “back-triangle”; Southwest
of Hubei (VII) belongs to the subtype A2 of “back-triangle”. Therefore, in Hubei Province, the sequence of comprehensive functions of the seven agroecological regions, from excellent, to good, and to bad, is: I > IV > II > V > III > VII > VI.

4. Suggestions: monitoring of the agroecological regions

Assessing agricultural systems in a given region not only provides us with valuable information about regional characteristics, resource endowment and potential for agriculture, but also allows us to have a better understanding of the region, especially its advantages and disadvantages. Based on the findings derived from such assessments, we are able to seek solutions that can maximize integrated benefits economically, socially and ecologically by enhancing management of ecosystems and optimizing systematic capability. At the meantime, the results derived from the systemic assessment can also be checked and further analyzed in a number of ways so that we are able to find out the problems of each of the regions and take particular measures to deal with these problems.

(1) Image monitoring. All data of the indexes in the monitoring regions are handled in unison as requested, and are input to the computer after preparing a computer program, which can compose some images of triangles representing comprehensive functions. By drawing a comparison of different types of triangles in different regions, macro-combination traits of regional comprehensive functions and the advantage and disadvantage of the three benefits can be appraised directly and vividly. For example, if a region falls into the “front-triangle” category and its image of triangle is above the average standard of the studied area as a whole (e.g. Region I), the region can be judged to have a consistency relationship among its economy, society and the environment and an excellent performance in its comprehensive functions. On the other hand, in the case of Region VI and Region VII, their performance in comprehensive functions is much poorer by comparing their triangles with others. It can also be observed that the lowest angle within a triangle is an indicator for the poorest performance in a certain aspect of the three benefit levels in the region. With images, comparative advantage and disadvantage of the three benefits in the regions can be distinguished, and the major problem hindering the development of a system can be identified. Thus, through monitoring the imagines, it is very helpful to seek policies and measures to maximize the benefits and reduce negative effects in the management and construction of these regions. For instance, in the case of Region I, with the rapid economic development and urbanization, much more attention should be paid to strengthening ecological construction and environmental protection in the Wuhan-Ezhou-Huanggang area.

(2) Index monitoring. Although image monitoring provides us with significant appraisal results and basic judgements to various regions, it seems to be too macroscopic and general to look at more details about the different regions. For this reason, index monitoring is needed to identify more specific problems in these regions, in a bid to seek solutions to those problems. Looking back to the index system we have discussed in the previous sections, it is possible for us to identify main problems of resource management and make proposals to deal with them in each of the seven regions. For example, there is a growing pollution and degradation in the environment in the urban-dominated Region I, so more attention should be paid to environmental protection, in particular, building urban green belts. Social function should be reinforced in Region II and IV, with a focus on developing rural energy. Economic development, especially the commodity rate of agricultural production should be emphasized in Region III. Special attention should be paid to social function, especially the cultural construction and the development of education in Region V. Because economic benefit in Region VI and VII are generally inferior, the focus of the two regions should be the augment of reasonable use and administration of land resources. Besides, the enhancement of productivity and the development of education are also very important for their sustainable development.

(3) Tracking dynamic monitoring. Along with the image monitoring and index monitoring, a dynamic monitoring is also needed to record and track the changes in each of the systems.
After putting these regions into a continuous and systematic monitoring network, it is very useful to get new information on the changes in these regions so as to find new problems and seek solutions to them. It is also important for us to adjust the main policies in rural resources management through constant and successive monitoring.

However, it should be noted that the model is just an attempt to study agroecological region by employing a new evaluation method. Obviously, it is far from perfect and further studies are needed to improve it, particularly in the aspects of the selection of indexes and definition of weights.

Acknowledgements

Foundation item: Under the auspices of the National Natural Science Foundation of China (No. 50099620).

References


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