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Agroecosystem functional assessment and its difficulties

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Abstract: Agroecosystem functional assessment indicators provide a necessary bridge between decision-makers and scientists. The development of acceptable indicators, however, remains a difficult task because the current knowledge and understanding of ecosystems is not sufficient to allow an objective assessment of all ecosystem functions. These difficulties were summarized from three perspectives. First, there are difficulties in individual function assessment. Of the four functions associated with agroecosystems-energy flow, materials cycling, information flow and value flow-data on material cycling and information flow remain difficult to obtain and the indicators relatively immature. Secondly, there are difficulties of integration. During the assessment process, the integration of the agroecosystem functions remains the biggest obstacle. Until now, there has been no practical or effective methodology established to resolve the problem. At present, the makeshift approach has been to weight the various indicators and then add them together. Thirdly, there is the problem of obscure concepts and concept confusion. When assessments of agroecosystems are conducted, concepts such as structure, function, benefit, and resource utilization are used extensively. To date, no logical relationship (either real or implied) has been developed between any of these concepts. Are they causes and results such that the relationship between them is linear, or are they independent from one another such that the relationship is parallel? Thus far, the essence of this question is yet to be explored.

Keywords: functional assessment; indicators; agroecosystems; ecological benefit

Introduction

There is a need to develop commonly accepted indicators of sustainable development to provide solid bases for decision-making at all levels that can contribute to a self-regulating sustainability of integrated environmental based socio-economic systems. What is lacking is a global process to arrive at a common approach and consensus on the technical validity, comparability and political acceptability of indicator use (UNEP, 1995). Information is one of the needs common to all decision makers concerned with sustainability. To be managed effectively, various system pressures and opportunities must be understood. Decision makers at all levels need information on the performance of a given system, why that system is behaving as it is, whether that performance is satisfactory, and how it is likely to behave in the future in response to potential changes in policies and other driving forces (Agriculture and Agri-Food Canada, 2000).

In practical terms, decision-makers need simple, efficient, and timely information that can be used effectively for management decisions. All too often, the information scientists provide is detailed beyond the scope necessary for effective application to the decision needs of management. Indicators, in this sense, provide the necessary bridge between decision-makers and scientists. They are built upon the detailed knowledge provided by science, but simplify the information as an understandable measure that can be quickly understood and applied in the decision-making process.

At the system level, ecosystem functional assessment requires the highest levels of integration compared to more specific assessment needs. But this is a difficult work, because all of the knowledge and understanding of ecosystems is not enough to make an objective assessment of all functions within an ecosystem. Until now, because of limitations in theory and methodology, the available criteria for assessing ecosystem functions and developing accurate indicators have not been well developed. This is particularly so with regard to agroecosystems. The following is a short summary of current difficulties in ecosystem functional assessment with a particular reference to agroecosystems and the Chinese perspective.

1 The difficulty in individual function assessment

The assessment of the three functions of natural ecosystems is summarized in Table 1 and the four functions of agro-ecosystems in Table 2.

Of the four functions associated with agroecosystems-energy flow, materials cycling, information flow and value flow-data on energy and value flow are relatively easy to obtain and the indicators relatively mature. Data on material cycling and information flow, however, remain difficult to obtain and the indicators relatively immature. Theoretically,

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Table 1 Assessment of natural ecosystem functions

Functions	Energy flow	Materials cycling	Information flow
Assessment target	Energy flow efficiency	Materials cycling efficiency	* Ecosystem stability
Assessment indicators	– Assimilation efficiency; – Growth efficiency; – Lindeman efficiency; – Productivity efficiency; – Consumption efficiency	– Materials turnover rate; – Materials cycling index	– Resistant capacity; – Restoration capacity
Availability of data	Relatively easy to obtain	It is hard to obtain	It is hard to obtain

* : Goh, 1975

Table 2 Assessment of agricultural ecosystem functions

Functions	Energy flow	Materials cycling	Information flow	Value flow
Assessment target	Energy flow efficiency	Material cycling efficiency	* Ecosystem stability sustainability and equability	Economic benefit
Assessment indicators	– Solar energy utilization rate – Average crop growth rate – Fodder resource conversion rate – Fodder resource utilization rate	– Material turnover rate – Material cycling index	– Productivity variation coefficient; – System inertia and elasticity; – Gennie coefficient	– Input/output – Net productivity – Labor productivity rate – Land productivity rate – Product commodity rate – Net income per capita
Availability of data	Relatively easy to obtain some data	Hard to obtain	Some of the data is easy to obtain and some is difficult to obtain	Easy to obtain

* : Conway, 1987

the cycling index is a good assessment indicator of materials cycling. However, because the cycling index is influenced by the chemical nature of cycled materials, the growth rate of plants and animals within the community, the decay and decomposition rates of organic matter, as well as by human activities the data are hard to obtain for large and complicated ecosystems.

An assessment indicator based on information flow faces a far more difficult task. The principal problem stems from the lack of a sound theoretical understanding of the nature and process of information flows within ecosystems. To date, there is not enough accumulated research in the area, limiting our understanding of ecosystem information flow, and therefore limiting the chances for a breakthrough in information function assessment methodology. The present operational choice has been to take "system stability" as the indicator in assessing information flow within the ecosystem (assuming the goal of information flow is to maintain the stability of the ecosystem). Even if we accept the simplified and reduced requirements of system stability as an indicator, the problem of data availability remains. First, it is difficult to determine the relevant scope of time and space needed for ecosystem assessment. Second, assuming we can come to consensus on the first, the extensive amount of time needed to obtain reliable and valid data is far beyond the operational time span for decision-making.

2 Difficulties of integration

Natural ecosystems are characterized by three main functions-energy flow, materials cycling and information flow. For agroecosystems, there is an additional function for value flow. During the assessment process, the integration of these functions remains the biggest obstacle. Until now, there has been no practical or effective methodology established to resolve the problem. The following cases help clarify the situation.

2.1 Sustainable development indicators of United Nations

Based on the cooperation of most national governments and organizations in United Nation's system, a sustainable development indicator program was launched by United Nations Commission on Sustainable Development (CSD) in 1995. In order to assess the sustainable development situation in every country, a sustainable development indicators list was proposed by CSD. The list consisted of four sectors—social, economic, environmental and institutional-and involved related chapters of Agenda 21. The indicators were further identified within a "pressure, state, and response" framework. This pressure, state, response framework received wide acceptance in use as a means of environmental assessment. The conceptual and operational use "pressure" as an indicator, however, did not extend well to the other sectors (social, economic, and institutional) identified by CSD. In order to be consistent with the structure implied by the other sectors identified by CSD, the pressure indicator was changed to "driving force", with the idea that its general acceptance in broader application would be increased. Driving force indicators were intended to show the impact of human activities on sustainable development and its processes and patterns. State indicators were intended to show the "state" of sustainable development, and response indicators intended to show the strategy and policy priorities of nations in their response to changes in sustainable development states. Within this framework, each indicator is independent. Because of the lack of appropriate integration methodology, however, the system contained no integrated indicators either within or between sectors.

2.2 Chinese models assessing agroecosystems

In China, the assessment indicator system for agroecosystems is based on three theories: (1) complex ecological system theory, which takes the agroecosystem as a complex ecosystem consisting of ecological, economic and social subsystems such that the assessment indicator system includes ecological, economic and social sectors, and a series of related sub-indicators (Tan, 1997); (2) ecological economy theory, which suggests that the assessment of agroecosystems is an integrated assessment of the economic and ecological benefits of the agroecosystem (the detailed contents of the social sector are reflected by the economic and ecological benefits with society as beneficiary (He, 1986); and (3) traditional economy theory, where the assessment indicator system is focused on the economic effects in the agroecosystem (He, 1984). With time, the first and second theories have become acceptable for most scientists. The third theory, however, remains ignored within the body of assessment research and application.

2.3 Indicator weighting

Because there is no ideal approach capable of integrating the various indicators from different sectors, the most widely used approach has been to weight the various indicators and then put them together as a single measure. The various methods utilized in assigning values to indicator weights can be cataloged into seven types: (1) estimation based on experience; (2) deductive logic; (3) analysis based on specific models/formula; (4) traditional statistics methods, such as Delphi and AHP; (5) sequential analysis; (6) principle component analysis; and (7) regression analysis.

3 Obscure concepts and concept confusion

When assessments of agroecosystems are conducted, concepts such as structure, function, benefit, and resource utilization are always used. However, there is no established logical relationship (either real or implied) between these concepts. They could be viewed as causes and results such that the relationship between them is linear, or are they could be viewed as independent from one another such that the relationship is parallel. Thus far, the essence of this question has not been explored in the literature. In our opinion, there is a linear cause-result relationship between structure, function and benefit. "Structure" refers to the nature and kinds of components within ecosystems, while "function" describes the purpose or role each of the components plays within that same system. "Benefit" is a unique concept because it is humanly defined. Humans represent both the consumers and beneficiaries of the ecosystem. While humans directly define and then receive the benefits of ecosystems, they rarely take consideration of the structure and function of ecosystems in defining their benefits.

With regard to "resource utilization", criteria such as solar utilization rate, feeder utilization rate, vegetative cover rate and the energy conversion rate (He, 1986) should be included within the functions associated with energy flow and material cycling. It is not reasonable to consider them as parallel sectors or as an independent sector in terms of assessment.

3.1 Functional benefit

In the assessment indicator systems developed by Wu (Wu, 1992) and Qi (Qi, 1995), used "ecological functional benefit" and "economic functional benefit" to assess ecological agriculture. The difficulty is that the terms "function" and "benefit" are more correctly viewed as causes and results rather than benefits. As such, their use as indicators reflects the more symptomatic approach to assessment issues. Because these concepts are not logically operational at the same level, they should not be put together and used as an indicator. Further, functional operations are typically best assessed in terms of efficiency, not benefit. In our opinion, function indicators are only suitable for functional assessment and should be related to the functional assessment sectors of materials cycling, or energy, information, and value flow.

3.2 Structure-function-benefit

In Zhang's article (Zhang, 1996), the indicator system consisted of three sectors-structure, function and benefit with each of these further divided into ecological, economic and social sub-sectors. In this kind of indicator system, however, where the sectors are treated in a parallel fashion, there is no way to know how to weight the values associated with the individual sectors. Accordingly, any assessment outcome from such an approach is consistently incomplete and fuzzy at best. The logical approach is to consider the relationship between structure, function and benefit as linear, thus avoiding difficulties associated with a lack of concept integration.

3.3 Function-benefit-resources and environment

Sun's indicator system (Sun, 1986) contained four sectors: (1) function; (2) economic and social benefit; (3) resources and the environment; and (4) benefits from ecologic-economic subsystems. In this system, function and benefit, which we propose to be linear in relationship, were put in a parallel position. Resources and environment, which we propose to be included in the function and structure sectors, were also put in a parallel position with function. In the articles of Wu (Wu, 1992) and Zhang (Zhang, 1996), "resources utilization" is still used as a sector in the indicator system, possibly the result of Sun's influence on indicator system development in China (Sun, 1986).

3.4 Social benefit

Of the theories on which assessment is based, one opinion considers the agroecosystem as a complex of natural, economic and social sub-ecosystems, the assessment of which should be conducted from their point of view. Another opinion believes that the assessment of agroecosystems is actually an integrated assessment of ecological and economic benefits within the agroecosystem, where social benefit is included within the context of the ecological and economic benefits. In some of the more recent assessments of agroecosystems conducted by Chinese ecologists, they have either given up on trying to account for "social benefit" or avoided the issue altogether.

Yuan(Yuan, 1994) and Meng(Meng, 1999) conducted assessments of agroecosystems based on "function" as the operational concept. In their assessment criteria, however, there was no "social benefit indicator." Recently, Ouyang (Quyang, 1999) made an assessment of the "service function" of Chinese terrestrial ecosystems and their ecological-economic values. Ecosystem services were defined as the conditions and processes by which natural ecosystems and the species that make them up sustain and fulfill life. They not only supply humans with ecosystem goods, but also perform fundamental life-support services (Tilman, 1997). Certainly ecosystem services are essential to civilization. Further, the service function concept is more appropriate for ecosystems (easier to quantify) and easier to implement than social benefit (usually subjective values) from an assessment perspective.

3.5 New thinking way

Recently, Cao(Cao, 1994a; 1994b) made an effort to understand agroecosystems based on the holographic relationship between ecosystems (agroecosystems) and organisms. Cao and Dawson(Cao, 2003a) also worked on an analogy between the materials cycling processes in agroecosystems and blood circulation in the human body. In further work on circulation efficiency, they developed a constant(K) capable of serving as an effective assessment criterion for the circulation function within integrated agroecosystems(Cao, 2003b). The value of K as an indicator may be seen in three areas. First, K offers decision-makers more concise and accurate information, forming the basis for further analysis of the system. Second, the set of criteria comprises four levels. In relative terms, the first level criteria are macroscopic, the fourth level microscopic, and the second and third levels are between microscopic and macroscopic. Using a mathematical formula to combine the criteria at various levels, the relationship between the criteria become neither parallel nor cumulative, thus helping solve the problem of subjective weight distribution. In addition, the criteria for the second, third and fourth levels are fewer in number and can be obtained by simple calculation.

4 Conclusions

The basic weakness of most current indicator systems is caused by their lack of depth in understanding the functions, regulating processes, and mechanisms of agroecosystems. For example, with regard to the flow of information, we do not understand much about the nature and the process of information flows within ecosystems. As such, it is very hard to select indicators capable of assessing the information flow function. Even if we accept the idea that ecosystem stability is a result of the information regulation function, we still must face the difficulty in reliably assessing stability.

Another reason for the delay in the greater development of ecological theory concerns the nature of the ecosystem itself. Because ecosystems are extremely extensive and complicated, both temporally and spatially, it is difficult to have breakthroughs in understanding all of its mechanisms and processes. If we truly want to develop assessment indicators, we should start from research on ecological theory. While much of the research on indicators for assessment of ecosystem has been of a practical nature, it is equally important that we not forget that it is also a theoretical and methodological issue.

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