Studies on Interpretive Structural Model for Forest Ecosystem Management Decision-Making

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Abstract. Characterized by their openness, complexity and large scale, forest ecosystems interweave themselves with social system, economic system and other natural ecosystems, thus complicating both their researches and management decision-making. According to the theories of sustainable development, hierarchy-competence levels, cybernetics and feedback, 25 factors have been chosen from human society, economy and nature that affect forest ecosystem management so that they are systematically analyzed via developing an interpretive structural model (ISM) to reveal their relationships and positions in the forest ecosystem management. The ISM consists of 7 layers with the 3 objectives for ecosystem management being the top layer (the seventh layer). The ratio between agricultural production value and industrial production value as the bases of management decision-making in forest ecosystems becomes the first layer at the bottom because it has great impacts on the values of society and the development trends of forestry, while the factors of climatic environments, intensive management extent, management measures, input-output ratio as well as landscape and productivity are arranged from the second to sixth layers respectively.

Keywords: Forest ecosystem management, Interpretive structural model, Factors, Decision-making.

1 Introduction

Although they have played certain positive roles in the history of forest management, traditional forest management modes have been seriously challenged because of their relatively single-purpose and irrational pursuit of timber production, and neglect of forest ecosystem functions in most cases. Since the concept of New Forestry [1, 2] was developed in 1980s, things have been gradually bettered via establishing and recognizing

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the new forestry theories focused on forest ecosystem functions. Consequently an ecological approach to forest ecosystem management, namely, a method for forest ecosystem management has been formed, and perfected step by step [3, 4]. Hereafter, forest ecosystem management has become a vital development trend of modern forestry [5]. Because it is very complicated and characterized by its diversity, complexity, openness and large scale [6], a forest ecosystem unavoidably interweaves with social system, economic system and other physical ecosystems [7, 8], thus forming a more complicated macro-system. In order to manage such a complicated forest ecosystem effectively, it is, first and foremost, necessary to understand fully the constituents that compose the system, the factors that fundamentally affect the system's formation and development, and the correlations that exist among the constituents. Interpretative Structural Modeling (ISM) is a process, with which groups can structure complex issues to form interpretable patterns. Developed in the period from 1971 to 1973 by John N. Warfield, an American scholar, as an initial process for ISM of a complex system at the Battelle Memorial Institute, the process was first described in Battelle Monograph Number 4, titled Structuring Complex Systems [9, 10], and it proved to be an effective means of studying complicated systems as well. Later, a variety of papers were published to further the studies of this field. Report by Warfield [11] showed how to order the elements of a system in such a way that much of the data required could be computed from supplied data. Another study described computer operations which assisted in the interpretation of complex structural models, thus a weighting matrix applied to the elements of a maximal cycle set permitted a set of digraphs to be developed [12]. Also in his another study, the problem of interconnecting two multilevel subsystems models defined by binary matrices A and B and a common, transitive, contextual relation to form a system model defined by matrix M is solved [13]. As a result, the overall structure in complex systems have been analyzed by means of relational matrix principles in graph theory, the correlations and both direct and indirect restraint conditions among the system constituents are interpreted via the relational matrix [14], and the results can be directly elaborated by graphics. From what has been described above, therefore, the correlations between the forest ecosystem constituents and factors can be systematically analyzed to lay reliable theoretical bases for the decision-making in forest ecosystem management by applying ISM principles and methods in spite of the extreme complexity of the forest ecosystem.

2 Determination of Decision-Making Constituents for Forest Ecosystem Management

As the most complicated and largest ecosystem on land, the forest ecosystem maintains its existence and development via circulation of materials, flow of energy and exchange of information. Owing to its openness, it is incessantly in exchange with exterior environments [15, 16]. Included in the exterior environments are not only the factors of climates and other living things beyond forest ecosystem, but also the more complicated factors of humans, society and economy, none of which have no great impacts on forest ecosystem. Only by taking all the factors above into full consideration according to the characteristics of forest ecosystems and modeling analyses on the ecosystems based on the ISM theory, can solid and reliable theoretical bases be laid for forest ecosystem management decision-making.

2.1 The Theoretical Base in Determining Decision-Making Constituents

The factors affecting forest ecosystem management decision-making are very complicated since their complexity lies chiefly in the multitude of the factors, and the nonlinear relations between system and factors as well as among the factors. Although there might be some other different approaches to dealing with these anfractuous relations, the authors of this present paper have selected and determined the major factors for forest ecosystem management decision-making according to the theories of sustainable development, hierarchy-competence levels, cybernetics and feedback.

The Theory of Sustainable Development

Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs, as defined by United Nations Environment Program. The theory focuses that a healthy economy should be developed on the decision-making bases of the ecological sustainability, social equity and people's active participation [17]. Since the sustainability of development lies on the sustainability of environments and resources, sustained yield can only be realized via rational exploitation and wise preservation of natural resources for present and future needs respectively. The index system for forest ecosystem management decision-making must, therefore, be determined in accordance with the above principles as an indispensable restriction of human exploitation activities, for the purpose of good circulation of ecological environments and optimal management for sustained yield of natural resources [18, 19].

The Theory of Hierarchy-Competence Levels

The theory of hierarchy- competence levels, or the theory of hierarchy-capacity levels, means that different hierarchies are functionally compartmentalized according to the status of various managed objects, a competence level of a hierarchy indicates the division of its function and the weight of its power, and the problems of various hierarchies should be treated in their relevant hierarchy- competence levels [20]. Involving the different hierarchies of economic, social and environmental macro-systems, forest ecosystem per se is composed of various subsystems connected with one another at various levels. The application of the theory of hierarchy-competence levels in forest ecosystem management, therefore, can not only reflect the exact features of forest ecosystem, but also make the decision-making more scientific and rational.

The Theory of Feedback and Cybernetics

Information transfer is one of the three major functions in ecosystem [21]. It is found that information transfers not only from input to output in the system, but also represents its feedback from output to input. In the light of cybernetics, it is the feedback of information that makes ecosystem adjustable and controllable. In the process of ecosystem management, information of constant feedback is collected from the dynamic ecosystem by means of monitoring and administration to control the activities and production modes in the controlled areas so as to maintain the optimum status of forest ecosystem management decision-making when the management objectives are fixed on the basis of the theory.

2.2 The Factors of Forest Ecosystem Management

Based on the theory of sustainable development, it is required that the objectives of forest ecosystem management be unified with economic objectives, social objectives and ecological objectives. The attainment of all these objectives, however, is affected by social factors, economic factors, physical environment factors, management factors, landscape factors, system productivity factors, etc. [22]. According to the theory of hierarchy-competence levels, feedback theory and cybernetics, it is revealed that the management objectives are the results integrated with these factors having their relevant impacts on the one hand, and in turn the objectives have effects on the selection of these factors on the other.

In this present study, the factors are categorized into seven groups as follows: Groups of management objective factors, socioeconomic factors, physical environment factors, management factors, landscape factors and system productivity factors. Group of management objective factors includes the factors: (1) economic objective, (2) social objective and (3) ecological objective. In group of socioeconomic factors, there are factors of: (4) the ratio between agricultural production value and industrial production value, (5) gross domestic product, and (6) policy, law and regulation. In group of physical environment factors, there are ten factors, i.e., the factors of: (7) annual average air temperature, (8) frostless period, (9) annual accumulated temperature, (10) annual precipitation, (11) altitude, (12) land feature, (13) aspect, (14) slope position and (15) vegetation type. Group of management factors consists of the factors of: (16) forest type, (17) investment per unit area, (18) amount of work per unit area, and (19) management measures. Group of landscape factors contains the factors of (20) landscape type and (21) landscape fragmentation degree. Included in group of system productivity factors are those of: (22) stocking volume per unit area, (23) growth increment per unit area, (24) input-output ratio and (25) employees' quality.

3 The Establishment of Interpretive Structural Model

A table of relationships among factors for forest ecosystem management (as shown in Tab. 1) is first established in the light of the factors for forest ecosystem management described in 2.2. In this table, if the element x_{ij} is 1, then this means Factor i has effect on Factor j, otherwise x_{ij} is 0. In step 2, an accessible matrix of all the forest ecosystem management factors as shown in Table 2 is obtained by means of computer operations. In step 3, the accessible matrix is divided into hierarchies, eliciting a distribution table of the layers and their factors in the ISM as presented in Table 3. In step 4, a figure of the ISM for forest ecosystem management decision-making (See Figure 1) has finally been developed on the basis of both Table 2 and Table 3 [23]. The results have systematically revealed the correlations among factors, thus laying solid theoretical bases and offering an excellent decision-making support for forest ecosystem management.

Table 1. The relationships among factors for forest ecosystem management

No. of Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	1	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
15	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
16	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
19	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0
20	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
25	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0

Table 2. The accessible matrix of forest ecosystem management factors

No. of Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0
5	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	1	1	0
6	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0
7	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
8	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
9	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
10	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
11	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0
12	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0
13	1	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0
14	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0
15	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
16	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
17	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	1	0
18	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	0
19	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0
20	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
21	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
22	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
23	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	1	0	0
24	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0
25	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1

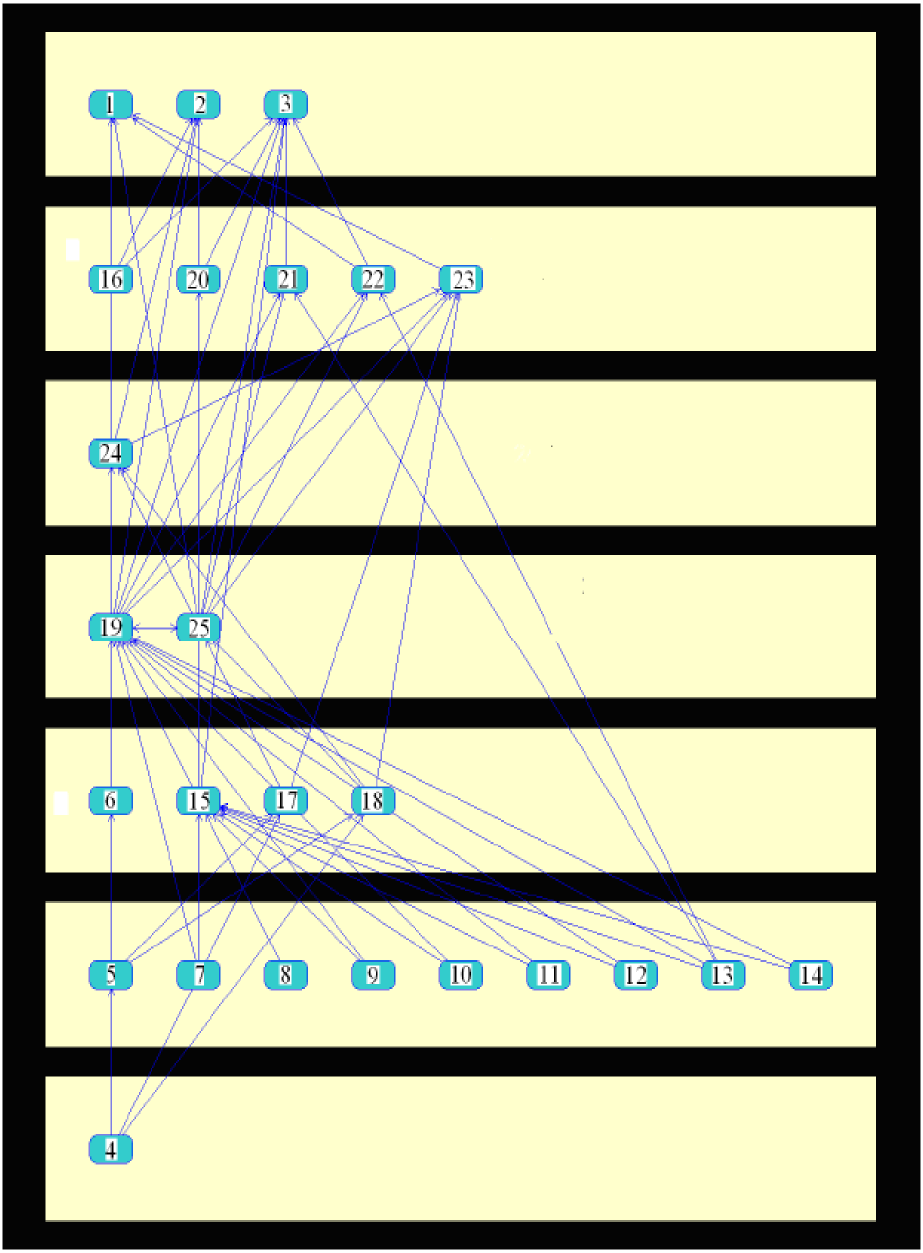

Fig. 1. The interpretive structural model for forest ecosystem management decision-making

No 1 to 25 represents the selected factors as follows: economical objective, social objective, and ecological objective as No 1, 2, 3; the ratio between agricultural production value and industrial production value, gross domestic product, and policy, law and regulation as No 4, 5, 6; annual average air temperature, frostless period, annual accumulated temperature, annual precipitation, altitude, land feature, aspect, slope position, and vegetation type as No 7, 8, 9, 10, 11, 12, 13, 14, 15; forest type, investment per unit area, amount of work per unit area, and management measures as No 16, 17, 18, 19; landscape type, and landscape fragmentation degree as No 20, 21; stocking volume per unit area, growth increment per unit area, input-output ratio, and employees' quality as No 22, 23, 24, 25 respectively.

Table 3. The layers and their factors in the interpretive structural model

Layers	Factors
VII (Top)	1, 2, 3
VI	16, 20, 21, 22, 23
V	24
IV	19, 25
III	6, 15, 17, 18
II	5, 7, 8, 9, 10, 11, 12, 13, 14
I (Bottom)	4

4 Discussion

(i) Forest ecosystem management decision-making is very complicated system engineering with multitudinous factors, including the environmental and socioeconomic factors outside of the system as well as the ones of its own. In stead of being isolated among them, all the factors are interwoven, interacted on and affected one another, they have been proved to be in various layers, and the factors in the lower layers dominate those in the higher layers, thus the factors in the lowest layer at the bottom are the most important and influential ones [24, 25].

(ii) Forest ecosystem is a multiple-objective management system [26], and its objectives include economic, social and ecological ones that compose the top layer of the ISM for forest ecosystem management decision-making.

(iii) The first layer at the bottom of the ISM consists of socioeconomic factor indicated by the ratio between agricultural production value and industrial production value. Since the ratio is one of important indices in socioeconomic development, it influences the values of a society greatly and the development trend of forestry as well. With the development of economy, people tend to require multiple demands including ecological ones from forestry rather than the traditional single need for timber. No longer should forestry pursue just economic benefits, therefore, it should pay more attention to social and ecological benefits instead [27].

(iv) The second layer from the bottom of the ISM consists chiefly of the factors of climatic environments that affect the distribution of forests [28] and produce the ecotypes of forests which, in turn, are the objects and bases of forest ecosystem management since different management measures should be taken according to different forest types. The factors are also the important factors for the division for forest ecosystem management while the division is a base of the ecosystem management. Consequently, the factors are selected in this layer.

(v) The third and the fourth layers are mainly composed of the factors of intensive management extent and management measures. Forestry production is implemented according to different types of the forest ecosystem management division, and relevant intensive management extents and measures are adopted to insure the realization of the objectives of forest ecosystem management. The factors as such are arranged in these two layers respectively.

(vi) The fifth layer is made up of the factor of input-output ratio that is also regarded as special one. Considering that an input-output ratio not only reveals how well a forest ecosystem is managed, but also affects the investment for the ecosystem management, the factor itself covers a layer. As the input-output ratio is proved to be an important factor that deals with whether forest ecosystem management is intensive or not, thus showing close effects on the factors in the sixth layer, the factor of input-output ratio is arranged in the fifth layer.

(vii) The sixth layer consists of both the factors of landscapes and productivity of a forest ecosystem. The types of a forest ecosystem are determined by the landscape factors, and every forest ecosystem type, in turn, has its own ecological service functions, whereas the productivity factors determine the degrees of realizing the system functions. As a result, the factors of landscapes and productivity are located at the top of the ISM as the seventh layer.

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