FORESTLAND CLASSIFICATION USING AN ECOSYSTEM APPROACH

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ABSTRACT:

This study focuses on using an ecosystem approach for forestland classification of the Liukuei Experimental Forest of Taiwan Forestry Research Institute. The content includes the delineation of ecosystem units using DTM, the development of a hierarchical ecosystem classification system using GIS and multivariate statistical analysis, the establishment of a forestland classification decision support system (DSS) and its application on site selection of a Taiwanese native species – Taiwania (*Taiwania cryptomerioides*). The results indicate that DTM is a fast, easy, feasible, and automatic approach for delineating ecosystem units of different spatial scales. The developed hierarchical ecosystem classification is a satisfactory scheme for Liukuei's forestland classification because the developed scheme coincides with the terrain characteristics along a continuum. The established DSS can effectively and feasibly analyze forestland classification under different spatial scales. Meanwhile, the system can easily perform site selection for Taiwania. From the results, it is concluded that techniques such as DTM, GIS, and DSS are useful for forest managers in the reasonable planning of forestland classification and management practice. In addition, the ecosystem approaches obtained from the Experimental Forest will be extended to island-wide forestland classification in Taiwan.

1. INTRODUCTION

There is a growing consensus that ecosystem management is essential to achieve desired future conditions of sustainable forests (Salwasser et al., 1992; Gregg 1994). The prerequisite process for ecosystem management is forestland classification using an ecosystem approach. To achieve forestland ecosystem classification, the determination of ecosystem units and the development of a hierarchical ecosystem classification scheme become important and necessary tasks. Several pieces of literature point out that watersheds can be treated as the basic ecosystem (Odum, 1969; Mather and Doornkanp, 1970; Omi et al., 1979; Lotspeich 1980), and there are two approaches for delineating watersheds: the manual and automatic approaches (O'Callaghan and Mark, 1984; Jenson and Domingue, 1988; Morris and Heerdegen, 1988; Cheng 1995). As for the hierarchical ecosystem classification scheme, several countries have proposed and implemented schemes for recognizing such scale levels (Salwasser, 1990). Among them, Miller (1978) proposed 1 scheme at 3 scales of perception (i.e., site, landscape, and ecoregion). Rowe and Sheard (1981) advanced a similar scheme. Bailey (1987, 1996) proposed a hierarchy of ecosystem units and suggested that there are 5 methods for identifying ecosystems: gestalt, map-overlay, multivariate clustering, digital-image processing, and control factors. For the controlling factor method, many possible primary factors are apparent, such as vegetation, soils, physiography, and watersheds.

In addition, the decision support system (DSS) that helps forest managers manage and assess forests has grown tremendously and is commonly used for many aspects of forest management, for example, to provide support in the complex process of problem formulation and task analysis; to make effective use of available data and knowledge bases; and to support rational use of the results (Bulger and Hunt, 1991; Jankowski, 1995; Mulder and Corns, 1995; Walker and Lowers, 1997; Reynolds, 1998; Rauscher, 1999; Varma et al., 1999). As for the DSS, Reynolds (1998) described how the USDA Forest Service Pacific Northwest Research Station in Corvallis, OR had developed an ecosystem management decision support (EMDS) system for ecological assessment. Varma et al. (1999) proposed a DSS using a combination of linear programming and GIS for formulating forestland use strategies to improve sustainability. Rauscher (1999) reviewed ecosystem management decision processes and the decision support systems available to implement them for federal forests in the United States.

In Taiwan, ecosystem management is greatly being emphasized currently, and the use of ecosystem classification to assist ecosystem management is underway. To establish this scheme as soon as possible, the Liukuei Experimental Forest of Taiwan Forestry Research Institute (TFRI) was chosen as a study site. The forestland classification of the Experimental Forest was originally finished in 1995 (Cheng, 1995). The method treated watersheds as an ecological unit and used multivariate statistical analysis for grouping watersheds. Although the method is better for understanding similarities and relationships among ecosystem, it is still limited because of manual delineation of watersheds and lack of a hierarchical classification scheme. For this reason, a further modification on the delineation of ecosystem units and the development of an ecosystem classification scheme are certainly needed. Therefore, this study focuses on using an ecosystem approach and techniques such as DTM, GIS and multivariate statistical analysis for forestland classification. Furthermore, the EMDS was applied to establish a forestland classification DSS for a case study of Taiwania site selection. The objective was to extend the forestland ecosystem approaches obtained from the

Experimental Forest to island-wide forestland classification in Taiwan.

2. MATERIALS AND METHODS

2.1 Study area and materials

The Liukuei Experimental Forest of the TFRI, located in Kaohsiung County of Taiwan (Figure 1), is divided into 25 forest compartments with a total of about 9616 ha. The major forest type is natural forest intermixed with a proportion of plantations, particularly Taiwania plantations. Elevations in this area range from 350 to 2400 m. The average annual temperature, rainfall, and relative humidity are 16-23 °C, 2150-3748 mm, and 71% -86%, respectively.

A digital terrain model (DTM) of the Liukuei Experimental Forest, located in the TFRI of Taiwan (Figure 1), was used as the material of this study. The resolution of each pixel is 40 m x 40 m. The DTM was used to derive 3 terrain data layers of elevation, slope, and aspect, and also to automatically extract watersheds, which are treated as basic ecosystem units. All 3 data layers were then incorporated into the GIS, which was applied to establish a hierarchical classification system. In addition, the EMDS system (Reynolds 1998) was used to integrate the database and the knowledge base in order to generate a forestland classification DSS. As for Taiwania site selection, soil data and a 1/5000-scale forest type map generated by digital photogrammetric techniques were also needed. In addition, the hardware used in this study included a PC computer, plotter, and color laser printer, and the software included ARC/INFO, ArcView, SAS, and EMDS.

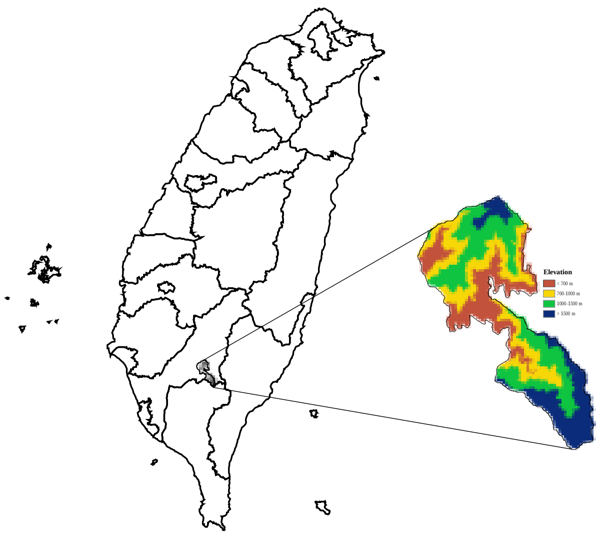

Figure 1. Study area and material of digital terrain model

2.2 Methods

To achieve the above objectives, the processes focused on the automatic delineation of ecosystem units using DTM, the development of a hierarchical ecosystem classification scheme using GIS and multivariate statistical analysis, the establishment of a forestland-classification DSS using the EMDS, and its application for Taiwania site selection.

2.2.1 Delineation of ecosystem units using DTM: Ecosystem delineation is a prerequisite for ecosystem classification. This study treated watersheds as the basic ecosystems and used the DTM to automatically extract watersheds as ecosystem units. Meanwhile, the watersheds extracted from different stream orders were regarded as ecosystems of different sizes. A computer program written in ARC/INFO AML (ARC Macro Language) was then developed for delineating watersheds. Two major steps were emphasized as follows.

2.2.1.1 Extraction of stream networks: In practice, the accuracy of extracted stream networks is correlated with the setting of a threshold value, which refers to the flow accumulation calculated from the DTM. There are several approaches for setting the threshold value (Montgomery and Foufoula-Georgiou, 1993). This study was based on previous studies (Cheng, 1993; Cheng et al., 2000) and used 400 as the threshold value to extract stream networks. Furthermore, each stream in the stream network was assigned a distinct number, and a numeric order using the Strahler method was given to assign the correct order for the watersheds after the watershed boundaries were delineated.

2.2.1.2 Delineation of watersheds: An automatic approach was used to extract watersheds in order to map ecosystem boundaries. However, one problem faced in this step was the delineation of different-sized watersheds for different ecosystem units. To overcome this, a modified automatic approach that differs from traditional automatic approaches was developed and implemented in this study. The approach is unique in its capability to automatically identify streams of different orders and to search for the outlets to watersheds using the stream networks extracted from the DTM.

2.2.2 Development of a hierarchical ecosystem classification using GIS and multivariate statistical analysis: To develop a hierarchical ecosystem classification, watersheds delineated based on streams of different orders were used to investigate spatial differences of the watersheds. Multivariate statistical analysis was then applied for grouping ecosystems according to their spatial similarities using SAS software. During the grouping process, the k-means approach of nonhierarchical clustering analysis was implemented for grouping smaller ecosystems into larger ecosystems, and cubic clustering criterion (CCC) was used for determining the optimal number of clusters. Meanwhile, only 3 data layers (i.e., elevation, slope, and aspect) were used as input variables for clustering analysis according to Cheng's (1995) research in the Liukuei Experimental Forest.

2.2.3 Establishment of a forestland classification DSS and its application on Taiwania site selection: The EMDS was used as a framework to establish a forestland classification DSS by integrating the above results of ecosystem classification with a GIS environment. During the process of establishing DSS, all GIS themes including different hierarchical ecosystems were first constructed as a database. Then the knowledge bases that describe relations among ecosystem states and processes of interest (e.g., forestland productivity) were also constructed. In this step, the truth value representing the basic state variable was applied to express an observation's degree of membership, and evaluations of degree of set membership were quantified in the semantics of fuzzy logic.

A case study concerning the Taiwania site selection was implemented for a demonstration of a forestland classification DSS. In this part, topographic factors (e.g., elevation and slope) and soil factors (e.g., soil texture and soil suitability) were assumed to be the main factors influencing the Taiwania habitat according to the management plan of the Liukuei Experimental Forest (TFRI, 1992). As for membership representation, soil texture focuses on moderate texture (e.g., sandy loam, silty loam, sandy clay loam, clay loam, and silty clay loam), and the other data are based on fuzzy arguments and standardized as 1 to -1, where 1 means the environmental condition is completely suitable for the Taiwania; -1 means completely not suitable; and the open interval (-1,1) means partially suitable. In addition, this case study only applied 1st-order watersheds for Taiwania site selection because the site selection was regarded as a forest management practice on a small scale.

3. RESULTS AND DISCUSSION

3.1 Delineation of ecosystem units using DTM

Figure 2 depicts stream networks extracted using 400 as the threshold value and the result of encoding streams with different orders according to the Strahler method. Figure 3 shows the result of delineating watersheds by specifying different stream orders as the minimum order. It is apparent that 4 different kinds of watersheds can be delineated in response to the need to consider watersheds of different sizes. The result shows that watersheds derived from different stream orders coincide very well with the distribution of the stream network when these two maps are overlaid together. Moreover, the number of watersheds varies with different stream orders, and the number of watersheds decreases as the stream order number increases. From the delineation of watersheds, it is obvious that the Experimental Forest cannot accept a stream order number that is higher than 2, because the upper part will disappear. Therefore, this study used 2nd watersheds to study their spatial differences and to develop the hierarchical ecosystem classification.

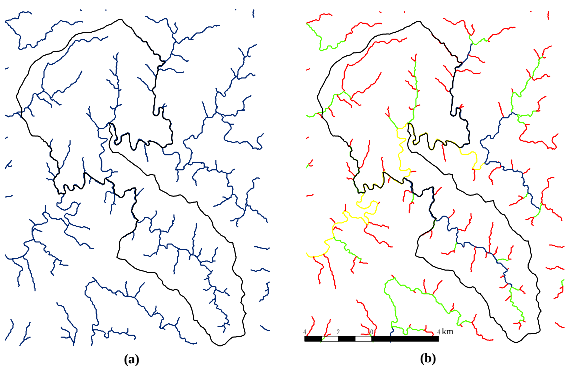

Figure 2. Extraction of stream networks. (a) Delineating stream networks. (b) Encoding stream networks. Red, green, blue, and yellow represent 1st, 2nd, 3rd, 4th order streams, respectively

This study adopted the use of watersheds as the basic ecosystem unit. However, there are several problems encountered when dealing with watershed delineation because different criteria and algorithms will generate different watershed maps for the same area. In addition, the map scale is an important factor affecting the delineation of watershed boundaries because the patterns of ecosystem boundaries on various maps may differ (Bailey, 1996). This study did not have a problem with this because the DTM with 40 m x 40 m resolution for each pixel was used for watershed delineation. No matter who delineates the watershed boundaries, the result will be the same when applying the extraction algorithm as proposed in this study. This is the reason why this study treats the watershed as a basic ecosystem unit and uses DTM for ecosystem delineation.

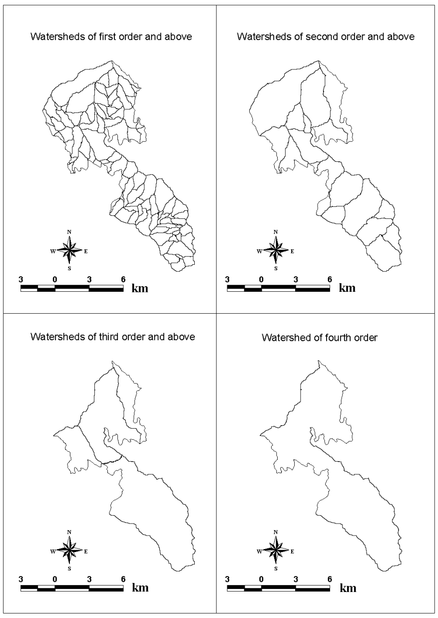

Figure 3. Delineation of watersheds based on different stream orders

3.2 Development of a hierarchical ecosystem classification using GIS and multivariate statistical analysis

Figure 4 shows the result of a hierarchical ecosystem classification using 2nd watersheds. It is clear that the Experimental Forest was classified into 3 different clusters (or zones) based on 3 data layers. The result is quite satisfactory because the distribution of the clusters coincides with the terrain characteristic and varies along a continuum. For example, the 1st cluster is located in the downstream area of lower elevation and slope, while the 3rd cluster is located in the upper stream area of higher elevation and slope. The result indicates that the Experimental Forest can be geographically divided into 3 large ecosystems if Miller's scheme of 3-scale perception (i.e., site, landscape, and ecoregion) is applied in this study.

As mentioned previously, ecosystems exist at multiple scales. Several countries have proposed and implemented schemes for recognizing such scale levels. In this study, a 3-scale scheme similar to Miller's approach (Miller, 1978) was implemented although more levels were suggested by previous literature. Therefore, the Liukuei Experimental Forest has 3 landscapes mosaics, and each landscape mosaic is composed of different sites. This scheme, proposed in this study on the basis of a hierarchical ecosystem classification system, looks satisfactory.

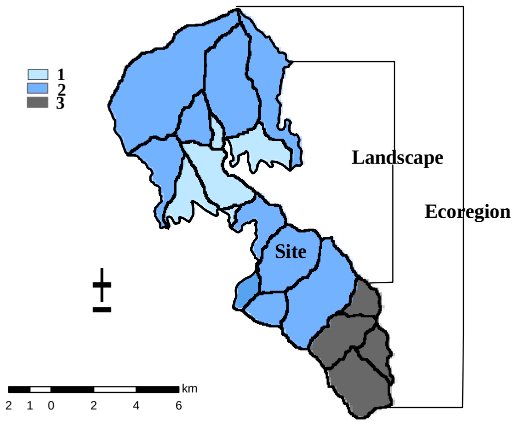

Figure 4. Hierarchical ecosystem classification of the Liukuei Experimental Forest

3.3 Establishment of a forestland classification DSS and its application on Taiwania site selection

A forestland classification DSS was established by integrating ecosystem classification with the EMDS framework. The system was then used for Taiwania site selection. Figure 5 is the output of site selection for Taiwania. If the result of Taiwania site selection is superimposed on and compared with actual Taiwania plantations derived from the forest type map, it can be seen that most northern areas in the study area match quite well, but the southwestern areas show much great differences. For example, more suitable areas with potential for Taiwania have no actual distribution of this species. From this case study, it is obvious that forest managers can easily apply this established forestland classification DSS for Taiwania site selection.

Although the established system performs well, there are still some problems with respect to the assignment of membership and the analysis unit. For example, the determination of the truth value needs further research and the result using different analysis units will differ. On the other hand, more suitable areas with potential for Taiwania have no actual distribution of this species, the reason may be that the southeastern area is connected to a natural reserve, and there is no forest road access.

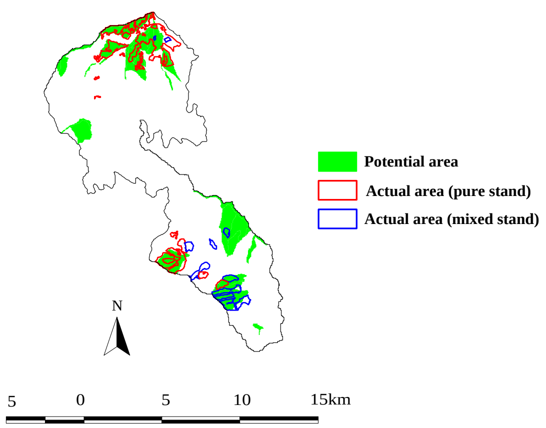

Figure 5. Comparison between potential area and actual area for Taiwania site selection

4. CONCLUSIONS

Forestland classification using an ecosystem approach is a prerequisite process for ecosystem management. This study applied DTM, GIS, and multivariate statistical analysis to classify forestland of the Liukuei Experimental Forest into different ecosystems and to form a hierarchical ecosystem classification system. Then the hierarchical ecosystem classification was integrated into the EMDS to become a forestland classification DSS which was used for a demonstration of Taiwania site selection. The conclusions are as follows. (1) The ecosystem delineation using DTM is a fast, easy, feasible, and automatic approach. (2) The developed hierarchical ecosystem classification using GIS and multivariate statistical analysis is a satisfactory scheme because the developed scheme coincides with the terrain characteristics along a continuum. (3) The established DSS can effectively and feasibly analyze forestland classification under different spatial scales, and easily perform site selection for Taiwania.

Conclusions obtained from this study imply that techniques such as DTM, GIS, and DSS are useful for forest managers in the reasonable planning of forestland classification and management practice. Also, it is essential to understand the relationship between ecosystem hierarchies and management hierarchies because if management hierarchies and ecosystem hierarchies are well correlated, management strategies will work better and form a more-consistent and efficient management process. Therefore, further challenge is that forestland ecosystem classification approaches obtained from the Experimental Forest will be extended to island-wide forestland classification in Taiwan, in addition to integrate ecosystem hierarchies and management hierarchies.

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