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A Composite Index Hierarchical Assessment of Forest Ecosystem Health: An Example of Pinus Tabulaeformis

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Abstract. Assessing forest ecosystem health is an effective way for forest resource management. Taking as an example Pinus tabulaeformis, a superior afforestation species in northern China, this study establishes a forest health assessment model and a three-level indicator system using the analytic hierarchy process. The results showed that Pinus tabulaeformis forest health is proposed for evaluation into four grades by composite index (HI), ill-health forest was 48.39% among the sample plots, and average HI was accounted for 25% of healthy forest. So Pinus tabulaeformis forest ecosystem was in development stage; additionally, at an altitude of 1500 ~ 1800 m, slope 35 ~ 40 °, Pinus tabulaeformis forest were the most healthy in western Qinling Moutain. Forest community stability change with altitude is evident unimodal curve form, stability is a downward trend when the elevation and slope is too low or too high. This evaluation indicator system is suitable for extending its application in forest health judgment. The evaluation results have certain guiding significance for regional forest management and nurturing.

Keywords: Forest health management, indicator system, Chinese pine

1 Introduction

In recent decades, rapid economic development, substantial population growth, and continuous improvement of people's living standards have led to increasing demands for forest products such as timber. Due to extensive deforestation, there are dramatic decreases in the biodiversity in forest ecosystems, continuous degradation of forest-associated eco-environment, and significant declines of forest ecosystem services; together with the frequent occurrence of natural disasters result in different degrees of forest degradation in many countries of the world [1] [2]. Therefore, effective management of forest resources has become a tough issue raised in forestry [3] [4]. In this context, forest health assessment is developed as an effective way for forest research management [5] [6].

In the 1990s, scholars started to monitor and assess the health condition and variation patterns of forest ecosystems in the United States [7]. A number of studies established specific assessment indicator systems for assessing forest health based on long-term monitoring projects [5] [6]. In China, forest health assessments have been reported since the 2000s [8] [9]. However, there remains great difficulty in accurate

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forest health assessment due to the complexity of forest ecosystems [1] [3]. Additionally, applications of the existing assessment methods in practice are largely limited due to their high specificity and involvement of various indicators [10]. Because of a lack of reliable and uniform assessment standards, research on the theory and methodology of forest health assessment is still in an exploratory stage [11].In view of the above issues, we carry out a forest health assessment for P. tabulaeformis in a mountainous forest area of Xiaolong Mountain, Gansu, northwestern China. The results will provide valuable reference data for rational forest management.

2 Plot design and field survey

Plot design and field survey for the forest area of Xiaolong Mountain (104°22'-106°43' E, 33°30'-34°49' N) is part of the west Qinling Mountains in southeast Gansu Province, China (Fig. 1). Thirty-one sample plots (20 m × 30 m) were set in the major distribution areas of Pinus tabulaeformis (Longmen, Liziyuan, Mayan, and Baihua Forest Farm in Xiaolong Mountain) by considering different altitudes, slope directions, slope positions, and forest types. In each plot, five sub-plots were respectively set for the shrub (2 m × 2 m) and herb layers (1 m × 1 m). After transported to the laboratory, the shrub and herbaceous samples were oven-dried at 80°C to constant weight and then weighed to calculate the biomass [12] [13]. For shrub species, the total biomass of all shrubs in a stand was taken as the stand shrub biomass [14]. Water contents of the main roots, lateral roots, stem, branches, and leaves were determined for a standard shrub species and then used to calculate the dry weights (biomasses) of individual organs [15].

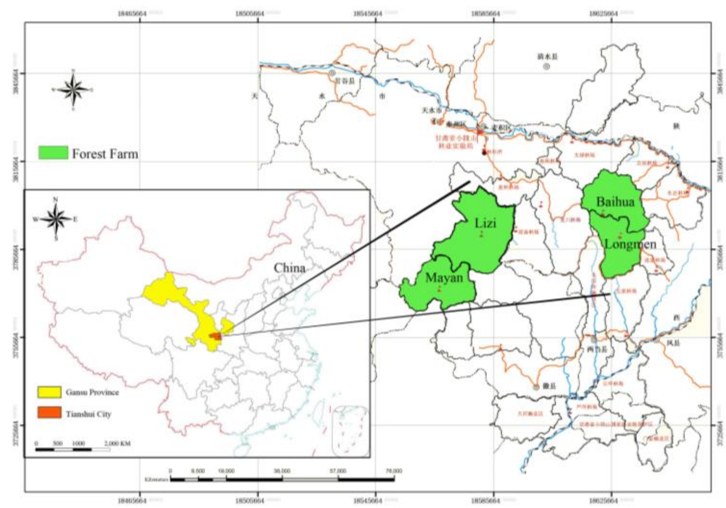

Fig. 1. Location of the study area in Xiaolong Mountain, Gansu Province, China.

Health assessment model is established based on the analytic hierarchy process. The comprehensive index assessment model is expressed as follows:

$$HI = S\sum_{i=1}^{5} S_i W_i + D\sum_{j=1}^{4} S_j W_j + T\sum_{k=1}^{3} S_K W_k$$

Where HI is the composite health index for Pinus tabulaeformis forest stand; S, D, T, is the criterion layer weighted value of the stand vigor, stand structure, system stability; W_i, W_j, W_k, is the index layer weighted value of the each contestant indexes; S_i, S_j, S_k, is the standardized value of the index layer.

3 Analysis on Forest Health Assessment

Establishment of forest health assessment model and a three-level indicator system using the analytic hierarchy process (Tab. 1).

Tab. 1 The weighted value of forest assessment hierarchical indicator

Target (A)	Item (C)	Weight Value	Index (I)	Weight Value
Pinus tabulaeformis forest ecosystem health assessment (A)	Stand vitality (C_1)	0.0936	Mean tree height (I_1)	0.0076
			Mean breast-height diameter (I_2)	0.0144
			Mean crown width (I_3)	0.0044
			Tree volume (I_4)	0.0432
			Shrub - herb biomass (I_5)	0.0240
	Stand structure (C_2)	0.6267	Stand density (I_6)	0.3393
			Canopy density (I_7)	0.0954
			Shrub - herb coverage (I_8)	0.0471
			Species richness (I_9)	0.1450
	System stability (C_3)	0.2797	Stand age (I_{10})	0.1782
			Number of stand layers (I_{11})	0.0293
			Number of seedling regenerated (I_{12})	0.0722

Composite index (HI) of Pinus tabulaeformis forest weighted by multiple factors, the results were randomly distributed between 0 ~ 1, according to the actual of Xiaolong moutain forest area, to take equidistant method, the HI of Pinus tabulaeformis is divided into four grades (Fig. 2). The forest health composite index (HI) relations with elevation and slope was in Fig. 2.

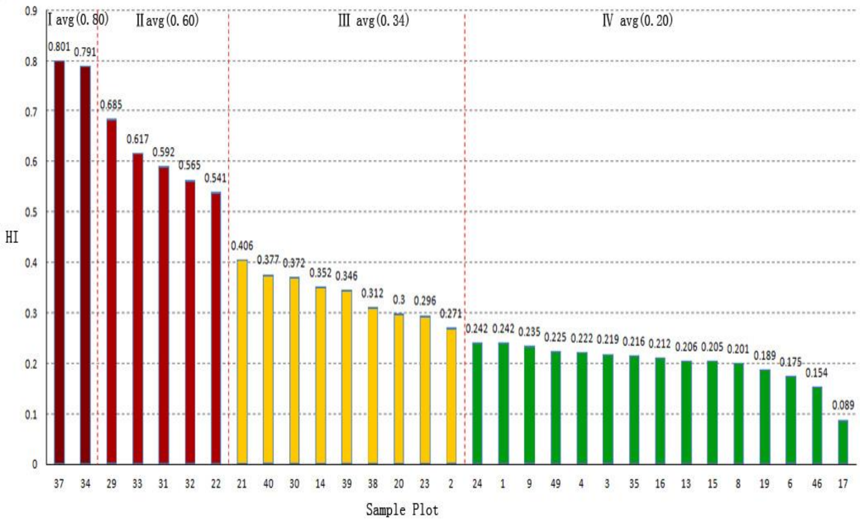

Fig. 2. Classification for the comprehensive evaluation index of Pinus tabulaeformis forest

I Health (HI＞0.75), including 2 sample plots, plot 37 (HI=0.801) , plot 34 (HI=0.791) respectively， $\overline{HI}$ =0.80；

II Good health (0.5-0.75), including 5 sample plots, were plot 29 (HI=0.685), plot 33 (HI=0.617), plot 31(HI=0.592), plot 32 (HI =0.565), plot 22 (HI =0.541), $\overline{HI}$ =0.60, accounting for 75% of the average healthy forest;

III Poor health (0.25-0.5), including 9 sample plots, were plot 21 (HI=0.406), plot 12 (HI=0.377), plot 30 (HI=0.372), plot 14 (HI=0.352), plot 39 (HI=0.346), plot 38 (HI=0.312), plot 20 (HI=0.300), plot 23 (HI=0.296), plot 2 (HI=0.271), $\overline{HI}$ =0.34, accounting for 42.5% of the average healthy forest;

Ⅳ Ill-health (0-0.25), including 15 sample plots, were plot 24 (HI=0.242), plot 1 (HI=0.242), plot 9 (HI=0.235), plot 49 (HI=0.225), plot 4 (HI=0.222), plot 3 (HI=0.219), plot 35 (HI=0.216), plot 16 (HI=0.212), plot 13 (HI=0.206), plot 15 (HI=0.205), plot 8 (HI=0.201), plot 19 (HI=0.189), plot 6 (HI=0.175), plot 46 (HI=0.154), plot 17 (HI=0.089), $\overline{HI}$ =0.20, accounting for 25% of the average healthy forest.

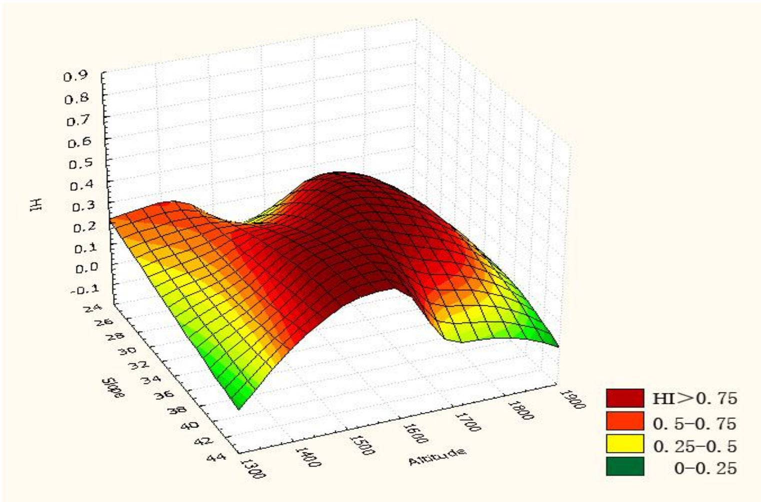

Fig. 3 Forest health composite index relations with elevation and slope

The results show that the most healthy Pinus tabulaeformis forest were at an altitude of 1500 ~ 1800 m, slope 35 ~ 40 °in western Qinling Moutain (Fig. 3). Forest community stability change with altitude is evident unimodal curve form, stability is a downward trend when the elevation and slope is too low or too high, which showed that the habitat conditions determines the forest community stability.

4 Conclusion

This study with a composite index (HI) is proposed for evaluation of Pinus tabulaeformis forest health into four grades, ill-health forest was 48.39% among the sample plots, and average HI was accounted for 25% of healthy forest. So Pinus tabulaeformis forest ecosystem was in development stage.

This study proposes a three-level model for forest health assessment using the AHP process, which enables the whole system analysis by sorting the quality grades of relevant indicators. All the indicators used in the model are parameters commonly used for forest stand survey. The convenience of raw data collection through sample plot survey helps to determine the numerical range and quality grade of each indicator. According to the theory of ecology, the structure of forest ecosystems determines their functions; optimal structure and potential function of forest ecosystems are largely controlled by the quality of forest site while closely related to forest management measures. To establish healthy forests and achieve the best ecosystem services, proper operation measures should be taken for adapting forest structure to the siting potential and functional requirements, ultimately obtaining the uniform of site condition, forest structure, system function, and operational management.

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