A New Perspective of Trees Competition Network Research

Shaohua Wang¹, Ting Yang¹, shengxiang Ouyang²

¹University of Arts and Science, Changde 415000, China.
²Changde Forestry Science Research Institute, Changde 415000, China.

Abstract: Forest competition is a key factor driving forest dynamics and stand structure, and is one of the core issues in ecological research. Competition is a complex ecological process with temporal changes, which is interrelated and affected with forest growth, stand structure dynamics and environmental changes. Although there have been many researches on competition, tree growth, stand structure and climate, the interactions among trees have been studied by static competition index measurement, which usually lacks temporal variation related to natural forest development and environmental conditions, and the response mechanism and related theory of competition to stand development and environmental fluctuation have been studied insufficiently.(2) Single tree competition index model;(3) Interaction between tree competition and tree growth, stand structure and environment;(4) Tree competition based on complex network. Finally, according to the complex interaction of tree competition, the research strategy of tree competition network structure with "single tree" as node and "single tree competition relationship" as edge is discussed, in order to provide reference for the study of tree interaction and forest ecosystem dynamics.

Keywords: tree competition; competition network; stand structure; environmental response.

1. Introduction

Forest plays an important role in the process of human history and civilization, and plays an extremely important and irreplaceable role in maintaining biodiversity, protecting ecological environment, mitigating natural disasters, regulating global carbon balance and biogeochemical cycle. Tree individuals are an important part of forest ecosystem, and their growth is affected by many external factors besides their own genetic factors. Competition and coexistence among tree individuals is always a core problem in ecological research. Community structure formation, productivity formation, system stability and community species diversity maintenance are closely related to this problem. Competition among plants refers to the interaction between two or more plants competing for the same environmental resources and energy. Competition directly causes differences in tree growth and shape, and is a key factor driving forest growth and stand structure dynamics. Forest structure reflects individual trees (structural elements) and their attributes Forest structure is the basic unit of forest structure, a comprehensive reflection of forest development process, an important factor in forest management and analysis, and a specific object of forest management activities[1]. As a component of stand structure, microenvironment of individual tree affects the future development of individual tree. Therefore, it is an important technical means of structured forest management to quantify microenvironment of individual tree based on adjacent tree relationship and analyze and study microcharacteristics of stand spatial structure. In the forest complex network structure composed of "individual tree-adjacent tree relationship", tree competition is the main driving force of forest community dynamics, affecting tree growth, stand productivity and stand structure. Some scholars often use interspecific and intraspecific competition index to understand tree interaction[2-4]. Meanwhile, tree growth dynamics, stand structure and external environment also have corresponding influence and restriction on tree competition effect.

In recent years, forest competition is mainly studied by static competition index measurement, which is usually used to analyze and evaluate the competition relationship of trees. This measurement usually lacks temporal changes related to natural forest development and environmental conditions, and the research on forest competitiveness is still mainly concentrated on the construction of index system based on adjacent tree relationship, staying at the level of static rating. Therefore, it is urgent to establish a dynamic theoretical framework of forest competitiveness according to the structural characteristics of natural forest, which is the main body of forest ecosystem, so as to provide new ideas and perspectives for the study of forest competition. This paper reviews the characteristics of the relationship between tree competition and stand spatial structure and
its related theoretical studies, mainly including the following aspects: (1) parameters of stand spatial structure; (2) competition index model of individual tree; (3) interaction response relationship between tree competition and tree growth, stand structure and environment; (4) tree competition based on complex network. Finally, the paper discusses the research strategy of tree network structure with "individual tree" as node and "competition relationship between individual trees" as edge, aiming at the complex interaction of tree competition, so as to provide reference for the study of tree interaction and forest ecosystem dynamics.

2. Characteristics and theories of the relationship between forest competition and stand spatial structure

Forest competition is a complex interaction, which directly causes differences in forest growth and characters, and is a key factor driving forest growth and stand structure dynamics, while forest growth dynamics, stand structure and environmental changes also have corresponding effects and constraints on forest competition effects. Network-based analysis is becoming one of the main trends in the study of interactions between biological communities and individuals. However, it has been neglected in the study of vegetation competition.

2.1 Stand spatial structure parameter

Stand microenvironment can reflect the size, distribution, species and extrusion of adjacent trees around the forest, reflecting the microscopic characteristics of the spatial structure of the forest, so scientific and accurate quantification of the microenvironment of individual trees is very important in structured forest management. Hui Gangying proposed a method based on the relationship between adjacent trees to accurately quantify the microenvironment of trees, In structured forest management, angular scale is used to adjust the spatial distribution pattern of forest stand in order to increase the randomness of trees; in order to increase the diversity of tree species, the isolation degree of trees is adjusted by mixing degree; in order to enhance the competitiveness of target trees, the competition relationship of tree species is adjusted by size ratio, and in order to increase the nutrient space of target trees, the crowding degree of trees is adjusted by density.

2.2 Single tree competition index model

Competition among trees is an important part of forest spatial structure [5]. Competition degree among trees is generally expressed by competition index. Competition directly causes differences in tree growth and shape, and competition index quantitatively describes competition among trees, formally reflects the relationship between individual growth and living space of trees, and essentially reflects the demand of trees for environmental resources and the competitive pressure they bear when fighting for environmental resources. Since 1960s, foreign scholars have put forward competition indexes related to distance and unrelated to distance, among which Hegyi competition index is the most widely used. On this basis, Chinese scholars have put forward some improved competition indexes. However, most of these competition indexes only consider unilateral or bilateral factors.

2.3 Interaction among competition, growth, stand structure and environment

Competition is a key factor driving forest dynamics and forest structure during stand development. Competitive indices calculated from competitive trees within a certain range can simulate the growth process of target trees at different time intervals. At the same time, continuous growth of trees regulates stand development, stand productivity and interactions within tree populations.

(1) Competition index is the basis of establishing individual tree growth model, and its quality directly affects the effect of individual tree growth model. Bhandari (2021) compared the validity of different competition indices in growth prediction models, and the results were consistent with those of other scholars. During these studies, scholars believed that changes in inter-tree distance and individual plant size led to changes in competition intensity and its impact on growth, which may be one of the reasons why competition indices had a significant impact on growth prediction [6].

(2) In the aspect of competition and stand structure, Chinese scholars analyzed the correlation between competition and stand density, DBH structure, tree height and crown width. Forrester found that interactions between tree species did not occur or were weak in low-density stands, while interactions between tree species occurred more frequently as stand density increased. Competing understory vegetation could also exert control over tree growth at early stages of stand development. Scholars found that competitive effects increased faster in dense stands and were exacerbated by lower water availability [7].

(3) In terms of competition and environmental factors, Roux [8] believes that climate change may affect individuals interacting with species by studying changes in vegetation interaction along two environmental gradients. Temporal fluctuations in the environment can change interactions between adjacent tree individuals [9], thus affecting the competitiveness of trees [10]. Understanding how competition evolves over time is therefore crucial to assessing forest dynamics under changing environmental conditions. Some scholars suggest that competition may be negatively correlated with climatic conditions affecting tree growth [11]. Other studies have found that tree growth and competition effects are highly dependent on local climatic conditions [12]. Therefore, competition effect of trees changes dynamically with stand growth, and competition pressure between target trees and competing trees may not be constant with time due to environmental changes. Although competition effect of adjacent trees on stand dynamics has been paid more and more attention, the
response of competition to environmental fluctuations and stand growth has not been fully explored.

2.4 Competition of Trees Based on Complex Networks

In recent years, network-based analysis is becoming one of the main trends in the study of interactions between biological communities and individuals[13]. Complex network theory has become a new perspective and new idea to reveal various ecological processes, but this method has been neglected in the study of plant competition for many years. Nakagawa[14] used complex network analysis to reveal some basic characteristics of individual competition in the same age stand of Abies curioies; The role of individual nodes in networks (and their removal) has been examined in studies of environmental dependence and plant interactions[15]. Vazquez showed that the intensity of interspecies interactions has a significant impact on the structure and dynamics of ecosystems. Mongus proposed a new approach based on complex networks, which enables higher precision prediction of future growth of individual trees by conceptually incorporating complex network theory into a structured representation of tree competition. Comprehensive analysis shows that tree competition is a key factor driving forest dynamics and stand structure, and is one of the core problems in ecological research. Competition is a complex ecological process with temporal changes, which is interrelated and influenced by tree growth, stand structure dynamics and environmental changes. Although studies on competition, tree growth, stand structure and climate have been carried out, the interactions between trees have been studied through static competition measures, which usually lack temporal changes related to natural forest development and environmental conditions, and the response mechanisms and related theories of competition to stand development and environmental fluctuations are insufficient.

3. Research prospects

3.1 Construction of Structured Forest Competition Network

The driving forces for the formation of structured stand networks were analyzed as shown in Figure 1. According to the spatial structure characteristics of the stand, a structured stand network was constructed by taking individual trees as nodes and "competition relations between individual trees" as edges connecting nodes. The microstructure of the structured stand competition network was studied from three aspects: individual state of trees (nodes), competition relations among trees (relations) and environment (resources) in which trees were located. The structural characteristics and linkage mechanism of structured stand network were revealed by analyzing the formation mechanism of structured stand network.

3.2 Construction of Forest Competitiveness Model Based on Dynamics

The paper analyzes the inherent mechanism and model characteristics of maintaining the structure characteristics of stand competition network, and quantitatively analyzes the spatial structure of stand competition network based on the node "point elements" and the relationship "edge elements" of connecting nodes, as shown in Figure 2. The nodes in the network represent the characteristics and functions of individual trees, and the edges represent the competition relations and intensities of adjacent trees. The state of the whole network is driven by a set of nonlinear parametric equations. By constructing a parametric function f such that $x_{n} = f_{n}(l_{n}, l_{col[n]}, X_{ne[n]}, l_{ne[n]})$, where $l_{n}, l_{col[n]}, X_{ne[n]}, l_{ne[n]}$ represent the characteristics of the current node, the edges of the node, the characteristics and functions of the adjacent nodes, respectively. In this undirected graph, the edges of the nodes are represented by adjacency symmetric matrices, and the relationships between all nodes are represented by adjacency matrices. At the same time, the concept of competition field of structured stand network is put forward, that is, the field formed by the definite force (attraction or repulsion) produced by single tree in stand network to adjacent trees in different positions in space. The competition field is divided into scalar competition field and vector competition field. The core elements and structural characteristics of competition field of structured stand network are analyzed and discussed. The static elements and dynamic elements in competition field of network are analyzed and discussed.

![Fig.1 The driving force behind the formation of structured forest stand networks](image)

![Fig.2 The spatial structure and adjacency matrix of the "node edge" network in forest stands](image)
3.3 Environmental Dynamic Response of Structured Tree Competition Network

The inherent mechanism and characteristics of structured tree competition network responding to environmental dynamics were analyzed and discussed. By collecting and pretreating the standing tree core samples, measuring the annual ring width and bark thickness of the samples, analyzing the radial growth and its annual variation in combination with the stand spatial characteristic indexes obtained from each tree scale of the sample plot, reconstructing the stand spatial structure in different years, analyzing and discussing the response and variation characteristics of the reconstructed stand spatial structure with time and environmental fluctuation in combination with the environmental factor indexes of the corresponding years. By analyzing and discussing the static and dynamic elements in multi-layer temporal competitive network, the fluctuation characteristics of forest competitive network model with multi-layer temporal network structure with time and environment were studied, which provided reference for the study of competition response to environmental fluctuation and forest growth.

To sum up, this paper looks forward to the construction of structured forest competition network and the research of forest competitiveness model based on dynamics theory. According to the microstructure characteristics and link mechanism of structured forest competition network, it is expected to reveal the mode and characteristics of structured forest competition network. At the same time, based on the data of tree core samples, the spatial structure of stand was reconstructed, and the environmental factors were combined to reveal the dynamic response mode and characteristics of multi-layer time-series stand network competition field to the environment, which provided a new idea and perspective for the study of tree competition, and had important significance for further developing the theory and application research of tree growth prediction, stand structure adjustment and biodiversity protection.

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References