Jour. Korean For. Soc. Vol. 97, No. 5, pp. 501~507 (2008)

JOURNAL OF KOREAN FOREST SOCIETY

Individual-based Competition Analysis for Secondary Forest in Northeast China

Fengri Li*, **Dongsheng Chen and Jun Lu**

School of Forestry, Northeast Forestry University, Harbin 150040, P. R. China

Abstract : The data of crown width with 4 directions, DBH, tree height, and coordinate for sample trees were collected from 30 permanent sample plots in secondary forest of the Maoershan Experimental Forestry Farm, Northeast China. In this paper, the competition of individual trees in stand were discussed for secondary forest by using iterative Hegyi competition index and crown overlap index that represented the competitive and cooperative interactions among neighboring trees. Active competitors of subject tree in the competition zone were selected to calculate the iterative competition index. Using the results of crown classification based on the equal crown projection area, a new distance dependent competition index called crown overlap index (*COI*) was developed for secondary forest. The *COI* performed well in describing the crown competition rather than crown competition factor (*CCF*). The individual-based competition index discussed in this paper will provide more precise for developing individual tree growth models for secondary forest and it can also use to adjust the stand structure for spatial optimal management.

Key words **:** *iterative hegyi competition index, crown class, crown overlap index, competition zone radius*

Introduction

Growth of individual trees on particular sites is influenced by a number of factors such as age, size, genetic characteristics, micro-site conditions and competition for light, water, and nutrients (Tome and Burkhart, 1989). However, competition occurs when resources requirements of plants are overlapped. It is generally agreed that competition is a factor which means the interaction between two or more plants competing for a certain resources and energy in same region (Zhang and Xu, 2001). Competition from neighboring plants is one of the most important biotic factors limiting plant growth. Often, larger plants have a disproportionately larger effect in competition, suppressing the growth of their smaller neighbors (Begon, 1984; Weiner, 1990).

Inter-tree competition implies that resource supplies are insufficient for supporting optimal growth of two or more trees. The effect of inter-tree competition on individual tree growth is very difficult to quantify. Individual tree growth model performance can be improved by knowing how growth varies at different levels of competition (Holmes and Reed, 1991). Since 1960s, many competition models were developed for individual tree to reflect the relationship between trees and living space (Biging *et al*., 1992). Many studies have compared indices to determine which index best expresses competition for a given species and stand type (Lorimer, 1983; Daniels *et al*., 1986). Some indices representing competition have been developed and incorporated into individual tree growth models (Ek and Monserud, 1974; Wensel *et al*., 1987; Davis and Johnson, 1987).

Competition indices can be divided into three general categories: (1) influence zone overlap, (2) growing space, and (3) size ratio. The influence zone of competition is the basis for many inter-tree competition indices (Gerrard, 1969; Opie, 1968; Bella, 1971; Arney, 1973; Ek and Monserud, 1974). Staebler's index measured the overlap area by using maximum radial width of subject tree's crown (Daniels, 1976). Area overlap introduced by Gerrard (1969) summed the area of competitor overlap regions. While the majority of these comparison studies were conducted in even-aged stands for intolerant species, only a few studies have been conducted in mixed species stands (Gerrard, 1969; Lorimer, 1983; Ek and Monserud, 1974).

In Northeast China, the most of the primary forests have disappeared and secondary forests have become the major forest due to extensive cutting and other human-disturbances. The area of secondary forest accounts for more than fifty percentage of total forest in this region (Li, 1992; Zhu and Liu, 2007). In order to develop individual tree growth models and adjust silvicultural thin-

*Corresponding author
E-mail: fengrili@hotmail.com

ning or harvest treatments, it is necessary to examine individual tree's competition indices for typical secondary forest in Northeast China. The objective of this study is to develop a new crown overlap index to describe the competition between individual trees for secondary forests.

Materials and Method

1. Study area

Data for this study were collected from natural hardwood-mixed stands of secondary forests in Maoershan experimental forest farm of Northeast Forestry University. The research sites are located in Shangzhi City, Heilongjiang province (127°30′ E~127°34′ E, 45°20′ N~45°25′ N). The elevation of the region varies from 300 to 800 m above mean sea level. Most of this region is located in a temperate seasonal wind climate zone. The average annual temperature is about 2.8°C. In winter, the average January temperature is -19.7°C, while for July, in summer, it is 20.9°C. The average annual precipitation is about 723.8 mm. Soil in this area is dark brown forest soil, and it is loam in texture.

The main forest type in this region is *Poplar-Betula* forest, precious hardwood forest, and other hardwood-mixed forest. The major broadleaved species are *Betula platyphylla*, *Tilia amurensis*, *Betula costata*, *Juglans manshurica*, *Phelodondrom amurense*, *Acer mono*, *Fraxinus mandshurica*, *Poplar* spp., *Ulmus* spp., and *Quercus mongolica*. Other conifer forests are plantation. The area of secondary forests is 89.3% of total forest area (22500 ha).

2. Field measurements

In the summer of 2007, 30 sample plots, representing the most of forest types in this region and different stand conditions such as site, density, and elevation, were established with different size ranged from 0.1 ha (20 m×50 m) to 0.21 ha (30 m×70 m) (Figure 1). The elevation varies from 300 m to 600 m, and stand density ranges from 400 ha^{-1} to 1800 ha^{-1}. All trees in the plots were measured for DBH, tree height, height to crown base, and crown radius (four directions: East, South, West and North) and then stem-mapped by relative coordinates (takes plot M702 as example, Figure 2). The aggregation index (Clark and Evans, 1954) for the uniformity of the spatial distribution is 0.6059, indicating a clustered spatial pattern.

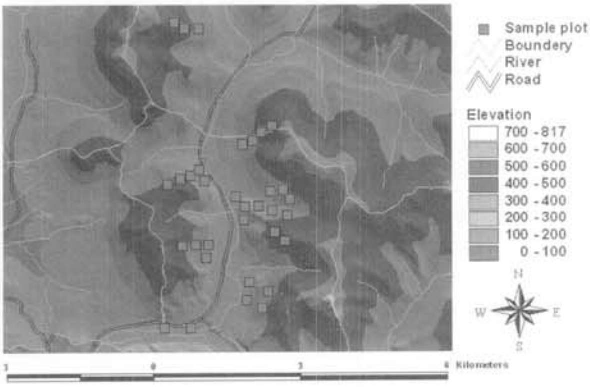

Figure 1. Location of 30 sample plots.

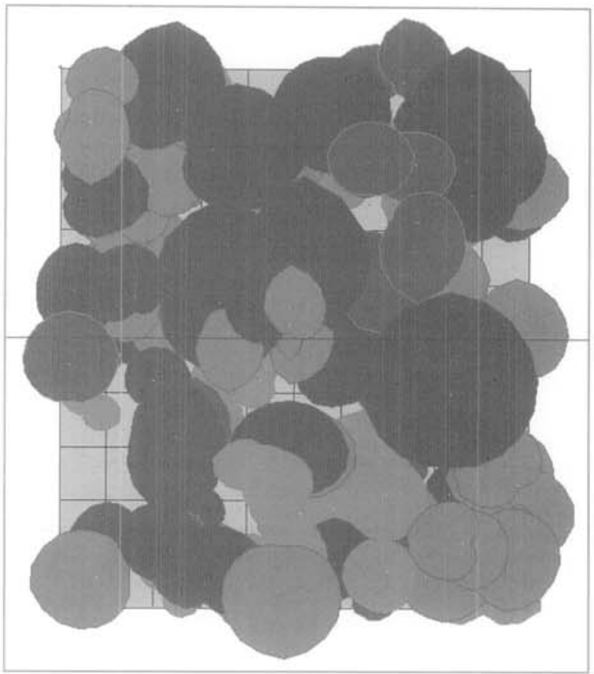

Figure 2. Stem map and crown area projection of the plot M702.

As Mitsuda *et al.* (2002) used buffer zone in the study on effects of competitive and cooperative interaction among neighbor trees on tree growth for a naturally regenerated even-aged *Larix sibirica* stand, the buffer zone was also defined as 5 meters in this study. The individual trees in the edge of stem-mapped stand was produced some errors in calculating the indices associated with spatial patterns (Moeur, 1993). Therefore, the edge correction of the plot is inevitable. Taking plot M702 as an example, it was showed in Figure 3.

The total sample trees in all 30 plots is 4237 with 3628 trees remained after deduction of the mortality and sub-arbor trees (Table 1).

3. Iterative hegyi competition index

Hegyi competition index includes individual tree competition index CI_i and stand competition index CI, using the following formula:

$$CI_i = \sum_{j=1}^{n} \frac{d_j}{d_i \cdot L_{ij}} \tag{1}$$

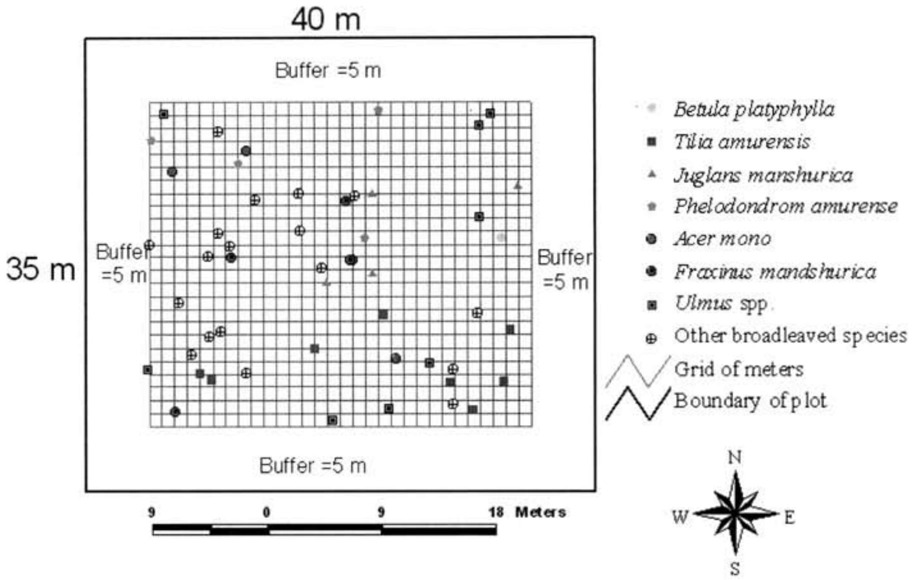

Figure 3. Edge correction of the plot M702 and sample trees distribution.

Table 1. Summary of sample trees.

Species	N	DBH			H		
		Mean	Minimum	Maximum	Mean	Minimum	Maximum
Betula platyphylla	124	14.06	5.5	42.5	14.23	7.0	26.3
Tilia amurensis	1001	14.99	5.0	52.1	12.64	2.5	25.7
Betula costata	96	23.70	5.9	52.9	19.65	7.9	28.8
Juglans manshurica	243	22.93	5.3	53.4	16.16	6.8	28.7
Phelodondrom amurense	135	20.02	5.8	40.9	14.20	6.2	28.4
Acer mono	802	10.26	5.0	41.9	10.40	4.1	24.8
Fraxinus mandshurica	214	19.37	5.0	47.4	15.3	5.2	31.1
Poplar spp.	128	24.24	5.1	59.5	17.19	5.1	28.5
Ulmus spp.	672	11.64	5.0	84.1	9.96	3.9	27.1
Quercus mongolica	213	19.33	5.0	56.9	13.24	5.9	28.3
Ohter broadleaved	455	9.20	5.0	54.1	9.12	3.5	24.2
Dead tree	154	9.68	5.0	38.9	-	-	-
Total	4237	-	-	-	-	-	-

Where, CI_i is the individual competition index of subject tree i; L_{ij} is the distance between subject tree *i* and competing tree *j*; d_i, d_j is *DBH* of subject tree *i* and competing tree *j* respectively; *n* is the number of competing trees.

Formula (1) indicates that the meaning of competition index reflects the competition pressure coming from competition trees to subject tree. In other words, the more competition pressure burdened by subject tree, the worse condition it lives.

The competition index of stand can be expressed as following formula:

$$CI = \frac{1}{N}\sum_{j=1}^{n} CI_i \tag{2}$$

Where, *CI* is a stand competition index, and *N* is the total number of stems in the stand.

The radii of competition zone defined by Hegyi was 3.05 m (10 feet) (Daniels, 1976) and the number of all competition trees within the zone was considered. But, how to judge the active competitors of subject tree in the competition zone is very important.

Lee and Gadow (1997) redefined the concept of competition zone and found following formula to calculate the dynamic radius of competition zone:

$$CZR = k \cdot \sqrt{\frac{10000}{N/ha}} \tag{3}$$

Where, *CZR* is the dynamic radius of competition zone, *N* is number of stems in the stand, *ha* is the area of the stand, and *k* is the parameter, generally, *k*=2, and the value of *k* is determined by situation of study area.

They also modified Hegyi competition index to be

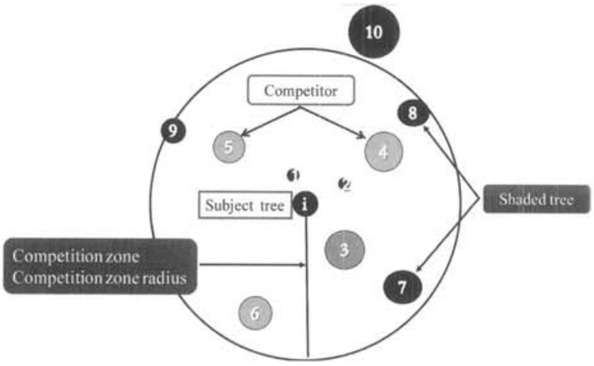

Figure 4. Iterative Hegyi competition index.

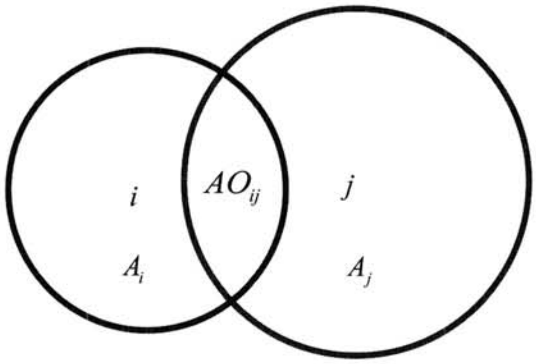

Figure 5. Schematic of crown overlap index.

more accurate, called iterative Hegyi index, in which a new method to select active competitors of subject tree in competition zone was introduced (see Figure 4).

Three rulers were used to determine the iterative selection of competitors: (1) in competition zone; (2) big enough ($D_j \geq D_i$); (3) active competitors. In Figure 4, stem No. 10 is not a active competitor because it is outside of competition zone; stems No. 1 and 2 are not active competitors, either, because of their DBH are not bigger than subject tree *i*., also, stems No. 7, 8, and 9 are not included due to shaded by the trees in front of them. Eventually, stems No. 3, 4, 5, and 6 are remained as active competitors of subject tree *i*.

4. Crown overlap index

There is a significant linear correlation between crown width and DBH of open growth trees. Thus, Krajecek *et al.* (1961) put forward crown competition factor (*CCF*) based on the correlation. *CCF* can merely reflect the competition intensity on stand scale and it was distance independent index. Actually, in secondary forest, the crown competition of individual trees is depended on the distance within the competition zone and *CCF* will be helpless. Therefore, a new competition index relative to individual tree's crown was introduced in this study, called crown overlap index (*COI*):

$$COI_i = \frac{1}{A_i} \cdot \sum AO_{ij} \cdot \frac{S_j}{S_i} \quad (4)$$

Where, COI_i is crown overlap index of subject tree *i*, AO_{ij} is the crown overlap area of subject tree *i* and competing tree *j*, and *S* is the product of tree height (*H*) and crown radius (*R*), and A_i is crown area of subject tree *i*.

Figure 5 showed a schematic of this relationship. From Figure 5, it denotes that when the position of subject tree *i* and competing tree *j* are tangency or separation, COI_i is 0, besides, COI_i is the ratio of area when subject tree *i* is contained within competing tree *j* completely. The principle of selecting compete tree *j* is the same as active competitors in iterative Hegyi competition index.

Based on distance between individual trees, crown projection area of subject tree, and active competitor judgement, crown overlap index (*COI*) shows more precision in calculation the competition of crown for secondary forests.

5. Crown class

The crown width of most broadleaved species is very big and the projection of crown area will generate many gaps on the ground. There is a progressive increasing relationship between the tree height and crown width. Crown of small trees with low height does not engender crown overlap on trees in upper canopy, which can only overlap the trees crown of same height class. In this study, the crown overlap index was calculated after classifying the crown projection area into several classes.

A variable named crown class (*CC*) was constructed to describe the affect of tree height on classified crown projection area. It was expressed as following:

$$CC = CW \cdot HT/2 \quad (5)$$

Where, *CC* is crown class, *CW* is crown width, and HT is tree height.

This concept takes tree height and crown width into account, simultaneously, and it is close to the area of crown vertical section. Especially, it can represent the biology meaning of crown.

Then, a sum of equal projection area was calculated to classify crown class into 5 classes, as following formula:

$$\sum_{j}^{N_m} CC_{mj} = \sum_{i}^{N} CC_i/5 \quad (6)$$

Where, *m* is number of ranks, *m*=1, 2, 3, 4, 5, *N* is number of living trees, and *j* is number of trees in each crown class.

Results

1. Iterative Hegyi competition index

Iterative Hegyi competition index and crown overlap

Table 2. Individual tree competition index and crown overlap index for each plot.

Sample plots	Species composition	Elevation (m)	Area (ha)	Density (ha^{-1})	CI	CCF	mean of COI
M701	4JM1BP1PA1OB1AM1US1TA	375	0.15	1344	4.6920	202.0824	190.1649
M702	2JM2FM1AM1TA1US1PA1OB	395	0.14	1100	4.5181	214.1075	170.9092
M703	4TA2JM1FM1US1BC1PA	459	0.135	1022	4.0369	169.1115	176.3258
M704	4JM2TA2US1PA1AM	370	0.12	1183	4.2673	192.7171	180.2467
M705	4TA2JM2PA1AM1PS	366	0.1	1570	5.3021	214.4468	203.1634
M706	2US2JM2FM1TA1PA1AM1PS	359	0.1	1430	5.0238	230.6565	201.2545
M707	4TA2AM2FM1PS1US	371	0.1	1260	4.9320	133.1839	195.4615
M708	4TA2QM1AM1PA1JM1FM	469	0.12	1158	4.3325	193.6645	218.2543
M709	3TA2AM3QM1JM1PS	475	0.12	1283	4.5854	140.0167	208.3215
M710	5TA1AM1PA1QM1US1JM	503	0.1	1420	5.0328	384.8417	223.0213
M711	4TA2QM1AM1PA1US1PS	490	0.12	1142	4.2031	135.3233	212.0569
M712	3PS2AM1QM1TA1JM1US1PA	522	0.1	1410	5.0893	159.502	206.4210
M713	4BC2JM1TA1PS1AM1QM	542	0.105	1238	4.7254	171.6145	190.1832
M714	2PA2FM2PS2QM1TA1AM	491	0.1	1310	4.2898	184.6267	170.0158
M715	6QM2TA1FM1US	501	0.075	1453	4.5910	160.0131	216.8590
M716	5TA2US1QM1AM1OB	444	0.105	1648	4.9336	157.0823	189.7561
M717	4TA3PS1FM1US1QM	469	0.105	1790	4.8025	242.093	202.6547
M718	6TA1AM1US1QM1PS	465	0.1	1360	4.0598	164.7801	195.9301
M719	4FM2TA2BC1AM1US	415	0.105	1095	3.9951	150.2607	200.3563
M720	6PS1TA1AM1JM1FM	396	0.15	820	3.3519	134.7354	203.1203
M721	3JM2AM1PA1OB1TA1FM	363	0.1	1440	4.1422	148.7153	205.1688
M722	4TA2JM2FM1AM1US	402	0.14	1093	3.5618	169.4554	186.3445
M723	2BC2TA1PS1OB1US1PA1FM1JM	413	0.14	764	2.8550	124.8031	135.1589
M724	3BP2AM1US1FM1QM1PS1TA	398	0.18	1094	4.0036	65.22022	155.8826
M725	4BC3TA1AM1US1FM	408	0.15	1060	4.0255	156.4474	168.0021
M726	5BP2QM1TA1FM1AM	366	0.18	1050	3.8957	64.54217	145.0362
M727	2TA2AM2BP1PA1BC1JM1OB	417	0.12	1117	4.4325	177.806	186.2480
M728	3US3JM2PA1TA1PS	345	0.1225	1322	4.6613	160.9199	180.5875
M729	5JM2US1PS1FM1BP	320	0.15	667	2.9587	158.5113	205.9567
M730	6US2FM1JM1OB	303	0.21	395	2.0147	172.895	150.1624

Where: *Betula platyphylla*-BP; *Tilia amurensis*-TA; *Betula costata*-BC; *Juglans manshurica*-JM
Phelodondrom amurense-PA; *Acer mono*-AM; *Fraxinus mandshurica*-FM; *Poplar* spp.-PS
Ulmus spp.-US; *Quercus mongolica*-QM; Other broadleaved species-OB

index by crown class were calculated for each sample plot. As shown in Table 2, iterative competition index was affected by species composition of each sample plot. Location distribution of trees in the plot and trees size was significantly correlated with competition index. The elevation was no specific effect on competition index.

There is an approximate positive relationship between the stand density and iterative competition index. The value of iterative competition index in sample plots M705, M710 and M712 are greater than 5, where densities are all more than 1400 stems per hectare. On the other hand, the value of iterative competition index in M720, M723 and M730 are around 3 and their densities are all less than 1000 stems per hectare. When plants are competing, larger individuals often obtain a disproportionate share of the limited resources and suppress the growth of their smaller neighbors. This phenomenon will be intensified when the stand density increasing.

2. Analysis of crown overlap index

Horn (1971) suggested intolerant species' crowns were narrower than those of tolerant species. The open grown crown radii of *Betula platyphylla*, *Tilia amurensis*, *Betula costata*, *Acer mono*, *Ulmus* spp. and other broadleaved species are smaller than those of *Juglans manshurica*, *Phelodondrom amurense*, *Fraxinus mandshurica*, *Poplar* spp. and *Quercus mongolica* for the same tree diameter. The value of crown competition factor (*CCF*) was also presented in Table 2. Obviously, it was not related to stand density or other variables. After calculating the competition zone radius (*CZR*) for each sample plot, crown

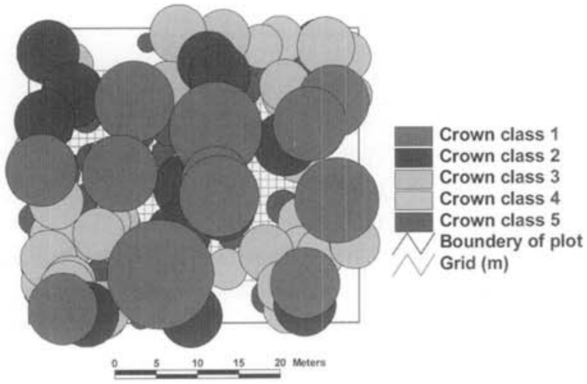

Figure 6. Illustration of Crown classification and overlp for sample plot M702.

overlap index of subject tree, which was the center of *CZR*, was computed by its active competitors (e.g., in M702, *CZR*=6.03 m). Additionally, the crown class for each tree plays an important role in the calculation of *COI* because some competitors were eliminated by their crown classes. For example, in plot M702 as shown in Figure 6, there are many trees with crown class 5 in the stand and these trees are distributed in the under canopy. These small trees with little crown radius and low height are suppressed by other trees with bigger one. However, the number of trees with crown class 4, 3 and 2 are gradually decreasing. The number of trees with crown class 1, representing the biggest and highest trees, is the least distributing in upper canopy.

From Table 2, it was known that crown overlap index (*COI*) was also slightly increased with stand density. But, it was not significant because of complex structure for secondary forest. The broadleaved trees with large crown radius, such as *Juglans manshurica*, *Fraxinus mandshurica*, and *Poplar* spp., overlap more other neighbor trees and the crown overlap index of neighbor trees have a big value. As a result, there are small values of *COI* for the trees with crown class 1 and the lager values for the trees with crown class 4 and 5.

Discussion

An ideal competition index should be expected to perform equally well in stands with similar age, structure, and composition. But, these characters become more difficulty to confirm because of the complexity of structure in secondary forest. Therefore, the value of competition index significantly varied in different stands (see Table 2) and this result was dependent on differences in number of stems per hectare for secondary forest.

Barring major disturbances in stand dynamics, competition is expected to remain relatively constant over short time intervals (Daniels, 1976; Lorimer, 1983). Hence, the iterative Hegyi competition index can be used to develop some distance dependent individual tree growth models for secondary forests. By searching a certain competition zone radius (*CZR*) for each tree in the plot, the iterative competition index can provide more accurate prediction of tree growth.

Evaluating competition indices for shade tolerance species in a mixed stand will provides an opportunity to compare index performance in relationship to tolerance. *Fraxinus mandshurica* is considered as the most shade-intolerant species in the study. *Ulmus* spp. and *Juglans manshurica* are slightly more tolerant than aspen. *Tilia amurensis*, *Acer mono*, and *Phelodondrom amurense* are considered as mid-tolerant species and *Betula platyphylla*, *Betula costata*, *Quercus mongolica* and *Poplar* spp. are the most tolerant of the all species.

Classifying trees into the strata based on tree height revealed differences in the mechanisms of tree interaction between strata. Bella (1971) also showed that the importance of interaction among neighboring trees on tree growth was different among size classes within a stand. Crown class (*CC*) is a new variable which can be used to classify different tree size into a proper stratum. Crown overlap index (*COI*) using species specific crown radii can be used to differentiate competition levels between tolerance classes. Results from this study indicate that species with smaller crown radii are more sensitive to changes in area overlap. This implies, as would be expected, that the less tolerant species are more sensitive to changes in light. Thus crown overlap index with species specific open grown crown radii could be used to identify different competition levels between species in secondary forests.

Acknowledgements

Financial support for this study is provided by the fifth project of National "Eleventh Five Year Program" Forest Science and Technology Support Program-"Demonstration of Protection and Sustainable Management for Natural Forest, Northeast China", project 2006BAD03A0805. We wish to thank all members of the team for their field work and staff of Maoershan Experimental Forest Farm for their coordinating our activities throughout the fieldwork. We would also like to thank the editor and anonymous reviewers for very useful comments.

Literature Cited

1. Arney J.D. 1973. Tables for quantifying competitive stress on individual trees. Canadian Forrest Service, Pacific Forest Research Center Information Report, BC-X-78. 16pp.

2. Begon, M. 1984. Density and individual fitness: asymmetric competition. pp.175-194. In: Shorrocks B. (eds), Evolutionary Ecology. Blackwell, Oxford.
3. Bella, I.E. 1971. A new competition model for individual trees. Forest Science. 17: 364-372.
4. Biging, G.S. and Dobbertin, M. 1992. A comparison of distance-dependent competition measures for height and basal area growth of individual conifer trees. Forest Science. 38: 695-720.
5. Daniels, R.F. 1976. Simple competition indices and their correlation with annual loblolly pine tree growth. Forest Science. 22: 454-456.
6. Daniels, R.F., Burkhart, H.E. and Clason, T.R. 1986. A comparison of competition measures for predicting growth of loblolly pine trees. Canadian Journal of Forrest Research. 16: 1230-1237.
7. Davis, K.P. and Johnson, K.N. 1987. Forest management. (3^{rd} Ed.). McGraw-Hill. New York.
8. EK, A.R. and Monserud, R.A. 1974. Trials with program FOREST: Growth and reproduction simulation for mixed species in even- or uneven-aged stands. pp. 56-73. In: Growth models for tree and stand simulation, Fries, J. (Ed.). Royal College of Forestry, Stockholm, Sweden.
9. Gerrard, D.J. 1969. Competition quotient: A new measure of the competition affecting individual forest trees. Michigan State University, Agriculture Experiment Station, Research Bulletin No. 20, 32pp.
10. Hegyi, F. 1974. A simulation model for managing jack pine stands. pp. 74-90. In: Growth models for tree and stand simulation, Fries, J. (Ed.). Royal College of Forestry, Stockholm, Sweden.
11. Holmes, M.J. and Reed, D.D. 1991. Competition indices for mixed species in northern hardwoods. Forest Science. 37(5): 1338-1349.
12. Horn, H.S. 1971. The adaptive geometry of trees. Monograph Popular Biology. No. 3: 113-115.
13. Krajicek, J.E., Brinkman, K.A. and Gingrich, S.F. 1961. Crown competition, a measure of density. Forest Science. 7: 35-42.
14. Li, G.Y. 1992. Management for secondary forest in North of China. Beijing: Chinese Forestry Publishing House. (in Chinese)
15. Lorimer, C.G. 1983. Test of age-independent competition indices for individual trees in natural hardwood stands. Forrest Ecology and Management. 6: 343-360.
16. Moeur, M. 1993. Characterizing spatial patterns of trees using stem-mapped data. Forest Science. 39(4): 756-775.
17. Tome, M. and Burkhart, H.E. (1989) Distance-dependent competition measures for predicting growth of individual trees. Forest Science. 35: 816-831.
18. Weiner, J. 1990. Asymmetric competition in plant populations. Trends in Ecology and Evolution. 5: 360-364.
19. Wensel, L.C., Meerschaert, W.J. and Biging, G.S. 1987. Tree height and diameter growth models for northern California conifers. Hilgardia. 55(8): 1-20.
20. Mitsuda, Y., Ito, S. and Takata, K. 2002. Effects of competitive and cooperative interaction among neighboring trees on tree growth in a naturally regenerated even-aged *Larix sibirica* stand in considering height stratification. Journal of Forest Research. 13: 185-191.
21. Zhang, S.Y. and Xu, H. 2001. An analysis on the golden section in the tree crown. Journal of Southwest Forestry College. 21(1): 14-19. (in Chinese with English summary)
22. Zhu, J.J. and Liu, S.R. 2007. Conception of secondary forest and its relation to ecological disturbance degree. Chinese Journal of Ecology. 26(7): 1085-1093. (in Chinese with English summary)

(Received May 20, 2008; Accepted September 1, 2008)