Annals of Silvicultural Research
37 (1), 2013: 55-63

http://ojs-cra.cilea.it/index.php/asr

Research paper

Early impact of alternative thinning approaches on structure diversity and complexity at stand level in two beech forests in Italy §

Claudia Becagli[1*], Nicola Puletti[1], Ugo Chiavetta[1], Paolo Cantiani[1], Luca Salvati[2], Gianfranco Fabbio[1]

Received 18/11/2013 - Accepted 20/12/2013

Abstract - Stand structure, tree density as well as tree spatial pattern define natural dynamics and competition process. They are therefore parameters used to define any silvicultural management type. This work aims to report first data resulting from a silvicultural experiment in beech forests. The objective of the trial is testing the structure manipulation in terms of diversity and the reduction of inter-tree competition of different thinning approaches. Alternative thinning methods have been applied in two independent experimental sites located in the pre-Alps and southern Apennines, in Italy. Specific goals were to: (i) verify the impact early after thinning implementation on forest structure through a set of diversity and competition metrics resulting from a literature review; (ii) the sensitivity of tested indexes to detect effectively thinning manipulation. Main results show the low sensitivity of stand structure indexes and the ability of competition metrics to detect thinning outcome.

Keywords - stand structure, beech forest, thinning, structure diversity, competition, indexes

Introduction

Forest structure plays today a major role in the analysis and management of forest ecosystems (Roberts and Gilliam 1995, Oliver and Larson 1996, Latham 1998, Zenner and Hibbs 2000, Neumann and Starlinger 2001). Both structural diversity and tree competition (Brand and Magnussen 1988) are considered main factors to describe stand dynamics and define ecologically sound and economically sustainable management practices.

Stand structure is defined by tree species composition, tree age, size distribution and spatial patterns, canopy layering, within the forest stand (Husch et al. 2003). Stand structure influences individual tree growth and a number of biotic and abiotic processes (Garcia 2006, Eerikainen et al. 2007, Fox et al. 2007a,b). Silvicultural practices as thinnings and regeneration cuttings, heavily manipulate stand structure (Bailey and Tappeiner 1998) and this impacts wildlife populations (Harrington and Tappeiner 2007, Yamaura et al. 2008), stand dynamics (Saunders and Wagner 2008), tree regeneration dynamics (Getzin et al. 2008) and understory vegetation (Kembel and Dale 2006).

Horizontal/vertical tree density and spatial arrangement, tree species composition and intermingling as well as the range of tree dendrotypes, are usually related to biological diversity, ecological stability, competition processes and forest ecosystem functioning (Sallabanks et al. 2002, Kint et al. 2004).

The analysis of stand structure, tree density and tree species diversity are basic tools to explain both spatial heterogeneity and mechanisms of inter-tree competition (Oliver and Larson 1996, Pommerening 2006). Indeed, structural parameters at the macro, meso, and micro level are reliable indicators of diversity and ability of persistence (Margalef 1982) of forest ecosystems, and thus of the sustainability of the applied management's option (Haber 1982).

Based on these premises, a number of indexes has been developed over the last decades to quantify forest structure (Pommerening 2002). It has also been suggested that different sets of indicators may usefully be used to assess and simulate the effect of silvicultural treatments according to specific research references. Indexes-based literature, however, mainly deals with high forests (Ladermann and Stage 2001, Neumann and Starlinger 2001, Staudhammer and LeMay 2001, Corona et al. 2005, Motz et al. 2010). Few authors analysed the suitability of structural diversity indexes in coppice forests (Fabbio et al. 2006, Becagli et al. 2009). As for studies devoted to competition processes, these were carried out both in naturally originated forests and plantations (Hegyi 1974, Brand and Magnussen 1988, Biging and Dobbertin 1992, Piutti and Cescatti 1997, Cescatti and Piutti 1997, Schroder and von Ga-

§ Funded within the project LIFE+09 ENV/IT000078 ManForCBD
[1] Consiglio per la Ricerca e la sperimentazione in Agricoltura, Forestry Research Centre, Arezzo (CRA-SEL), Italy
[2] Consiglio per la Ricerca e la sperimentazione in Agricoltura, Centro di ricerca per lo studio delle Relazioni Pianta-Suolo, Roma (CRA-RPS), Italy
[*] corresponding author: claudia.becagli@entecra.it

http://dx.doi.org/10.12899/ASR-802

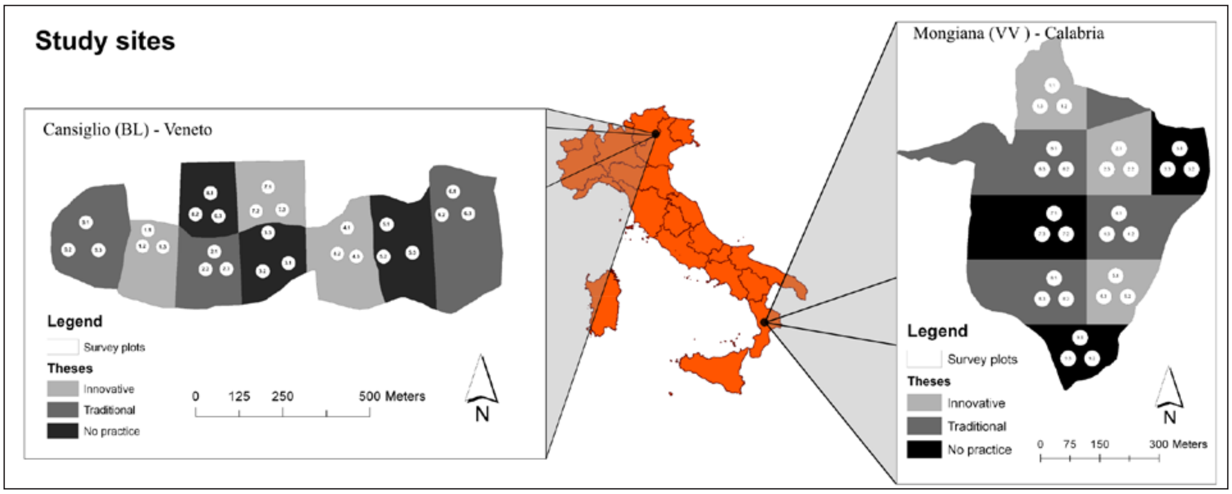

Figure 1- Location of the study areas.

dow 1999, Fichtner et al. 2012, Fichtner et al. 2013).

The knowledge of stand dynamics supports the focus on management goals by (i) predicting the future stand structure and relative pattern; (ii) reducing silvicultural costs, on average and (iii) increasing stand productivity and developing diagnostic criteria for describing, prescribing and marketing decisions for silvicultural operations (Oliver and Larson 1996).

Objective of the analysis is to evaluate the early change in stand structure following thinning practice by a set of indexes and the modification arising from the differently-based silvicultural interventions applied to managed beech forests. A more specific goal is to answer the following question: are all the calculated indexes capable to detect the effect of the intermediate removal and of criteria of intervention on stand structure and tree competition level immediately after their implementation at the tested sites?

Materials and methods

Study sites

The study was carried out in the pre-alpine region (Cansiglio-Veneto) and in southern Apennines (Mongiana-Calabria), two main beech vegetation areas (Fig. 1).

The study area located in the plateau of Cansiglio consists of an even-aged (120 to 145 yrs) compartment. The forest has age-long custom in forest management. Regular applied silviculture along the stand life-cycle consisted of low-mixed thinnings repeated every 20-25 years on the same management unit. Stand regeneration was successfully established following the group shelterwood system. Standing crop is quite uniform resulting from the long-lasting repetition of practices aimed at growing an one-storied structure. Natural variation in site-index makes the only evidence of a different arrangement in the crown layer.

The main management goal in these forests was to get uniform and well-shaped logs for the production of quality timber. Rotation time has been anyway shifting over the last decades and, as in other forest districts, from the customary age of 100-120 years to indefinite ages at now, this better matching the emerging recreational, scenic and mitigation functions besides wood-production goal. Site and climate characteristics are optimal for beech vegetation, these conditions well-supporting the extension of standing crop permanence time (Tab. 1).

The study area established in Mongiana consists of a forest aged about 70 years originated by a set of regeneration cuttings, the group shelterwood system, the clear-cut and clear-cut with reserves. The resulting standing crop is made by a main even-aged stand, where some trees of former cycle are present both grouped and along streams crossing the compartment. The patchy presence of silver fir mother trees and cohorts of regeneration provides spots of compositional and structural diversity. The forest position in the upper part of the mountain system facing the Tyrrhenian sea, the interception of fogs, wet winds and rain, makes physical environment

Table 1 - Site characteristics.

	Cansiglio Forest	Mongiana Forest
Area (ha)	30 - 35	30
Geographical coordinates (UTM-WGS84)	46° 03'N, 12°23' E	38° 30'N, 16°14'E
Altitudinal range (m a.s.l.)	1100 – 1200	1100
Landscape morphology	Gently sloping mountainsides and plains	Patchy succession of small hills (slope 40%), valleys and plateaux
Bedrock	Limestone, Marlstone (Cretaceous Med.- Sup.)	Granite ("Serra and Sila" formation)
Mean Temp °C	5.6	10.1
Max Temp °C (average warmest month)	14.8, August	18.4, July
Min Temp °C (average coldest month)	-4, January	2.2, February
Total Rainfall (mm)	2004	1808

consistent with beech vegetation in this southern Apennines area. Here too, the customary management system based on low to mixed thinnings usually does not open lasting canopy gaps. The random or patchy presence of trees much older than the dominant crop age, makes the physiognomy less regular and to some extent diverse than the typical even-aged beech forest.

Experimental design

An area of 30 hectares was devoted to the management trials at each site. Three theses were identified and randomly assigned in three replicates to each compartment (1 to 9). One thesis is made by the customary thinning practice (T), i.e. the low-mixed thinning as applied by local managers. The second silvicultural option is made by the innovative (for the forests concerned) criterion (I) consisting in a crown thinning at Cansiglio and on the selection of 45-50 trees per ha, with removal of direct competitors at Mongiana. Number of selected trees per unit area was determined on the foreseeable number of mother trees needed to carry out the future regeneration stage. The no-thinning thesis (control C) completes the experimental layout. A cluster of three circular sampling plots (radius 20 m) was established within each compartment according to a systematic design to survey mensurational parameters.

Structural and competition indexes

The impact of silvicultural practice on forest structure following each applied criterion has been assessed by a set of structural diversity and competition metrics resulting from a literature review. Both "spatial" and "non-spatial" indexes were accounted, the term "spatial" being referred to the information needed to get each index. Indexes requiring the calculation of individual tree position were considered as spatial indexes; all the others were considered as non-spatial indexes. To avoid the edge effect, trees at plot border were not considered as references. Selected indexes of stand structure and inter-individual competition are listed in Table 2. The Aggregation index by Clark and Evans (CE) characterizes the horizontal trees' distribution pattern at the stand level by the method of the nearest neighbouring trees. The theoretical range of CE lies between 0 (the maximum aggregation) and 2.1491 indicating a regular, hexagonal distribution pattern. Values about 1 comply with a random distribution. Diameter (TD) and tree height (TH) differentiation indexes provide information on tree size distribution of neighbouring trees. Values range between 0 and 1, with increasing values highlighting higher dbh or tree height variability.

Further non-spatial indexes of tree size diversity are the dbh ($STVI_{dbh}$) and Htot. ($STVIH_{tot}$) variance, They range between 0 and 1. The index is 1 when the parameter (dbh, Htot) distribution is uniform and is 0 when all values are equal or the distribution reaches its maximum bimodality. The advantage inherent to these indexes is their objectiveness compared to class-based indexes. Subjectivity is limited to maximum theoretical values, these being set at 150 cm (dbh) and 40 m (Htot) following Staudhammer and LeMay (2001).

As for tree competition, Hegyi (HG) index, a tree level, spatial indicator where neighbouring trees (competitors) are being selected according to a circle count criterion (Hegyi 1974) using Htot/3 of the reference tree as default distance, was considered. A modified version (HG_{MOD}) was tested too, to take into account larger neighbouring trees lying outside the default distance. Neighbouring trees are being selected here in accordance with an horizontal angle count (Pretzsch 2009).

A second competition index (Schroder and von Gadow 1999) is BAL_{MOD}, a distance-independent competition index derived from the basal area in larger trees (BAL) index combining individual tree's basal area percentile with a relative-spacing stand-density measure (RS_i). BAL_{MOD} assumes value equal to zero for the largest tree in a stand with a basal area percentile equal to 1, assuming that the largest tree provides the maximum growth rate. The minimum growth rate corresponds with the maximum index value. Within this range, the BAL_{MOD} index of trees with the same basal area percentile increases exponentially as RS_i decreases. Assuming constant stand density, the index provides the biologically reasonable effect that a high rank tree has a lower index value than a low-hierarchy tree.

Canopy structure was also assessed, since incoming light is a major driver of inter-tree competition (Kimmins 1987). Two canopy indexes, i.e. crowns coverage (CC) and the sum of crown projections (SCP) were selected to describe canopy structure. CC is a distance-dependent index representing the portion of horizontal space covered by at least one tree crown, theoretically ranging from 0 to 100. SCP, a spatially-independent index, is the sum of all crown areas per ground area unit and is a positive real number $\gtrless 100$.

Values before (BT) and after-thinning (AT) were compared also in terms of relative change (RC) of a specific index (i) as follows:

$$RC_i = \frac{(AT - BT)}{BT} \quad [1]$$

BAL_{MOD}, HG and HG_{MOD} indexes are being calculated iteratively for each tree. To assess the ranks of tree population promoted by thinning practice, the first quartile was adopted as the reference value. Hegyi distribution per competition classes was also considered in the analysis.

Non-parametric inference was used to compare the selected indexes among the different silvicultural treatments due to the restricted sample size and the deviation from normality of many variables. Mann-Whitney U statistics was carried out testing for differences between the applied treatments at different probability levels.

Table 2 - List of the stand structure diversity and inter-tree competition indexes.

Index	Equation	Range and reference values
Aggregation index [CE] (Clark and Evans 1954)	$CE = \frac{r_A}{r_E}$ Where: $r_A = \sum_{i=1}^{n} HDist_i$ $r_E = \frac{1}{2}\sqrt{\frac{A}{N}}$ $HDist_i$ = Euclidean distance between *i-th* tree and its nearest neighbour A = plot area N = total number of trees in the plot	Min value = 0 Max value = 2.1491 CE = 1 → completely spatially random distribution CE < 1 → spatially clustered distribution CE > 1 → spatially regular distribution
DBH-Differentiation [TD] (Pommerening 2002)	$TD = \sum_{i=1}^{N} \frac{1}{n} \sum_{j=1}^{n} \left(1 - \frac{\min(DBH_i, DBH_j)}{\max(DBH_i, DBH_j)}\right)$ Where: n = number of the first 4 nearest neighbours DBH = diameter at height = 1.3 m N=total number of trees in the plot	Min value = 0 Max value = 1 TD = 0 → all neighbors have equal DBH TD = 1 → all neighbours have different DBH
Height-Differentiation [TH] (Pommerening 2002)	$TH = \sum_{i=1}^{N} \frac{1}{n} \sum_{j=1}^{n} \left(1 - \frac{\min(H_i, H_j)}{\max(H_i, H_j)}\right)$ Where: n = number of the first 4 nearest neighbours H = total stem height N=total number of trees in the plot	Min value = 0 Max value = 1 TD = 0 → all neighbours have equal height TD = 1 → all neighbours have different height
Diameter diversity based on variance [$STVI_{dbh}$] and Height diversity based on variance [$STVI_{Htot}$] (Staudhammer and LeMay 2001)	$\begin{cases} 1-\left(\frac{S_U^2 - S_k^2}{S_U^2}\right)^{p1} & if\ S_k^2 \le S_U^2 \\ 1-\left(\frac{S_U^2 - S_k^2}{m \cdot S_{max}^2 - S_U^2}\right)^{p2} & if\ S_k^2 \ge S_U^2 \end{cases}$ Where: S_k is the empirical variance (dbh or tree height) S_U is the variance of the univariate uniform distribution (dbh or tree height) S_{max} is the maximum possible variance (when the distribution is maximally bimodal)	Min value = 0 Max value = 1 STVI= 0 → when all values (DBH or Htot) are equal or when DBH (or Htot) distribution is very close to be maximally bimodal STVI = 1 → highest diversity
BAL modified [BAL_{MOD}] (Schroder and von Gadow 1999)	$BALMOD_i = \frac{1 - p_i}{RS}$ Where: p_i is the basal area percentile of the reference tree RS is a relative spacing index (stand level)	Min value = 0 The higher the value the higher the competition the reference tree is subjected to
Hegyi [Hg] (Hegyi 1974)	$Hg_i = \sum_{i=1}^{n} \frac{DBH_j}{DBH_i \cdot HDist_{ij}}$ Where: DBH_i = diameter at breast height of the competitor trees DBH_j = diameter at breast height of the reference tree $HDist_{ij}$ = Euclidean distance between *i-th* tree and its nearest *j-th* neighbor n = number of competitors (all trees that fall within a distance of $1/3 \cdot H_i$)	Min value = 0 The higher the value the higher the competition the reference tree is subjected to
Hegyi modified [Hg mod] (Pretzsch 2009)	$Hg_i = \sum_{i=1}^{n} \frac{DBH_j}{DBH_i \cdot HDist_{ij}}$ Where: DBH_i = diameter at breast height of the competitor trees DBH_j = diameter at breast height of the reference tree $HDist_{ij}$ = Euclidean distance between *i-th* tree and its nearest *j-th* neighbour n = number of competitors (trees identified from an horizontal angle count sample)	Min value = 0 The higher the value the higher the competition the reference tree is subjected to

Results

Main mensurational parameters are reported in Table 3. Values at each site well-depict the differences between, mainly due to stand age and former applied silviculture. Mean values of structural diversity indexes before and after the occurrence of silvicultural practices are reported in Table 4. Thinning operations slightly changed the former values at both sites. CE index moved from random towards regular trees' distribution for both the applied criteria at Cansiglio, whilst it remained quite steady (i.e. random) at Mongiana. As for diameter differentiation (TD), dbh variability was low at Cansiglio and increased slightly at Mongiana (both criteria). As for tree height differentiation (TH), height variability was reduced by customary practice at Cansiglio only. Dbh variance ($STVI_{dbh}$) was kept close to zero by the occurrence of practices at Cansiglio; the same index did not show any significant change following thinnings at Mongiana. Tree height variance ($STVIH_{tot}$) was also very low and kept unchanged (innovative practice) or dropped (customary practice) at Cansiglio, whilst the opposite took place at Mongiana.

Values of relative change (Fig. 2) referred to the set of structural indexes do not exceed 15%, this showing the slight structural differences recorded across the theses.

As for tree competition, the first quartile (Tab. 5) and relative change (Fig.2) were examined. All indexes showed higher values at Mongiana than at Cansiglio before and after the implementation of thinning practices, independently of the applied criterion. All of them proved to be sensitive to the manipulation of stand structure, each one showing a reduction in accordance with the own algorithm. The innovative thesis promoted a higher cut of tree competition than the customary practice at both sites.

The Hegyi distribution pattern per competition classes was also recorded (Fig. 3). The graphical arrangement is similar as for Cansiglio (both theses) and Mongiana (innovative trial), i.e. the increase in low competition classes, the heavy reduction in medium-low competition classes and the zero setting in medium-high competition classes. On the contrary, a much more smoothed pattern across all competition classes was produced by customary practice at Mongiana.

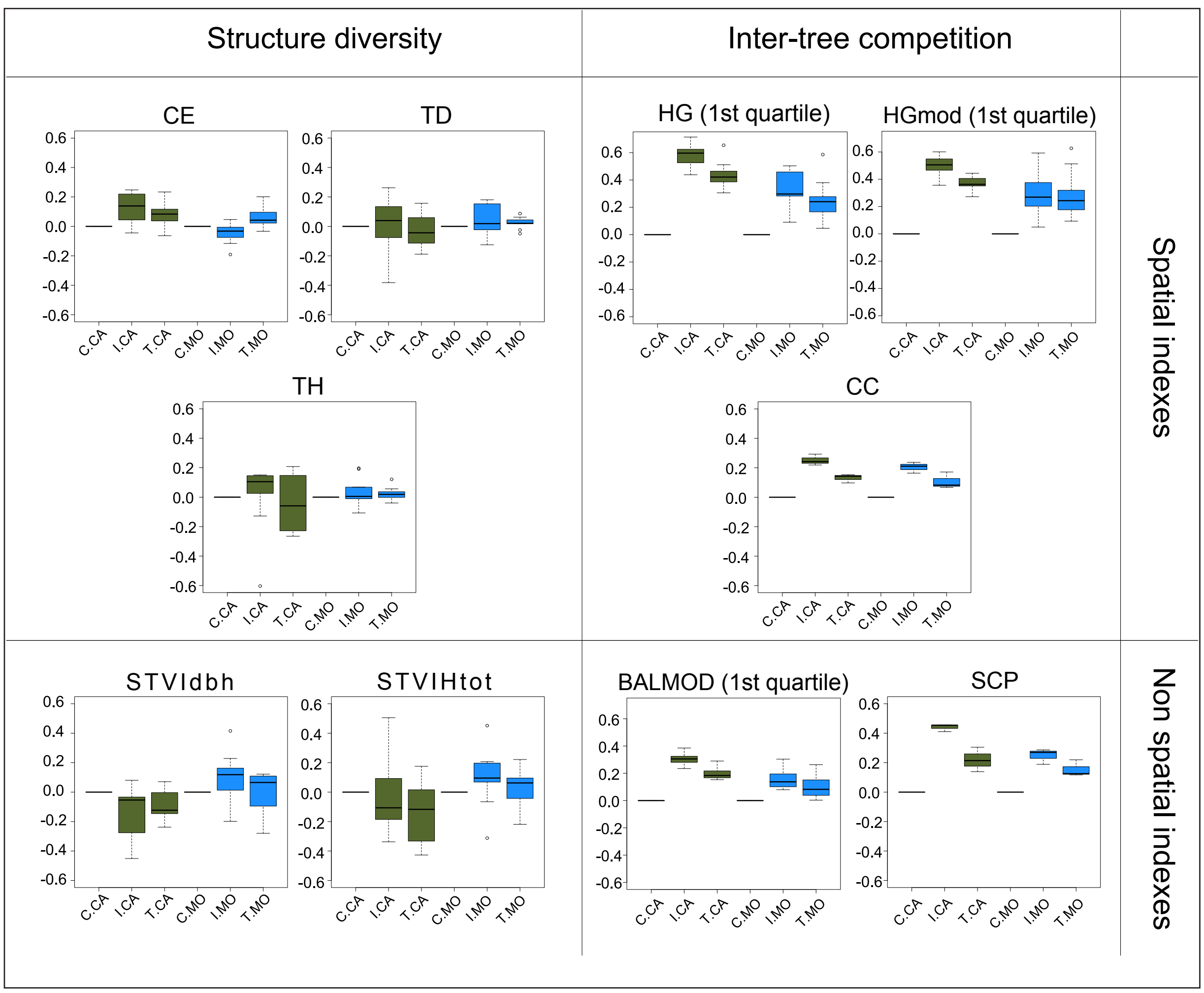

Figure 2 - Relative change of stand structure diversity and inter-tree competition indexes following thinning implementation per forest and thesis.

Table 3 - Main mensurational parameters (±sd) at sites.

Parameters	Before thinning		After thinning			
	Cansiglio	Mongiana	Cansiglio		Mongiana	
			Innovative	customary	Innovative	customary
Tree Density	323±65.9	510±130.4	187±9	235±29	409±100	408±168
Basal area m²/ha	40.9±5.2	41.2±7.3	26.3±1.3	30.3±4	33.7±7.7	31.6±3.1
Mean Height (m)	26.6±0.5	23.3±1.5	27±0.7	26.5 ±0.4	23.3±1.5	23.5±2
Mean (DBH) (cm)	40.6±3	32.9±6.1	43.7±2.4	40.5±2.6	33±6.2	33.4±8.2
Dominant DBH (cm)	49±3.6	46.2±6.8	48.1±0.8	46.9±1.2	47±7.9	47.0±7
Dominant Height (m)	27±0.6	26.2±1.2	27±0.1	26.6±0.1	24.2±1.6	26.0±1
Standing Volume (m³)	543±72	497±110.8	358±16	402±60	401±123	376.7±55.3

Table 4 - Mean values of stand structure diversity indexes before and after thinning implementation.

index	Before thinning		After thinning			
	Cansiglio	Mongiana	Cansiglio		Mongiana	
			Innovative	customary	Innovative	customary
CE	1.2	1.1	1.4	1.4	1.1	1.2
TD	0.2	0.2	0.2	0.2	0.3	0.3
TH	0.08	0.1	0.09	0.05	0.1	0.1
STVIdbh	0.1	0.2	0.09	0.09	0.3	0.1
STVIHtot	0.1	0.2	0.1	0.03	0.1	0.2

Table 5 - Tree competition indexes: 1stq before and after thinning implementation. Cansiglio = CA; Mongiana = MO.

thesis	BAL_{MOD}		Hegyi		$Hegyi_{MOD}$	
	before	after	before	after	before	after
CA_innovative	0.64	0.45	0.75	0.32	0.97	0.48
CA_customary	0.66	0.53	0.79	0.43	0.91	0.57
MO_innovative	0.96	0.81	1.21	0.79	1.27	0.88
MO_customary	0.88	0.81	1.13	0.80	1.21	0.81

Results of statistical tests are reported in Table 6. A significant difference ($p < 0.01$) is detected as for tree distribution pattern (CE) - innovative thinning thesis - at Cansiglio. A highly significant difference ($p < 0.001$) is present at the same forest for both thinning theses and all tested competition indexes. A significant differences ($p < 0.01$) is also reported by BAL_{MOD} at Mongiana - innovative thesis. Less significant ($p < 0.1$) are the differences recorded by HG and HG_{MOD}. No differences are detected as for the customary thesis at Mongiana.

Finally, mean values of crown-based indexes (Table 7) showed a notable reduction at both sites following thinning practices. Values before, different at each forest, were adjusted unlike. At Cansiglio, SCP dropped drastically with the innovative thesis (-44%) and less with the customary thesis (-19%), whilst, as expected, CC showed a lower reduction (-25% and -13 % respectively). At Mongiana, values before were much lower and, in accordance with the reduced cover before, CC dropped a bit more than SCP in the innovative thesis and followed the same pattern as in Cansiglio as for the customary thesis.

Discussion

The main outcome from the use of stand struc-

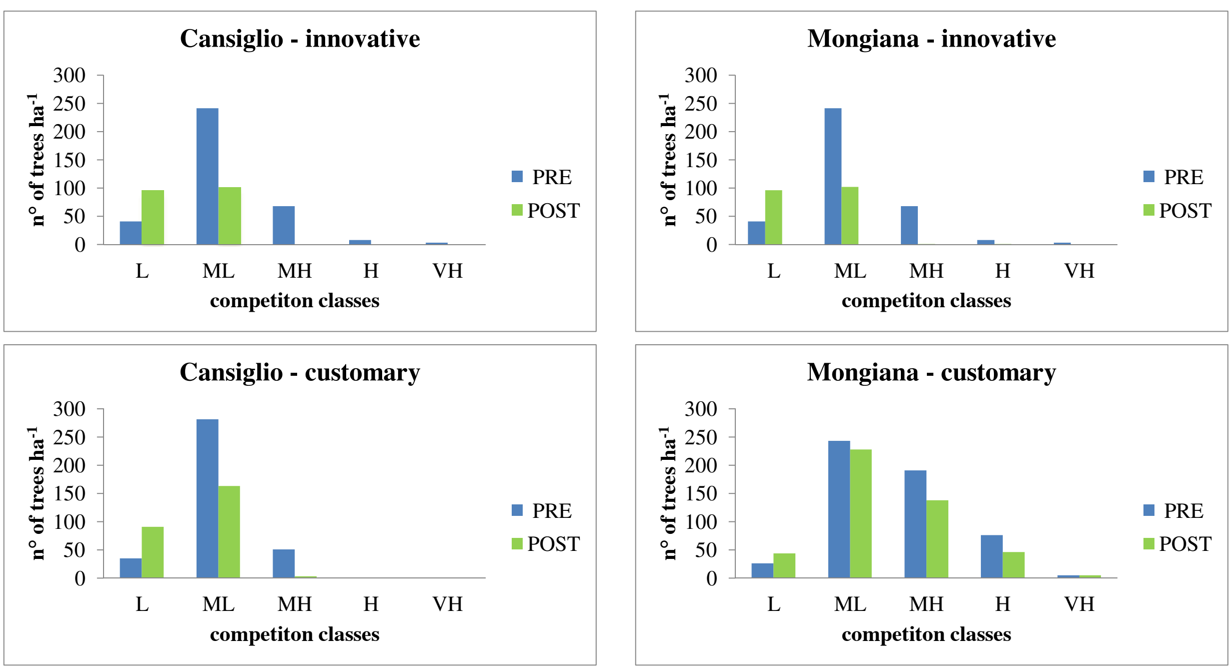

Figure 3 - Tree frequency distribution per competition classes (L: low, ML: medium low, MH: medium high, H: high, VH: very high).

Table 6 - Non-parametric statistics of tested indexes (Cansiglio = CA; Mongiana = MO). Asterisks indicate significant difference at * p < 0.1, ** p < 0.01, *** p < 0.001.

Comparison	Site	test	CE	TD	TH	$STVI_{dbh}$	$STVI_{Htot}$	BAL_{MOD}	Hegyi	$Hegyi_{MOD}$
innovative pre vs innovative post	CA	Mann Whitney U	10**	39	39	23	34	2***	7***	0***
customary pre vs customary post	CA	Mann Whitney U	16	35	39	32	34	1***	1***	0***
innovative pre vs innovative post	MO	Mann Whitney U	28	36	34	36	39	11**	16*	17*
customary pre vs customary post	MO	Mann Whitney U	31	34	39	40	39	25	22.5	19.5

tural indexes to highlight possible, early differences in tree texture and tree sizes was from the Aggregation Pattern index CE. It showed to be sensitive to stand manipulation and able to discriminate the higher heterogeneity of standing crop at the younger site (Mongiana) with respect to the older site (Cansiglio), it being manipulated for a much longer life-span. This sensitivity is well-summarized by the still random trees' horizontal distribution following thinning operations in Mongiana compared with the more regular pattern in Cansiglio. Among the applied theses in Mongiana, customary practice slightly moves the distribution towards regular distribution, given this intervention is performed all over the forest ground.

As for tree diameter differentiation, both spatial (TD) and non-spatial index ($STVI_{dbh}$), highlight similar dbh values in the sample considered. This peculiar feature is linked to the shade-tolerance of beech able to grow quite dense stands made of trees sized likewise. Both indexes do not detect any change as for the condition post-thinning at Cansiglio, whilst an even reduced sensitivity is proved at Mongiana. The typical even-aged structure and the one-storied arrangement of beech forests further promote this attribute.

Important differences are on the contrary detected in tree height variability by TH and $SVTI_{Htot}$ at Cansiglio. Here, values drop following the customary intervention and remain steady after the innovative practice. The steady pre-post condition is recurring at Mongiana for both interventions' criteria. The result in Cansiglio is explained by the higher stand age which ranked tree height arrangement into a thicker one-storied structure. Here, the customary intervention has harvested small to medium-sized stems (i.e. dominated up to a few sub-dominant trees) reducing the height range of standing crop (Roberts and Gilliam 1995). This result does not apply to the innovative criterion acting in the main crop layer made by co-dominant to dominant trees. The less-differentiated tree height layer into the younger stand of Mongiana allows only a slight record of both thinning practices.

Competition indexes (first quartile) are quite responsive - further to the expected reduction - to thinning theses (Brand and Magnussen 1988). They describe properly the targeted criterion of reducing tree competition in the dominant layer (Cansiglio-innovative), and in the neighborhood of a number of selected canopy trees (Mongiana-innovative), as well as the overall competition at stand level (customary thesis) at both sites. Response applies to low up to medium-high competition classes (Piutti and Cescatti 1997, Cescatti and Piutti 1998). Exception is made by customary criterion in Mongiana resulting vice versa into the prevailing reduction of inter-individual competition into medium-high and high classes, i.e. in the most dense patches of the less regular texture characterizing this forest.

Non-parametric statistics confirm the reduced sensitivity of stand structure indexes at this early-post intervention stage. Exception is made for the Aggregation Pattern index CE. The high sensitivity of tree competition indexes is also proved. As for crown-based indexes, the much higher figures of SCP and CC at Cansiglio compared to Mongiana describe a forest stand aged nearly twice Mongiana, much less dense and displaying a quite similar basal area (Fichtner et al. 2013b, Kimmins 1987). That means the establishment of the age-dependent crown interface made up of a more structured layer both in terms of coverage and overlapping, in spite of lower tree density.

Conclusions

The analysis highlighted the response ability of spatial and non-spatial tree diversity and competition indexes to describe the early manipulation following crown, selective and low-mixed thinning practices performed into two beech forests aged differently. The Aggregation index CE showed to be sensitive, moving towards a more regular tree

Table 7 – Crown-based indexes: mean values before and after thinning implementation. Cansiglio = CA; Mongiana = MO.

thesis	SCP before	SCP after	CC before	CC after
CA_innovative	115%	71%	90%	65%
CA_customary	90%	71%	79%	66%
MO_innovative	76%	51%	66%	46%
MO_customary	75%	60%	65%	54%

distribution at the more aged crop, independently of the applied criterion, and maintaining a random pattern at the younger and less homogeneous stand.

A slight or null sensitivity is showed by Diameter and Tree height differentiation, as well as by dbh and tree height variance, i.e. the other spatial and non-spatial tree diversity indexes tested. The condition here analyzed immediately after thinning practice will progressively change over time as a function of tree size differentiation following the applied practice. In fact, thinning makes available higher growing space to released trees, enhances stem radial growth and crown development, reduces symmetrical competition, in the perspective of differentiate further their next growth rate. The use of the above indexes becomes therefore more profitable and their response more consistent at intermediate steps between thinning practice.

All tree competition indexes tested HG, HG_{MOD} and BAL_{MOD}, recorded effectively the change in progress because they do register the different spatial arrangement following the intermediate removal and do not need any growth reaction to be established. As for crown-based indexes, they were able to differentiate thinning criteria much more than what recorded by mensurational parameters e.g. the difference in basal area removed.

Acknowledgements

Study funded within the project LIFE+09 ENV/IT000078 'Managing Forests for multiple purpose: Carbon, Biodiversity and socio-economic wellbeing' (ManForCBD).

The authors wish to thank the anonymous referees for their helpful comments that contributed to improve the paper.

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