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Characterizing forest stand structure through structural indices. Tests carried out in Silver Fir (*Abies alba* Mill.) stands in the Manez Valley (Trento Province, North-East Italy)

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Contents

Abstract

Ecosystem diversity is an inspiring principle of sustainable forest management where ecosystem stabilty is strictly bound to the reached degree of diversity. Ecosystem diversity is subdivided in alpha, beta and gamma diversity. This work is aimed on alpha diversity: the diversity inside an ecosystem, in our case a forest ecosystem, where alpha diversity is subdivided and identified by species diversity, tree positions diversity and dimensional diversity. These three attributes are as well defining forest structure.

Evaluation of forest structure diversity provide informations on present state, growth processes inside a forest stand, informations on habitat suitabilty for species and overall species diversity.

In this work three neighbourhood distance-dependent indexes (Winkelmass, Species Mingling and Diameter at Breast Height Dominance) and one distance-independent (Tree Height Diversity Shannon Index) were applied to characterize the forest structure of 27 sample plots; of 2826.00 m^2 each, placed inside managed silver fir forests. The management of the forests under study is classified as close-to-nature silviculture while the area of study is situated in Manez Valley, on the southern border of the Adamello-Brenta Natural Park in the Eastern Alps, inTrento Province, Italy.

The first step in this work is to characterize forest stands with structural indices: The Winkelmass (Uniform Angle Index) was adopted to characterize the spatial distribution of individuals, the Species Mingling to evaluate the species mixture and the Diameter at Breast Height Dominance for the relative dimensional diversity. Tree Height Diversity Shannon index was here used to describe the vertical aspect of diversity in the sample plots under study.

The second step inside this work is the statistical evaluation of neighborhood indexes values. From the 27 circular main sample plot areas with a 30 m radius (2826.00 m^2) concentric sub-samples were extracted using a criterium based on radial dimensions. In each of the 27 main sample plots analyzed and for each neighborhood index singularly a statistical comparison between the population of the main (30 m radius) sample plot and the populations depending to sub-plots.

This process is made to verify if a population of values of one neighborhood index collected in a circular sample plot with given dimensions (30m radius) can be represented by the respective population of values coming from a sub-plot of smaller dimensions.

The purpose is to reduce the sampling efforts in field work and evaluate the possible implementatation of these indices inside management plans and forest inventories.

Riassunto

La caratterizzazione di popolamenti forestali tramite utilizzo di indici strutturali: prove di applicazione nelle abietine della Val Manez (Trento).

La diversità ecosistema è principio ispiratore per una gestione forestale sostenibile nella quale la stabilità ecosistemica viene strettamente collegata al grado di diversità raggiunto. Essa è suddivisa in diversità alfa, beta, gamma e delta. Questo lavoro è incentrato sulla diversità alfa in un ecosistema, in questo caso un ecosistema forestale, dove la diversità alfa consiste in diversità di specie, diversità di posizione all'interno di uno spazio e diversità dimensionale. Questi tre tipi di attributi definiscono anche la struttura forestale.

La valutazione di diversità di struttura fornisce dettagli per la previsione sulla crescita e sullo stato attuale di popolamenti forestali oltre che informazioni per a valutazione di idoneità dell' habitat per specie e la valutazione della diversità specifica complessiva.

Nel nostro lavoro ci siamo serviti di tre indici dipendenti dalle distanze di "vicinanza": l'indice di Winkelmass (Uniform Angle Index), l'indice di mescolanza specifica (Species Mingling) e l'indice di dominanza diametrica (Diameter at Breast Height Dominance) e di un indice indipendente dalla distanza: l'indice di Shannon per la diversità di altezza (Tree Height Diversity) al fine di caratterizzare la struttura di 27 aree campione, ciascuna di 2826.00 m^2, situate all'interno di abietine gestite secondo criteri di selvicoltura naturalistica nella Val Manez in Provincia di Trento, sul confine meridionale del Parco Naturale Adamello-Brenta.

In questo lavoro lacaratterizzazione di popolamenti forestali viene effettuata tramite l'indice di Winkelmass relativamente alla valutazione della distribuzione spaziale degli individui, l'indice di mescolanza specifica per la valutazione della mescolanza di specie ed invece l' indice di dominanza per la determinazione della diversità di dimensione. L'indice di Shannon per la diversità verticale è stato utilizzato per descrivere l' aspetto dimensionale verticale delle aree campione sotto studio.

Un secondo passo all'interno del nostro lavoro è costituito dalla valutazione statistica dei valori calcolati per i tre indici di vicinanza. Dai dati delle 27 aree campione circolari di 30 metri di raggio (2826.00 m^2) sono stati ricavati dei sotto gruppi di dati, afferenti ad aree di raggio inferiore. In ognuna delle 27 aree in oggetto e singolarmente per ognuno degli indici di vicinanza è stato effettuato un confronto statistico tra la popolazione dell'area principale (30 m raggio) e le popolazioni di dati provenienti da sotto-aree e quindi valutare se la popolazione di valori in un area principale possa essere rappresentata da una popolazione di una sotto-area di dimensioni inferiori. Il proposito di questo procedimento è il rendere più efficiente il lavoro di raccolta dati e valutare la possibile implementazione di indici strutturali in inventari forestali o piani di assestamento.

1. Introduction

1.1 Concepts of diversity and forest structure

Even if the term diversity is widely used, overall definition still need to be accepted.

Smitinand (1995) defines diversity as variety and variability among organisms, defined by number and frequency of different items organised at many levels, starting from genes and arriving to ecosystems. In other words we can understand that diversity is dependent to the chosen scale. Example of diversity are species diversity; in forestry field we can mention genetic, functional and structural diversity as remarkable.

The topic of diversity is present in forestry field since long time but the term became popular expecially within the term sustainability in the past decades, following Rio Declaration on Environment and Development in 1992 by United Nations Commission on Environment and Development (UNCED) and Lisbon conference (Ministerial Conference on the Protection of Forests in Europe-MCPFE) in 1998.

In forestry, assessment and monitoring of diversity at ecosystem level of perspective is: "a key issue for conservation, productivity, nutrient cycling, pest damage dynamics and a prerequisite of sustainable forest management" (Fabbio *et al*., 2006). Diversity within an ecosystem is strictly connected to its stability; therefore it is fundamental to evaluate diversity in order to quantify stability.

Ecosystem diversity by spatial and areal scale is subdivided in: alpha diversity, beta diversity, gamma diversity and delta diversity (Mac Arthur, 1965; Whittaker, 1972; Lähde *et al.,* 1999, Pommerening, 2002). When we apply these concepts to forest ecosystems alpha diversity refers to divertsity within a stand, beta diversity to the degree of change in diversity between forest stands, while gamma and delta diversity operates at larger scales (Mac Arthur, 1965, Whittaker, 1972, Lähde *et al.,* 1999). The present study focuses on alpha diversity, that is the scale in which forest management plans have effect on ecosystems.

Alpha diversity in a forest stand can be divided according to Gadow (1999), Pommerening (2002) and Pommerening (2006) in: diversity of tree species, diversity of tree positions, and diversity of tree dimensions. The first represent the spatial arrangement of species. The second refers to small scale patterns of tree locations, that can be regular, clustered and random, plus combination of these. The third concerns the spatial arrangement of dimensions like diameter or height. In other words, alpha diversity is fitting the concept of forest "structure" and according to the previous definitions, we can reconstruct alpha diversity through measures of three types of structural aspects.

The structure of a tree stand is one of the characteristic attributes (Gadow and Hui, 2002); it can be defined in terms of mingling patterns of tree species, tree size distribution and spatial arrangement of trees (Gadow and Hui, 2002). Moreover it is the reflection and driving factor of different growth, competition, birth and death processes: successional, autogenic developmental (regeneration patterns, competition and self thinning), disturbance events and regimes. Precisely on managed forest we have to take into account the silvicultural treatments as the major disturbance. Any impact on forest stand is primarily reflected on forest structure.

Stand structural diversity, when defined, can be indicative of habitat suitability, overall species diversity (Kuuluvainen *et al.*, 1996; LeMay and Staudhammer, 2005), useful in forecasting stand growth and provide within stand details for forest inventories (LeMay and Staudhammer, 2005, Pommerening, 2002). Structural diversity is the topic on which this work is based on.

The intermediate scale of forest structure at the tree stand level is probably the most important aspect affecting organisms. Trees are ecological engineers: starting from individual dimension to the dimension of community, they affect the distribution over time and space of water, light, temperature and growing space, together with effects on nutrient cycling, especially carbon cycling. Horizontal and vertical arrangement of foliage and woody biomass defines the spatial distribution of microclimatic conditions within canopy space and understory (Kuuluvainen *et al.*, 1996), and consequently drives the establishment, development and evolutive pattern of the associated forest floor communities. Even the type of tree species has effect on organisms, in fact particular organisms feed or place nesting sites on particular species. In other words spatial arrangement of trees defines the three dimensional geometry of habitat characteristics for birds, insects, tree epiphytes, understory plants and soil micro-organisms (Morse *et al.,* 1985; Kuuluvainen *et al.*, 1996).

In addition heterogeneous stands are theorized to give more habitats to species than homogeneous ones, especially to species specialized on particular habitats (Kuuluvainen *et al.*, 1996). For example, the complexity of vertical vegetation structure has been found to be related to the number of insect and bird occupying a given forest area (McArthur and McArthur, 1961; Murdoch *et al*., 1972, Kuuluvainen *et al.*, 1996).

To summarize we can say that managing forest for biodiversity may be accomplished by managing for structural biodiversity (Önal, 1997). This possibility is still nowadays topic of discussion and further analysis.

When we focus on human influence on ecosystems, it is accepted that natural stands are generally more complex and diverse than managed stands (Kuuluvainen *et al.*, 1996; Lähde *et. al.*1999) and as a consequence biodiversity values of managed forest result lower than natural ones (Rouvinen and Kuuluvainen, 2005). The definition of "Natural Ecosystem" nowadays cannot be divided from human influence factor. In other words different extent of human pressure define the environment as "natural" or "non-natural" forest. Some authors define "natural environment" as a system free from human influence (Ruovinen and Kuoki, 2008) but the trend in this definition is moving towards a definition of a system where human influence do not exceed influence of other species (Ruovinen and Kuoki, 2008) or do not "significantly alter/affect" the ecosystem. Human induced processes like global warming and ozone depletion help us to understand how the first definition can be right but not based on reality. Even the largest and remote areas are not immune from these effects of industrial civilisation (Ruovinen and Kuoki, 2008). The discussion on the concept cannot be seen as a mere search for definition but as a starting point for practical use. For example attempts were made in finding and studying natural boreal forests (Ruovinen and Kuoki, 2008) for protection purpose as well as guideline, when stressing on the dynamic process in these systems, for restoration activities and "close-to-nature" management (Ruovinen and Kuoki, 2008, Mason *et al.,* 2007). In fact natural stands can be used as an example on which forest management, based on ecology and sustainability, can be inspired or calibrated (Ruovinen and Kuuluvainen, 2005 Kuuluvainen, 2002; Pommerening, 2002).

1.2 Structural indices

Objective and affordable measures are needed to quantify ecological, economical and social values to be used in the decision and management process. Structural indices have been developed to serve as tools inside these processes, to provide measures that distinguish between stands of different forest structure and provide surrogate indices of habitat quality (Pommerening, 2002; Kuuluvainen *et al*., 1996). Moreover, Pommerening (2002) claims that indices quantifying forest structures can be used to measure differences in time and space, generate forest structures, analyse differences between observed and expected structures and charactherize modifications of forest structure resulting from selective harvesting, especially in cases of continuous cover forestry methods, based on selective harvesting. In the case of indices based on spatial arrangement of individuals in a stand it is possible to retrieve general information on species ecology. For example in regular distributions individuals are evenly distributed over space, indicating avoidance (due to territoriality or shading effects); in random distributions individuals are distributed in an unpredictable manner and thus there is equal probability of an organism occupying any point in space; in clumped distributions we can understand that individuals tend to be attracted to one another or resources are distributed patchly.

Positive aspects of structural indices are the reduction of information and giving as result mean values or distributions. Their effort consist in providing clarity in interpretation and facilitate comparisons, especially in complex forest structures. A structure index to be considered as affordable should account for spatial variability, be addressed in the field, have low cost retrieving data as well as be descriptive, synthetic and comparable.

Several authors have proposed indices of stand structure based on tree attributes like species or tree size. Other indices based on spatial arrangement have been developed. Successively, some authors proposed indices or continuous functions that combine spatial diversity and tree attribute diversity into an overall structural index. Pommerening (2002) gave an interesting description and review of structural indices dividing them between "distance-dependent" and "distance-independent". The "distance-dependent" group of indices describes structure considering spatial arrangement, while in the "distance-independent" group of measures spatial arrangement is separated. The distance-dependent group is successively separated by Pommerening (2002) in three groups as follows: 1) individual or single parameters based on neighbourhood relations, accounting for small scale in biodiversity, 2) distance dependent measures to describe forest stand structure at stand level, 3) continuous functions.

In our work we calculated three distance-dependent indices and one distance independent index. The objective of this work is to describe structure through the used indexes, to help improving their efficiency and data collection methods. Indices tested in this work are distance-dependent neighbourhood-based: Uniform angle index (W_i) (von Gadow *et al.,* 1998;

Von Gadow and Hui, 2002), (M_i) Species Mingling (Gadow and Hui, 2002) and Diameter at Breast Height Dominance (U_i) (Gadow and Hui, 2002) and distance-independent Shannon index for heights-Tree Height Diversity (Shannon, 1948; Kuuluvainen, 1996). The scale at which this work is aiming is a forest and stand scale rather than landscape and regional scale.

1.3 Concept of Sustainability

Originally sustainabililty in forest management was mainly considered as the sustained yield of timber that permitted the regeneration, in a certain period of time, of the same quantity of timber resource by a released stock. The concept of sustainability came to us from forest management and since centuries ago; with the passing of time it developed and acquired new aspects. Biodiversity, soil erosion, water resources, hydrogeologic risk, global warming, renewable energies became important topics in different fields of economy as well as in the forestry sector only during the past decades. So different types of sustainability were recognised, studied and perceived. Ecological sustainability is an example: conservation of ecosystem functionality and resilience capacity are strictly connected with biodiversity values. Biodiversity in an operational way is based on closely interrelated components: species (including genetic) diversity, habitat diversity (or ecosystem structure) and functional diversity (or ecosystem functioning). Ecological sustainability as a consequence is reached through the maintenance of these three components. The sustained use of forests is nowadays not reached solely with the product of timber but with the sustained production of functions. This aspect is reflected in forest sector by the definitions given in conferences in past decades: one of the most interesting examples is "sustainable development", which has been defined in the Bruntland Report of World Commission on Environment and Development of United Nations (WCED, 1987) as: "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs". A set of economical politics for the sustainable development have successively been defined in United Nations Conference of Environment and Development (UNCED) held in Rio de Janeiro in 1992. Rio Conference principles inspired the Ministerial Conference on the Protection of Forests in Europe (MCPFE) in Helsinki in 1993, where in the first resolution (Resolution H1), a common concept of sustainable forest management was elaborated. Sustainable Forest Management (SFM) definition of MCPFE is: "The stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfill, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems". A system of six criteria were adopted in Lisbon MCPFE in 1998, which altogether with indicators (C&I) consist in the core elements of SFM. Using simple words Criteria reflects values recognised as important while Indicators are measures that demonstrate progress towards objectives.

Criteria of Sustainable Forest Management are:

1. Maintenance and appropriate enhancement of forest resources and their contribution to global carbon cycles;
2. Maintenance of forest ecosystem health and vitality;
3. Maintenance and encouragement of productive functions of forests (wood and nonwood);
4. Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems;
5. Maintenance and appropriate enhancement of protective functions in forest management (notably soil and water);
6. Maintenance of other socio-economic functions and conditions.

Voluntary-based Pan-European Operational Level Guidelines were adopted in the second MCPFE in Lisbon. Their functionality is on planning and management scales with the purpose of being useful in the implementation of the SFM at the national or regional scale and at practical level.

1.4 Objectives

Objectives of this work can be summarized as follow:

- The first objective consists in description and characterization of forest structure in sample plots collected in Manez area through implementation of structural indexes.

  Structural indices should provide quantitative informations and characterize forest structure in an alternative (with respect to the normal parameters collected) and useful way.

- The second objective is to define till which we can reduce the dimension of sample plot for a neighborhood index while conserving a satisfactory descriptive potential. In detail we want todefine a minimum dimension of a sample plot where each population of index values can be considered descriptive of a stand.

- So it would be be possible to reduce data collection time and better evaluate the adaptability of indices use inside forest inventories.

2. Materials and Methods

2.1 Area of study

Manèz Valley is situated in the southern Retic section of the Italian Alps, in Trento Province, in Giudicarie Valley. Precisely Manez Valley position is in the southern part of Brenta Dolomites mountain chain; the nearest inhabitated area is the town of Montagne, with its outlying administrative division called Binio. The development of the valley follows North/Northeast-South/Southwest gradient, starting from Malghette (or Margole) Pass (1723 m a. s. l.) Northwards and reaching Binio Southwards.

Manèz territory borders on the East (orographic right) with Algone Valley through the ridge that lies between Tòf Mount (2032 m a.s.l.) Northwards and the Iròn Mount Southwards (1854 m a.s.l.); on the West (orographic left) with the Rendena Valley. On the South-East the valley is protected by the ridge between the Iron Mount and Ancis Peak (1442 m a.s.l.). Southward the valley ends at 1100 m a.s.l. with private properties of Montagne municipality and connects to the lateral slope of the Central Giudicarie Valley.

The climate of the area is a transition between the prealpine (in Rendena Valley) and continental (in Sole Valley). The mean annual rainfall amount of the area is 1256 mm, following data recovered from Montagne weather station (955 m.a.s.l.) for the period concerning 1961-1990 (data from Dipartimento Protezione Civile-Provincia di Trento). The highest values of mean monthly rainfall are in May (156 mm) and in October (130mm), the minimum value is resulting in the month of January (71 mm). Snow cover lasts from November till March-April. The mean annual temperature interpolated through the data of Tione di Trento station (Bronzini, 2005) is 9°C at the bottom of the Valley. The valley is characterized by inversion.

Concerning hydrography we can say that it is very limited due to draining and carsic phenomena. The Valley is crossed by Manèz stream which has seasonal characteristic and originates in the Malghette Pass area.

Concerning geological aspects the basal rock of the valley is calcareous; the orographic right of the valley is constituted by limestones and argillites, while the orographic left is constituted by dolostone on the bottom zone and in the upper zone by the calcareous-dolomitic series.

Soils are comprised in the carbonatic series, from leached-brown soils, to calcareous brown soils to rendzina (especially in pasture above tree-line). Brown soils are usually not well developed due to the high degree of slopes; or due to the effects of past heavy human activities.

Manèz Area is crossed by the Adamello-Brenta Natural Park (PNAB) South-Western border, which comprises the northern part of the valley in its territory. The part of the valley comprised in the Adamello-Brenta Natural Park area is in turn comprised in the IT3120009 “Dolomiti Brenta” - *Site of Community Importance* (SIC) European protection area defined by the Habitat Directive (91/43/CEE) of the European Commission.

Manèz area is property of the Regole Spinale-Manez community, which is an ancient pastoral community, owned by the population of three villages (Preore, Ragoli, Montagne) and is based on common use of lands. The community manages the common and inalienable properties (buildings, lands) in order to regulate the sustainable land-use, support the traditional use of the natural resources and distribute benefits to the community members.

The known past land-use of the area is connected to the excessive use of forests and pastures. The past forestuse in this area consisted in extraction of timber and firewood; firewood in turn was used for charcoal and burnt lime production altogether with its primary use. Unforested areas were created diffusely to grant areas for grazing and agriculture (meadows). The grassland used for pasture during the last decades returned to forestland due to heavy abandonment of grazing. General fertility of the soils is still nowadays affected by the past use of pastures and forest; especially after decades the effects of past use is still having effects on actual forest development. From Table 2.1 we have a quick and effective overview of the development of forests after 1970 in Manez area, taking into account abandonment of pastures; and on the other hand the results of forest management actions made in order to increase the stock.

Period	Prod. Surface (ha)	Total Mass (m_t^3)	Mass/ hectare (m_t^3/ha)	Annual increment / hectare (m^3_t/m^3_{t-1})/ha	Picea %	Abies %	Larix %	Fagus %	Annual calculated harvest mass (m_3/y)	Annual increment Mass (%)	Annual harvested Mass (%)
1970-1979	**413**	**73809**	**179**	**3,6**	**35**	**58**	**4**	**2**	**807**	**2**	**1,2**
1980-1994	**431**	**105269**	**244**	**5,9**	**37**	**52**	**4**	**4**	**1000**	**2,4**	**0,9**
1995-2004	**431**	**127477**	**295**	**5,4**	**38**	**50**	**5**	**5**	**1200**	**1,8**	**0,8**
2005-2014	**431**	**135835**	**315**	**5,6**	**38**	**49**	**5**	**6**	**890**	**1,8**	**0,6**

Table 2.1: General variables estracted from Management plans regarding Manez forest stands (data from Piano di assestamento dei beni silvo-pastorali-Comunità delle Regole di Spinale e Manez 2005-2014).

Present multifunctionality of forest is recognised in: production of timber and firewood (non wood forest production is limited only to mushroom picking); protection of inhabitated areas and roads; conservation of nature; hunting estate function; tourism and cultural attraction.

Our data-gathering was carried in mountain and high-mountain belt of Manèz mesalpic valley in Silver fir (*Abies alba* Mill.) dominated forests. Following Pignatti (1998) Silver fir stands in alpine region are usually located between continental and oceanic climatic conditions, in which respectively spruce and beech prevale. In this intermediate belt silver fir is typically dominating consortia like *Abieti-fagetum* and *Abietetum*. In Italian situation these forests have been transformed several times in spruce-dominated forests, due to antropic influence, but the typical herbaceous flora of silver fir forests is the one that is bound to beech stands.

The definition "mesalpic" comes from Italian Alpine forest district classification based on climatic, morphological and geo-lithological means; here precipitations are high (around 1400 mm) and uniform during the year; low temperature starts to be a problem to competitiveness of broad-leaf trees, and is better tolerated by evergreen individuals; in other words it is a tension area between broad-leaved and evergreen species (Del Favero, 2004). Mesalpic is a transition district of Alps between esalpic and endalpic districts.

Manez valley altitude covers altitudinal belt that go from the mountain (800-1000; 1400 m a.s.l.), to high-mountain (1400-1700 m a.s.l.), to subalpine (1700-1900 m a.s.l.). Mountain band and Mesalpic district see as important in ecological and coltural sides multispecific silver fir (*Abies alba* Mill.) stands constituted by silver fir, beech (*Fagus sylvatica* L.) and Norway spruce (*Picea abies* Karst.) in different percentage; in altimountain belt the dominated silver fir stands are usually present but the types of stand charachteristic are Norway spruce or European larch (*Larix decidua* Mill.) stands (Del Favero, 2004).

The majority of silver fir stands in Manez area are defined following the Trento Province system of forest-type classification as: "tipical mesalpic silver fir dominated stand on carbonatic substrate and mesalpic subtype" ("Abieteto calicicolo tipico, sottotipo mesalpico") and are localized in the valley floor and on the lower slope part, especially in the orographic left. In the orographic right or in situation on the central part of slopes usually it is found a version of the previous classification, typical of soils where hydric suplly is evaluated as limited ("abieteto calicicolo tipico, sottotipo mesalpico, in variante xerica"). In the Southern and lower part of the valley the conditions of the soils are more favorable and hydric conditions too, in this case the stands are classified as "silver fir dominated stand on soils characterized with intermediate hydric supply"("abieteto calcicolo tipico, sottotipo mesalpico, dei suoli mesici").

The system of categorization of stands and subdivision in functional forest units followed is the one proposed in Trento province by Odasso (2002), inspired by the characterization of forest types proposed and studied for the Veneto province by Del Favero (see Del Favero *et. al.*, 1990; Del Favero *et al*., 1991; Del Favero and Lasen, 1993).

Forestuse management plan used to retrieve information on composition, localisation of stands, type of management is the one relative to the properties of Regole Spinale-Manez community ("Piano di assestamento dei beni silvo-pastorali-Comunità delle Regole di Spinale Manez 2005-2014") and it is an instrument owned by Trento Province forest service. Forest management plan divides territory in compartments; areas which can be considered similar in ecologic, economic and coltural aspects.

2.2 Measures and instruments

The compartments selected in the Manèz area are classified as Silver fir dominated forests by the management plan. Silver fir forms high forests and in selected parcels the silviculture follows close to nature criteria. Fellings mimic natural disturbance, which consists in gap felling of groups of individuals (2-4 individuals or 4-6 individuals). These forests compartments of defined forest-type were successively submitted to field examination. Vertical structure range selected is very wide, from multistoried to single-storied. Selective criteria were used to localize and establish sample plots inside the compartments. Twenty-seven (27) sample plots were established inside seventeen (17) compartments; which means that in some cases more than one area (maximum two) were established inside each compartment.

Compartments selected and management plan information on stand characteristics are presented in Table 2.2.

Compartment	Elevation (m. a.s.l.)	Structure	Forest type	Vegetational Belt	*Abies alba* (Mill.) (%)	*Picea abies* (Karst.) (%)	*Fagus sylvatica* (L.) (%)	*Larix decidua* (Mill.) (%)	*Pinus sylvestris* (L.) (%)	Various	Mean height (hg)(m)	Max height (S) (m.)
1	1180-1310	Composite	"Abieteto calcicolo tipico, sottotipo mesalpico in variante xerica"	F.A.	41	45,1	0,1	10,2	3,6		23	30
3	1240-1430	Composite	"Abieteto calcicolo tipico, sottotipo mesalpico in variante xerica"	F.A.	24,2	51,4	0	6,5	17,9		21	28
4	1280-1510	Composite	"Abieteto calcicolo tipico, sottotipo mesalpico in variante xerica"	F.A.	55,3	42,6	1,1	0,8	0,2		22	30
5	1310-1580	Irregular	"Abieteto calcicolo tipico, sottotipo mesalpico in variante xerica"	F.A.	56	34,5	3,5	4,5	1,5		20	27
6	1390-1580	Composite	"Abieteto calcicolo tipico, sottotipo mesalpico in variante xerica"	F.A.	52,3	43,7	2,7	1,3	0		22	30
7	1430-1510	Disetaneous	"Abieteto calcicolo tipico, sottotipo mesalpico in variante xerica"	F.A.	45,5	46,6	5,6	2,3	0	PNAB-SIC	22	27
11	1420-1640	Irregular	"Abieteto calcicolo tipico, sottotipo mesalpico in variante xerica"	F.A.	51,5	35,7	8	4,8	0	PNAB-SIC	21	28
12	1370-1590	Irregular	"Abieteto calcicolo tipico, sottotipo mesalpico"	F.A.	67,1	25,9	3,6	3,2	0,2	PNAB-SIC	21	28
14	1310-1560	Irregular	"Abieteto calcicolo tipico, sottotipo mesalpico"	F.A.	56,9	38	2,2	1,1	1,8		20	27
15	1180-1360	Composite	"Abieteto calcicolo tipico, sottotipo mesalpico"	F.A.	46,4	47,5	0,2	1	4,9		24	30
16	1190-1360	Coetaneous	"Abieteto calcicolo tipico, sottotipo mesalpico"	F.A.	43,9	55,2	0,8	0,1	0		31	33
17	1360-1560	Composite	"Abieteto calcicolo tipico, sottotipo mesalpico"	F.A.	61,6	32,5	5,8	0,1	0		22	33
19	1360-1560	Composite	"Abieteto calcicolo tipico, sottotipo mesalpico in variante mesica e xerica"	F.A.	72,7	25,8	1,3	0,2	0		18	28
20	1180-1380	Composite	"Abieteto calcicolo tipico, sottotipo mesalpico, dei suoli mesici"	F.A.	56,9	42	0,4	0,7	0		26	34
22	1100-1320	Composite	"Abieteto calcicolo tipico, sottotipo mesalpico, dei suoli mesici"	F.A.	51,9	34,8	0	13,3	0		23	34
24	1580-1770	Coetaneous	"Abieteto calcicolo tipico, sottotipo mesalpico, dei suoli mesici"	F.A.	27,8	43,8	25,2	3,2	0		18	26
31	1350-1610	Irregular	"Abieteto calcicolo tipico, sottotipo mesalpico"	F.A.	60	31,5	2,3	0,8	5,4		28	27

Table2.2:General characteristics of management plan units, measures and qualitative description.

Field work took place during spring and autumn 2012.

Each plot has a circular shape with a diameter of 60 meters (horizontal distance), which correspond to an area of 2826.00 m^2. This area is comparable to areas used in research for stand structure evaluation as to be representative of a forest stand. Here we consider the 2826.00 m^2 representative of the forest stand and used to evaluate forest stand structure(examples Aguirre *et al.,* 2003; Kuuluvainen *et al.*, 1996)

Inside each circular plot center coordinates were taken using Garmin® GPSMAP® 60CS in UTM cartographic representation, WGS84 datum and GRS80 ellipsoid.

In each plot the following measures were taken using Haglöf Sweden AB Vertex IV ultrasound hypsometer: total height (meters), crown insertion height (meters) and horizontal distance from the center (meters) for each individual.

Diameter at breast height (1.30 m) (DBH) (centimeters) was measured for each individual above 7,5 cm in each plot; instrument used is a tree caliper.

Measure of the angle (azimuth) in the central point between the North direction and tree individual was measured in degrees (°) for each tree using a compass KONUS® #4075KONUSTAR-11.

Set of collected single individual attribute values were: species, distance from the center (m), azimuth (°), DBH (cm), height (m), crown insertion height (m).

Using Windows Excel summary statistics and Shannon index as Tree Height Diversity (THD) for each stand were elaborated.

Data for each sample plot were analysed with nearest neighbour structural indices using CRANCOD program. CRANCOD is a computer software for the analysis and reconstruction of spatial forest structure, developed by Prof. Dr. Arne Pommerening and the School of Agricultural, Forest and Food Sciences of the Bern University of Applied Sciences. CRANCOD program was used to calculate nearest neighbour indices for each individual in each plot of our study and the mean value of neighbourhood indices for each plot, as in the functionalities of this program. Successively the program calculated indices values for concentric sub-areas on each individual of each plot. Starting from a radial measure of 30 m, which has an area of 2826.00 m^2, sub-areas were identified with radial dimension of 20, 13, 10 meters which respectively cover an area of 1256.00 m^2, 530.66 $m^2$and 314.00 m^2.

For the whole set of sample plot areas and relative sub-areas the edge effect was not taken into account.

Addinsoft XLSTAT, Microsoft Excel statistical add-in was used to carry out statistical analysis on the set of 27 sample plots and its 20 meters, 13 meters and 10 meters sub-plots.

Normality test used to evaluate statistical normality of the data is Shapiro-Wilk.

Non-parametric tests were applied to evaluate differences between the datas of the 30 meters radius areas and corresponding 20, 13, 10 meters radius sub-areas. The tests applied are to evaluate the hypothesis of belonging between separated groups of data (20, 13 and 10 meters radius areas) and the statistical population (30 meters radius areas); test applied are Mann-Whitney and Kruskal-Wallis. Mann-Whitney (bilateral test) to between two datasets; Kruskal-Wallis between *k* sets of data.

Shapiro-Wilk test is a statistical test that verify the null hypothesis that a sample (x_1,....x_n) came from a normally distributed population. The statistics W has a range between 0 and 1: when the value is considered by the user as too small the hypothesis will be rejected. The test rejects a normal distribution (where values are normally distributed) when the corresponding p-value is less than a chosen alpha-level. The test accepts that data are coming from a normally distributed population when p-values are higher than alpha level.

Kruskal-Wallis one way analysis of variance by ranks is a non-parametric method; applied in this work for testing whether samples originate from the same distribution or not. It is a test based on the analysis of the median in independent samples. The test it is used to compare more than two samples and for groups that have unequal size. In the case of significant results, Kruskal-Wallis method depict differences between samples but does not define where the differencies are located or how many cases of differences are found.

Mann-Whitney's test U is a method used to compare medians of two independent groups. The test is analyzing if two groups of variables have statistically significant difference. H0 hypothesis is that two sample plots are extracted from the same population and that their probability distributions are identical.

2.3 Indexes

The main reasons for using structural indices lies in describing and characterizing forest structure with different individual distribution, species composition and size distribution in an accurate way, with affordable and quantitative assessment techniques.

Synthesis of forest structure can be reached with the characterization of α-diversity through the three types of attributes referring to species, positions, and size.

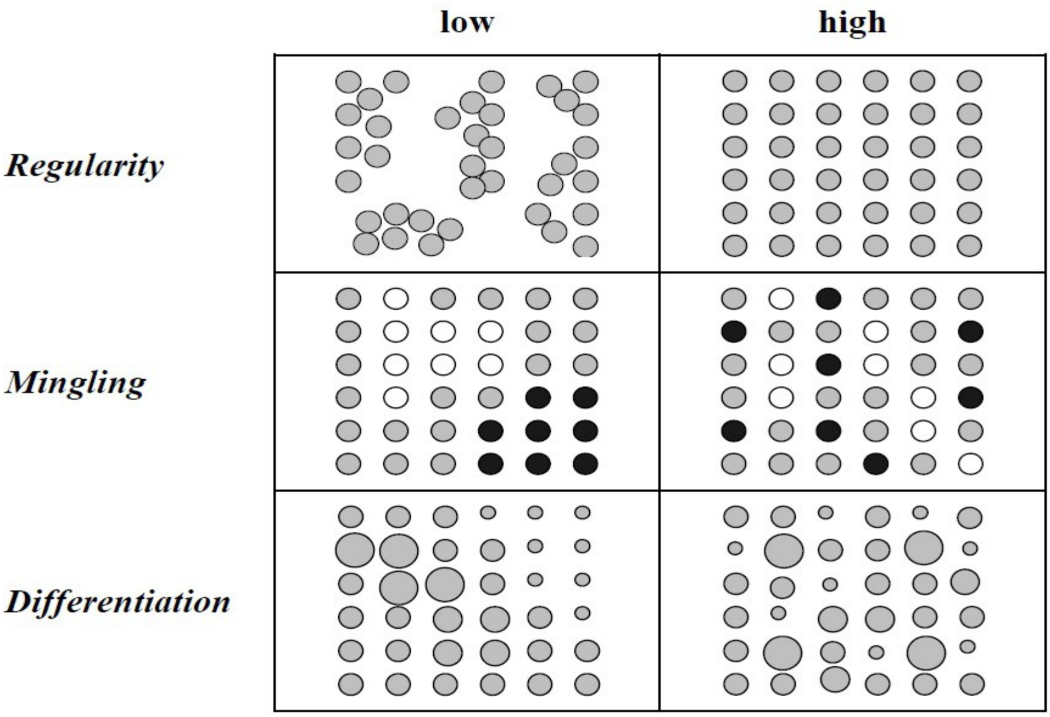


Figure 2.1: Graphical representation of main elements of forest spatial structure: regularity of tree positions, species mingling, and size differentiation. Figure from Gadow and Hui, 2002.

In this work the attribute species was quantified through mingling using the Species Mingling index, the spatial attribute through the degree of regularity using Winkelmass and the dimensional was quantified through dominance attribute using Diameter at Breast Height Dominance (DBHD) index (Gadow and Hui, 2002; Aguirre *et al.*, 2003) in relation to diameter, and Shannon index in relation to height. Winkelmass, DBH Dominance, and Mingling index were developed since 1992 by a research group at the Institute of forest Management of the University of Göttingen (Germany), and are single tree and neighbourhood-based, while Tree Height diversity (THD) is a direct derivation of the Shannon-Weaver formula (Shannon and Weaver, 1949) modified by Kuuluvainen *et al.*

(1996) and considers the total number of trees in the plot.

In the past decades many indices quantifying forest structure have been developed to simulate and describe spatial forest structure (Pommerening, 2002). Aggregate indices too have been studied and developed to account for the different constituting aspects (examples: Pastorella and Paletto, 2013). Attempts to evaluate these indices were conducted (Pommerening, 2006). One possible method was to correlate indices and more direct measures of biodiversity (e.g. abundance of a rare species), while the second was to evaluate the ability to synthesize spatial forest structure; this method mainly consisted in simulations of different forest structures starting from data collected in real sample plots.

2.3.1 Neighbourhood-indexes

Neighbourhood indexes are structured to be calculated on point or tree base, where in both of cases species, dimensions, and positions will result as spatially segregated or exhibit an high degree of "mingling".

In the point-based case a number of closest neighbours, usually four, is selected in the proximity of a sample point and parameters requested for the index (species, dimensions, positions) are collected. In the second case a sample tree closest to a sample point is chosen as the reference tree while the neighbours selected are the closest to the reference tree. In other words in the point-base case we focus on a group analysis, where an individual value of the index is referring to a point, while in the tree-base case we develop a single-tree analysis, where a value of the index is assigned to each single tree. The approach used by these type of indexes is similar to the ones describing the structure of chemical molecules or cellular automata where the quantification of immediate neighbourhood is a basilar aspect (Pommerening, 2006).

These types of indices allow the calculation of mean values to represent a forest stand, but usually a frequency distribution of their value is more informative on the overall structural situation of a stand.

Pommerening (2006) claims that point-based neighbourhood indices have certain advantages if connected with inventories, while tree based are conceptually more similar to cellular automata.

The main advantage of these types of indexes consists in the opportunity of description of the spatial structure and avoidance of time-consuming measurements of distances between neighbouring individuals.
Another advantage is represented by the adaptability of these types of indices on forest inventories. In fact the data needed to describe structure are already present in management plans, and the procedures of field data collection are almost equal or can be easily implemented with simple variations. For example Pommerening (1997, quoted in Pommerening, 2002), Pommerening and Schmidt (1998, quoted in Pommerening, 2002) and Pommerening and Gadow (2000, quoted in Pommerening, 2002) evaluated the sampling method "structural group of four" and applied it to the standard fixed-area plot commonly used in forest inventories; then found that Winkelmass and Mingling are useful and imply only a small sampling method.
Practical aspects may represent a strong point towards selection and implementation of these indexes in management plans.
Neighbourhood-based indexes focus on small scale differences in structure of forest, when presented as frequency distribution of index values. A problem connected to these types of indexes is the scale and the neighbourhood concept: there is no minimum and maximum distance at which the selected nearest neighbour can be; this implies that it can be on a different ecological scale, at a distance in which the two individuals are not interacting. Functions give more information on forest structure and more information on ecological scale together with an understanding of competition effects in mixed stands but with high data requirements.

Winkelmass index

The Uniform Angle Index (UAI) or Winkelmass index W_i is an easy-to-implement tool used in forest management for inventorying forest stand structure. It is a single-tree and neighbourhood based index. In this field the index describes the degree of regularity in spatial distribution of a certain number of *k* neighbouring trees with respect to one central point . The central point can lay on a tree position (*Tree- based Winkelmass*) or not (*point- or area- based Winkelmass*). The *point- or area- based Winkelmass* version is usually the preferred one on an operational scale (Aguirre *et al.*, 2003), even if Pommerening (2006) suggests the use of tree-based indices that fit better the concept of cellular automata. In this work we use the *tree-based Winkelmass*.

The data needed for the index are the values of angle α_j (j=1,...,k) between each two immediate neighbours of the *k* neighbouring trees. The neighbouring trees have to be chosen between the closer to the central point and in *k* number. Usually the amount of trees preferred is four (Aguirre *et* al., 2003), but the number can be flexible. The angle α_j has to be the least wide between two neighbouring trees following a given clockwise or anticlokwise direction (even if there is a special case in which the clockwise or anticlockwise direction has to be inverted to select the least wide angle). Subsequently it has to be compared with a reference angle α_r. The angle α_r is the angle that we expect to have in a totally homogeneous distribution; it is determined dividing the round angle (perigon) by the number *k* of neighbouring trees selected. Eventually the value obtained in the comparison is a binary value z_j and is determined in this way:

$z_j=1$ when $\alpha_j < \alpha_r$

$z_j=0$ when $\alpha_j \geq \alpha_r$

The binary value of the angle is calculated for the *j* angles that lay in group. A mean value W_j of the binary value for the sample group is calculated.

$$W_i = \frac{1}{k} \cdot \sum_{j=1}^{k} z_j$$

The values obtained through this index have a range between 0 and 1. Values of W_i close to 0 represent a regular spatial structure, while values close to 1 represent a clumped spatial structure, It comes that values around 0.5 represent a casual spatial structure.

In the most common case of four neighbours (Aguirre et al. 2003) the value of W_i will have five possible results with five degree of regularity, as presented below:

W_i=0.00 very regular

W_i=0.25 regular

W_i=0.50 random

W_i=0.75 irregular

W_i=1.00 very irregular

In the case of a casual or systematic sample in a forest the mean value of the Winkelmass index for a stand is:

$$\overline{W} = \frac{1}{k} \cdot \sum_{j=k}^{k} W_j$$

where *k* represent the number of sample points.

In a case of regular spatial distribution if the central point is placed near the center of the group of *k* individuals the value of W_i can be influenced and gives an interval of values in the middle between a regular and a casual distribution.

Thus, a tolerance percentage is applied to the reference angle. The percentage applied is 20%: it means that we have to multiply α_r by 0.8, and the resulting value will be the new α_r (Gadow, 1999, quoted in Corona *et al.*, 2005). Hui and Gadow(2002, quoted in Gadow and Hui, 2002) found, by means of simulation studies, that an average standard angle of 72° produces an average value of $\overline{W}$= 0.5 for a random distribution.

To understand if we are in a regular distribution or not we can evaluate in a subjective way or by using instruments based on the reference angle.

Gadow and Hui (2002) claim that, even if the mean value $\overline{W}$ is an affordable method to characterize a point distribution, it is advisable to study the distribution of the W_i-values that describes the structural variability in a stand.

Diameter at Breast Height Dominance (DBHD) index

Diversity of trees dimensions may be evaluated in a similar way as the other neighbourhood indexes like Winkelmass and species mingling. It can be evaluated on a *tree-based* or *point-based* approach. In this work we used the *tree-based* approach.

The description of forest structure through the analysis of variability in trees dimensions can be improved with the introduction of other attributes of each individual, such as the species.

Dominance as a tree attribute: Hui et al. (1998, quoted in Gadow and Hui., 2002) proposed the attribute dominance to connect relative dominance of a tree to its immediate neighbourhood through silvicultural significance or species (species-specific *dominance*). The attribute dominance is the proportion of the *k* nearest neighbours of a reference tree which are smaller than the reference tree. The formula applied in this case is derived from the previous tree based structural parameters;

$$U_i = \frac{1}{k} \sum_{j=1}^{k} v_j$$

Following the Aguirre *et al.* (2003) definition of the index, the value v_j will have value 1 when the neighbour *j* is smaller than the reference tree and 0 as result in all the other cases. The range of values U_i can assume will be between 0 and 1.

In the most common case, where the value *n* correspond to four, the value of U_i will assume five values with respective dominance classes as follows:

0.00= very suppressed

0.25= moderately suppressed

0.50= co-dominant

0.75= dominant

1.00= strongly dominant

These five values U_i can correspond to social classes developed by Kraft (1884, in Gadow and Hui, 2002) used by forest managers in Germany.

We can use the *dominance* criterion to describe the relative dominance of a particular tree species (e.g. Gadow and Hui, 2002; Aguirre et al. 2003).

Mingling index

Quantification of species diversity is an important aspect connected with forest management. Several parameters have been developed to describe species diversity.

Gadow and Hui (2002) proposed the evaluation of species diversity in the vicinity of a reference tree (*mingling as a tree attribute*) or a sample point (*mingling as a group attribute*).

In this work we evaluated the mingling attribute on a tree-base.

Mingling as a tree attribute: the attribute mingling M_i is expressed by the proportion of the *k* nearest neighbour trees of the *i*th reference tree that do not belong to the same species (Gadow and Fűldner, 1992, quoted in Gadow and Hui, 2002). Generally it is used to derive a distribution of trees that belong to a certain structure class. In the formula the value v_j is a binary value connected to the reference tree attribute species. The value of each neighbour tree *j* has 0 value when it belongs to the same species of reference tree; whereas it has value 1 when neighbouring tree and reference tree belong to different species.

$$M_i = \frac{1}{k} \sum_{j=1}^{k} v_j$$

The mingling attribute M_i can assume values between 0 and 1. Mingling, in the case of four neighbouring trees, can be represented and translated in this way:

0.00= zero mingling

0.25= weak mingling

0.50= moderate mingling

0.75= high mingling

1.00= very high mingling

The calculation of the mingling variable for a whole stand consists in the sum of all the M_i values divided by the number of trees. In this case a high value of mean mingling M represent a high intermingling of the different species, while a small value near 0 will indicate large groups of one single species and segregation.

Pommering (2002) suggest the use of distribution of the mingling variable to represent the current state of a forest.

Particular interest is stressed on the species-specific mingling by Gadow and Hui (2002) and Aguirre *et al.* (2003).

2.3.2 Distance-independent indices:

Tree Height Diversity Shannon index

Tree height diversity (THD) is a distance independent indexes that characterize forest structural diversity at stand-level through values of tree-size diversity. THD is a direct derivation of the Shannon-Weaver, also known as Shannon-Weiner, formula (Shannon and Weaver 1949), from which the Shannon's index is calculated. The Shannon's index is a very common species diversity index.

The formula is based on the probability of one individual, taken at random from an infinite population, will belong to a certain species. If the probability is low we are in a situation of high diversity.

The formula is presented as follows:

$$H' = -\sum_{i=1}^{S} p_i \ln(p_i)$$

Here p_i is the proportion of individuals in *i*th (class) species and S represent the number of species detected. The maximum value of species occurs when each class (species) has an equal value to the others; in this case the value of the H' index will be of ln(*S*).

Several variations were applied changing the type of value chosen to be representative for each species. Staudhammer and LeMay (2001) summarized variations on the data chosen as value: starting from number of individuals (Franzreb 1978; Swindel et al. 1991; Niese and Strong 1992; Condit et al. 1996, quoted in Staudhammer and LeMay, 2001), basal area (McMinn 1992; Harrington and Edwards 1995; LeMay et al. 1997, quoted in Staudhammer and LeMay, 2001), stems per hectare (McMinn 1992; Harrington and Edwards 1995, quoted in Staudhammer and LeMay, 2001), foliar cover (Swindel et al. 1984; Lewis et al. 1988; Qinghong 1994; Corona and Pignatti 1996, quoted in Staudhammer and LeMay, 2001), and biomass (Swindel et al. 1984; Swindel et al. 1991, quoted in Staudhammer and LeMay, 2001).

Mac Arthur and Mac Arthur (1961) used Shannon index to elaborate a new index called foliage height diversity index (FHD). In which the total height of a stand is subdivided in layers and where the amount of vegetation is measured. In this index S, the former number of species was replaced by the number of layers and the value accounted is the proportion of foliage in *i*th layer.

The same procedure was used to modify the Shannon index using amount of diameter classes *S* and p_i as proportion of basal area in *i*th diameter class versus the total; this index is Tree Diameter Diversity (TDD). The same procedure was used to create the Tree Height Diversity index (THD) in which we substitute the height classes.

Continuous values are usually grouped in classes applying arbitrary thresholds to calculate proportions. Concerning foliage height diversity (FHD) Mac Arthur and Mac Arthur (1961) divided height in three horizontal layers. Two-meter deep horizontal layers were applied in the calculation of the tree height diversity (THD) by Kuuluvainen et al. (1996).

Regarding diameter classes several options were applied: Lähde et al.(1999) used three diameter groups (2-10, 11-25, and >25 cm). Wikström and Eriksson (2000, quoted in Staudhammer and LeMay, 2001) used 5-cm diameter classes; the same as Gove et al. (1995, quoted in Staudhammer and LeMay, 2001). Solomon and Gove (1999, quoted in Staudhammer and LeMay, 2001) used 2,5-cm classes. There is no agreement in literature about class width, and number of classes; however it is uncertain how sensitive is the index to the change in class width.

In this work the THD was calculated with the same procedure adopted by Kuuluvainen (1996) where *S* was the number of 2 meters deep layers and p_i is the proportion of individuals in each class.

Index (reference)	Formula	Where	
Uniform angle index (Gadow *et al.*, 1998; Hui and Gadow,2002)	$W_i=\frac{1}{k}\sum_{j=1}^{k} v_j$	$v_j=\begin{Bmatrix} 1, \alpha_j<\alpha_0 \\ 0, otherwise \end{Bmatrix}$	$\alpha_0=\frac{360°}{k+1}$
Species Mingling (Füldner, 1995; Aguirre *et al.* 2003)	$M_i=\frac{1}{k}\sum_{j=1}^{k} v_j$	$v_j=\begin{Bmatrix} 1, species_j \neq species_i \\ 0, otherwise \end{Bmatrix}$	
DBH dominance Gadow and Hui, 2002; Aguirre *et al.*, 2003)	$U_i=\frac{1}{k}\sum_{j=1}^{k} v_j$	$v_j=\begin{Bmatrix} 1, DBH_i \geq DBH_j \\ 0, otherwise \end{Bmatrix}$	
Tree Height diversity (THD) (Kuuluvainen, 1996)	$H'=-\sum_{i=1}^{S} p_i \ln(p_i)$	p_i= *proportion of individuals in the ith class*	*S= number of 2 meters width classes*

Table 2.2: Quick overwiew of indices applied in this work.

3 Results

3.1 Characterization of stands under study

In Table 3.1 the characterization of each single plot is presented. Parameters presented above are typically used in management plans to describe forests, evaluate stock, density site fertility, and other quantitative and qualitative parameters. Each sample plot name represent the referring management plan compartment number, and the progressive number of the sample plot placed in the compartment. Range of altitude (Alt.) of plots is from 1194 m.a.s.l. (sample plot 1,1) to 1663 m a.s.l. (24,1). Aspect seen in the whole sample plots is missing only the South-West and North directions; while mean terrain slope range is between 13.6° (1,1) and 35° (4,1). Stems per hectare (SPH); basal area (m^2) per hectare (G); (dg) quadratic mean diameter (Diameter at Breast Height-DBH) (cm) represent the density of the stand, and their capacity in regeneration. Values of individuals per hectares varies from 212.3 (16,1) to 870.5 (1,2). Basal area per hectare vary from 30.22 m^2 (3,1) to 59.77 m^2 (14,2). Quadratic mean diameter consists in diameter of the mean basal area tree, its values ranges from 25.36 cm (7,1) to 49.56 cm (16,1).

Concerning heights we can say that is usually a parameter connected to fertility of soils especially the value of Maximum height. Two parameters are here presented: Mean height (hg) and Maximum height (S). Mean height is the Mean stand height (m) corresponding to the related mean squared diameter. Mean stand height is estimated by inputting the quadratic mean DBH (dg) in the function of the stand height curve: the minimum value is 19.57 m and maximum is 34.27 m. Top height is a measure of the four or five highest individuals in a stand, it is typically a measure of fertility for multi-storied stands, but applied even to even-aged stands; values are inside the range from 29.03 m (3,0) to 43.13 m (22,1).

Species composition is represented through percentage of total basal area or of number of individuals belonging to a certain species class in each plot. First of all we can notice some discontinuous presence: *Larix decidua* (Mill.) which usually was favored by man in the past (forested pasture) has high dimensions and small numbers; *Pinus sylvestris* (L.) is found in sample plots in the vicinity of areas with xeric situations (31,1) or in the vicinity of a mountain stream with soil erosion situations. The three main species are *Abies alba* (Mill.), *Picea abies* (Karst.) and *Fagus sylvatica* (L.) which have different weight in each stand. *Abies* *alba* (Mill.) minimum presence on basal area is found in sample plot 16,1 with 38.8 % while maximum presence on basal area is found in sample plot 4,2 with 81.3 %. Forest stands are classified as *Abies alba* dominated forest by the management plan but in sample plot 16,1; 19,1; 14,1 and 20,1 *Picea abies* (Karst.) covers the higher basal area, respectively 61.1 %; 56.0 %; 47.4 %; and 53.3 %. Number of individuals on the other side see in all cases dominance of silver fir. This aspect can be explained by the typical characteristic of this forest type that see the presence of silver fir and Norway spruce that are, situation by situation, dominating or dominated. Beech should be the third actor of this type of forests, but in this case the presence is low in basal area [min 0.1 % (16,0)-max 23.8 % (24,2)] even if number of individuals of beech [69 (14,1); 48 (17,1)] in some sample plots is higher than Silver fir [65 (14,1); 43 (17,1)] and Norway spruce [48 (14,1); 24 (17,1)] one. These two informations coupled represent lower dimensions of beech individuals in sample plots with respect to silver fir and Norway spruce.

Sample plot	Alt. (m.a.s.l.)	Aspect	Mean slope (°)	SPH	G (m^2/ha)	dg (cm)	hg (m)	S (m)	N Individuals					% G Composition				
									Abies alba	Picea abies	Fagus silvatica	Larix decidua	Pinus sylvestris	Abies alba	Picea abies	Fagus silvatica	Larix decidua	Pinus sylvestris
1,1	1194	SE	13,6	516,6	47,86	34,35	27,79	35,28	85	55	4	2		51,0	45,5	0,2	3,3	
1,2	1258	SE	21,9	870,5	46,33	26,04	20,26	33,60	177	44	23	1	1	66,2	29,4	3,0	1,2	0,2
3,1	1289	S	15,6	527,2	30,22	27,02	19,57	29,03	78	51	17	2	1	53,9	38,1	2,6	4,8	0,6
3,2	1353	SE	24,7	608,6	44,45	30,50	24,47	37,98	89	48	31		1	51,4	39,9	2,8	5,0	0,9
4,1	1363	E	35	658,2	42,53	28,69	21,84	32,63	132	26	28			78,7	15,2	6,0		
4,2	1353	SE	18,5	644,0	50,25	31,53	23,31	33,38	125	28	29			81,3	15,6	3,1		
5,1	1520	SE	20,1	477,7	40,34	32,80	23,46	33,53	73	21	37	4		64,4	19,6	10,5	4,6	
5,2	1610	E	19,8	396,3	43,25	37,29	23,55	31,25	60	36	15	1		53,9	35,1	8,1	2,8	
6,1	1555	E	27	463,6	51,51	37,62	26,68	33,10	72	27	26	6		56,5	27,4	9,7		
6,2	1481	SE	22,6	690,0	50,78	30,62	22,61	31,90	118	50	27			68,8	22,4	8,9		
7,1	1500	E	21,3	863,4	43,59	25,36	20,06	30,13	117	98	29			62,4	34,0	3,6		
7,2	1501	SE	18,4	668,8	39,56	27,45	21,01	31,75	94	77	18			65,4	32,4	2,2		
11,1	1588	W	23,5	516,6	50,92	35,43	24,60	34,43	71	42	33			51,0	41,2	7,7		
11,2	1513	W	21,5	636,9	50,19	31,68	22,25	32,63	85	36	59			54,0	34,0	11,9		
12,1	1428	W	23	629,9	40,21	28,52	20,49	30,35	89	43	46			62,6	32,6	4,8		
12,2	1478	W	21,3	481,2	49,35	36,14	24,99	35,45	64	49	23			57,2	40,5	2,3		
14,1	1344	NW	15,4	644,0	41,24	28,56	22,30	33,25	65	48	69			44,3	47,4	8,3		
14,2	1342	W	25,2	537,9	59,67	37,59	27,16	33,88	106	43	2	1		67,7	31,5	0,2	0,6	
15,1	1261	W	15,6	537,9	45,11	32,69	27,30	34,90	76	73	2	1		52,3	46,7	0,2	0,8	
16,1	1311	NW	27	212,3	40,94	49,56	34,23	40,38	30	29	1			38,8	61,1	0,1		
17,1	1402	NW	30,7	406,9	41,06	35,85	27,68	40,98	43	24	48			47,8	44,3	8,0		
19,1	1432	W	26	541,4	54,76	35,90	25,71	33,23	65	60	28			40,6	56,0	3,4		
20,1	1274	NW	30,5	385,7	53,72	42,12	31,97	39,75	52	42	15			45,2	53,3	1,5		
22,1	1256	NW	24,5	276,0	46,14	46,15	32,72	43,13	40	18	10	10		51,2	26,8	2,3	19,7	
24,1	1663	NE	25,9	509,6	49,19	35,07	23,61	32,33	96	15	30	3		63,2	13,3	15,0	8,5	
24,2	1353	SE	16,9	389,2	43,07	37,55	24,31	34,55	41	33	35	1		49,4	24,8	23,8		
31,1	1378	S	30,7	859,9	43,93	25,51	20,10	33,95	119	63	57	2	2	51,7	39,4	6,9	1,6	0,4

Table 3.1: General characterisics of sample plots

3.2 Characterization of forest structure using indices

In Figure 3.1 the percentage frequency distribution of Uniform Angle Index (UAI) values are presented. Percentage frequencies are displayed in order to describe and charachterize horizontal structure and to evaluate differences in various forest stands. In this work each sample plot belongs to the same forest type. According to the Winkelmass (Uniform angle index) index, the random distribution (0.5 value) represents the more frequent value for the totality of the sample plots. Moreover the distribution of UAI usually resemble a symmetric distribution for the totality of the cases under study. The frequency of random distribution (0.5 value) registered in each area can vary: in some areas the amount of this distribution can have higher values (1,1; 1,2; 7,1; 7,2; 12,1; 14,2; 19,2 with values respectively of: 60.2%; 60.6%; 61.1%; 60.3%; 61.8%; 62.2%; 62.7%), or lower values (examples: 3,1; value 41.6%), resulting in higher values for the other components. In some cases we can appreciate the skeweness of the distribution, which can be oriented towards a regular distribution (examples: 5,1; 14,1; 15,1;24,1) or towards an irregular or clumped distribution (1,1; 3,1; 3,2; 4,1; 4,2; 5,2; 6,2; 7,1; 7,2; 11,1; 11,2; 12,2; 16,1; 17,1; 22,1; 31,1).

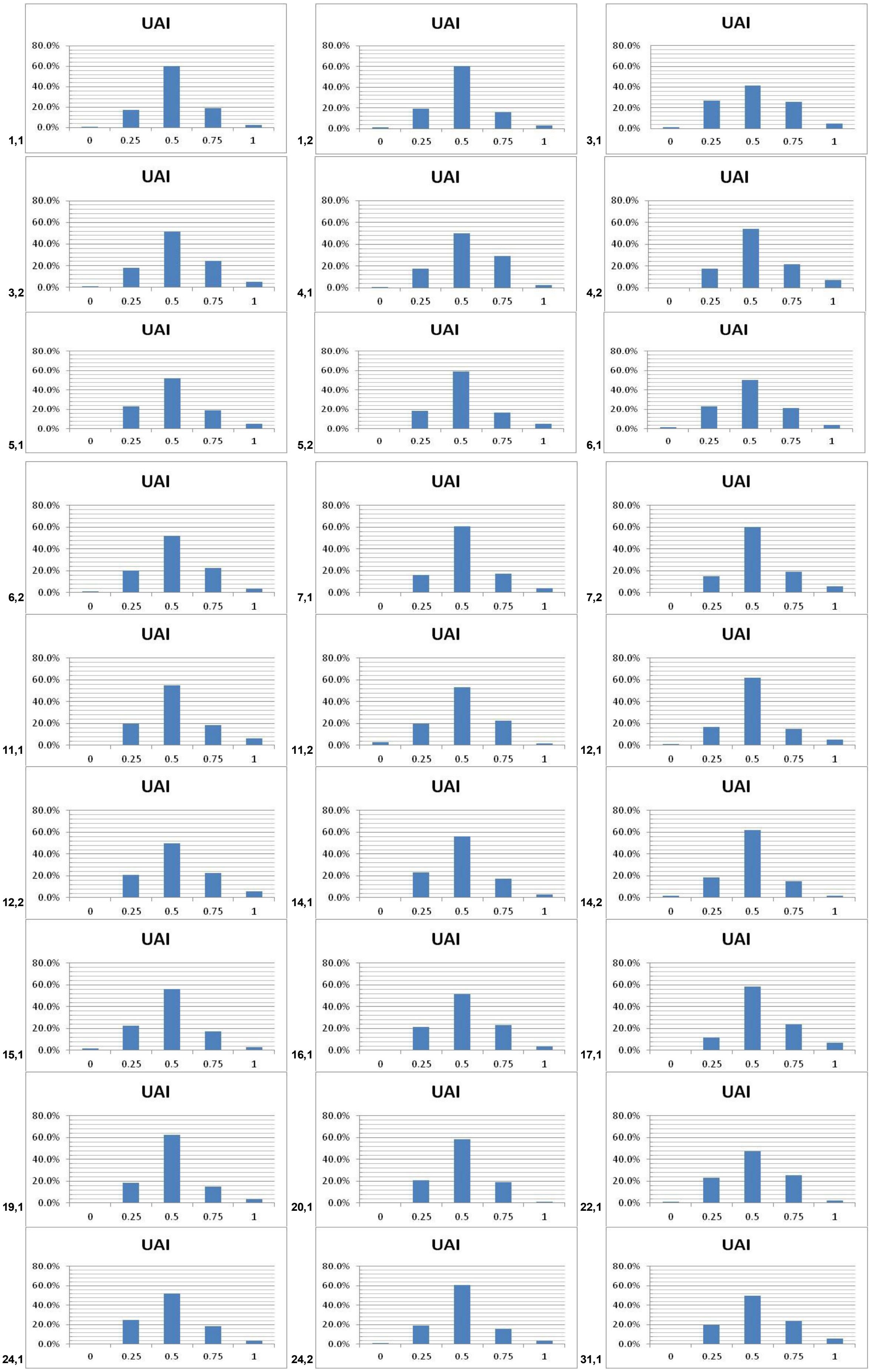


Figure 3.1: Percentage frequency distribution of Winkelmass index in each sample plot.

In Figure 3.2 percentage frequency distributions of Mingling index are presented. Graphs of percentage frequency distributions describe in each of the 27 sample plot areas a general mixture between different species. Current state situations depicted by Mingling index seem to have a considerable variability throughout the 27 areas. In sample plot areas: (7,1; 11,1; 11,2; 12,1; 17,1; 20,1; 22,1 and 31,1) we can appreciate a higher component in 0.75-value class in which three of four neighbours belongs to different species; in other words it is registered a higher presence of multi-specific groups; or a high mixture measured at small scale. On the other hand in some situations (sample plot: 4,1 and 14,2) small monospecific groups are more present (0-value). Generally, considering each sample plot area, we can notice a trend of the mingling values distribution towards monospecific groups (1,1; 1,2; 4,1; 4,2; 6,1; 12,2; 14,2; 15,1), towards situations of mean mingling (3,1; 3,2; 5,2; 6,2; 7,1; 7,2; 11,2; 14,1; 16,1; 24,1;) or towards multi-specific groups (5,1; 11,1; 12,1; 19,1; 17,1; 20,1; 22,1; 31,1; 24,2). Mean values of each area will be presented to give a detailed and short evaluation of situation of Mingling index for each sample plot area.

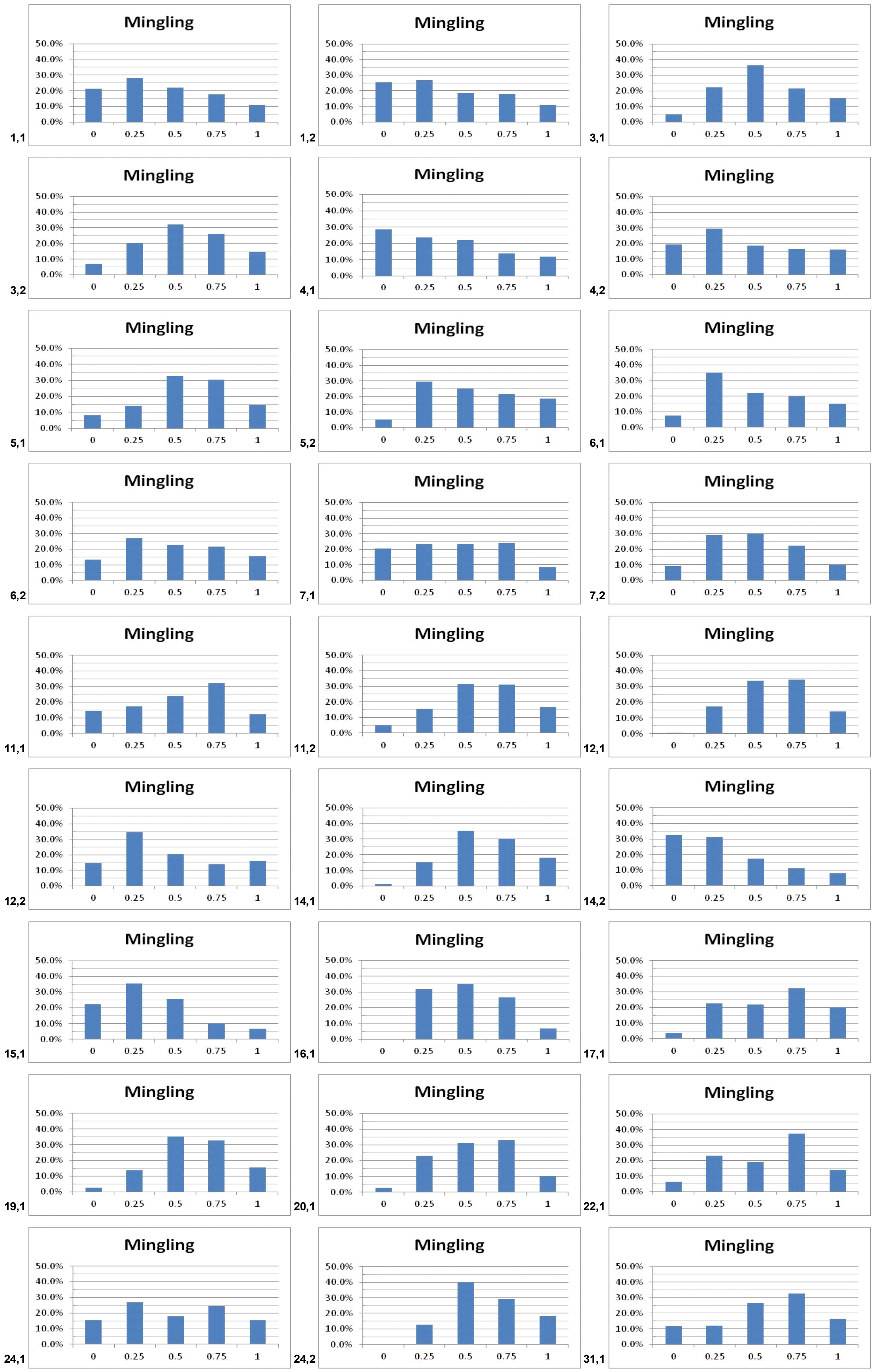


Figure 3.2:Percentage frequency distibution of Mingling index in each sample plot

In Figure 3.3 the percentage frequency distribution of Diameter at Breast Height Dominance (DBH Dominance) are presented respectively for the 27 sample plot areas. The 27 areas are under a "close-to-nature" management which creates gaps inside the forest mimicking natural disturbance and regeneration in Alpine areas. Sample plot Areas with higher frequency of suppressed individuals (0 value) (sample plot n.:1,1; 1,2; 12,1) or moderately suppressed individuals (0.25-value: sample plots: 4,1; 4,2; 6,1; 11,2; 14,1; 14,2; 15,1; 16,1; 17,1; 20,1; 24,1) see a majority of individuals dominated by lesser group of trees, with higher dimensions, in their vicinity. This can be explained by a multistoried situation inside the forest stand which is composed of younger and dominated layers under a dominant layer. Co-dominant higher frequencies (0.5 value) registered in sample plots 3,1; 3,2 and 31,1 are probably consequent to situations where dimensions are finely intermingled and majority of individuals have in their vicinity higher and smaller dimensions; altogether with the lack of dominated dimensions, which are small but high in number. Strongly dominant (1-value: sample plots 6,2; 12,2; 24,2) or dominant (0.75-value; sample plots: 7,1; 7,2; 19,1; 22,1) see a majority of individuals that have higher dimensions than the respective neighbours; this can be explained through a hypothesis of the young age of the stand, where dominant individuals have small sizes and are quite numerous. Another hypothesis is the absence or reduced group of dominated young individuals; which normally are very numerous and would decrease the dominant percentage .

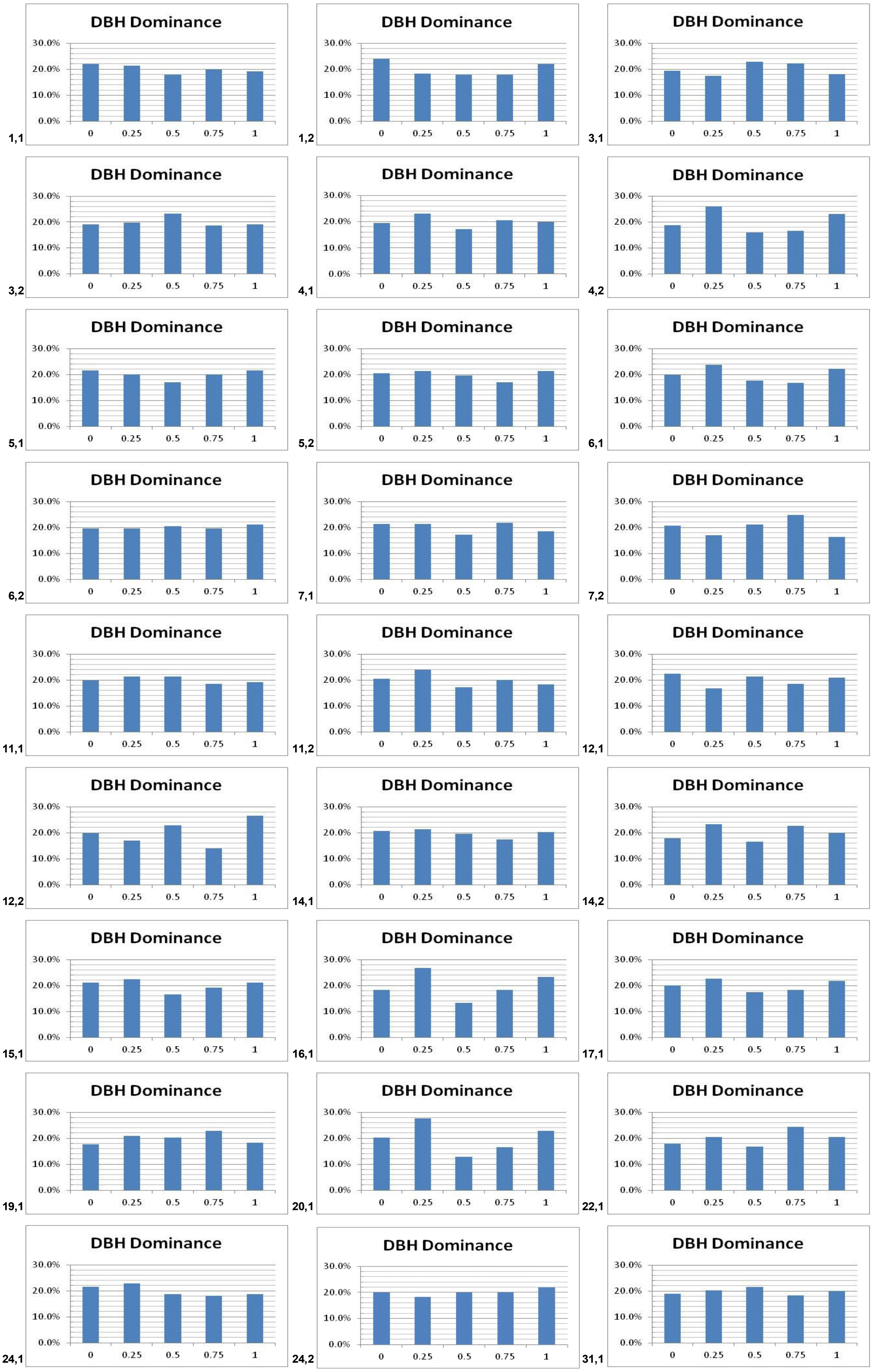


Figure 3.3: Percentage frequency distribution of Diameter at Breast Height Dominance (DBH Dominance) in each sample plot.

Figure 3.4 Shows sample plot areas 4,2; 14,2 and 31,1 value of neighbourhood indexes (UAI, Mingling and DBH Dominance) percentage frequency distribution. Table 3.5 is an example of report of the structural situation of selected sample plots using these type of indexes.

For example sample plot 4,2 shows right-skewed frequency distribution of Uniform angle Index; which means that the horizontal structure, or the individuals in this area have random distribution with irregular features; a distribution of Mingling index can be interpreted as a higher presence of situations with low mingling of the different species. The distribution of DBH dominance with two peaks (0.25 value and 1 value) can resemble two divided levels of hierarchy; a level of dimensions dominant and one dominated.

Sample plot 14,2 has a higher value of random distribution of individuals than 4,2, and even a smaller general mixture of different species. The Diameter at Breast Height Dominance shows two peaks on value 0.25 and 0.75; which can be explained in the same way as plot 4,2 with groups of dominant and dominated individuals which are separated by small differences in dimensions. Sample plot 31,1 shows a right-skewed frequency distribution of Uniform Angle Index, with a peak on the 0.5 value (random distribution) and an important component of irregular distribution. Species mingling index frequency is right-skewed, showing a tendency to mixture and not to segregation. DBH Dominance index shows very few differences in amount between percentage of dominant individuals and dominated individuals, probably due to high spatial mixture of different dimensions.

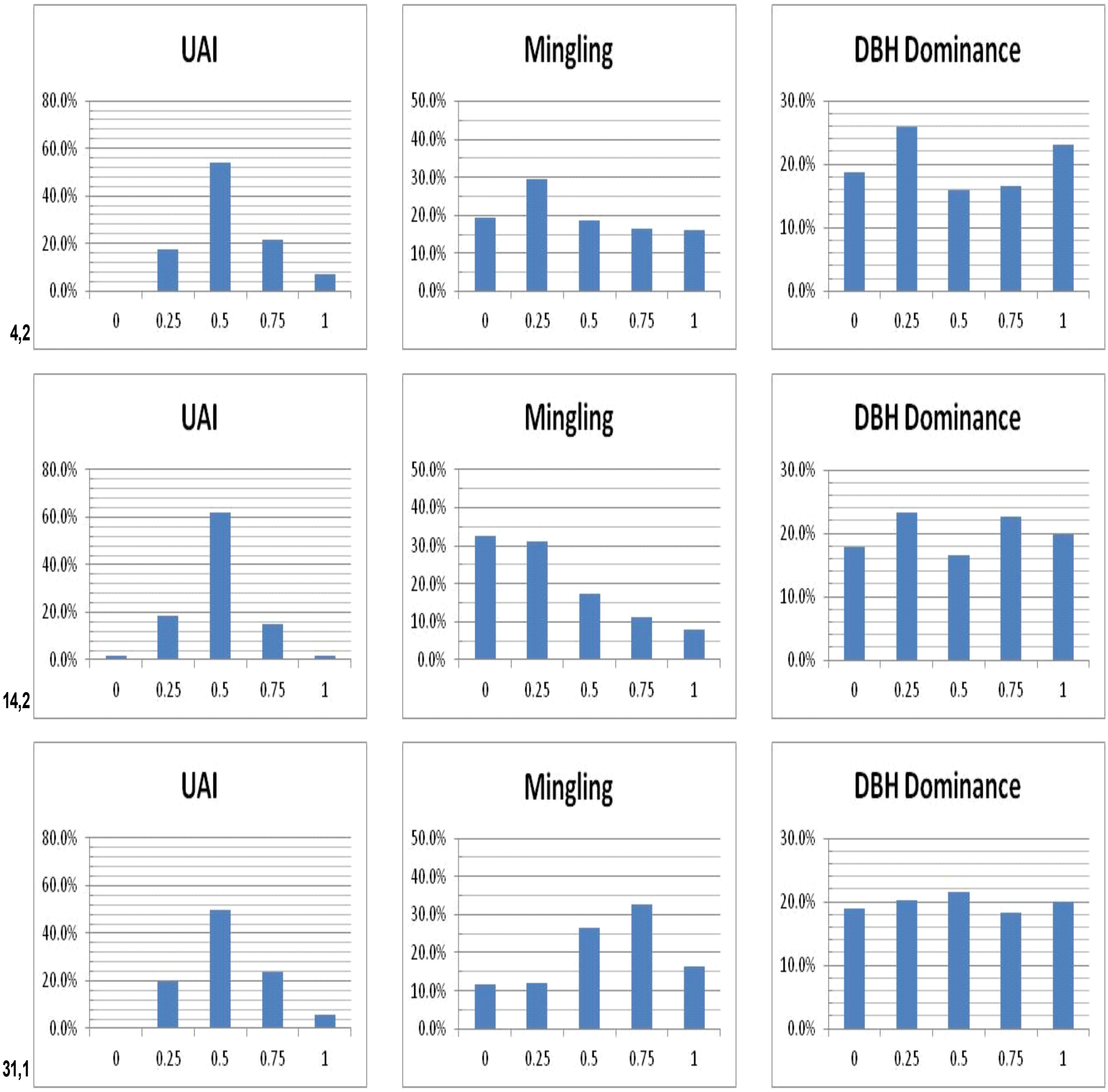


Figure 3.4: Percentage frequency distribution of Winkelmass, Mingling and Diameter at Breast Height Dominance; characterizing structure of sample plot 4,2; 14,2 and 31,1.

Species specific mingling is presented as percentage frequency in Figure 3.5. Each of the five values (relative 4 neighbours) of the index (on x-axis) is then differentiated between groups of individuals of the same species. The percentage is relative to the total number of individuals of the stand measured in a specific sample plot. This presentation help us to evaluate the present mingling situation of one species, between different species and between different stands.

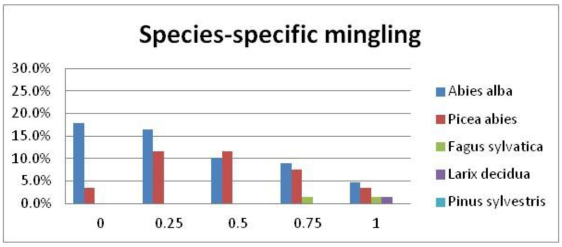
Silver fir is the species that is more numerous in all of the 27 areas (Table 3.1). It is a shade-tolerant species and it usually (except for some pure forest types) forms mixed stands with Norway spruce and beech, in different extent. Competition between these species is a peculiar aspect: Norway spruce is better adapted to low temperatures and beech is the worse adapted between the three. Nevertheless beech is better adapted to higher temperature. Norway spruce is the less shade tolerant between the three. Silver fir and beech are considered as shade-tolerant species (Gellini and Grossoni, 1996). In this type of forests slightly different climatic, compositional, soil conditions, altitude and management changes will result situation by situation in different species survival. Substitution of individuals of one species by new generations of different species is a distinctive trait normally happening in silver fir dominated forest types (Del Favero, 2004); a trait that in the forest types under study is present but less pronounced due to the type of soils and management.

Silver fir higher values are registered in different mingling aspects. Left skewed distribution (top percentage value on 0 and/or 0.25 value) are found in 1,1; 1,2; 4,1; 4,2; 5,2; 6,1; 6,2; 7,1; 7,2; 11,1; 12,2; 14,2; 15,1; 22,1 and 24,1 sample plot areas. In these areas silver fir, even if it is found in multi-specific groups, have an higher attitude towards monospecific or dominant groups; probably this situation is the result of small-dimension group fellings and general climatic condition which favored replacements by silver fir individuals. Areas with top percentage on 0.5 mingling index value (3,1; 3,2; 5,1; 12,1; 14,1; 16,1; 19,1; 24,2 and 31,1) have a generally mixed situation: probably in these situations Norway spruce and beech are more intermingled and competitive due to higher light or temperature altogether with type of felling and soil situation. Right-skewed distributions (top percentage value on 0.75) are found in 11,2; 17,1 and 20,1 where environmental (soils ad temperature) and management schemes allowed regeneration and intermingling of the three species.

For which concerns Norway spruce this species has lower numbers than silver fir in all the 27 plots. Even if it is an important presence in most of the 27 stands its monospecific groups are found in sample plot 1,1; 5,2; 7,1; 12,2; 14,2; 15,1; 19,1; 20,1; 31,1 with low values. Only in sample plot number 12,2 pure groups component (0.0 value) exceeds the one of silver fir. It reaches the top of percentage on 0.25 value in sample plots: 1,1; 7,1; 12,2; 14,2 and 15,1; top value on 0.5 value of mingling index in sample plots: 1,1; 3,1; 5,2; 6,1; 6,2; 19,1 and 24,2. top value on 0.75 in: 1,2; 3,2; 4,1; 5,1; 6,1; 7,2; 11,1; 12,1; 14,1; 17,1; 20,1; 22,1 and 31,1 and top value on 1 in sample plot areas 4,2; 11,2; and 24,1. Generally we see a higher mingling with respect to silver fir, probably due to lesser numbers than the previous one and a higher attitude to mix with other species. With respect to silver fir mingling distribution it is possible to distinguish two different behaviors in mingling attitude: one is depicted in graph 12,2; 14,1; 15,1; 16,1; 17,1; 19,1; 20,1 and 24,2, where Picea abies has lesser percentage than silver fir but has similar mingling distribution. The second behavior noticed in all the remaining sample plots see right-skewed Norway spruce distribution where the one regarding silver firs is right-skewed. The first behavior seem to relegate Norway spruce to high mingling options, especially in sample plot where silver fir is very numerous and constitute monospecific groups (Norway spruce have fewer individuals). The second behavior seems to follow the mingling distribution of silver fir, where silver fir contributes in less extent to the stand as a whole: here Norway spruce and silver fir seem to have similar distributions: with similar trend towards monospecific groups or towards mixture.

For which concerns beech we can notice that this species, all over the sample plots, covers less importance than the other two, by dimensions and by numbers (see Table 3.1). Even if in the management plan it is said that an increment of individuals and dimension of this species is needed it still has long way to reach desired levels (Bronzini....). This informations are reflected in mingling distributions, where even if the number of individuals are sometimes high (sample plots 4,1; 4,2; 5,0; 11,2; 12,1; 14,1; 17,0; 24,0; 24,2 and 31,0;) the majority of mingling distributions are right skewed (exceptions: 5,1; 11,2; 14,1; 17,1; and 24,2). Having small dimensions (Table 3.1) the species is still depressed by the dimension of other two and it is depicted in many of the sample areas that in a situation of colonization this species is mixing with the other two. Moreover beech has a shade-tolerant attitude which means that does not suffer to be under canopy and intermingle with the other two species.

Interesting is the sample plot 14,1 where beech follow the distribution of the other two species; in 14,2 area the species seem to be well intermingled.



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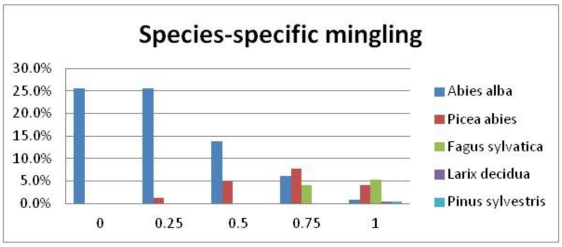

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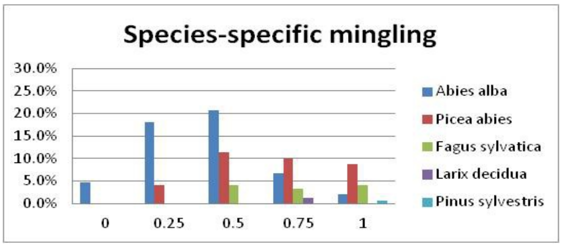

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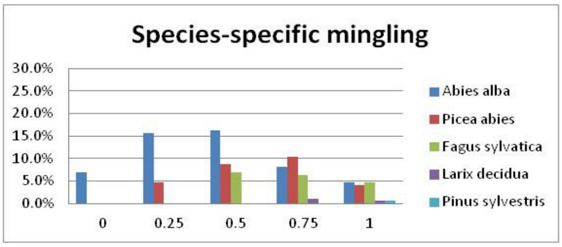

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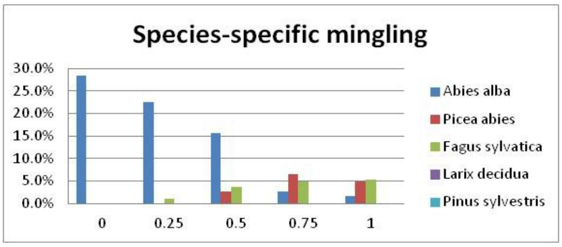

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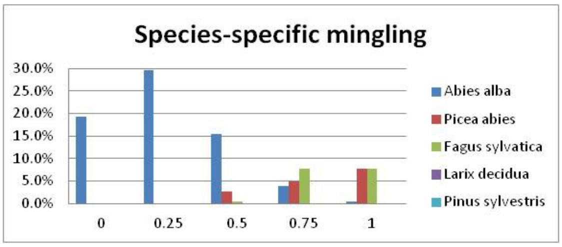

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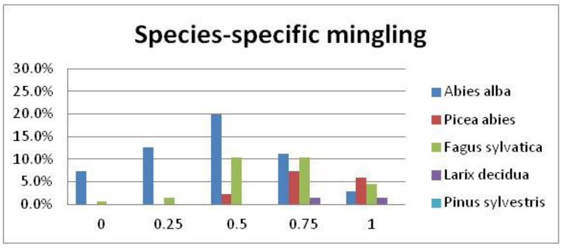

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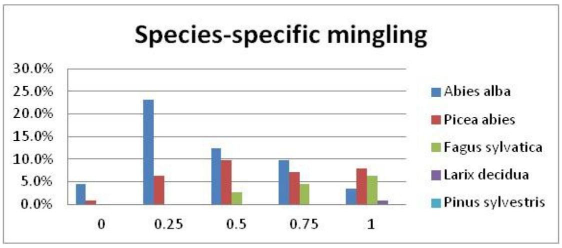

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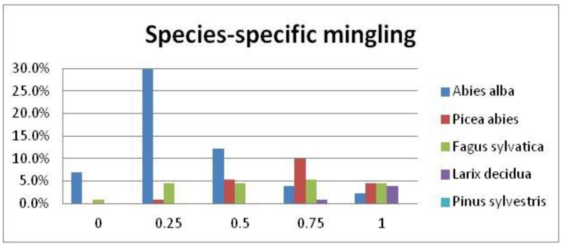

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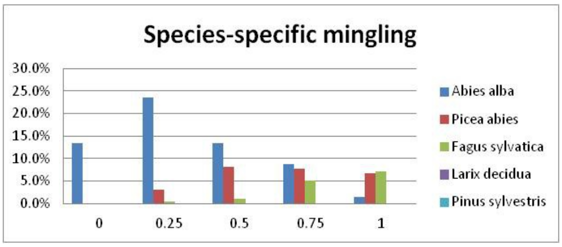

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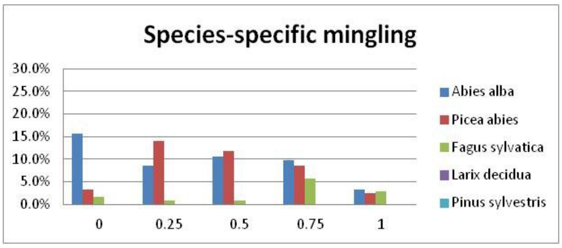

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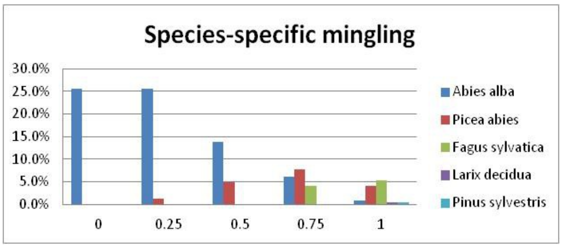

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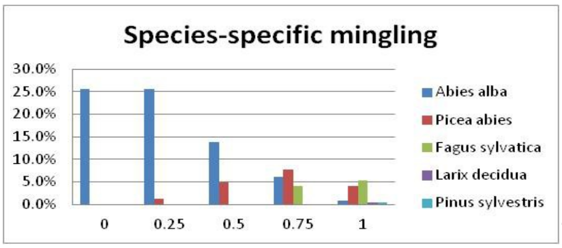

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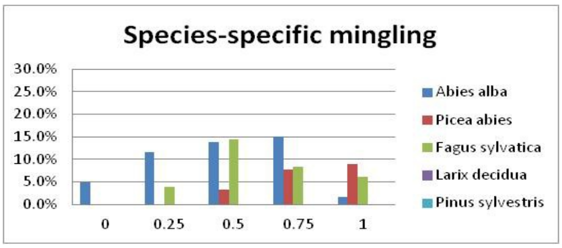

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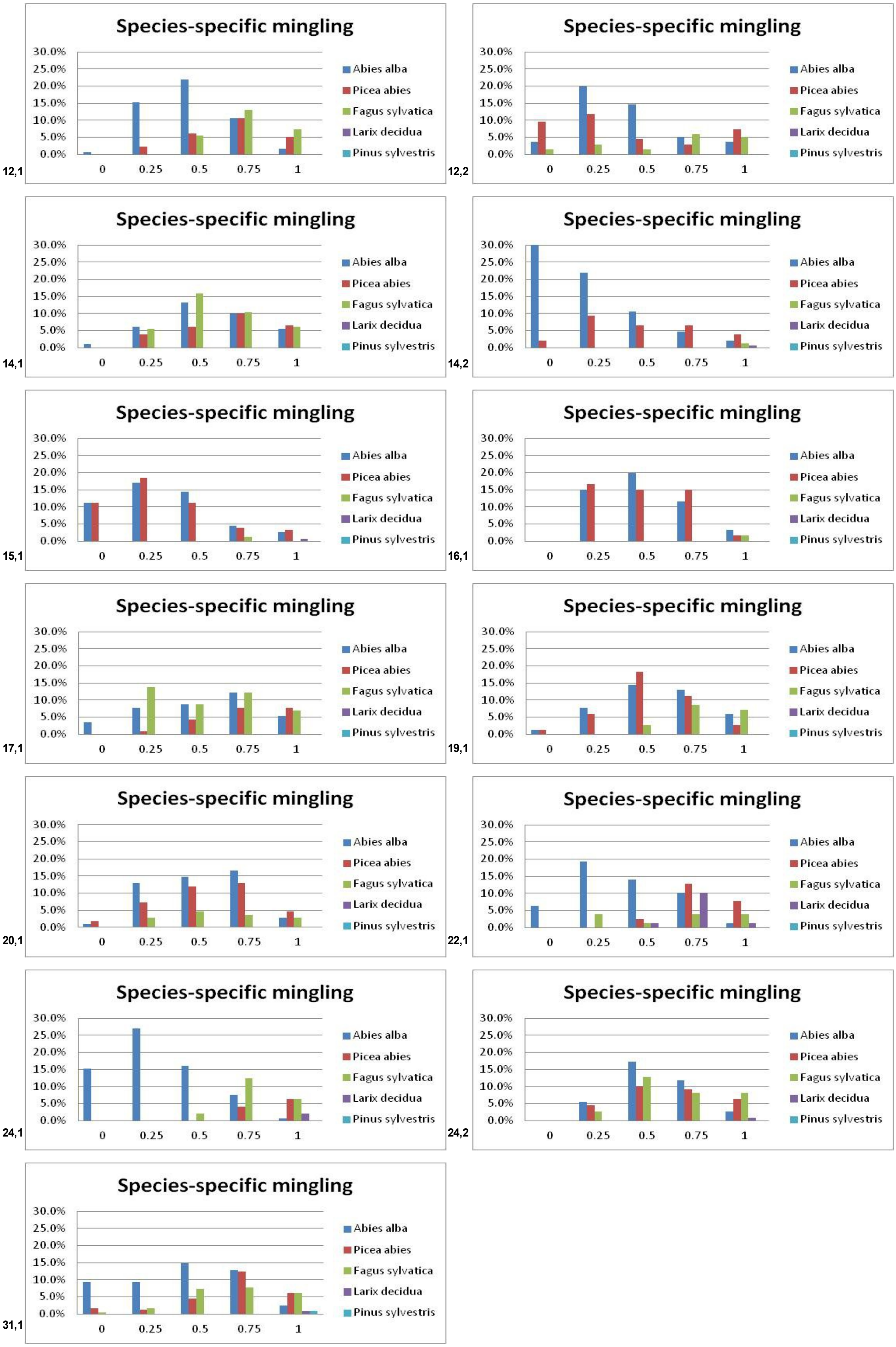


Figure 3.5: Percentage frequency distribution of mingling variable presented for 27 sample plot areas; differentiated by species belonging.

In Figure 3.6 Species-specific percentage frequency distributions (y-axis) of Diameter at Breast Height Dominance index value (x-axis) are presented. Each graph represent one of 27 sample plot areas under study in Manèz Valley. Values are divided following species belonging criteria. Percentage of each species is calculated on the totality of individuals of sample plot area.

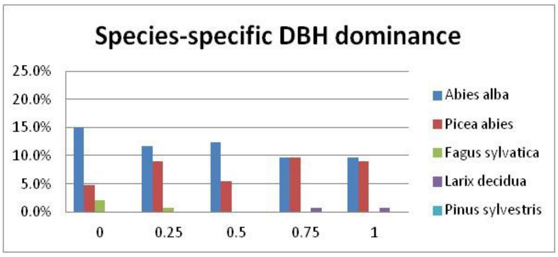
Diameter at breast height dominance value for each individual give as a result the relative dominance on the four closer neighbours; the resulting dominance has to be evaluated considering small groups scale and relative dimensions between individuals inside the groups.

Silver fir has aconsiderable amount percentage registered in every DBH Dominance index value, mainly it has different types of distributions: from left-skewed, plain, symmetrical and right-skewed , the interesting attitude of this species in our sample plots is to be present in all the hierarchical positions, and subsequently to have different dimensions. Probably this attitude is favored by the shade tolerant adaptations of this species and its attitude to form multistoried stands.

Silver fir has higher frequency values than other species in "strongly dominant" position (1-value) in all the sample plots except 16,1; 19,1 and 20,1 where it is surpassed in percentage by Norway spruce. Norway spruce has lesser individuals than Silver fir; but its individuals have high weight on dimensional side in each sample plot (see % G Composition of *Picea abies* in Table 3.1). In fact Norway spruce in the same way has in all the 27 plots a component (variable plot by plot) of individuals that are strongly dominant (1 value) in their neighbourhood. Moreover this species covers in all the areas all the values of the dominance attribute (except 0 value in sample plot 17,1). These two aspects could help us to understand that Norway spruce is participating to the stands in a similar way to silver fir , but usually with a less extent (except sample plots 16,1; 19,1 and 20,1).

Beech covers (sample plot 4,1; 4,2; 5,1; 5,2; 6,1; 6,2; 7,1; 7,2; 11,2; 12,1; 12,2; 17,1; 24,1and 24,2) small percentage in strongly dominant position. Frequency distributions of beech are generally left-skewed (except sample plot 24,2) which means that this species higher frequencies are classified as suppressed (value 0.00) or moderately suppressed (0.25 value) in their neighbourhood. It is found that this species does not have individuals in all classes of DBH dominance (sample plots 1,1; 1,2; 3,1; 3,2; 4,2; 11,1; 14,1; 14,2; 15,1; 15,2; 19,1; 20,1 and 22,1). The species, thus, is mainly dominated in these stands, by number and dimensions and still is not present in all hierarchical positions, but, as some cases explain (24,2), probably in the future it will have this possibility.

Interesting is the situation presented in sample plot 16,1 where Norway spruce distribution is right-skewed and silver fir distribution is left-skewed: in this area we see the dominant part of the forest covered by Norway spruce, while the dominated by silver fir. In some other cases (example: 14,1) the dominated part (value 0) is covered mainly by beech and secondly by silver fir and Norway spruce, which in turn have a right-skewed distribution.



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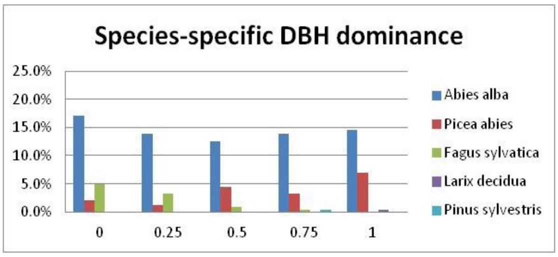

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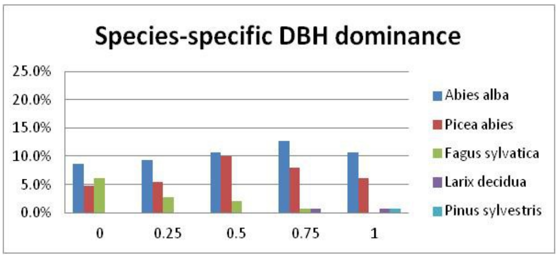

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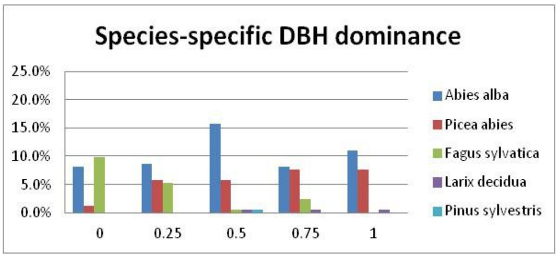

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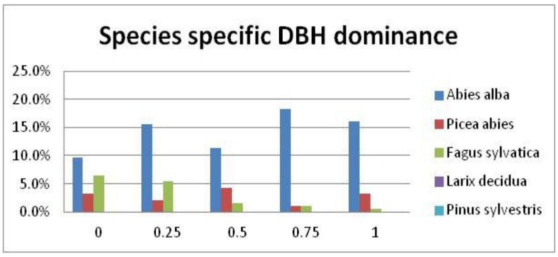

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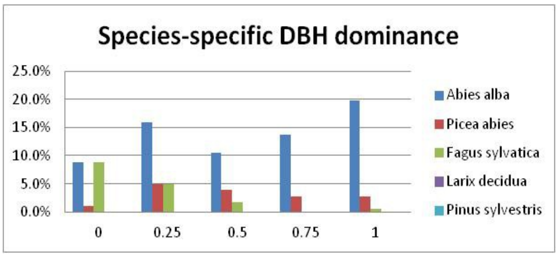

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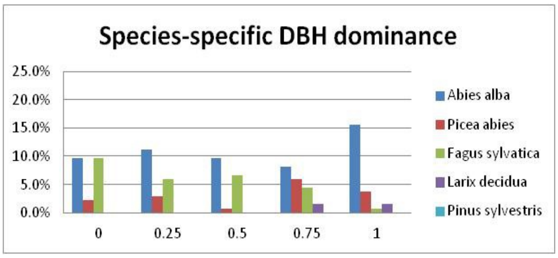

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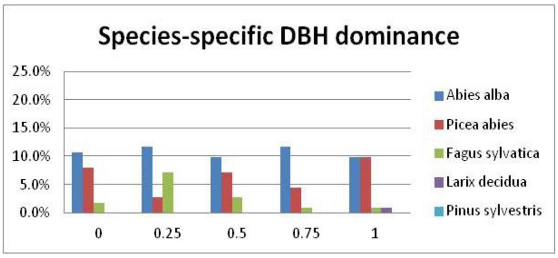

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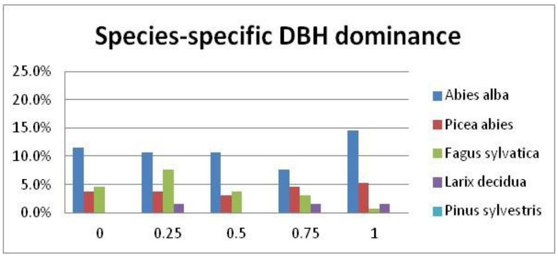

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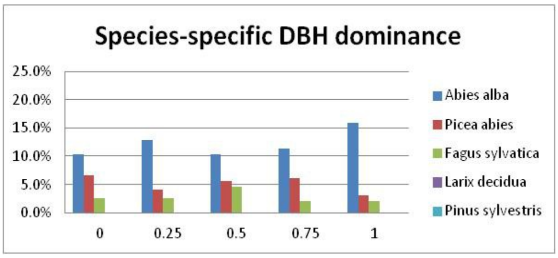

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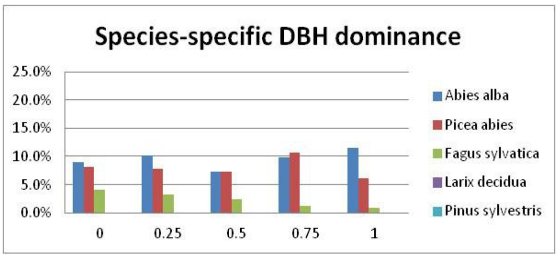

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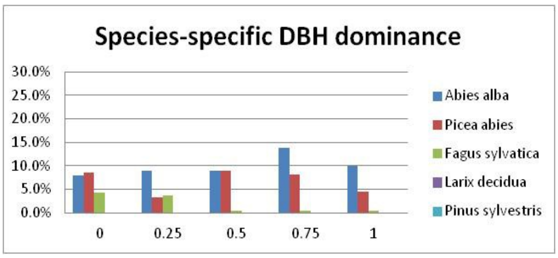

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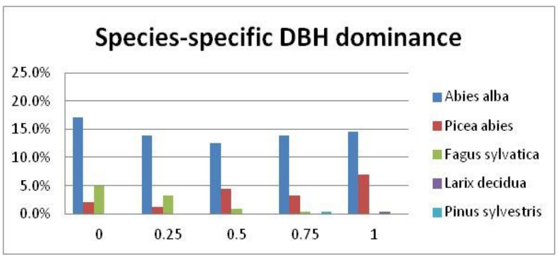

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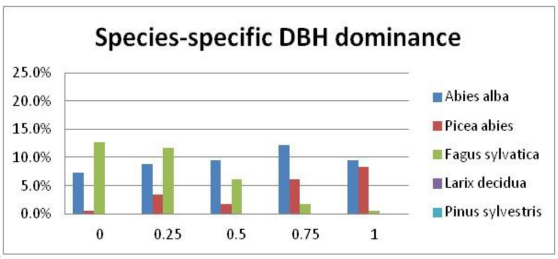

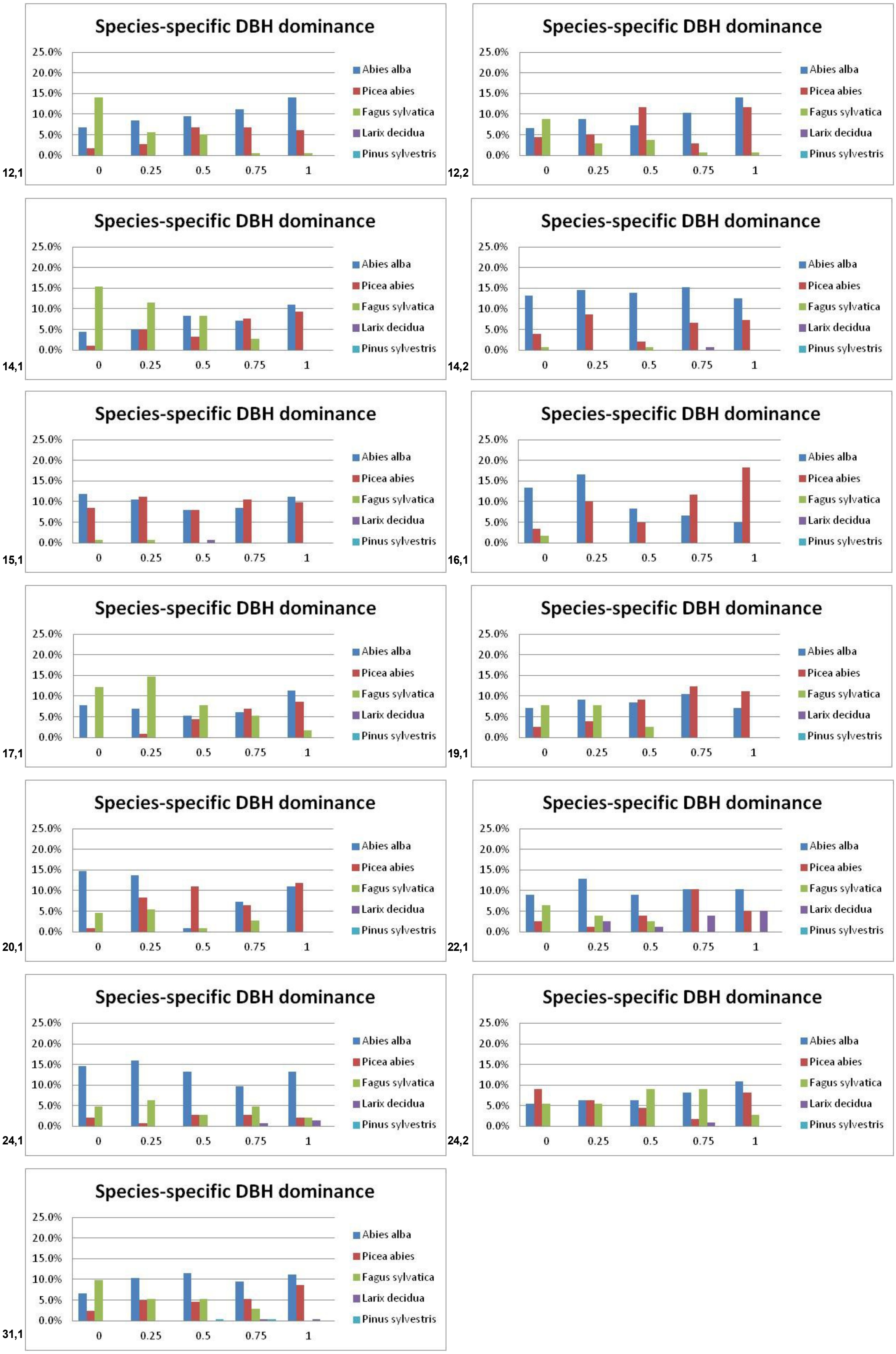

Figure 3.6: Percentage frequency distribution of variable dominance in the 27 sample plots: variable is differentiated by species belonging.

Table 3.2 displays mean values of neighborhood indices under study, calculated for each sample plot stand; respective mean values and standard deviations are provided. Altogether with mean values and standard deviations from the mean in Table 3.7 the result value of Tree Height Diversity (THD) Shannon index on each stand under study is presented.

Regarding Uniform angle index the maximum value is reached in sample plot 17,1 with an average value $\overline{W}$=0.562. The minimum value is $\overline{W}$=0.486 reached in sample plot 24,2. Standard deviation reaches its maximum in sample plot 3,1 with 0.219, while its minimum is 0.167 in sample plot 20,1.

For the classification of different horizontal structure the one suggested by Gadow and Hui (2002) was applied, where on simulation basis the values of $\overline{W}$, which are less than 0.475 are most likely to form regular distribution, while values that are higher than 0.517 are most likely to form a clumped distribution. These are not exact thresholds, due to simulation consequences; but transition values are rather narrow. This classification is applied when using a standard angle of 72°. Following this scheme generally random distributions are assigned to sample plots:1,1; 3,1; 5,1; 6,1; 11,2; 12,1; 14,1; 14,2; 15,1; 19,1; 20,1; 22,1; 24,1 and 24,2. Clumped distributions are assigned to sample plots :1,2; 3,2; 4,1; 4,2; 5,2; 6,2; 7,1; 7,2; 11,1; 12,2; 16,1. 17,1 and 31,1. No regular distributions are registered, probably due to the type of management that is practised inside the Manez Valley.

Species Mingling mean value for a stand (M) see lower value for sample plot 14,2 (M= 0.328) where the stand has a poor intermingling between different species; in fact in this stand less than two individuals, on an average, are of a different species than the central tree. Higher value of mingling index is registered in sample plot 24,2 (M= 0.632). The values of other sample plots are situations that represent a gradient in between the two extremes. Maximum value of standard deviation is reached in sample plot 4,2 with a value 0.339 and the minimum value is reached in sample plot 24,1 with a value of 0.234.

Diameter at Breast Height Dominance see higher value in sample plot 12,2 with 0.526 and lower value in sample plot 24,1 with 0.474. In the first case a dominance pattern is recognizable, while in the plot 24,1 a is shown higher dominated component. Standard deviation of the mean value of Diameter at Breast Height Dominance is reached in sample plot 1,2 with a value of 0.371 and minimum value in sample plot 19,1 (0.343).

Three height diversity (THD) Shannon index is an index evaluating tree size diversity based on height measures taken in each sample plots. The higher value registered is reached by sample plot 3,2 with value H'=2.783 and the lower value is registered in sample plot 16,1 with H'=1.913. Plot 3,2 has the most diverse structure between the 27 plots using height as dimensional component.

SAMPLE PLOT	UAI	ST.DEV. UAI	SM	ST. DEV. SM	DBHD	ST. DEV. DBHD	SHANNON THD
1,1	0,515	0,177	0,423	0,322	0,483	0,359	2,402
1,2	0,502	0,182	0,404	0,333	0,489	0,371	2,533
3,1	0,513	0,219	0,552	0,275	0,505	0,346	2,551
3,2	0,536	0,204	0,552	0,284	0,497	0,347	2,783
4,1	0,539	0,190	0,392	0,337	0,496	0,355	2,647
4,2	0,545	0,201	0,451	0,339	0,499	0,363	2,619
5,1	0,513	0,203	0,574	0,283	0,500	0,365	2,569
5,2	0,522	0,189	0,547	0,301	0,493	0,361	2,367
6,1	0,508	0,203	0,500	0,304	0,494	0,362	2,349
6,2	0,518	0,196	0,496	0,321	0,508	0,355	2,345
7,1	0,519	0,183	0,443	0,316	0,487	0,356	2,563
7,2	0,540	0,185	0,488	0,283	0,499	0,345	2,601
11,1	0,524	0,202	0,527	0,312	0,490	0,351	2,618
11,2	0,503	0,194	0,597	0,273	0,479	0,353	2,577
12,1	0,515	0,188	0,610	0,239	0,496	0,362	2,493
12,2	0,531	0,207	0,456	0,326	0,526	0,368	2,660
14,1	0,497	0,184	0,622	0,249	0,488	0,358	2,672
14,2	0,492	0,177	0,328	0,314	0,508	0,352	2,453
15,1	0,490	0,191	0,357	0,284	0,492	0,363	2,507
16,1	0,521	0,191	0,521	0,231	0,504	0,367	1,913
17,1	0,565	0,188	0,607	0,287	0,498	0,362	2,659
19,1	0,505	0,176	0,613	0,250	0,508	0,343	2,544
20,1	0,500	0,167	0,562	0,253	0,486	0,369	2,490
22,1	0,513	0,201	0,574	0,291	0,522	0,354	2,696
24,1	0,498	0,195	0,493	0,330	0,474	0,356	2,563
24,2	0,486	0,191	0,632	0,234	0,514	0,360	2,596
31,1	0,539	0,201	0,576	0,305	0,501	0,350	2,586

Table 3.2: Sample plot mean values and Standard Deviation (ST. DEV.) of neighbourhood indexes: Uniform Angle Index (UAI), Species Mingling (SM) and Diameter at Breast Height Dominance (DBHD). Sample plot values of Tree Height Diversity (SHANNON THD) Shannon index.

3.3 Statistical analysis

In Table 3.3; 3.4; 3.5 the values of mean Uniform angle index, Species Mingling and Diameter at Breast Height Dominance are presented. Values are describe sample plot areas (y-axis) and sub-dimensions of sample plot areas (x axis). The indexes in Table 3.8; 3.9; 3,10 are provided with standard deviation from the mean and number of individuals.

Winkelmass index, Species Mingling and Diameter at Breast Height Dominance mean values have been calculated in each sample plot for 30 m radius area (2826.00 m^2) and re-calculated with datas coming from the concentric sub-areas, which are: 20 meters radius area that covers respectively 1256.00 m^2; 13 m sub area with 530.66 m^2 and 10 m sub-area with 314.00 m^2.

Values are provided in order to describe sample plot areas and established sub-areas.

Concentric sub-plots are constituted with the purpose of being analysed through statistical analysis. The statistical analys is objective is to quantify the existing connection between index values of populations of one plot and its sub-plots.

WINKELMASS	10 METERS RADIUS			13 METERS RADIUS			20 METERS RADIUS			30 METERS RADIUS		
SAMPLE PLOT	**MEAN**	**ST. DEV**	**N. TREES**	**MEAN**	**ST. DEV**	**N. TREES**	**MEAN**	**ST. DEV**	**N. TREES**	**MEAN**	**ST. DEV**	**N. TREES**
1,1	0,548	0,170	21	0,539	0,212	32	0,525	0,183	69	0,515	0,177	146
1,2	0,528	0,160	27	0,536	0,177	49	0,512	0,176	107	0,502	0,182	246
3,1	0,521	0,163	24	0,533	0,183	30	0,513	0,240	77	0,513	0,219	149
3,2	0,600	0,249	20	0,563	0,194	40	0,551	0,218	78	0,536	0,204	172
4,1	0,528	0,187	36	0,528	0,180	54	0,542	0,207	107	0,539	0,190	186
4,2	0,661	0,270	14	0,555	0,208	32	0,536	0,189	77	0,545	0,201	182
5,1	0,500	0,167	10	0,500	0,177	17	0,542	0,206	42	0,513	0,203	135
5,2	0,517	0,176	15	0,548	0,203	21	0,547	0,191	48	0,522	0,189	112
6,1	0,646	0,249	12	0,550	0,224	20	0,509	0,190	56	0,508	0,203	131
6,2	0,534	0,160	22	0,500	0,207	36	0,511	0,182	95	0,518	0,196	195
7,1	0,578	0,223	29	0,549	0,194	51	0,521	0,162	118	0,519	0,183	244
7,2	0,589	0,207	28	0,532	0,162	47	0,548	0,181	83	0,540	0,185	189
11,1	0,597	0,212	18	0,547	0,215	32	0,535	0,199	64	0,524	0,202	146
11,2	0,583	0,190	24	0,547	0,215	32	0,515	0,193	83	0,503	0,194	180
12,1	0,603	0,199	17	0,528	0,127	27	0,538	0,199	80	0,515	0,188	178
12,2	0,605	0,225	19	0,563	0,211	28	0,557	0,181	53	0,531	0,207	136
14,1	0,590	0,227	25	0,523	0,152	43	0,508	0,183	89	0,497	0,184	182
14,2	0,467	0,217	23	0,528	0,222	36	0,507	0,180	74	0,492	0,177	151
15,1	0,479	0,179	24	0,528	0,214	36	0,486	0,205	88	0,490	0,191	152
16,1	0,575	0,265	10	0,571	0,228	14	0,587	0,211	26	0,521	0,191	60
17,1	0,563	0,217	12	0,583	0,183	21	0,554	0,190	65	0,565	0,188	115
19,1	0,607	0,169	21	0,543	0,205	35	0,528	0,172	81	0,505	0,176	153
20,1	0,583	0,122	15	0,557	0,132	22	0,505	0,179	46	0,500	0,167	109
22,1	0,639	0,220	9	0,679	0,228	14	0,544	0,226	40	0,513	0,201	78
24,1	0,521	0,225	12	0,531	0,239	16	0,496	0,192	57	0,498	0,195	144
24,2	0,558	0,208	13	0,500	0,229	20	0,533	0,180	46	0,486	0,191	110
31,1	0,581	0,213	37	0,534	0,196	58	0,527	0,194	131	0,539	0,201	243

Table 3.3: 30 m radius area and sub-areas (20, 13, 10) m radius respective values of mean Winkelmass (UAI) index values, Standard deviation (ST. DEV) and number of individuals (N. TREES). Vales divided by sample plot area (y-axis).

SPECIES MINGLING	10 METERS RADIUS			13 METERS RADIUS			20 METERS RADIUS			30 METERS RADIUS		
SAMPLE PLOT	MEAN	N. TREES	ST. DEV	MEAN	N. TREES	ST. DEV	MEAN	N. TREES	ST. DEV	MEAN	N. TREES	ST. DEV
1,1	0,405	21	0,330	0,328	32	0,350	0,366	69	0,320	0,423	146	0,322
1,2	0,352	27	0,296	0,306	49	0,316	0,397	107	0,327	0,404	246	0,333
3,1	0,604	24	0,244	0,625	30	0,243	0,529	77	0,284	0,552	149	0,275
3,2	0,563	20	0,242	0,563	40	0,225	0,513	78	0,282	0,552	172	0,284
4,1	0,313	36	0,313	0,278	54	0,310	0,343	107	0,327	0,392	186	0,337
4,2	0,179	14	0,267	0,406	32	0,352	0,494	77	0,337	0,451	182	0,339
5,1	0,625	10	0,295	0,632	17	0,219	0,661	42	0,182	0,574	135	0,283
5,2	0,767	15	0,148	0,762	21	0,216	0,594	48	0,295	0,547	112	0,301
6,1	0,458	12	0,298	0,500	20	0,354	0,504	56	0,318	0,500	131	0,304
6,2	0,511	22	0,304	0,486	36	0,292	0,463	95	0,328	0,496	195	0,321
7,1	0,310	29	0,318	0,436	51	0,299	0,479	118	0,292	0,443	244	0,316
7,2	0,545	28	0,297	0,537	47	0,255	0,539	83	0,242	0,488	189	0,283
11,1	0,514	18	0,277	0,516	32	0,342	0,492	64	0,309	0,527	146	0,312
11,2	0,563	24	0,278	0,516	32	0,342	0,611	83	0,266	0,597	180	0,273
12,1	0,706	17	0,238	0,676	27	0,206	0,609	80	0,231	0,610	178	0,239
12,2	0,461	19	0,326	0,527	28	0,322	0,514	53	0,292	0,456	136	0,326
14,1	0,630	25	0,281	0,610	43	0,269	0,629	89	0,247	0,622	182	0,249
14,2	0,326	23	0,324	0,333	36	0,333	0,361	74	0,293	0,328	151	0,314
15,1	0,396	24	0,294	0,375	36	0,271	0,386	88	0,273	0,357	152	0,284
16,1	0,400	10	0,269	0,500	14	0,240	0,558	26	0,204	0,521	60	0,231
17,1	0,500	12	0,282	0,548	21	0,302	0,592	65	0,267	0,607	115	0,287
19,1	0,643	21	0,245	0,679	35	0,261	0,627	81	0,263	0,613	153	0,250
20,1	0,617	15	0,186	0,534	22	0,259	0,598	46	0,250	0,562	109	0,253
22,1	0,278	9	0,341	0,214	14	0,292	0,469	40	0,301	0,574	78	0,291
24,1	0,646	12	0,198	0,641	16	0,182	0,382	57	0,338	0,493	144	0,330
24,2	0,692	13	0,341	0,663	20	0,284	0,696	46	0,229	0,632	110	0,234
31,1	0,453	37	0,332	0,448	58	0,347	0,597	131	0,300	0,576	243	0,305

Table 3.4: Mean Species Mingling index value with respective standard deviation presented for each sample plot area and sub-plots(30m,20m, 13m and 10 m radius). Number of individuals (on which the analisys is based) in each sample plot area and respective sub-area.

DBHDOMINANCE	10 METERS RADIUS			13 METERS RADIUS			20 METERS RADIUS			30 METERS RADIUS		
SAMPLE PLOT	**MEAN**	**ST. DEV**	**N. TREES**	**MEAN**	**ST. DEV**	**N. TREES**	**MEAN**	**ST. DEV**	**N. TREES**	**MEAN**	**ST. DEV**	**N. TREES**
1,1	0,512	0,349	21	0,563	0,336	32	0,496	0,350	69	0,483	0,359	146
1,2	0,519	0,392	27	0,480	0,388	49	0,495	0,382	107	0,489	0,371	246
3,1	0,521	0,368	24	0,508	0,368	30	0,513	0,349	77	0,505	0,346	149
3,2	0,500	0,354	20	0,494	0,332	40	0,500	0,358	78	0,497	0,347	172
4,1	0,486	0,343	36	0,481	0,346	54	0,502	0,358	107	0,496	0,355	186
4,2	0,571	0,409	14	0,477	0,361	32	0,500	0,376	77	0,499	0,363	182
5,1	0,500	0,333	10	0,500	0,364	17	0,488	0,362	42	0,500	0,365	135
5,2	0,500	0,378	15	0,500	0,395	21	0,521	0,375	48	0,493	0,361	112
6,1	0,458	0,382	12	0,438	0,352	20	0,504	0,386	56	0,494	0,362	131
6,2	0,489	0,349	22	0,556	0,344	36	0,516	0,353	95	0,508	0,355	195
7,1	0,517	0,353	29	0,471	0,370	51	0,487	0,365	118	0,487	0,356	244
7,2	0,527	0,362	28	0,500	0,330	47	0,506	0,351	83	0,499	0,345	189
11,1	0,417	0,374	18	0,469	0,352	32	0,496	0,344	64	0,490	0,351	146
11,2	0,521	0,390	24	0,469	0,352	32	0,470	0,354	83	0,479	0,353	180
12,1	0,471	0,384	17	0,481	0,366	27	0,488	0,375	80	0,496	0,362	178
12,2	0,526	0,381	19	0,563	0,358	28	0,514	0,362	53	0,526	0,368	136
14,1	0,510	0,385	25	0,494	0,364	43	0,483	0,353	89	0,488	0,358	182
14,2	0,500	0,354	23	0,514	0,353	36	0,503	0,350	74	0,508	0,352	151
15,1	0,510	0,357	24	0,507	0,380	36	0,500	0,371	88	0,492	0,363	152
16,1	0,550	0,438	10	0,554	0,382	14	0,538	0,385	26	0,504	0,367	60
17,1	0,417	0,389	12	0,452	0,359	21	0,496	0,374	65	0,498	0,362	115
19,1	0,476	0,325	21	0,479	0,350	35	0,485	0,359	81	0,508	0,343	153
20,1	0,467	0,364	15	0,523	0,377	22	0,484	0,359	46	0,486	0,369	109
22,1	0,444	0,349	9	0,482	0,346	14	0,519	0,364	40	0,522	0,354	78
24,1	0,521	0,376	12	0,500	0,329	16	0,491	0,363	57	0,474	0,356	144
24,2	0,577	0,359	13	0,500	0,372	20	0,489	0,373	46	0,514	0,360	110
31,1	0,473	0,348	37	0,509	0,341	58	0,496	0,352	131	0,501	0,350	243

Table 3.5: Mean Diameter at Breast Height Dominance, standard deviation from the mean and number of individuals values calculated for 10, 13, 20 and 30 m concentric radius dimensions. Representative values for sample plot areas on y-axis.

Statistical analysis was made in order to compare each circular sample plot, which originally has a radius of 30 meters and an area of 2826.00 m^2, to its concentric sub-plots. Sub-plots are extracted from the main sample plot and have dimensions of 1256.00 m^2 with a diameter of 20 m; 530.66 m^2 with 13 m radius and 314.00 m^2 with 10 meters radius. Sub-plots are circular, and have the same center as their respective main sample plot. Smaller dimensions comprise individuals that are already present in the main one.

Evaluation of neighborhood indices is done in 30 m radius and repeated for each of the smaller sub-areas (20, 13, 10 m)

Neighborhood indices are calculated for the main dimension area without accounting for edge effects; this setting is maintained throughout the calculation in smaller areas. This last setting will affect the index result: in fact when one individual is near a border, neighborhood indexes will account as neighbors only the neighbours inside the area and not the ones outside. No edge effects are accounted for 30, 20, 13 and 10 meters areas.

Statistical analysis was performed using Addinsoft XLSTAT, Microsoft Excel statistical add-in. Tests applied are: Shapiro-Wilk Normality test; Kruskal-Wallis one-way analysis of variance and Mann-Whitney U test.

Shapiro-Wilk statistical test that verify the null hypothesis(H0) that a sample (x_1,....x_n) came from a normally distributed population. The test rejects a normal distribution when the corresponding p-value is less than a chosen alpha-level and accept the hypothesis when p-values are higher than alpha level.

Winkelmass (Uniform Angle Index); Species Mingling and Diameter at Breast Height Dominance indexes values distribution of each plot were individually (by index) analysed with Shapiro-Wilk statistical test to verify the hypothesis of normality of values distributions. Test was carried out for each 30-m radius plot using an alpha level (level of significance) of 5% (0.05). The hypothesis H0, where sample plot variables are distributed as in a casual normal population was rejected (p-value < 0.05) for all the indexes values distributions in all the 27 sample plots. It was instead suggested to accept the alternative hypothesis Ha where the variable extracted from the plot doesn't follow a normal distribution.

For this reason non-parametric tests were applied to analyze whether one sample of the main plot (30-m radius) and sub populations of 20, 13 and 10-m radius are statistically connected.

Kruskal-Wallis was applied in this work for testing whether more than two samples originate from the same distribution or not. In the case of significant results, Kruskal-Wallis method depict differencies between samples but does not define where the differencies are located or how many cases of differences are found.

In this work the Kruskal-Wallis test objective is to evaluate if the main sample plot group of values and its smaller sub-plots groups of values are depending to the same statistical population; if this result is not reached the statistical analysis will proceed and find differences between main sample plot values and sub-plots data that will be analyzed using Mann-Whitney test. Main sample plot is the one regarding a 30 meters radius area; while sub-plots tested with Kruskal-Wallis method are the ones with dimensions of 20, 13 and 10 m. In this work we considered as reliable a significance level of 5%.

The Mann-Whitney's test is analyzes if two groups of variables have statistically significant difference. H0 hypothesis is that two sample plots are extracted from the same population and that their probability distributions are identical.

The test was carried out with a level of significance of 5%; and developed on each sample plot by default to compare two dimensions:30 m radius sample group and 10 m radius area sample group.

Uniform Angle Index groups of variables analyzed with Kruskal-Wallis method with a level of significance of 5% (alpha 0.05) registered in 25 of 27 (92.6%) sample plot areas a p-value that was superior to the significance level. This aspect confirmed the hypothesis H0 where the sample group data are belonging to the same population; or in other words confirmed that the risk of rejecting the null hypothesis H0 is superior to the significance level. Sample plot areas 19,1 and 22,1 resulted in a rejection of the null hypothesis H0 with values reported in Table 3.6.

	Sample plot	
Kruskal-Wallis	**19,1**	**22,1**
K (Observed value)	8,426	8,092
K (Critical Value)	7,815	7,815
d.f.	3	3
p-value (Bilateral)	0,038	0,044
alfa	0,05	0,05

Table 3.6: Kruskal-Wallis method results on Uniform Angle Index populations of values in sample plot 19,1 and 22,1.

Sample plot 19,1 and 22,1 group of values were independently analyzed with Mann-Whitney test to evaluate dimensional sample groups two by two and find at which level the p-value was higher than statistical significance.

In Sample Plot 19,1 result of Mann Whitney comparison between different dimensions pointed out that only in the comparison between the 30 meters sample plot area and the 10 meters sub-plot area the null hypothesis had to be rejected and confirmed a statistical diversity. In other words the 2826.00 m^2 (30 meters radius) sample plot variables have statistical affinity with an area that is at least 13 m radius.

In sample plot 22,1 result of Mann-Whitney comparison between different dimensions pointed out that only in the comparison between 30 meters sample plot area and the 20 meters sub-plot area the null hypothesis cannot be rejected. In this case only the values of a 20-meters radius area have statistical affinity with the main sample plot.

Kruskal-Wallis and Mann-Whitney pointed out that 10 m radius sample plot areas values can be considered statistically not diverse (coming from the same population) to their respective 30 m radius area in 25 on 27 cases (92.6%). 13 m radius samples were considered statistically not diverse from their respective 30 m radius in 26 of 27 cases (96.3%). 27 on 27 cases (100%) of the 20 m radius sample plots were considered statistically not diverse from their respective 30 m radius area.

Species Mingling index groups of variables depending on different sample plot sizes were analyzed with Kruskal-Wallis method with a level of significance of 5% (alpha 0.05). The statistical comparison registered in 22 of 27 (81.4%) sample plot areas a p-value that was superior to the significance level. The hypothesis H0 where the sample group datas are belonging to the same population was confirmed; more in detail it was confirmed that the risk of rejecting the null hypothesis H0 is superior to the significance level.

Sample plot areas 4,2; 5,2; 22,1; 24,1 and 31,1 registered a rejection of the null hypothesis H0 with values reported in table 3.7.

	Sample plot				
Kruskal-Wallis	**4,2**	**5,2**	**22,1**	**24,1**	**31,1**
K (Observed value)	12,213	15,384	19,018	12,550	13,332
K (Critical Value)	7,815	7,815	7,815	7,815	7,815
d.f.	3	3	3	3	3
p-value (Bilateral)	0,007	0,002	0,000	0,006	0,004
alfa	0,05	0,05	0,05	0,05	0,05

Table 3.7: Kruskal-Wallis rejection of null hypothesis about comparison in four dimensions samples (30,20, 13 and 10 m radius);population of values of Species Mingling index.

Mann-Whitney test was carried out in each sample plots 4,2; 5,2; 7,1; 22,1; 24,1 and 31,1 to compare different dimensional sample groups two by two with the purpose in finding the level at which the p-value was higher than statistical significance, and by this confirm the statistical affinity between populations coming from different dimensions. Sample plot 7.1 was studied even if Kruskal-Wallis method depicted null hypothesis as hypothesis to be accepted; Mann-Whitney resulted a statistical difference between samples coming from a 30 m radius area and the samplecoming from a 10 m area.

Mann-Whitney test on sample plot 4,2 and 7,1 resulted with a null hypothesis rejection only in the comparison between 30 m sample plot area and the 10 m sub-plot area and confirmed a statistical diversity. 2826.00 m^2 (30 m radius) sample plot variables have statistical affinity with an area that is at least 13 m radius wide.

Results of Mann-Whitney comparison in sample plot 5,2; 7,1; 22,1; 24,1 and 31,1 regarding different dimensions resulted in a confirm of null hypothesis (with absence of positions) for the comparison between 30 m sample plot area and the 20 m sub-plot area. In this case only the values of a 20-m radius area have statistical affinity with the main sample plot.

Kruskal-Wallis and Mann-Whitney confirmed that that all 27 on 27 cases (100%) of the 20 m radius samples were considered statistically not diverse from their respective samples coming from 30 m radius area. 23 of 27 (85.2%) of 13 m radius samples were considered statistically not diverse from their respective 30 m radius areas samples. 10 m radius sample plot areas values can be considered statistically not diverse (coming from the same population) to their respective 30 m radius area in 22 on 27 cases (81.5%).

Diameter at Breast Height Dominance values in each sample plot in each dimensions, using Kruskal-Wallis method and Mann-Whitney pointed out that H0 hypothesis cannot be rejected, for both of the statistical tests and for the executed analysis.

Uniform Angle Index population of values belonging to sub-dimension of main sample plot (30 m radius) when analyzed, resulted as being part of the same population and statistically represented the circular area with 30 m radius in 96,3% of the cases for a sub plot with 10 m radius, 96,3% of the cases for a sub-plot with a 13 m radius and in 100% of the cases the 20 m radius. The significance level is set on 5%.

Species Mingling sub-plot population of values analyzed resulted as being part of one statistical population with the main sample plot (30 m radius or 2826.00 m^2), and thus represent the circular area with 30 m radius in 81,5% of the cases for a sub plot with 10 m radius, 85,2% of the cases for a sub-plot with a 13 m radius and in 100% of the cases the 20 m radius. Each analysis was done with a 5% significance level.

The statistical analysis evidenced that Diameter at Breast Height Dominance population of values belonging to a circular area of 30 m radius (or 2826.00 m^2) can be described by 100% of all the examined sub-dimensions (10m, 13m and 20m radius). In fact all the populations of sub-areas examined resulted as being statistically not different from the main 30 m radius sample plot, with a significance level of 5%.

The data analyzed pointed out that sampling efforts in one circular area of 30 m radius (2826,00 m^2) which is a dimension that is considered representative of forest structure, can be reducted in 100% of the cases till a reduced 10 m radius sample plot for Diameter at Breast Height Dominance and till 20m radius sample plot for Uniform Angle Index and Species Mingling Index.

Sample plot dimension of 13 m radius can describe the forest stand of a 30 m radius plot: by 85,2% of the cases for the Species Mingling Index, by 96,3% for the Uniform Angle Index and with DBH Dominance Index values in 100% of the cases.

4: Discussion and Conclusions

Forest structure in Europe is an important topic on which forestry based on ecological objectives is more and more focusing in the last decades. Forest structure characterization is made in order to evaluate development of the forest ecosystem, effects of disturbance and effects of management regimes. The characterization forest structure diversity in order to evaluate the suitability of habitats for plant or wildlife species is another important process even if research has to be done in this direction.

The evaluations done in this work are referred to and affecting silver fir forest types and under management regimes. Even if similar research, especially the decriptive part, took place in other forest types it could be interesting to extend research efforts to several forest types and in old growth forests.

Neighborhood indexes can be measured with very small effort (in fact they do not require intertree distances or tree coordinates) and evaluate the present state of a forest while giving alternative informations with respect to management plan data. Moreover neighborhood indices with a structural analysis core based on small scale groups ("structural group of *k* trees") could be inserted in geographical information systems.

The evaluation of neighborhood indices percentage value distribution is reported in the results of this work to evaluate the structural variability of the stands under study. In fact, even if the neighbourhood indices are structured to evaluate the small-scale "structural group of four", an evaluation of the distribution percentages of contagion, mingling and dominance attributes classes of a forest stand, will give important informations on the whole stand structure (examples in von Gadow, 2002; Pommerening 2002; Aguirre *et al.* 2003) and how it is diversified at small scale inside the stand. This action is helpful too in a comparison between stands.

The evaluation of TDH Shannon index depicted stand diversity and valuable differencies between stands.

Another step in this process was to create percentage values distributions differentiated by species belonging, for Species Mingling and Diameter at Breast Height Dominance. This step gives informations on the present hierarchical position and mixture of one species inside the analyzed stand to evaluate species mingling and dominance trends, which reflects ecology and management regimes.

Mean indices values in each sample can give a straightforward evaluation of the balance of small scale patterns inside a forest stand. In fact the mean contagion, mingling and dominance value is influenced by the amount of each attribute class. This type of information is giving less informations on the structural diversity inside a stand but it is representative of the trend of a whole stand.

Statistical analysis depicted that all (100%) of the 20 meters radius circular sub-sample plots populations of index values can be considered as belonging to the same population of main (30 m radius) sample plot for all the three neighbourhood indices analyzed. All the indices analyzed can be measured on a 20 meters radius sample plot to describe a silver fir forest stand.

Statistical analysis that compared the 30 meters radius circular sample plot of index values with the 13 m radius sub sample plot resulted in a different way, depending on the neighbourhood index analyzed: Uniform Angle Index values described (was statistically belonging to the same population) the main area in 96.3% of the cases; Species Mingling values described in 85,2% of the cases its main area; Diameter at Breast Height Dominance described its main area values in 100% of the cases. This radius measure is important considering that is usually adopted in circular areas in national forest inventories all around the world. Not all the indexes have high descriptive responce with this measure, especially Species Mingling. The results could be helpful to better evaluate the implementation to forest inventories and the descriptive capability of each index applied with these dimensions.

30 meters radius sample plot compared with the 10 m radius sub sample plot had different results depending on the neighbourhood index analyzed: Uniform Angle Index values described (were statistically belonging to the same population) the main area in 96.3% of the cases; Species Mingling values described in 81.5% of the cases its main area; Diameter at Breast Height Dominance described its main area values in 100% of the cases.

Considering the silver fir forest type under study, the silviculture management under study and all the three indices the option that can describe a forest stand without errors due to sampling area dimensions is the one that have 20 meters in radius. The 30 m radius ($2826.00m^2$) area is considered here as representative of a forest stand.

The 13 meters area can give totally affordable informations only in the case of Diameter at Breast Height Dominance; while in the case of Uniform Angle Index and Species Mingling have to take into account that the index value can be not descriptive for a forest stand. In our work the amount of forest stands not described by an area of 13 m radius were 3.7% in the case of Uniform Angle index measurements and 14.8% in the case for Species Mingling measurements. The 30 m radius ($2826.00m^2$) area is considered here as representative of a forest stand.

The 10 meters area is totally affordable in describing a forest structure in the case of Diameter at Breast Height Dominance index but in the case of Uniform angle index we found 3.7% of the areas that were not representative of the forest stand and in the case of Species Mingling we found 18.5% of the cases were not descriptive of the forest stands. The 30 m radius ($2826.00m^2$) area is considered here as representative of a forest stand.

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