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SPATIAL ANALYSIS OF A MIXED BEECH, SPRUCE AND FIR STAND IN THE EASTERN ALPS

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ABSTRACT

In a forest reserve, located in the Eastern Italian Alps, a 4 ha permanent plot has been set up in a beech-spruce-fir multilayered forest, left to natural evolution for more than 30 years, in order to detect stand structure and spatial patterns. Additionally, within the 4 ha, we selected 1 ha where data related to age were collected (coring all the individuals above 6 cm in diameter) and to test the efficiency of the statistics at 2 different spatial scales. The methods employed were the univariate and bivariate O-ring statistic together with autocorrelation indexes such as Global Moran's *I* and local *Gi**. Thus, it has been possible to perform both the point pattern and the spatial structure analyses. Diameters' distribution highlights a slightly multilayered structure for groups whose tend to be even-aged and monospecific. O-ring statistics have highlighted a general aggregation pattern up to the oldest stages while the spatial structure analyses have highlighted a macroscopic trend which divide the stand in two distinct and homogeneous big groups of individuals. Secondly, a different behavior is detected among the species, i.e. the beech is likely to prefere to regenerate under the old spruce and the two conifers prefer to grow in very localized conditions. A huge lack of young individuals has been detected due to deers' browsing. Lastly, the age has proved to be a fundamental parameter to fully describe, together with the most common species, diameter and height, the structure of forest stands. The comparison between the 1- and the 4-ha analyses has confirmed the key role of the dimension of the larger permanent plot in detecting the whole range of spatial features within a stand.

The results obtained from this work provide an important support for the analyses of similar stands in terms of evolution and natural dynamics occurring after the human pressure decreasing.

1. INTRODUCTION

The recent developments of the so called "close-to-nature silviculture" implies a deep understanding of the dynamics of the forest-ecosystem as a whole with the aim of managing and developing forest stands that are comparable to natural ones regarding the structure, composition and regeneration processes (Colak et al., 2003; Motta and Edouard, 2005; Wolynski, 1998). To satisfy these purposes, natural disturbances must be mimed by human management and the self-regeneration and self-regulation processes of the forests are seen as a natural course to follow and to implement in the management (Bruchanik, 2006). Single tree selection and irregular shelter wood systems are examples of selvicultural systems based upon these principles which allow the growth of multilayered and un-even aged structures. However, at present time, the biggest challenge is posed by the refinement of such silvicultural systems in order to make them able to guarantee environmental as well as production and social aspects of forest management to be combined (Bradshaw et al., 1994; Grassi et al., 2003; Groven et al., 2002; Heiri et al., 2009; Rouvinen and Kuuluvainen, 2005).

Nowadays, to cope with these challenges, is clearly understood the importance of spatial analyses in order to define the forests' spatial structures and, consequently, understanding their dynamics. This kind of analyses, is mainly possible by the establishment of permanent plot area where all or most of the trees are mapped within a coordinate system in order to create a picture of the stand where performing several quantitative analyses.

Indeed, thanks to the estabilishment of long term monitoring plots (Lter, 2000) within near natural forests is possible, by repeating the analyses, to assess the current forest structure and evaluate how such structure evolves in time (Soraruf, 2008). In addition, the establischment of the permanent plot will be a source of data available for the future and an useful tool for monitoring the forest's evolution. Further, data from such areas, along with those from forest reserves where silvicultural activities are banned, can be usefully integrated in the forest dynamic research and used as a reference point for forest management (Motta and Edouard, 2005; Motta and Garbarino, 2003).

Nevertheless, such long term studies are rare because the relevant time scale exceeds the duration of a research career, and financing is usually difficult over sufficiently long periods (Franklin, 1989).

However, in some forests such as the mixed fir-spruce-beech, which is the most common multilayered forest in the Alps (Del Favero, 2004), the dynamics could be fast enough to provide useful information in a relatively short time span; at least compared to what is needed in tree line.

Nonetheless, at least in Italy, most of the permanent plots have been set-up in these latter environments. Dealing with plot dimensions, currently, most of the spatial analysis are 1-ha based (Batllori et al.; Carrer and Urbinati, 2001; Hao et al., 2007; Lingua et al., 2008; Lopez et al.; Mason et al., 2007; Motta et al., 1999). We want to stress on the importance of setting at least 4 ha permanent plots since, especially due to the higher number of trees and the broader dimension of the area under analyses, we are able to identify patterns which at smaller scale are not detectable.

Within the frame of such analyses, the first step to do is identify patterns. This must be done for two reasons: for implementing the point pattern analysis; which is the statistic able to detect whether the distribution of trees is random, clumped or regular (Camarero et al., 2000) and, secondly, because ecological data are usually characterized by spatial structures due to spatial autocorrelation referred to the pattern where the events are located (Fortin et al., 2002). Autocorrelation is indeed very important because most of the characteristics of a population result spatially associated (Levine III, 2004).

Despite the long time known importance, most of these techniques have been developed only in recent years: until four decades ago, the parameters analysed to investigate the structure of forest biocenosis were mainly constrained to stem diameter distribution and basal area/volume of the stands. The recent development of faster and more precise sampling methodologies, spatial statistics and powerful software programs, allowed the creation and evolution of several new tools to evaluate ecological patterns and plant distribution.

Since the 1970s, spatial statistics initially developed for geographical studies were brought to the attention of ecologists and biologists. It is in those years that two of the now commonest and most informative tools in ecology (the already mentioned point pattern analysis and spatial autocorrelation analysis) were implemented to assess trees distribution. The former methodology was developed mainly by Ripley (1981) through the Ripley's K function which is used for the point pattern analysis.

In particular, one of the most debated issues related to mixed forests is the ecological explanation of plant coexistence. Many theories have been developed: from the niche assembly theories, which predict that spatial clustering of species might be due to environmental heterogeneity and biological interactions, to dispersal-assembly theories which instead hypothesize that dispersal limitations can account alone for the emergence of spatial clustering (Wiegand, 2007). Spatial clustering of a species is seen as the prodrome of species segregation and therefore co-existence. In this context, second order statistics such as the bivariate and the univariate statistics whose are implemented to perform the point pattern analysis, are useful tools to describe the characteristics of the relationships between individuals over a certain distance.

Spatial autocorrelation instead, developed by other scientists (Sokal and ODEN, 1978) , has been used to assess if a variable at one position is significantly dependent on values of the variable at neighbouring positions. These tools play nowadays a major role in identifying and evaluating forest dynamics, ecological patterns and interactions between plants. In particular, spatial patterns have been used to investigate how the tree species distributes in space (Chen and Bradshaw, 1999), if there are differences between pattern of recruitment of trees (i.e. light demanding *vs* shade tolerant) (Aldrich et al., 2003) and to evaluate the presence of particular regeneration niche (Getzin et al., 2006). Those researches have been undertaken in most of the forest of the world from tropical to boreal.

In our study, we also carried out the analyses related to age structure. In particular, it is interesting to highlight how such parameter is correlated with the DBH. Age parameter, is indeed one of the fundamental component of a stand's structure, but getting it is in the same time a high effort and a difficult task. However, it is able to provide useful informations allowing an understanding of stand's dynamics under a different, but fundamental, perspective.

Actually, the dynamic processes whose have determined the present state of a forest, can be understood thanks to the age parameter.

Therefore, the aims of the present study were:

- Describe the stand structure of a mixed beech, fir and spruce stand;

- Assess whether and how the forest structure is still affected by the past human management

- Testing the efficiency of the statistics at 2 different spatial scales.

2. MATERIALS AND METHODS

The choice of this permanent plot was carried out following the LTER (Long Term Ecological Research) protocol (Lter, 2000) and the requirements of this study, which needed a representative forest stand undisturbed by human where the recovering of natural dynamics could be visible (von Oheimb et al., 2005).

The size of the study area was set to 4 ha to capture as better as possible the forests diversity and complexity.

2.1 STUDY AREA

Cansiglio forest, located in pre-Alpine mountain chain of North East Italy is one of the largest forests of Northern Italy. It has a long history of human management which can be track back to the XV century, when the Republic of Venice utilized the wood for building of ships and oars. Thanks to its importance, the first raw management plans were developed since the XVI century.

The study area representative of a previously managed *Abies-Fagus-Picea* forest is located in the "Pian di Landro – Baldassare" oriented nature reserve, in the Tambre d'Alpago municipality of Veneto Region (Cord: 46° 06' N; 12°25' E). The reserve, which covers an area of 265 ha, protects the northern portion of the Cansiglio forest. The 4 ha (200 x 200 m) permanent plot which has been established for this study is characterized by a limestone bedrock, a gentle topography with numerous dolinas caused by karsts processes which allow both a deep soil formation and emerging rocks throughout the plot. The mean altitude is 1100m a.s.l. and the mean slope is between 5 and 10° (Piano di gestione Riserve Naturali del Cansiglio (1986)). The mean annual temperature is 6.6°C with July as the warmest month (15.5° C) and January the coldest (-2.4° C)(Soraruf, 2008). The particular orography favours a strong winter thermal inversion which can results in temperature below -30°C. The mean annual precipitation is 1800mm well distributed throughout the year, which nevertheless peaks in May and September. The climate therefore, typically oceanic with cold winters, allows the coexistence of many different tree species. The soil is a dark, humid, humus rich rendzina with local accumulation of clay (Piano di Gestione Riserve Naturali del Cansiglio (1986)). As it was previously stated, the human management of this forest has a long history: in 1404 A.d. the community of Belluno donates the Cansiglio forest to the Venice Republic. The Republic has always been in need of wood both for ship building and for fuelwood. The importance of the forest and of its maintenance is evident from the numerous essays which the Belluno's major was exchanging with the Venice governor, mainly concerning the management and the productivity of

the forest. However, until the end of the XVIII century, the volume of wood exploited annually from the forest was probably much lower than the growing increment. Some unorganized selective cutting was the predominant silviculture management system which was condensed on the most accessible portion of forest closer to roads.

After this period, nevertheless, increased demand of fuelwood, unorganized harvesting both in time and space and the widespread cattle grazing had a negative impact on the forest: the forest area was reduced and the structure turned to be much more evenaged over vast area. In particular, this dynamic has been accelerated by the enormous amount of wood cut during the First World War which was fought in the nearby area. Just to give an idea of the devastation suffered by the forest, approximately 400.000 m^3 were cut in 4 years, 7-8 times the annual growing increment (Soraruf, 2008). In between the two World Wars, the forest management plan encouraged the forest coetanisation though shelterwood system over vast area, in order to make easier the harvesting planning and organisation (Piano di Gestione Riserve Naturali del Cansiglio (1986)).

This was particularly true for the pure beech part of the forest. Moreover, the most degraded areas were artificially regenerated using mainly Norway spruce and/or silver fir.

This area was declared protected in 1971 and since then no human intervention have altered its natural dynamic.

2.2 SAMPLING

The selection of the location for the permanent plot followed the LTER guidelines: the selected area should be representative and homogeneous in respect of the forest ecosystem object of the research. Therefore, the sampling in proximity of roads/paths should be avoided, as well as in areas which are peculiar for some physiological/structural parameters.

The permanent plot has a square shape with 200 m long side. Borders have been defined by means of an optical laser device (TRUPULSE 360B), able to identify azimuth, real distance and inclination. The origin of the coordinates X-Y used to localize the trees has been set at the North-East angle of the plot. Inside the plot, all living and standing dead trees bigger than 1 cm DBH and higher than 1.3 m have been measured. For each tree, a label with an identification number was attached at the base of the stem and position, species, DBH, height, height of the lowest living branch (on northern and southern side) and length of the projection of 4 crown radii on the ground have been measured. The already mentioned TRUPULSE 360B has been used to localize the trees (azimuth,real distance and inclination for eah tree) and to measure the heights. For crown radii has been used a laser distance meter (TRULASER TLM 100i).

Moreover, in addition to the measures mentioned above, 1 ha of the plot has been chosen in order to assess the age of the.Such area has been simply limited starting from the north-west angle of the

permanent plot and then, an increment core from all living and standing trees above 6 cm DBH have been extracted by means of the Pressler borer.All the cores have been fixed on a support with a vinilyc glue,then classified according to a 8 characters code and finally prepared forthe tree ring measurement.

2.3 DATA ANALYSIS

Based on class abundance and silviculture parameters, the whole plot have been divided into diameter classes from 5 up-to 100 cm DBH in order to define its structural characteristics. For spatial analyses, instead, we have divided the trees into three main categories in order to have a clear differentiation among the extreme values: *Small* have been defined all the individuals smaller than 17.5 cm DBH; *medium sized* are the trees with DBH in between 17.6 and 29.9 and finally *big* the individuals bigger than 30cm DBH. In the 1 ha plot, the trees have been divided according to age as well. For structural characteristics we have used classes from 10 up-to 110 years and for spatial analyses the following 3 main categories: *young* have been defined all the trees younger than 35 years old; *adult* are the trees between 35 and 70 years old and *mature* the ones equal or above 70 years old. All the following analyses have been performed on the most representative tree species in the forest: *Abies alba*, *Fagus sylvatica* and *Picea abies*. Other species were present (i.e. *Fraxinus excelsior*, *Corylus avellana*, *Sorbus aucuparia, Acer pseudoplatanus* and *Populus tremula*) but their number were too small to provide any significant results, therefore they were not considered. The variety of analyses which were performed on those data will be described hereafter.

2.3.1 POINT PATTERN ANALYSIS

According to Bailey's classification (Bailey and Gatrell, 1995), the point pattern analysis is the tool for understanding point distributions, i.e. trees in this case, where each one of them can, but it is not mandatory, be associated to a quantitative value. This technique is known since decades (Anselin, 1995) to be effective and successful in ecological applications and, in this study, will also be merged together with spatial autocorrelation analyses such as Moran's *I* (Moran, 1948) and Local *Gi** (Getis and Ord, 1992; Getis and Ord, 1996) indexes.

For a sake of clarity, from this point forward we'll call "events" every occurrence in the space of the observed phenomenon, i.e. trees, whereas all the other locations arbitrary selected will be called "points". Each event "i " will be univocally identified by means of coordinates X_i and Y_i but, following the type of spatial analysis involved, they can be also charactrized by values related to weight (in order to distinguish if the plants belong to the same distance class) and intensity, i.e.stem's diameter at breast height.

Thanks to point pattern analysis we can rigorously determine whether the events are randomly distributed, clustered or homogeneous analyzing the properties of first and second order of the events which are, respectively, determined by the density pattern. According to previous researchers (Wiegand and Moloney, 2004), these analyses are increasing their importance in ecology, since is often needed the characterization of spatial patterns to develop hypothesis on underlying processes. The same authors have moreover developed a dedicated software called Programita ®allowing to perform the already mentioned statistics which are approaching to discuss.

 Although for analyse the spatial patterns of forest communities is still often used the "classic" Ripley's K (r) function (Ripley, 1981), we have used instead the pair-correlation function *G(r)* which is a recent development of the Ripley's *K(r)* (Zhang et al., 2009). In particular, this latter represents the estimated number of points in a circular area of radius r, centred in a random point, divided by the intensity of the pattern (Wiegand, 2004):

$$K(r) = \frac{\lambda^{-1} \sum_{i=1}^{n} \sum_{j=1}^{n} I_t(e_i, e_j)}{n}$$

Where the point intensity , λ, is estimated as the density *n/A*, I_r is an indicator function which takes value 1 when e_j is within distance *r* of event e_i (and 0 otherwise) and *n* is the total number of events. But its most used form is the linearized one (Fortin et al., 2002; Soraruf, 2008):

$$L(r) = \sqrt{\frac{K(r)}{\pi}} - r$$

The function *G(r)*, instead, substitute the circular areas with rings of a certain, chosen width.Indeed, one of the deficiencies of the *K(r)* is the accumulation of the information relative to shorter distances when analysing a larger radius. In other words, the result at larger scales maintains a "memory" of the results obtained when smaller areas have been examined.Merging the effects at large scales with those at small scales creates difficulties in evaluating the patterns over large distances (Hao et al., 2007). The O-ring *G(r)* function, instead, isolates each specific distance class, avoiding this negative effect. The main scope of the univariate analysis is to give information about the characteristics of the point pattern over a range of inter-tree distances (Wiegand, 2004).

Before reading the result, however, it is necessary to evaluate the significance envelopes.

The significance is obtained by comparing the observed, real distribution pattern with Monte Carlo envelopes created from the analysis of multiple simulations of a null model.The null model used was the complete spatial randomness (CSR), that can be implemented as an homogeneous Poisson process, i.e. the location of each point in the simulations is randomized over the entire study region so that it's independent in respects to the location of the others points. The significance envelope was generated by running 99 simulations which guarantees a 99% confidence envelopes (Diggle, 2003). Consequently, positive values of $G(r)$ above the confidence limit represent aggregation (the points tend to be clustered one to each other); value of $G(r)$ below the confidence limit represent inhibition (the points tend to be regularly distributed in the space); finally, values of $G(r)$ inside the confidence envelope indicate a random point pattern distribution.

Those analyses have been performed on the three tree species and for the different DBH categories of small,medium sized and big. Additionally,for the 1 ha plot,also the three main age categories of young,adult,and mature have been subjected to the same analyses.

All the univariate O-ring analyses have been performed using software Programita ® (Wiegand, 2004b) with a spatial resolution (ring width) of 5 meters up to 50 meters distance from the selected point.

The bivariate O-ring statistic is instead used to assess the relationships between two point patterns by evaluating the combined distributions of distances between two population: the statistic $G_{1,2}$ represents the expected number of points of pattern 2 at a given distance r of an arbitrary point of pattern 1 (Chen and Bradshaw, 1999).

Analogously to Univariate O-ring, Bivariate O-ring $G_{1,2}$ is an evolution of Ripley's $K_{1,2}$, with the only difference of replacing the circles of radius r with rings of width r (Wiegand, 2004). The choice of the ring width in the bivariate O-ring statistics is particular important: a too narrow width might consider only a reduced number of points, whereas a larger width might compromise the ability to evaluate the relationships at some specific distance scale. Positive value above the confidence envelops show attraction between the two patterns, negative value shows repulsion and values of $G_{1,2}$ in between show no interaction/independence. Where attraction/repulsion are defined here as the tendency for trees of the two patterns (for instance two different species) to be closer/farther apart than what would occur if they were distributed independently one to each other (Peterson and Squiers, 1995). The significance envelopes were created by running 99 simulations which gave a 99% confidence limit.

The analysis of bivariate point pattern is more complicated than that of univariate patterns since various different null models in addition to CSR become possible. The appropriate null model of

the bivariate analysis must therefore be selected carefully based on the biological hypothesis to be tested (Wiegand, 2004).

Here we used the "independence" model to test the relative distributions of the species. The assumption is that the two point patterns are spatially independent one to each other or, in other words, that there is no significant spatial interaction between them (Chen, Bradshaw, 1999).

In order to assess the relationships mature trees-young trees and small-big trees the "antecedent condition" null model was used. Since the locations of adult trees did not change during the seedlings development, their pattern is maintained fixed in space. On the contrary, seedlings pattern is randomized (Wiegand, 2004). The evaluation of the combined distribution of distances between the two point patterns reveal the $G_{1,2}$ value.

The bivariate O-ring statistics have been computed comparing all the small trees of each species with the big trees of every species. Additionally, within the 1 ha plot, young trees of each species and mature trees of each species have been subjected to the same performance.

All the bivariate O-ring analyses have been performed using Programita ® (Wiegand, 2004b) with a spatial resolution (ring width) of 5 meters up to 50 meters from the selected point.

2.3.2 SPATIAL AUTOCORRELATION ANALYSES

The concept of spatial autocorrelation is one of the most important among spatial analyses techniques and it's based on the geography's first law: "everything is related to everything else, but closer things are more related than others" (Tobler, 1970).

In particular, a positive autocorrelation is found where the events tend to be aggregated (i.e. forming clusters), whereas a negative autocorrelation occurs when the events tend to be scatterd in the space (Boots and Getis, 1988). It's clear that point pattern analysis as such can already provide some informations about autocorrelation because, for instance, there cannot be autocorrelation without aggregation. Nevertheless, it can detect details such as the mean clusters's size, but not the number and the location of the clusters either.

Therefore,the concept of autocorrelation is opposite to the independence one:indeed the events of a distribution are independent if no relationship determines their position. There's a simple empirical evidence which makes this analysis so important:most of the characteristics of a population result spatially associated (Levine III, 2004).

Nevertheless, from a statistical point of view, this latter situation represent a problem rather than a resource. Indeed, most of the "traditional" statistical tools are based on the assumption that the events of a distribution are each other independent and,therefore such methods are always biased.

To deal with this problem, several statistics such as the following Moran's I and Local Gi have been developed in order to measure the degree of spatial autocorrelation.

Moran's I coefficient have been utilized to assess the spatial pattern of tree diameters within the 4 ha plot and, additionally, to assess the age patterns within the 1 ha plot. This coefficient highlights the DBH and age variability within patches of trees and it is defined by the following formula:

$$I(r) = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} (x_i - x)(x_j - x)}{W \sum_{i=1}^{n} (x_i - x)^2}$$

Where: I (r) is the Moran's coefficient;n is the number of trees considered; x_i the value of DBH or age at point i; x_j the value of DBH or age at point j where $i \neq j$; x is the mean of the considered variable; w_{ij} is the weighting factor for the pair of the two samples i and j, it assumes value 1 if they belong to the same spatial lag, otherwise it's 0; W represent the sum derived from the weight matrix $\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}$.

Each DBH and age measure is firstly attached to the corresponding tree's coordinate then, by computing the Moran's I autocorrelation index, it's possible to evaluate the autocorrelation of the DBH and age variable between all pairs of points separated by a given spatial lag(Rozas et al., 2009).The resulting graph can reveal the presence of patches of even-sized or even aged trees inside the forest. In particular, it shows how autocorrelation varies according to distance without considering the directions; revealing precious information about the mean patch size: the spatial correlogram produced indeed, starts with positive value of autocorrelation at short distance, decreases and crosses the abscissa axis until it reaches negative values. The mean patch size of trees with similar DBH is indicated by the distance at which the autocorrelation equals to 0 (correlogram crossing abscissa axis).

Global significance has been tested with Bonferroni test,which approximate the significative probability corrected for multiple tests;in this case there are multiple distance lags (Soraruf, 2008).Bonferroni's correction consist in setting the probability level α',used for testing the whole correlogram,with the ratio between the probability level α and the number of spatial lags κ (this latter is 20 for the whole plot and 10 for the 1 ha plot):therefore α'= α / κ .A correlogram is considered significative if at least one significative value,at α' level,is plotted (Fortin et al., 2002).

The value used to generate the graph is the *Z(I)* which compares the empirical distribution of DBH or age with the theoretical distribution,i.e it's an index to test the results obtained and it's defined as follow:

$$z(r) = \frac{I(r) - E[I(r)]}{\sqrt{var[I(r)]}}$$

Indeed, Cliff and Ord (1973,1981) have demonstrated that Moran's index tend to a normal distribution according to a bigger size of the sample.

Therefore, the results are significant when $Z(I)$ is above 1.96 or below -1.96 (95% significance envelope of the statistics). All the calculations of the Moran's Autocorrelation Index have been computed with the Excel add-in Rookcase (Sawada, 1999).

The global autocorrelation indices have been computed both for the whole 4 ha plot and for the 1 ha plot regarding all the trees and every single species.

The lag distances analysed has been set to 10 m and the numbers of lags to 20 for the whole plot and to 10 m distance and 10 lags for the 1 ha plot in order to cover all the surfaces of the two permanent plot. The lag distance of 10 m has been set since it represent the best balance between the advantage of a large lag distance (more stable value of $Z(I)$ and easier readability) and the higher accuracy of shorter lag distances.

So far, we have considered only statistics whose results are averages of the values found for each spatial lag around each event. This is actually what we can see plotted on the graphs.

Unlike all the mentioned analyses,the index we're going to discuss is plotted for each tree and not for each spatial lag considered. Therefore it results as a completely different graphical representation.

The main difference between a global measure of autocorrelation and a local measure of autocorrelation is that the latter is able to identify the contribute of every single point to the local patterns and that they evaluate the association of nearby locations with a much smaller scale compared to the global view of other indices, like Moran's I (Fortin et al., 2002; Soraruf, 2008). This can be useful to identify local "hot-spot" or clusters in a more defined scale (Ord and Getis, 2001). Moreover, the local statistics present the results associated with their relative coordinates. This can be considerably useful in order to create maps of the autocorrelation indices which can be overlapped to the real x,y maps. Of course the results, having a local scale, should be interpreted according to the global autocorrelation indices (Ord and Getis, 2001).

In this study we have evaluated the local autocorrelation using Local-Gi*, a parameter developed in the last twenty years by Getis and Ord (Getis and Ord, 1992; Getis and Ord, 1996). The index evaluates the spatial association of a point pattern within a distance d which is set by the operator (Soraruf, 2008) and is represented by the following formula:

$$G_i* = \frac{\sum_j c_{ij}(r)X_j}{\sum_j X_j} \quad i = j$$

Where $c_{ij}(r)$ is a binary filter and it assumes value 1 for all neighbours J (and i also) within distance r of i, 0 for all the locations greater than r. Therefore: at the numerator we find the summation of all X_J within r of i, whereas at the denominator there is the summation of of all X_J (Getis and Ord, 1992; Premo, 2004). Of course, *X* represent the value of the variable considered (age or DBH).

As for Moran's I, the plotted value is the standardized normal deviation z-Gi*(r) computed in the same manner. As we'll see, such index can assume different values if we consider the same pattern with different scales (4 ha plot and 1 ha chosen within it). It means that the same trees could be recognised as cluster-forming at 4 ha scale, but they couldn't at 1 ha scale.

These differences are already reflected at global scale by the Moran's I because the 2 indexes are each other in accordance. Understanding the reasons which lies below them can be quite intuitive regarding the Moran's index because if, for example, in the 1 ha plot would be located just one big cluster, the lag of the curve falling above positive significant values would be relatively large. If, instead, we regard the whole 4 ha plot, it will encompass both small and big clusters; returning therefore a different and, probably, a more heterogenous pattern of the curve.

Unlike for Moran's index,for the local Gi the reason which lies below the mentioned scale differences is less intuitive because the computation is made at individual level.

However, since the summation at the denominator of the local Gi*is influenced by the amount of pattern's points, it's clear that the results will be different according to the size of the point pattern considered. By the way, this topic is treated in great detail by Getis and Ord (1992).

Concerning the significance: the confidence limit, representing the 95% significance envelop of the statistics, is reached for z-Gi* values above/below 1.96/-1.96 respectively.

Positive/negative value of the z-Gi*, over the significant envelopes, represents aggregation between the bigger/smaller value of the variable analysed (in our case, DBH and Age).

In order to provide a clear representation of this statistic, we plotted the results into "bubbles graphs", where each bubble's size is proportional to the z-Gi* value which is referred to: they have been developed for every species both for the 4 ha and for the 1ha study plot.

In order to allow an easier and more statistically correct comparison between the global value of autocorrelation and the local one, the lag distance has been set to 10 m as well. All the calculations have been computed using the Excel add-in Rookcase (Sawada, 1999).

3. RESULTS

The results found at the 1 ha plot level will be compared with the ones found at the 4 ha plot;except for the analyses related to age,which is a datum available only for the first.

3.1 STRUCTURAL CHARACTERISTICS

In the Tab.1 we can see that the total number of trees in the whole 4ha permanent plot is 3227, of which 2508 alive (626 per hectare) and 719 dead ; for the 1 ha plot, instead, the total number of trees is 514, of which 470 alive and 44 dead.The most common species is in both cases beech, with 316 individuals per hectare for the whole plot and 268 individuals in that hectare chosen within it. Beech is followed by spruce (206/ha) and fir (94/ha) in the whole plot but this order is not reflected in the smaller one, where fir is the most represented species after beech with 103 individuals, whereas spruce counts 95 individuals. Other species are presents in the 4 ha sampling plot with sporadic individuals: 13 *Fraxinus excelsior* have been recorded, followed by 12 *Sorbus aucuparia*, 8 *Corylus avellana* and 7 *Acer pseudoplatanus*. Only 4 individuals of these species (globally considered) were located in the hectare plot. Among the standing dead trees,considering the whole area, spruce is the most represented species (536) while beech and fir have much lower numbers (124 and 54, respectively). They are represented according to a different order within the 1 ha plot: beech (22 individuals), spruce (12 individuals) and fir (10 individuals).

The total alive basal area per hectare is 48.39 m^2: spruce is the leading species with 20.3 m^2/ha followed by beech with 18.1 m^2/ha and fir with 9.8 m^2/ha. If we consider just the hectare chosen within the whole area we can see the same order with spruce (17,7 m^2),beech (15,2 m^2) and fir (13,9 m^2).The maximum height recorded at 4 ha level is 42.1 m for spruce and beech and 40.6 m for fir; whereas at 1 ha scale we can see 38,4 m for fir, 37,4 for beech and 30,6 for spruce.The highest mean DBH has been recorded in fir (28.5 cm), but if we consider only the single hectare, spruce reaches the biggest mean (40,6 cm). Considering again the whole area, spruce and beech follow with 20 cm mean DBH for both. At smaller scale, instead, spruce is followed by fir (35,6 cm) and beech (21,7 cm). Similarly to the order shown for the mean DBH values, at 4 ha scale the biggest diameter recorded was a fir (95 cm), followed again by spruce (92 cm) and beech (78.5 cm). The mean DBH values are in accordance with biggest diameters recorded in the 1 ha plot as well: for spruce the biggest diameter is 86 cm, for fir 73 cm and for beech 64 cm.

The mean age is 62 years for all the most represented species and the oldest tree is a beech 101 years old.The oldest trees among firs and spruces are 90 years old and 70 years old respectively.

	AA	FS	PA	Other Sp.	TOT
Mean DBH (cm)	28,5	20	20	11,4	
Min DBH (cm)	1,5	0,2	0,5	1	
Max DBH (cm)	95	78,5	92	37,5	
N	379	1264	825	40	2508
N/ha	94	316	206	10	626
H max (m)	40,6	42,1	42,1	28,3	
N Dead	54	124	536	5	719
G/ha (m2/ha)	9,8	18,1	20,3	0,19	48,39

	AA	FS	PA	Other Sp.	TOT
Mean DBH (cm)	35,6	21,7	40,6	14,8	
Mean Age (years)	62	62	62	45	
Min DBH (cm)	1,5	1	1,5	9,5	
Max DBH (cm)	73	64	86	18,5	
Oldest living tree age	90	101	70	65	101
N	103	268	95	4	470
H max (m)	38,4	37,4	30,6	18,1	
N Dead	10	22	12	0	44
G/ha (m2/ha)	13,9	15,2	17,7	0,01	46,9

Tab.1: Mean parameters for the 4 ha plot (above) and for the 1 ha plot (below) . DBH: diameter at breast height; N: tot number of plant ; H: Height; N Dead: Total number of dead individuals; G/ha: Basal area (m^2) per ha. (AA: *Abies alba*;Fs: *Fagus sylvatica*; Pa: *Picea abies*).

In figure 1 we can appreciate the main differences between the whole 4 ha plot and the hectare within it. Concerning the basal area composition we can immediately see how the spruce is much more represented at the bigger scale respect to the smaller one even if, in both cases,such species account for the biggest percentage. Another clear difference is the percentage of the fir's basal area. Indeed, it accounts for the 13% more at 1ha scale respect to the 4 ha one.

If we look at the species composition, the most significant differences are more evident especially for spruce,which is represented by 20% of the individuals on the 1 ha plot but, in the contest of 4 ha, it accounts for the 40% of the trees.Beech, instead, is much more numerous at 1 ha scale because it's represented by 54% of individiduals against the 45% at 4 hectares scale.
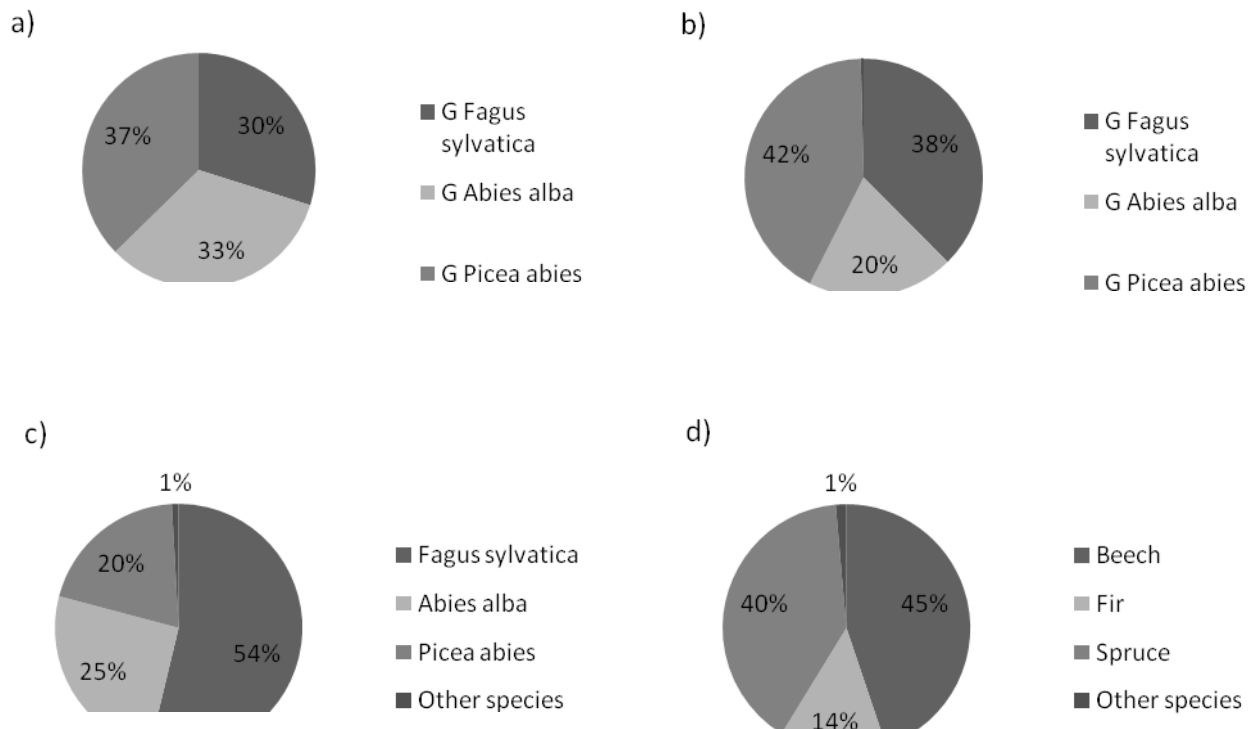
Fig.1: Basal area composition for: a)the 1 ha plot, b) the 4 ha stand. Species composition for:c)the 1 ha and d) the 4 ha plots.

Considering the DBH distribution of all trees together (Fig. 2) in the whole 4 ha plot, it is a mixture between the typical reverse J-shaped distribution of uneven-aged forests and a unimodal distribution of even-aged trees skewed towards larger diameters. The distribution has been created dividing the tree DBH in classes of 5 cm, starting from 0 to 5, 5 to 10 and so on.

Considering all the trees together, the peak in the frequency distribution is at 10 cm DBH. The distribution follows a pattern such that the first DBH class is underrepresented compared to the second class. From the third class (10-15 DBH) the number of individuals in each size class decreases quite rapidly until the 30 DBH class and more slowly until the final class (95 DBH).

Analyzing the DBH distribution for the three main species separately (fir, beech and spruce) some considerations can be added. Starting with fir, the peak in the distribution at the 20 DBH class, very low value have been recorded for the first two classes (2 individuals only) and the second one. The frequency slowly decreases with a smaller, second peak at the 45 DBH class,until the biggest DBH of the entire permanent plot 95 cm.

Beech, the most common species in the forest, presents the peak of the distribution at the 10 DBH class, again the first class is underrepresented compared to the second one. The number of trees per class decreases constantly until the 35 DBH class, then the frequency remains almost constant until the 45 DBH class and finally it decrease again towards the last class (80 DBH).

Finally, spruce shows a different DBH distribution structure: the number of individuals per DBH class is less diversified than the others two species and tends to be more constant. Again the peak of the distribution is not in the first DBH class but is in the third one (10-15).The frequency slowly decreases until the 50 DBH class and then increase again until the 60 DBH class which represent the second peak of the distribution.Towards the largest diameter a third, smaller, peak is present for the 75 cm DBH class.
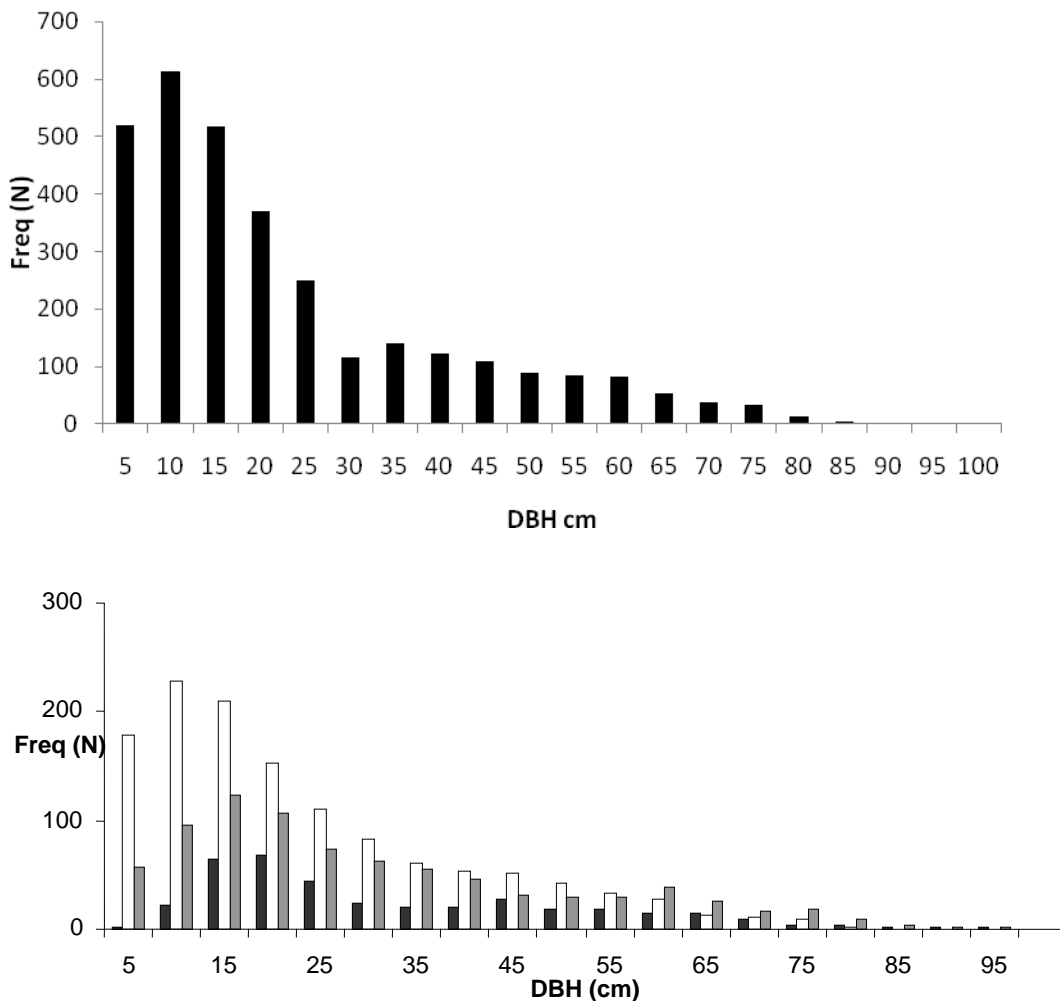
Fig. 2:DBH distribution for all tress and divided by species within the 4 ha plot. Dark grey: *Abies alba;* white: *Fagus sylvatica;* light grey: *Picea abies*

In figure 3 is possible to appreciate the ipsometric curves for the 3 main species of the whole 4 ha plot. Apart from spruce, of which the best fit is the linear regression, all the other curves are fit by a power function. In all cases the correlation coefficient is at least 0,8, i.e. is very likely that as bigger is the tree as higher it will be.
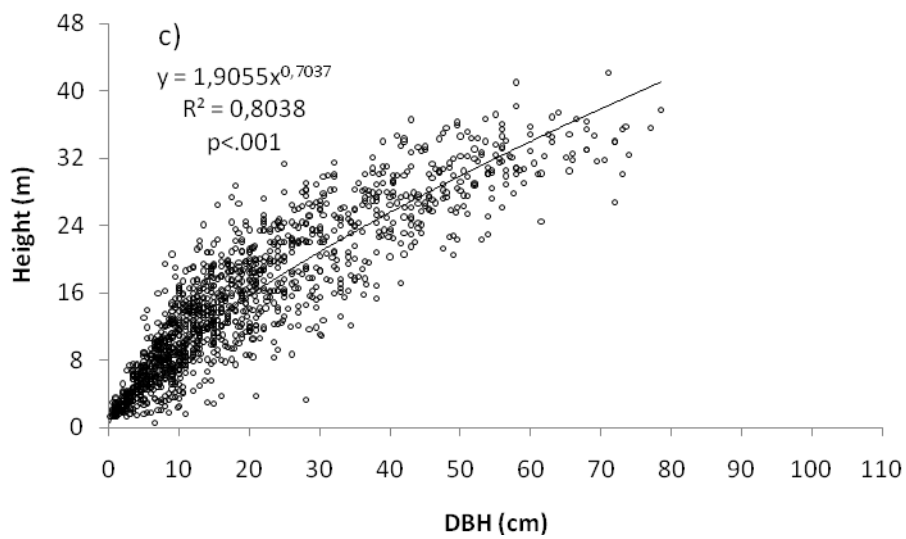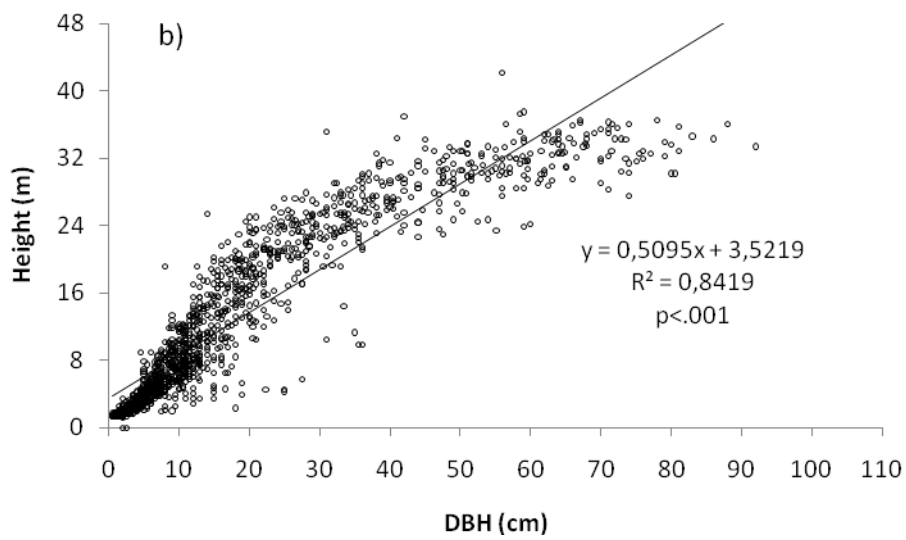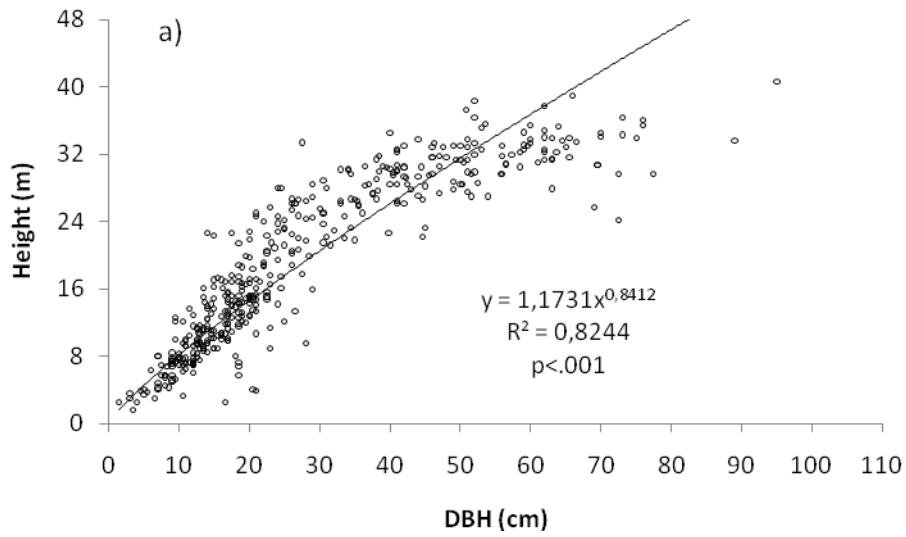
Fig. 3: Height related to DBH for the 4 ha stand: a)Abies alba,b)Picea abies, c)Fagus sylvatica

Now, we'll focus the attention at 1 ha scale in order to appreciate the structure related to age as well.

In figure 4 we can see the distribution of the 3 mean age classes in terms both of absolute numbers and in percentage. It's clear that the class of 35 (young) has the smallest number of trees and fir in particular has a contribution of just one individual. Beech instead, despite the very small number, contributes for approximately 85% to this category. Spruce, even though is a bit better represented than fir, is hugely far from beech in terms of percent contribution.

Within the 35-70 years class (adult trees), we can see a different pattern where, in general, the number of individual is the highest and already reflects the Gauss-trend of the distribution which differs respect to the J-shaped one found for the DBH distribution. In terms of percentage, beech is still the most represented species since it encompass alone almost the 50% of the individuals. The remaining 50% is shared by the conifers with a slight bigger contribution of fir respect to spruce.

If we look at the class of the matures (70 years old or older), we can see that beech is predominant here as well. In terms of absolute numbers there are few individuals but almost 70% is filled by such species whereas,similarly to 35-70 years old class,the remaining 30% is shared by the conifers.

b)
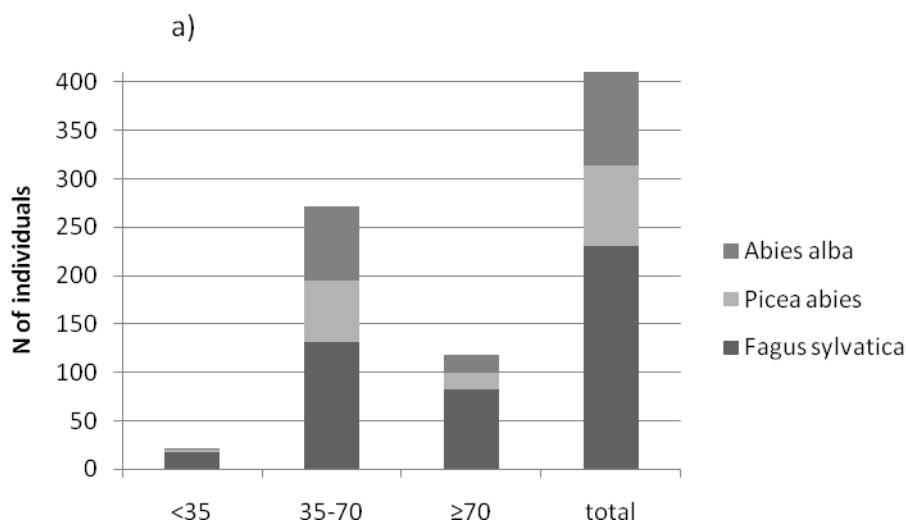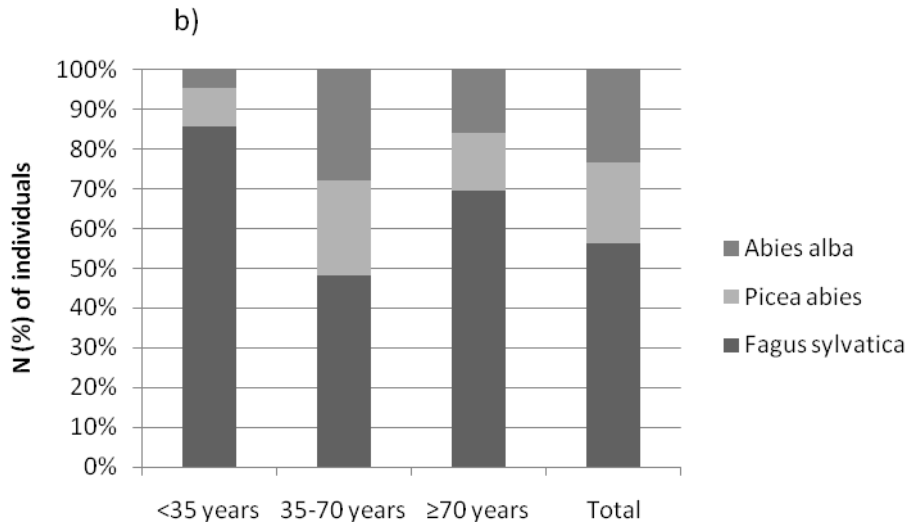
Fig. 4: Species mixture of the three different age classes of the 1 ha plot in terms of a) absolute numbers and b)percent.

In figure 5 is shown the low correlation between the diameter size with age of all trees.Such behavior is particularly evident as long as we approach towards the higher age classes and it's the reason of the different distribution of age respect to the DBH one.This latter indeed is similar to the one found at 4 ha scale but,differently,the peaks of the distribution,which are still located in the smaller classes (15 and 20 cm DBH),decrease more gradually.Age,instead,follows a Gauss distribution with the highest amount of individuals located at the intermediate classes (60 and 70 years old).
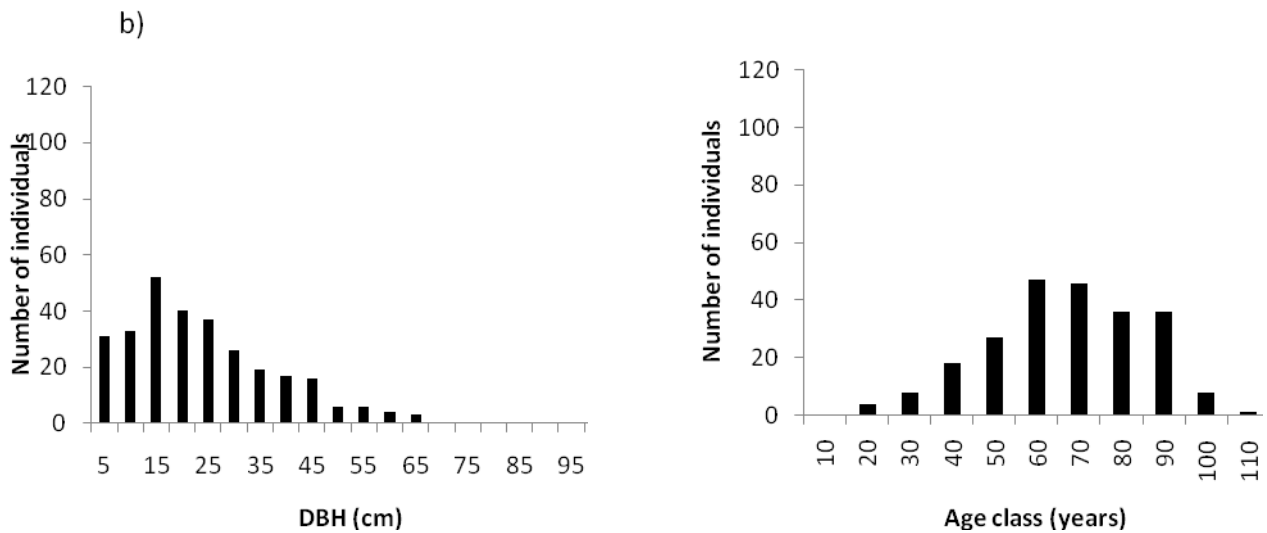
a)

$$y = 0,1375x^{1,2889}$$
$$R^2 = 0,3658$$
$$p<.001$$
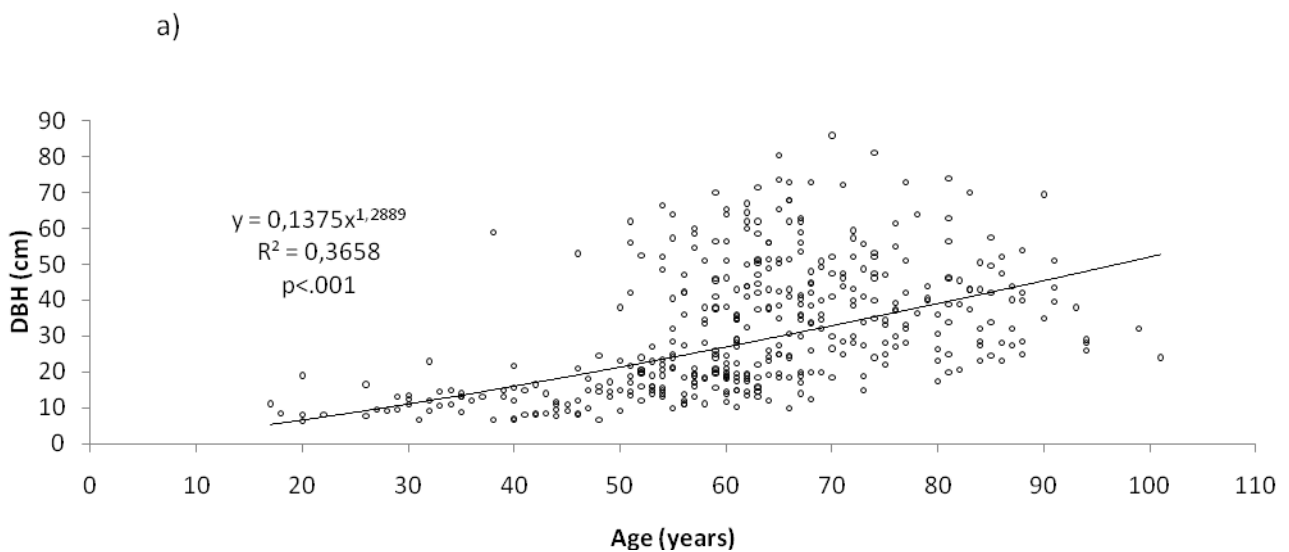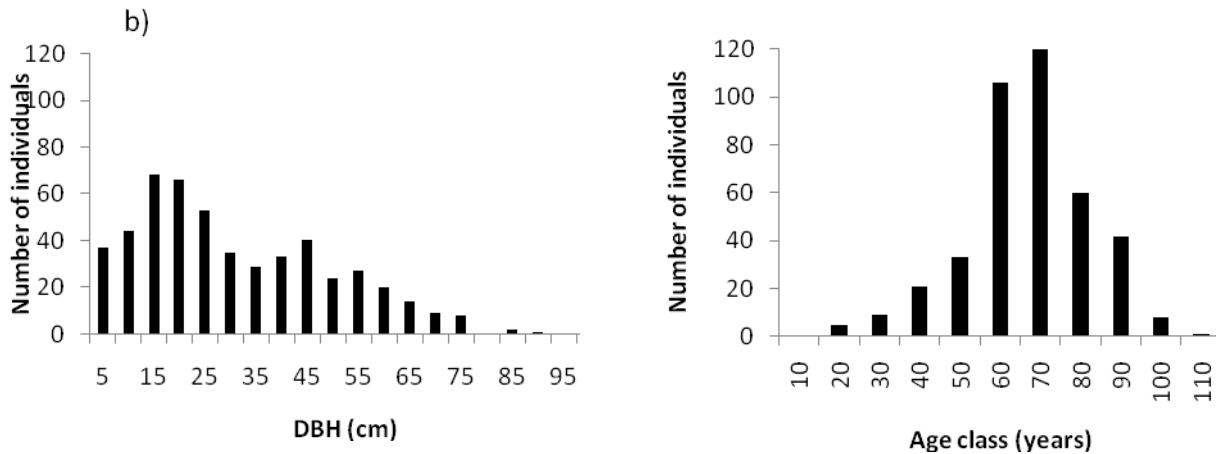
Fig. 5: a)Scatter plots with best fit regression of all trees' DBH versus age within the 1 ha plot.b)Comparison between DBH and age distribution.

In figure 6, we can see the same plots mentioned above but related only to fir. Such species shows the lowest correlation between DBH and age and the comparison between the plot of DBH and age distribution is a further demonstration of this evidence.

Indeed , DBH distributions shows 2 peaks at 20 cm DBH class and at 45 cm class but,in general,all the classes are somehow represented. In the age distribution plot, instead, we can identify 2 peaks very close each other both by the quantitative point of view (around 40 individuals)and by the classes where they are located (60 and 70 years old classes). Moreover, a lot of fir's age classes are not represented at all (basically all the ones belonging to the young stages).
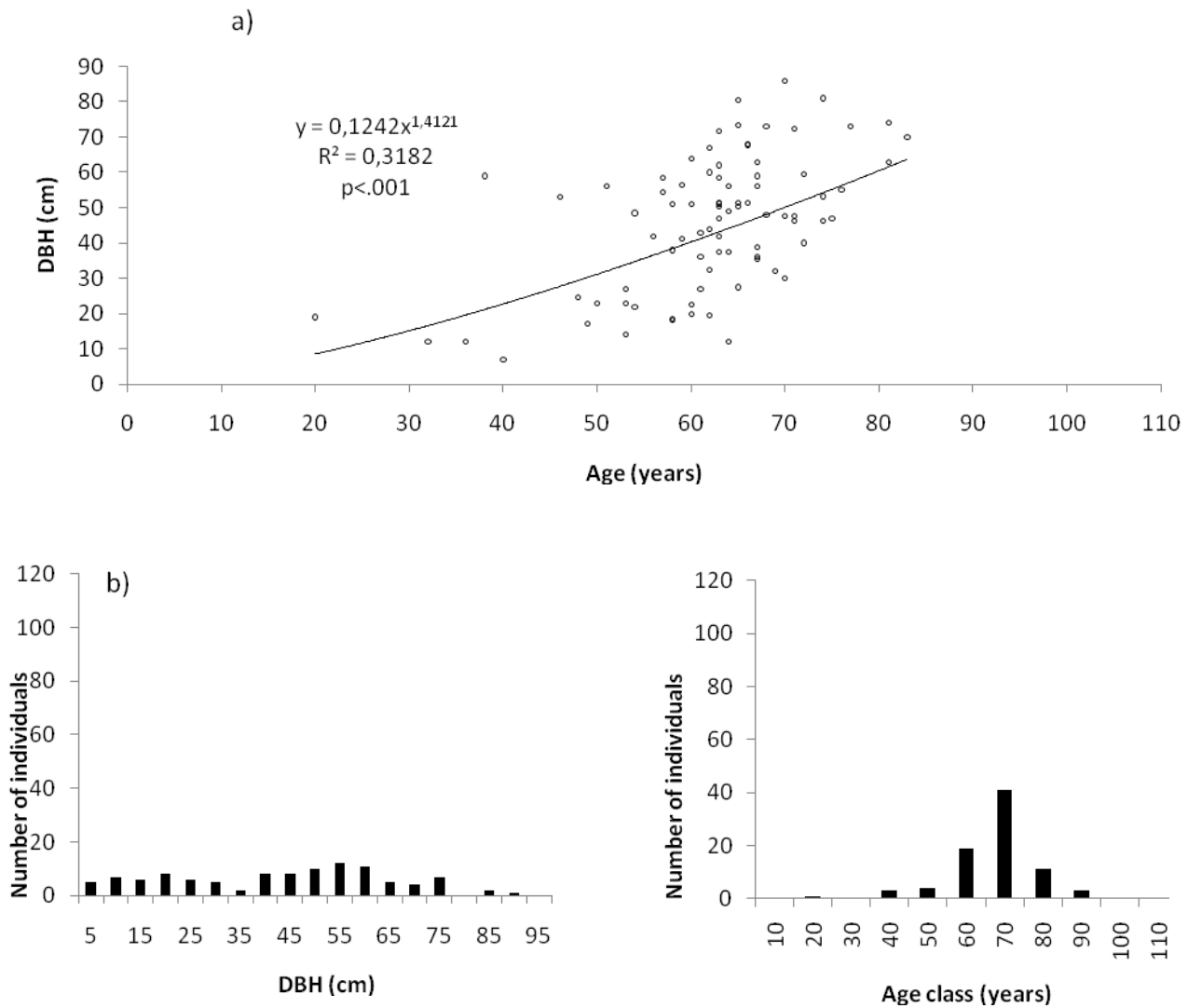

$$y = 0,1607x^{1,3007}$$
$$R^2 = 0,1505$$
$$p<.001$$
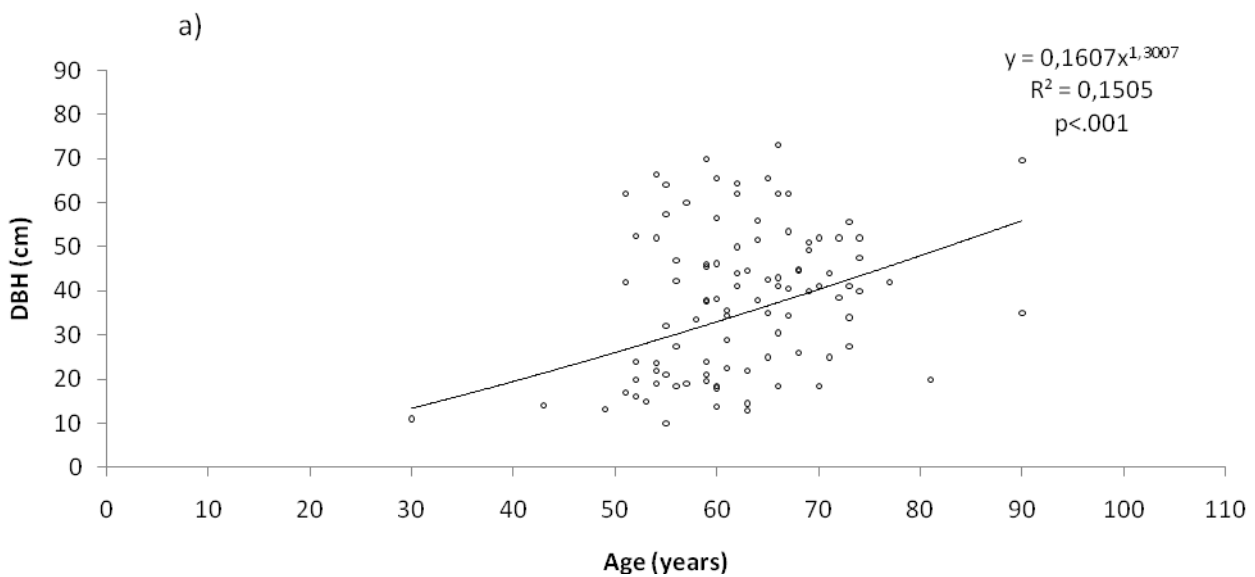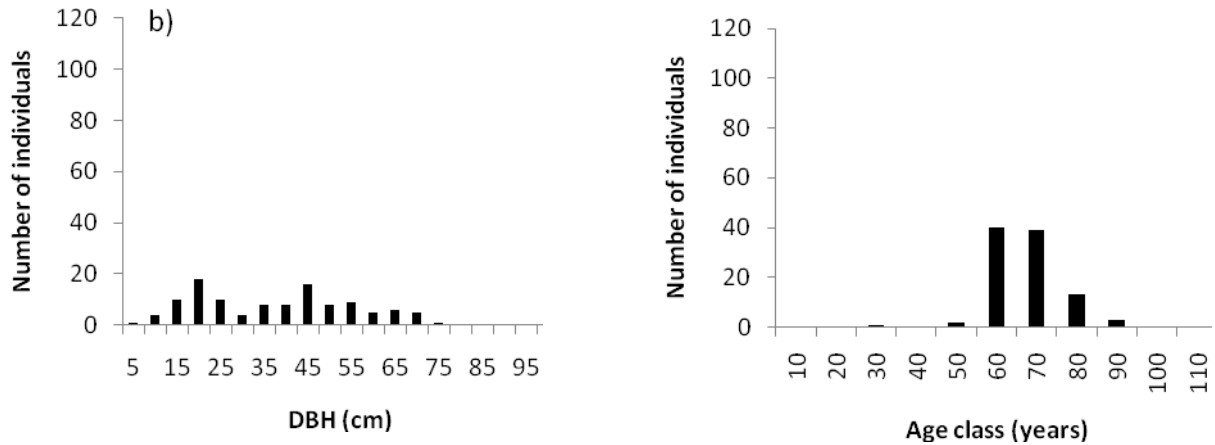
Fig. 6: a)Scatter plots with best fit regression of Abies alba DBH versus age within the 1 ha plot. b)Comparison between DBH and age distribution.

In figure 7 are plotted the relationships between age and DBH distribution for beech. Although still very low, the correlation coefficient for such species shows its highest value compared to the one of the others.

Looking at the DBH distribution is possible to see how the pattern is rather similar to the one shown at 4 ha scale. Age classes instead are mostly represented between 60 and 90 years old class. The amount of individuals per class increases very regularly until the 60 years class, where it reaches a peak. Afterwards,the trees per each class start to decrease slowly until an abrupt drop at the 100 years class.

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b)
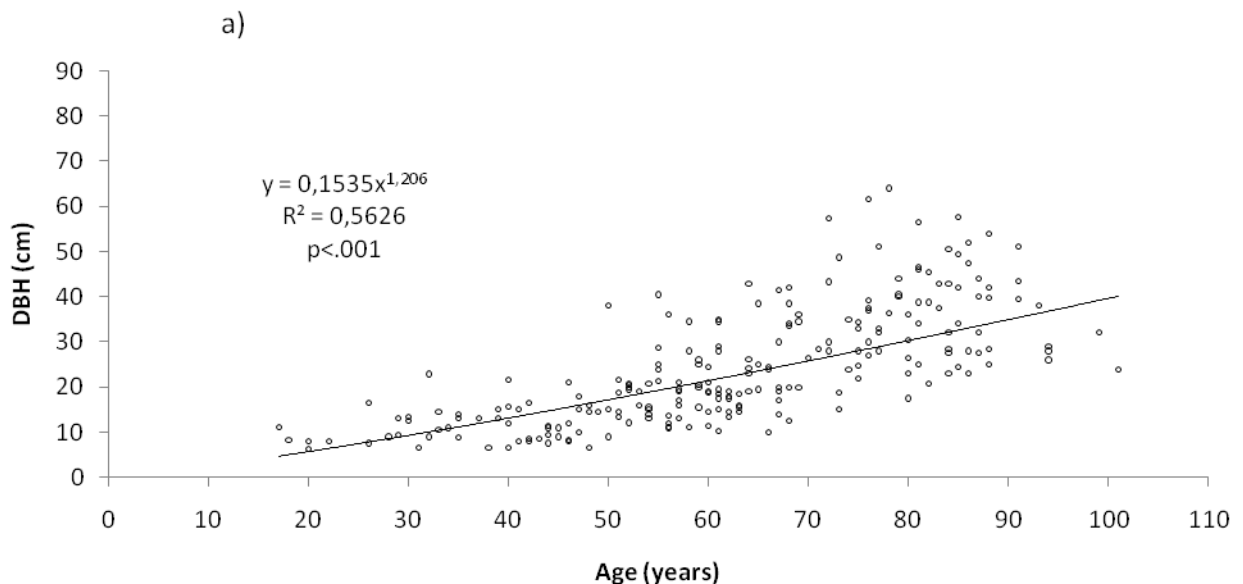
Fig. 7: a)Scatter plots with best fit regression of Fagus sylvatica DBH versus age within the 1 ha plot. b)Comparison between DBH and age distribution.

Finally, in figure 8 we can see what concerns spruce, which is a kind of intermediate between the other main species considering the age/DBH correlation. If we look at the DBH distribution, there's a quite uniform representation among almost all the DBH classes even if there's a slight smaller number of individuals in classes between 5 and 35 cm DBH respect to the classes between 40 and 60 cm.

Unlike the others, spruce has a certain number of individuals, although very small, even among the highest diameter classes (75-90 cm).

Age distribution is similar to the fir's one but the classes equal or below 50 years old are better represented than fir's ones.

a)

$$y = 0{,}1242x^{1,4121}$$
$$R^2 = 0{,}3182$$
$$p<.001$$

b)

Fig. 8: a)Scatter plots with best fit regression of Picea abies DBH versus age within the 1 ha plot. b)Comparison between DBH and age distribution.

In figure 9 we highlight the relationships between height/dbh and height/age for each species.

All curves show the best fit with a power function, apart from beech which is best represented by linear regression. In all the species, the correlation is higher for height against DBH than correlation for height versus age. Fir in particular shows the lowest correlation for the latter whereas beech the highest one. Spruce shows values of height rather concentrated around 32 meters towards the intermediate-high age classes.
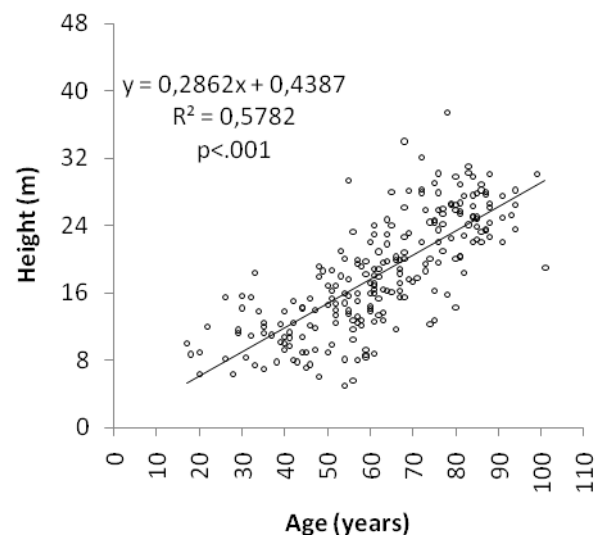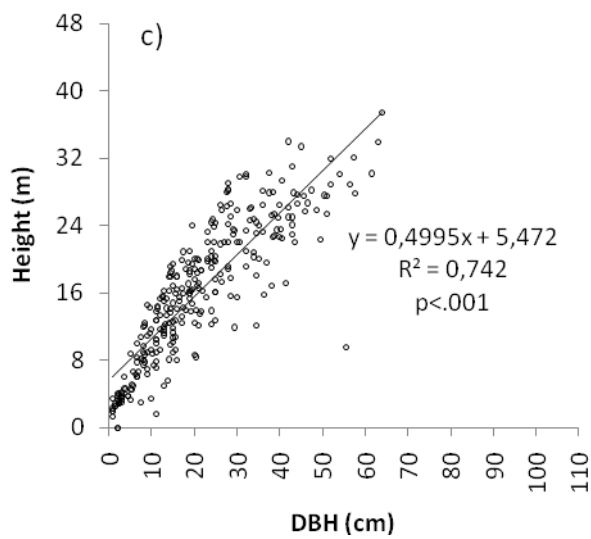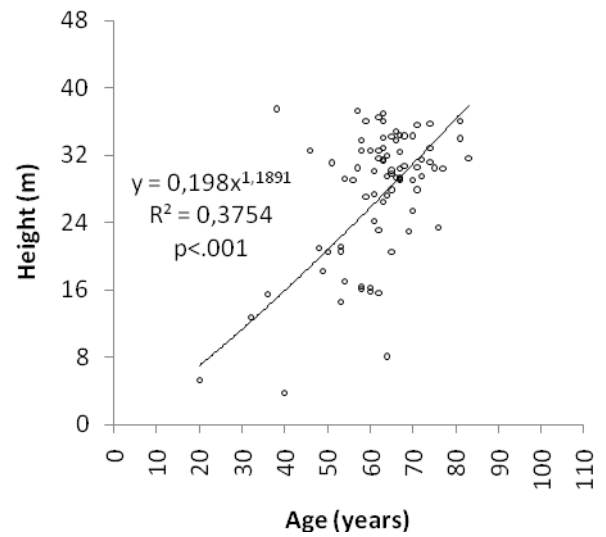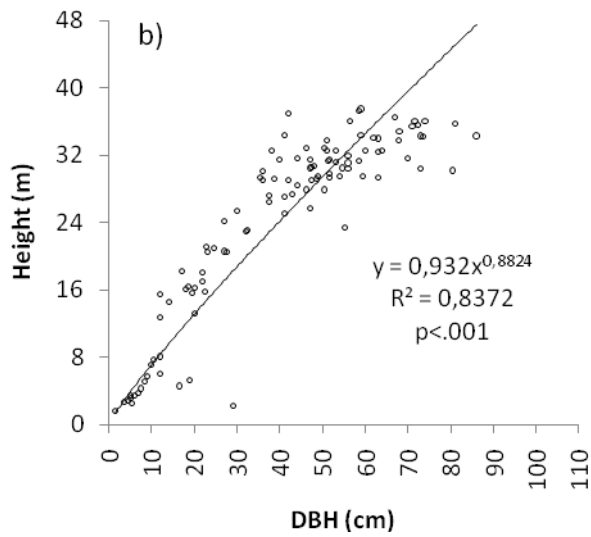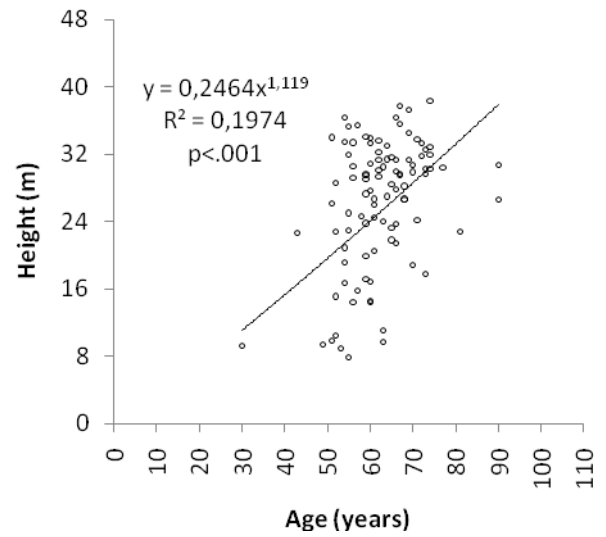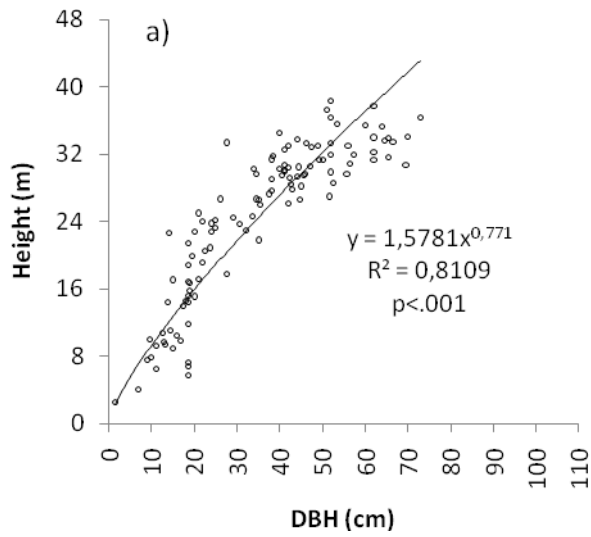
Fig.9: Comparison between height related to DBH and AGE with best fit regression for the three main species within the 1 ha plot: row a)Abies alba, row b)Picea abies, row c)Fagus sylvatica.

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## 3.2 SPATIAL DISTRIBUTIONS-UNIVARIATE ANALYSES

We evaluated how the spatial patterns of trees varies according to their DBH size and age class: in particular, we wanted to highlight how the strength and the range of clustering evolve through the three different DBH size and age classes we have previously selected.

In figure 10 have been plotted all the results related to all trees and each DBH category:

The entire trees population (A) shows a strong aggregated distribution for each spatial scale (from 1 m to 50 m) especially considering the 4 ha scale (left side).This is highlighted by the values of G(r) well above the confidence limit in each distance class. Not exactly the same can be said at 1 ha scale (right side). In this case the aggregation is indeed less strong, although still significant. Moreover, it's not held for all the distance classes: the pattern start to be randomly distributed from approximately 35 meters forward.

By dividing the whole population in the three categories (small, intermediate sized and big), it was possible to evaluate the importance of self-thinning processes (Getzin et al., 2006). In general, the graphs show how, in both cases, the strength of aggregation is decreasing as DBH size class increases .Small individuals present the highest degree of aggregation for each distance at 4 ha scale (left side of B). Differently, at 1 ha level (right side of B), aggregation is even stronger at close distances but it already doesn't present significant aggregation from approximately 15 meters forward. Between approximately 25 and 30 meters, significant aggregation appears but, apart from this lag, it's not shown anymore forward. Shifting back at 4 ha scale, the aggregation reduces in the intermediate-sized class (left side of C), even if it remains always above the confidence limits. The same can be said at 1 ha scale (right side of C) apart that significant aggregation is not held for all distance lags but, instead, it disappears from approximately 30 meters forward. Finally, in the big DBH category, the trees are regularly distributed up to approximately 4 m both at 4 ha scale and at 1 ha scale (row D).Then, considering the whole 4 ha plot (left side of D), are randomly distributed from 4 until 6 m, aggregated between 6 and 13 m and again random from 14 until 22 m. Above this distance they tend to be slightly aggregated. At 1 ha scale (right side of D) we find a slightly different situation where, from about 4 m forward, the distribution is random.
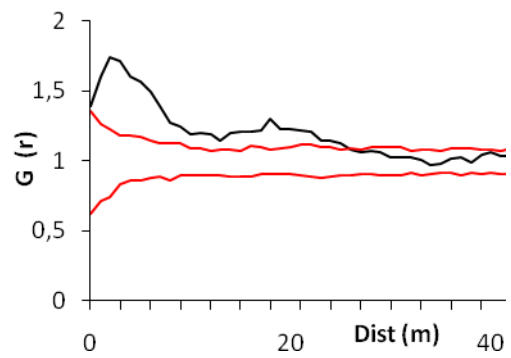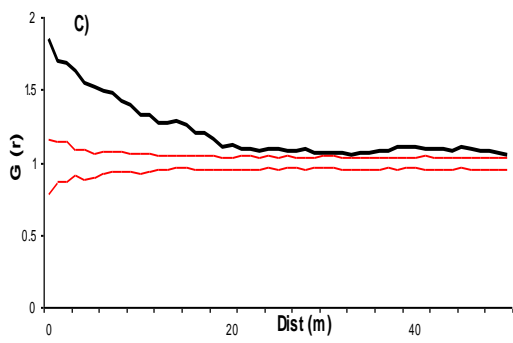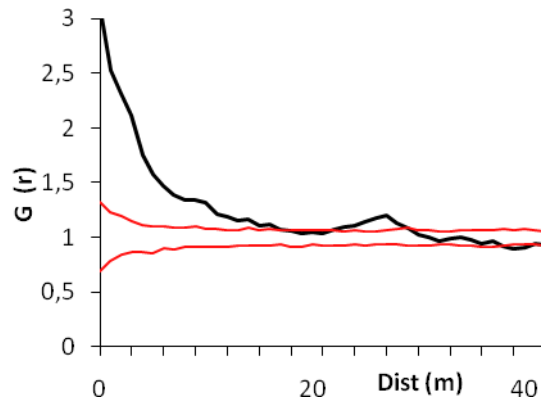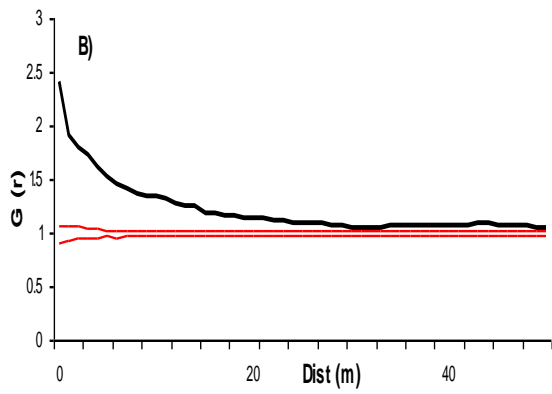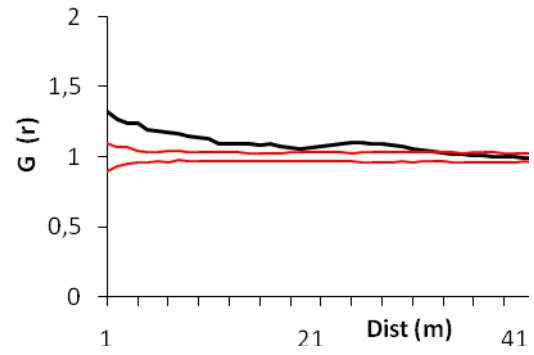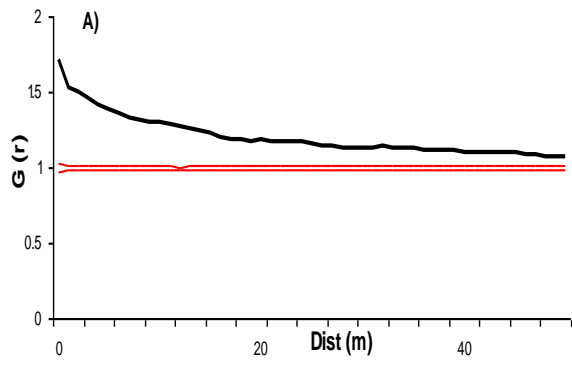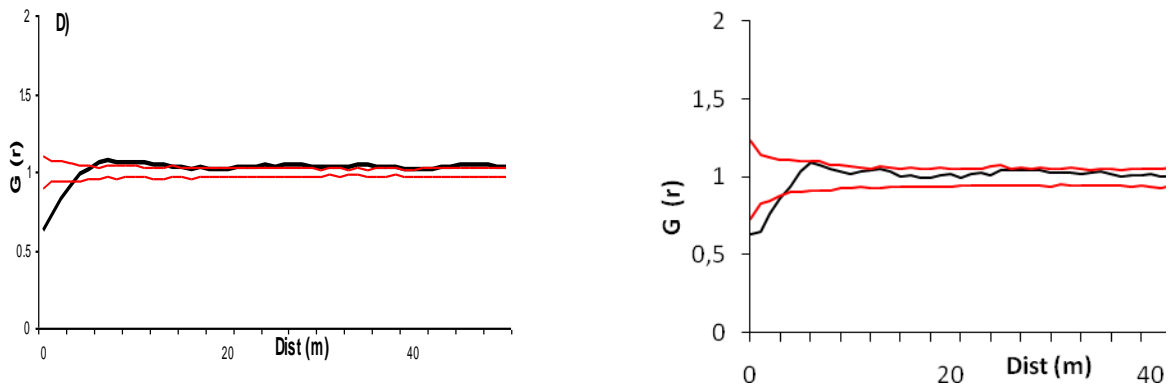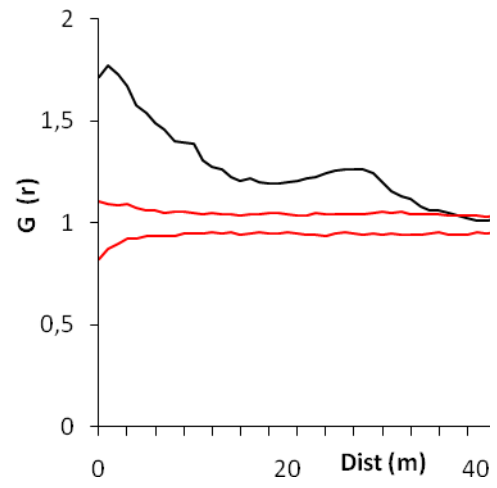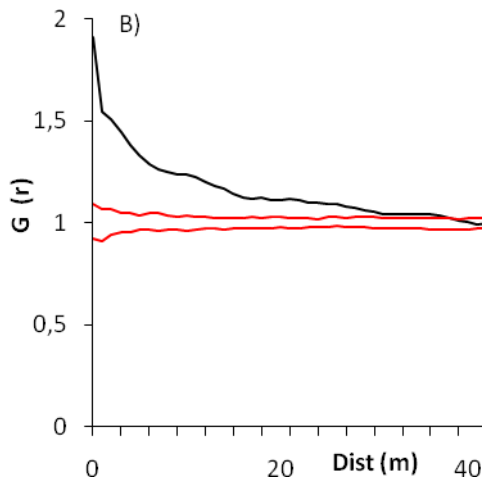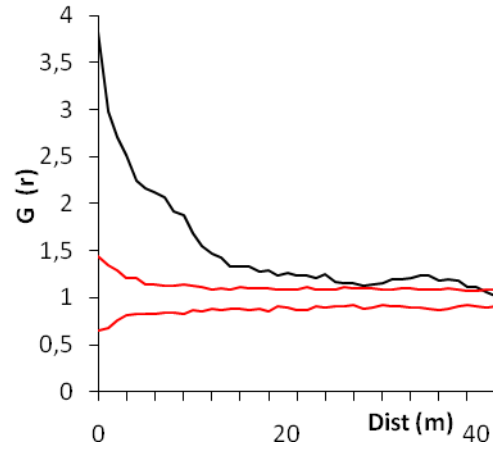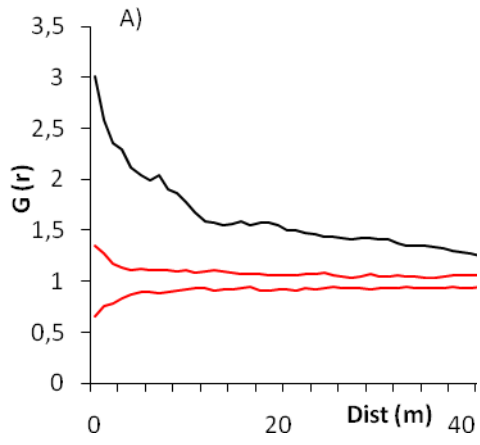
Fig.10: Comparison between the 4 ha stand (left) and the 1 ha plot (right): Univariate O-ring statistics for A)All trees, B)All small trees, C)All medium sized trees, D)All big trees.In black G (r), in red confidence limits. Values above the red line:clustered distribution; below: homogeneous distribution

Successively we analysed the spatial pattern for all individuals of each single species comparing each plot related to the whole 4 ha plot with the one related to the ha chosen within it

Figure 11 highlights a strong aggregation for all the species at 4 ha scale (left side).In particular, fir and spruce are strongly and significantly aggregated at all distances while beech is clustered up to 39 m and randomly distributed above this distance.

If we look at 1 ha scale (right side),there's the same pattern in both fir and beech but,differently,the distribution start to be random around 40 meters and reach significant repulsion around 50 meters.Spruce,instead,shows a very different pattern at 1 ha scale.Indeed,if in the whole plot is the species which shows the strongest aggregation,in this case there's significant aggregation (not even so strong) from about 4 meters up to 20 meters.Moreover,along this lag,the curve falls several times within the confidence limit and,from 20 meters forward, ther's just a little lag around 30 m above the confidence envelope.
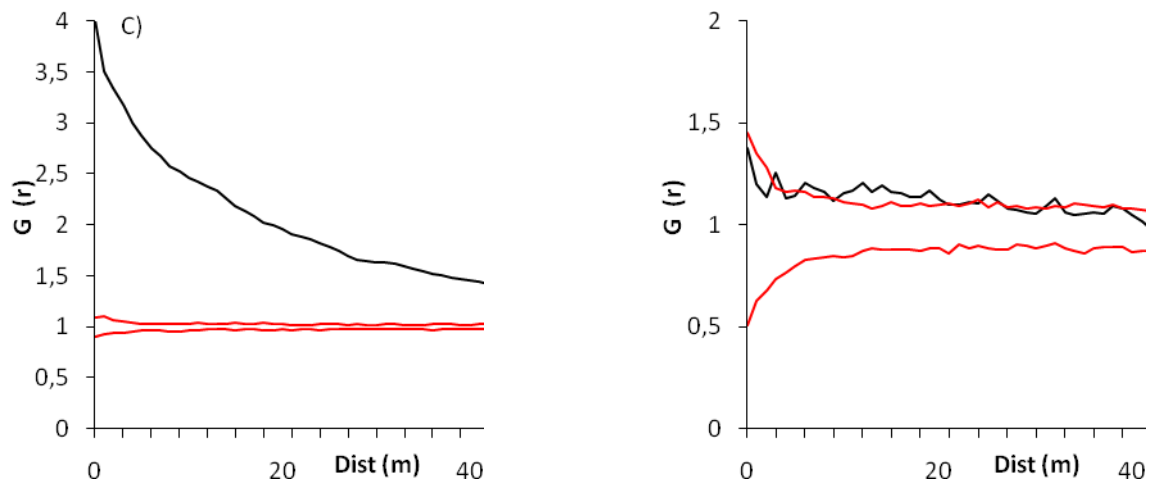
Fig. 11: Comparison between the 4 ha stand (left) and the 1 ha plot (right): Univariate O-ring statistics for a) Abies alba, b) Fagus sylvatica, c) Picea abies. In black G (r),in red confidence limits. Values above the red line:clustered distribution; below: homogeneous distribution

To conclude the univariate analysis,the statistic has been carried out for each age category at 1 ha level as plotted in the figure 12. Young trees (A) show a random distribution along all distances except for 3 peaks: the first around 10 m (aggregation), the second around 38 m (repulsion) and the third qapproximately within 50 m (aggregation again).

Adult and mature trees (B and C respectively) have a similar pattern; in the sense that both show significant aggregation until about 40 and 38 m respectively. The main difference among them is that in mature trees the aggregation path is stronger than in adult.
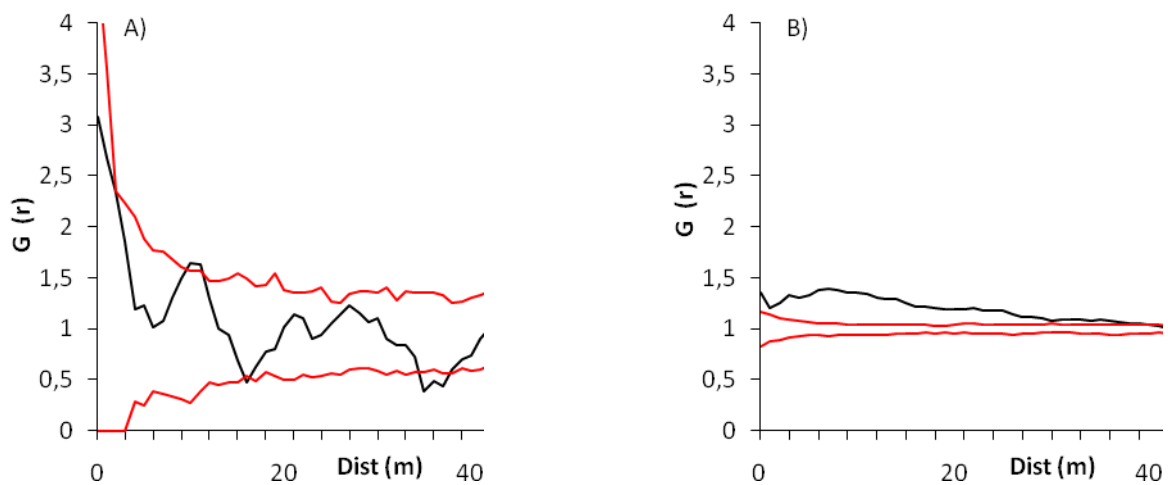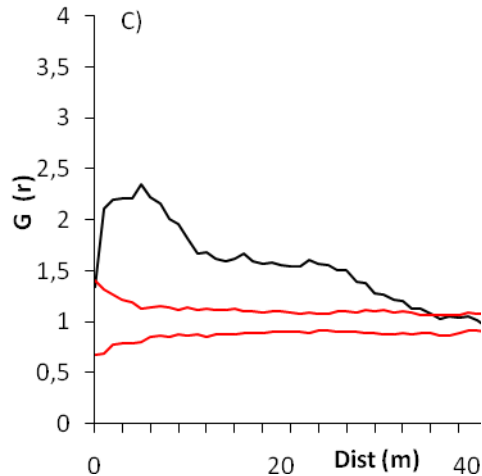
Fig.12: Univariate O-ring statistics within the 1ha plot for: a)young trees, b)adult trees, c)mature trees. In black G (r), in red confidence limits. Values above the red line:clustered distribution; below: homogeneous distribution

3.3 SPECIES TO SPECIES RELATIONSHIPS:BIVARIATE O-RING STATISTICS

The bivariate o-ring statistics allows inferring the relationships between two species. By fixing the location of the specie 1 (big or mature trees only) and randomizing the location of species 2 (small or young individuals only) we checked if the observed spatial distribution of specie 2 is occurring on average more (or less) frequently within the neighbourhoods of specie 1 than expected by chance alone (Wang et al.).

We will start evaluating the relationship between small fir with big fir, big beech and big spruce. The results will be compared at the 2 scales as carried out for the previous analysis.

As it is possible to appreciate by the graphs in Fig. 13; in the whole plot (row 1,left side), at short distances (from 0 to 3 m) small fir shows strong aggregation with big individuals of the same species while at larger distances this behaviour is not clear (there are, however, 3 peaks of attraction around 10, 18 at 26 m).At smaller scale (row 1 right side) there is basically the same pattern apart that the aggregation occurs up to definitely shorter distance and,afterwards,the curve is always within the confidence envelope. Small fir instead shows, at 4 ha scale, a strong and constant aggregation towards big beech for all the distances (row 2,left side), whereas at the single hectare level (row 2, right side) the curve is within the confidence envelope for its entire length with only one small significant peak in the aggregation side around 10 meters. Completely opposite behaviour instead has been recorded for small fir against big spruce, at least regarding the 4 ha plot, since the curve is for all its length in the repulsion side (row 3,left side). Differently, at 1 ha scale (row 3,right side), the pattern very similar to the one shown for the small fir versus big beech.

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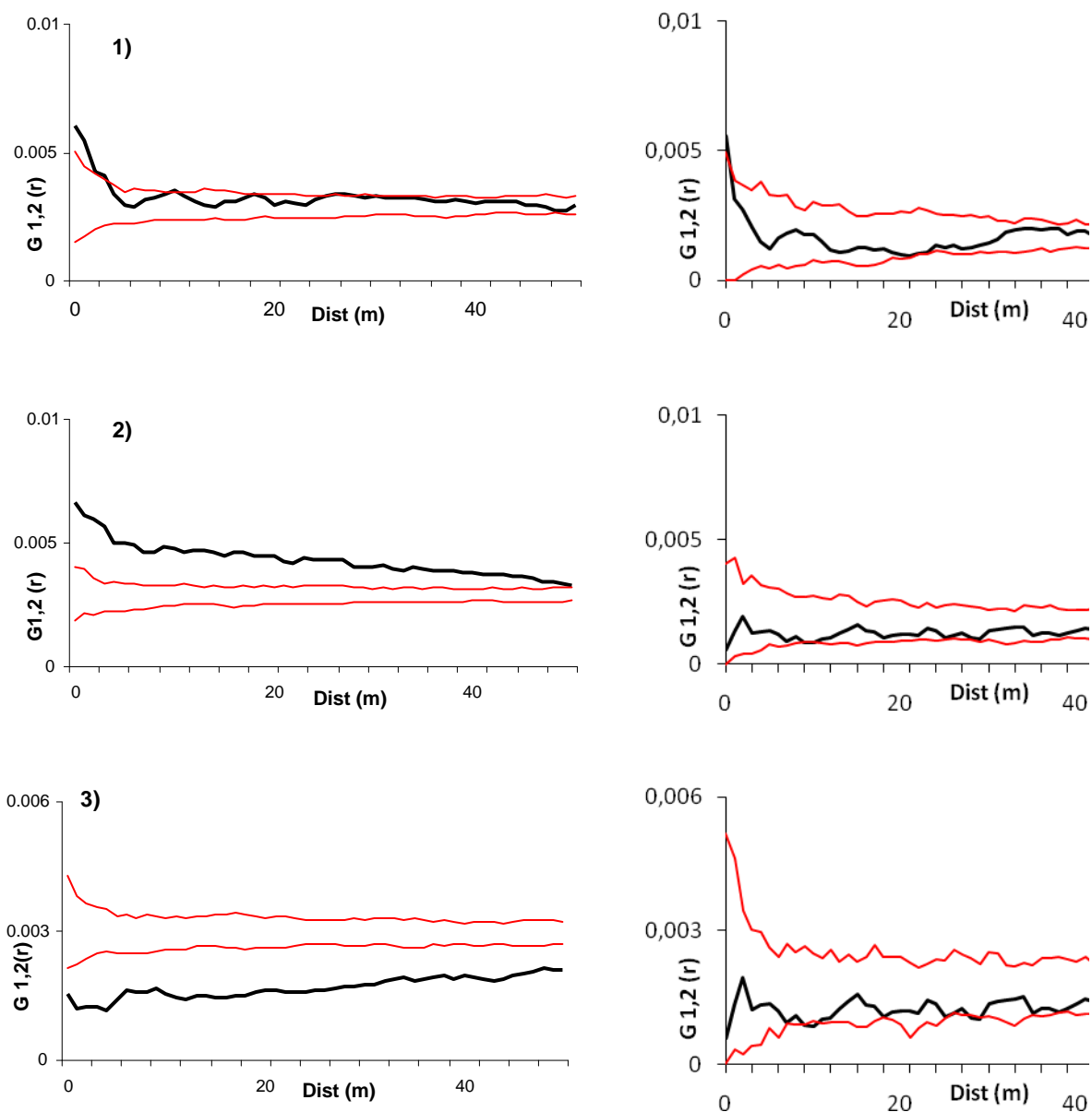
Fig. 13: Comparison between the 4 ha stand (left) and the 1 ha plot (right): Bivariate O-ring statistics for small Abies alba vs: 1)Big Abies alba, 2)Big Fagus sylvatica, 3)Big Picea abies. In black G 1,2 (r),in red confidence limits. Values above red line: aggregation; below: segregation.

Next analyses will be focused on small beeches (Fig. 14): Beech small trees show positive aggregation at short distances (approximately from 0 to 3 m) with big fir at 4 ha scale (row 1,left side), nor attraction or repulsion between 4 and 25 m and repulsion above this distance. At 1 ha scale (row 1,right side), beech small trees are indifferent respect to big firs'locations up to 40 meters, where a slight, although significant, repulsion up to 45 meters is detected. Afterwards, the curve reveals back indifference towards big fir. The main difference respect to the bigger scale is that the pattern has never shown attraction.

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Towards its own conspecific big instead, strong repulsion has been found at all distances, if the higher scale is considered (row 2,left side). Differently, at smaller scale, small beech trees are indifferent towards their big conspecific until approximately 23 meters (row 2,right side), where a small lag of attraction begin but it ends before 40 meters distance. After this point, the pattern highlights indifference. In this case, the main difference respect to the whole plot is that in the hectare has not been detected any significant repulsion. Strong aggregation between small beech and big spruce has been instead recorded at 4 ha scale (row 3, left side); basically it's an opposite pattern respect to the one shown for small beech towards its conspecifics. Differently, considering the smaller scale (row 3,right side), the pattern reveals indifference for all the distance, apart for a small significant attraction peak at about 50 meters.
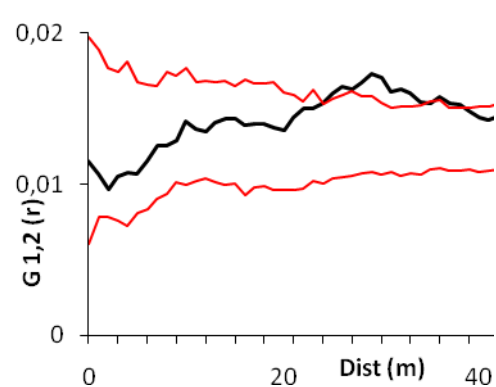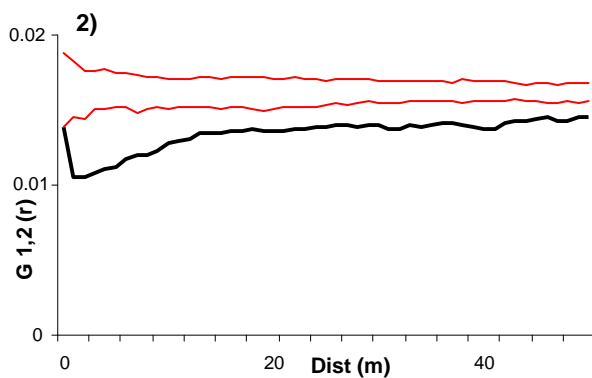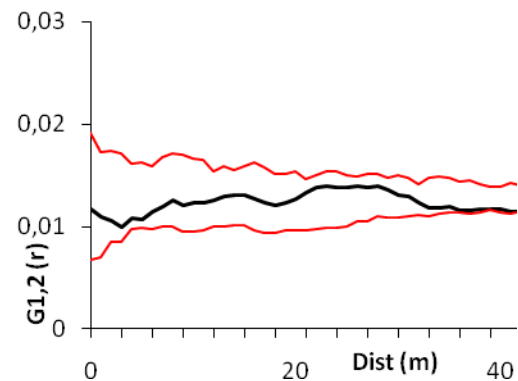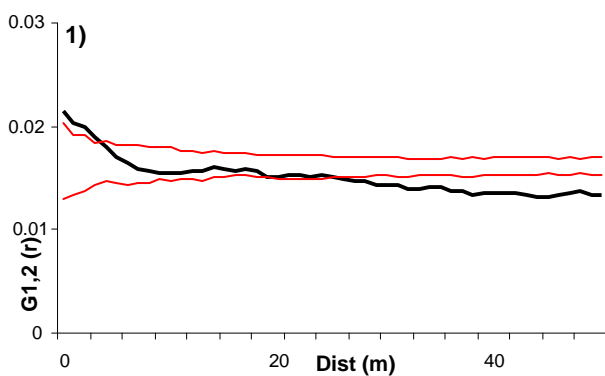
Fig.14: Comparison between the 4 ha stand (left) and the 1 ha plot (right): Bivariate O-ring statistics for small Fagus sylvatica vs: 1)Big Abies alba, 2)Big Fagus sylvatica, 3)Big Picea abies. In black G 1,2 (r), in red confidence limits. Values above red line: aggregation; below: segregation.

Final analyses regard spruce small trees (Fig. 15):

Small spruce shows strong repulsion at all distances towards fir big individuals at 4 ha scale (row 1, left side) whereas, if we look just at the single hectare, it's indifferent for all the distance classes (row 1, right side). Indifference is shown also towards big beech if we consider the whole plot (row 2, left side). At 1 ha scale (row 2, right side), the pattern is similar but, approximately between 10 and 18 meters, there's a small significant lag revealing attraction. Another little lag is found just few after 20 meters up to 25.

Towards its big conspecific, instead, spruce shows strong attraction at all distances in the whole plot (row 3, left side). Differently, looking just at the single hectare, small spruce seems to be indifferent towards its conspecific's location (row 3, right side).
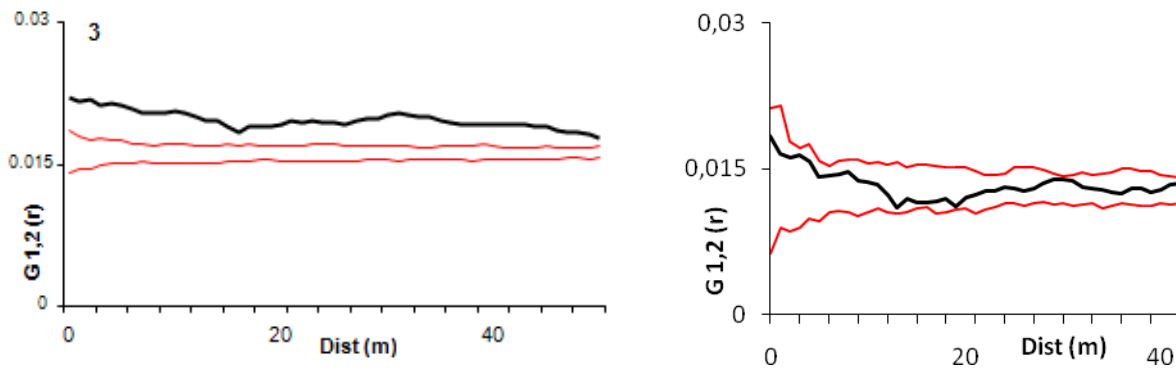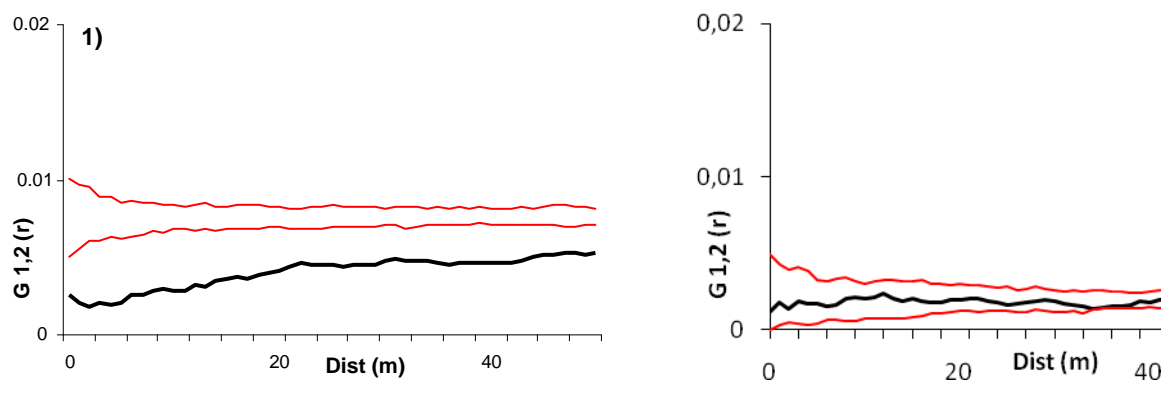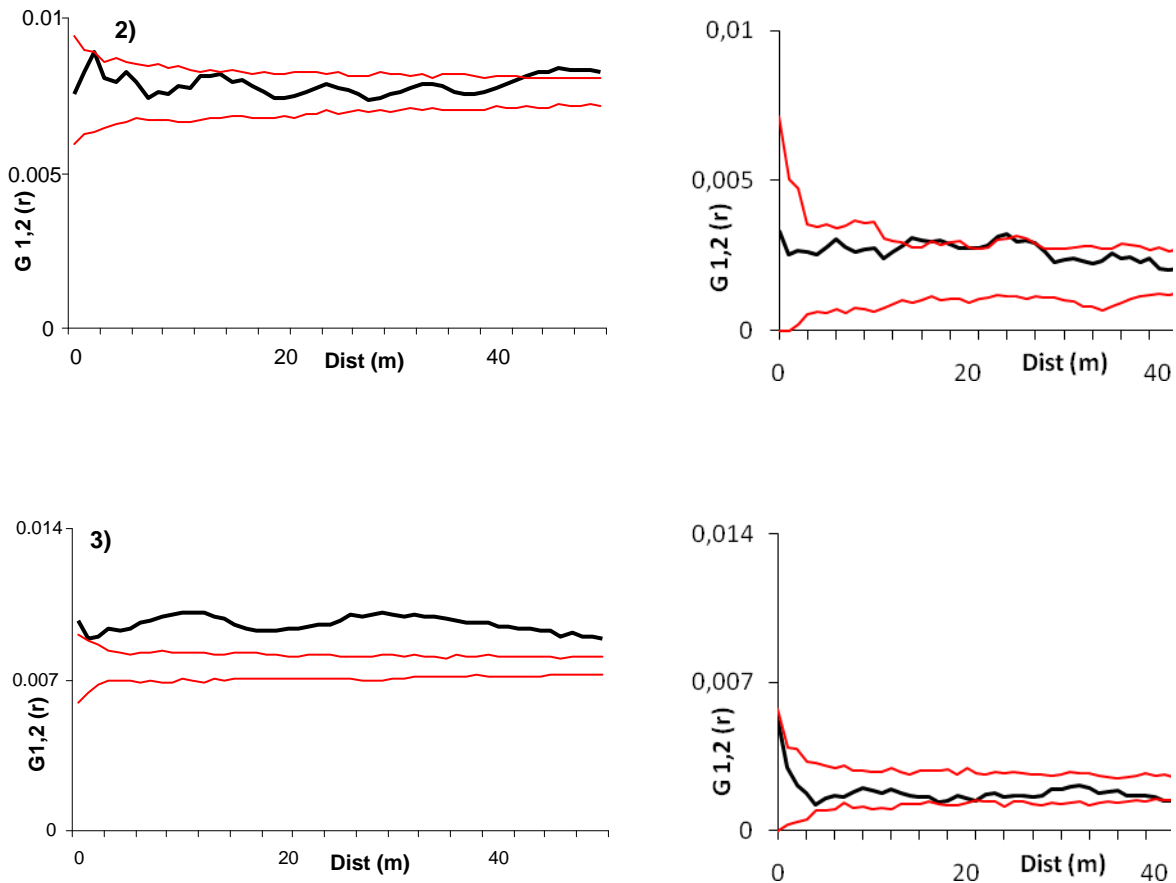
Fig. 15: Comparison between the 4 ha stand (left) and the 1 ha plot (right): Bivariate O-ring statistics for small Picea abies vs: 1)Big Abies alba, 2)Big Fagus sylvatica, 3)Big Picea abies. In black G 1,2 (r),in red confidence limits. Values above red line:aggregation; below:segregation.

In Figure 16 will be described the relationships between young beech and mature individuals considering each species. Of course, the statistic regard only one hectare of the whole plot as done for the previous analyses related to age.Statistics are not available both for young spruce and for fir versus the others,basically due to the absence of young individuals.

Young beech seems indifferent towards the presence of mature fir (1). Only 2 peaks of significant attraction are detected (around 10 m and just before 40 m), whereas repulsion occurs just in a lag between 45 and 50 m. Towards its conspecifics (2), young beech seems to be again indifferent apart from a lag of significant attraction occurring between few after 20 m and before 30 m. Basicallly the same can be said towards spuce (3).
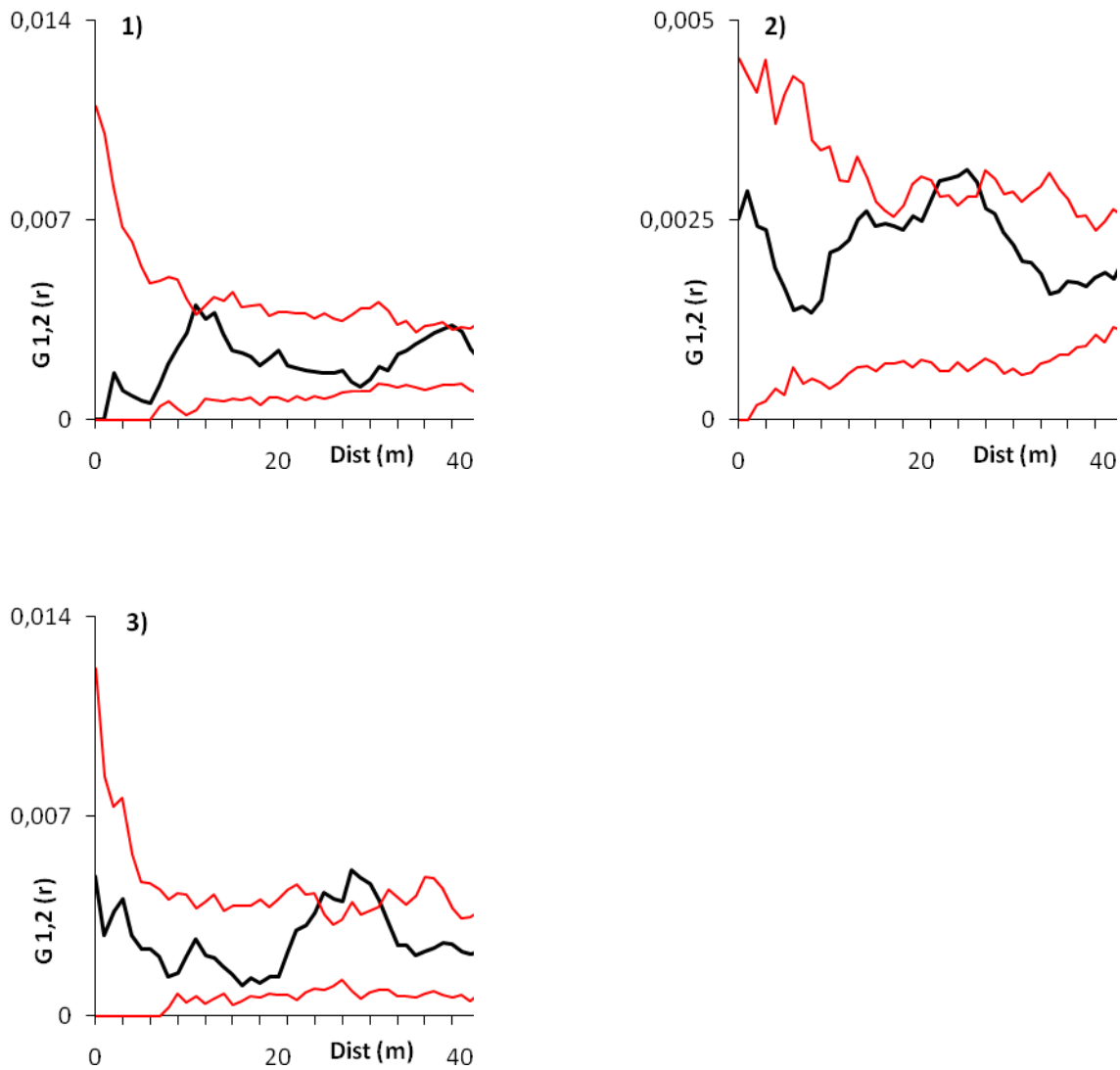
Fig. 16: Bivariate O-ring statistics within the 1 ha plot for young Fagus sylvatica vs: 1)mature Abies alba, 2)mature Fagus sylvatica, 3)mature Picea abies. In black G 1,2 (r),in red confidence limits. Values above red line:aggregation;below:segregation. Statistics are not available both for young Picea abies and for Abies alba versus the others,basically due to the absence of young individuals.

3.4 SPATIAL AUTOCORRELATION

After the evaluation of the trees distribution previously performed, we will establish if patches of trees with similar/dissimilar DBH or age (available only for one ha) are present by using the global autocorrelation index Moran's I. First, an overall picture of the whole trees population, aiming at highlighting patches of forest with homogeneous/inhomogeneous DBH size or age classes, will be analysed. Subsequently, we will evaluate the spatial structure of each species separately.

To better evaluate the patches size and location in the forest we will add a map with the value of the local spatial autocorrelation index local G*. Thanks to the geographical representation of the information

obtained indeed, this index can be a valuable tool to assess the area interested by the groups of trees revealed by the global spatial autocorrelation.

The value of the global autocorrelation for all trees compared between the 2 scale levels is plotted in figure 17. The entire plot population (Fig 17 a) shows a clear gradient: starting from positive values at short distances the Moran's I decrease to negative values and finally switch its trend towards positive value at long distances . In particular the mean size of the groups of trees can be identified. A mean patch size of approximately 70 m (from 10 to 80 meters) is detected whereas from 90 to 180 m distance is detected the mean distance between groups with different DBH which is approximately 90 m. It means that,moving from whatever point within the area, there is a high probability of finding trees with similar DBH within a lag between 10 and 80 meters distance from the mentioned point; if instead we are in a lag between 90 and 180 m distance ther's a high probability of finding trees with dissimilar DBH value.

The same trend is found at 1 ha scale but the mean patch size is smaller (Fig.17 b): 20 m big (from 10 m to 30 m) and the distance between the diverse groups is less than 10 m big (approximately between 90 m and 100 m).
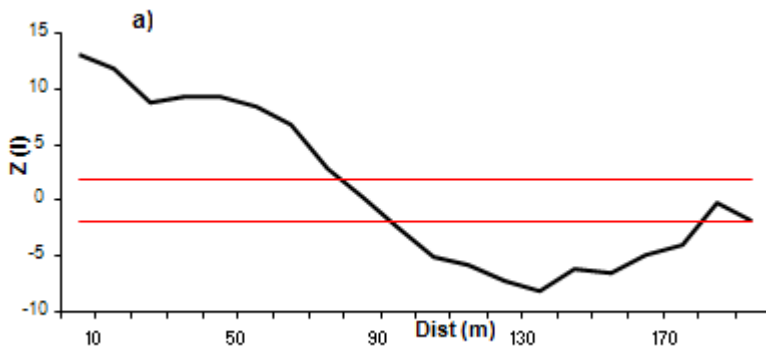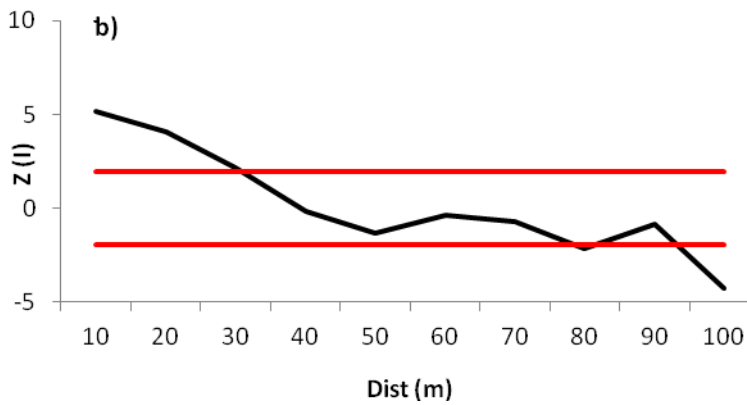
Fig.17: Comparison between the Moran's I for the DBH of all plants at the whole 4 ha plot level (a) and at 1 ha plot level (b).In red confidence limits. Lag distance:10 m

The local G* statistics reveal some precious information about the spatial distribution of those groups (Fig 18). In particular, for the whole 4 ha plot (a), two main groups of trees are easily recognisable.On the upper left square there is a cluster of big trees, which by the way correspond to the single ha seen at 4 ha scale; whereas more on the right are located the small trees forming the biggest group.They fits indeed with the interpretation of the Moran's I correlogam. Other smaller clusters of small trees are then recognisable close to the lower part of the map.

The complexity of the forest of course, makes the two groups partially overlapped as can be seen in the lower portion of the map, but the division revealed with Moran's I is remarkable.

As highlighted by the yellow dotted line in the map above, if we look at the smaller scale in the figure 18(b), it's clear that a lot of trees don't contribute in the formation of the same cluster seen for the whole plot. In accordance to its own Moran's I distribution, within the smaller area the groups are recognised as smaller.As shown in the graph, they are located at the lowest part of the plot.
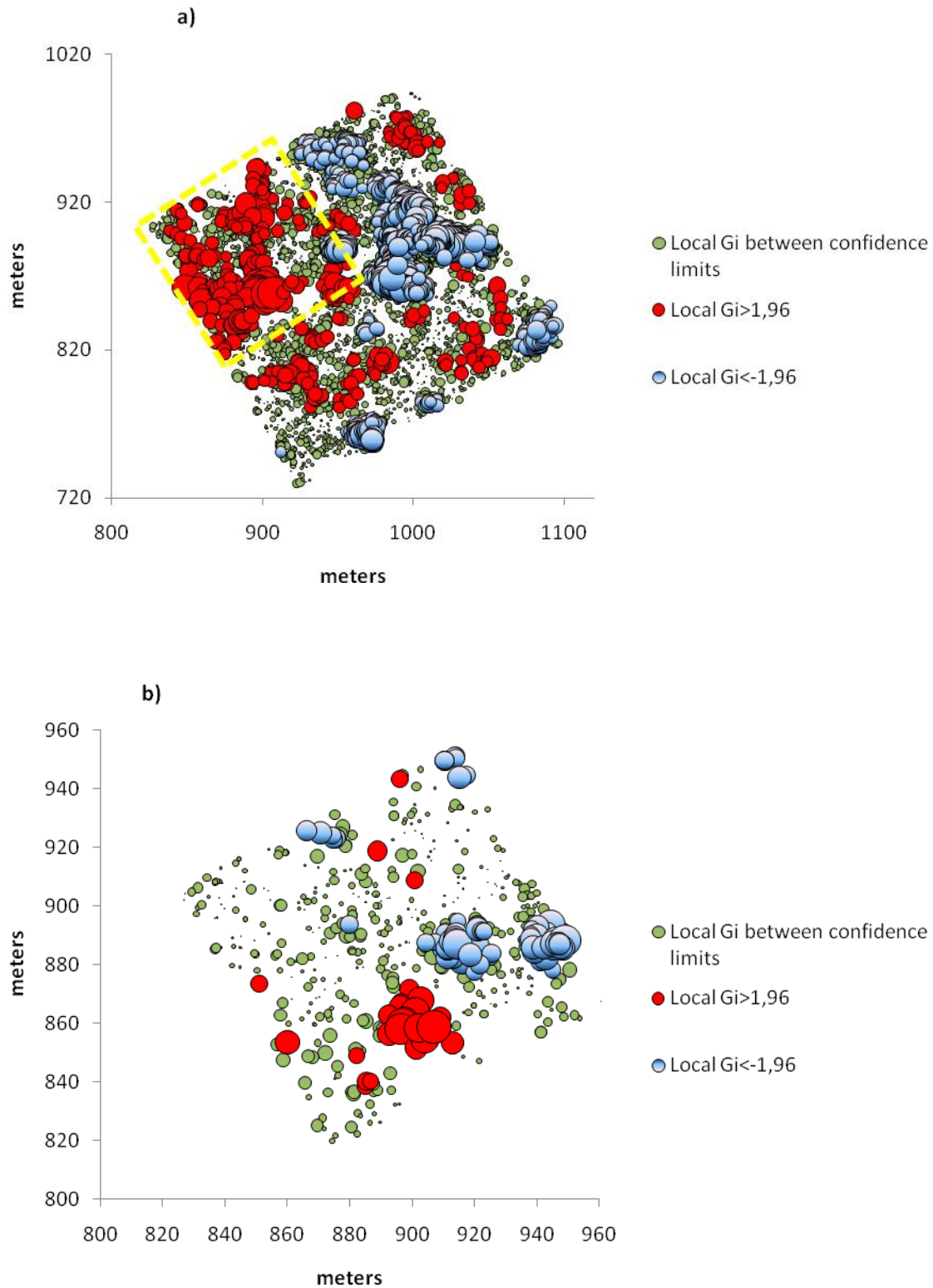
Fig.18: Comparison between the local Gi* for the DBH of all plants at the whole 4 ha plot level (a) and at 1 ha plot level (b). Blue colours are the significant values for small individuals; red colours are the significant values for big individuals. Dotted yellow line is the 1 ha plot location within the stand. Lag distance: 10 m.

For the single hectare, the autocorrelation for the age of all trees has been carried out as well.

Moran's I puts in evidence the mean size of the groups and the distance occurring between them (Fig. 19 a). Thanks to local Gi*we can appreciate that they are made of different similar age (Fig. 19 b). The mean size is approximately 40 meters big (from 10 meters up to 50). The distance between the groups is approximately 40 meters big as well (from 60 up to 100 meters).

According to local Gi* map (Fig.19 b), we can identify the locations of the clusters within the plot.The first is made by young plants and it's located in the middle of the plot, whereas the other one is made by old individuals and is located along the right side of the plot.
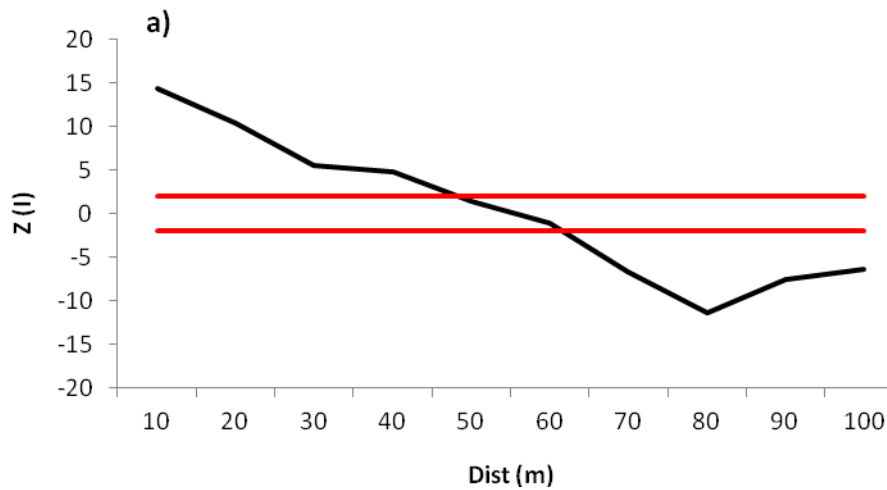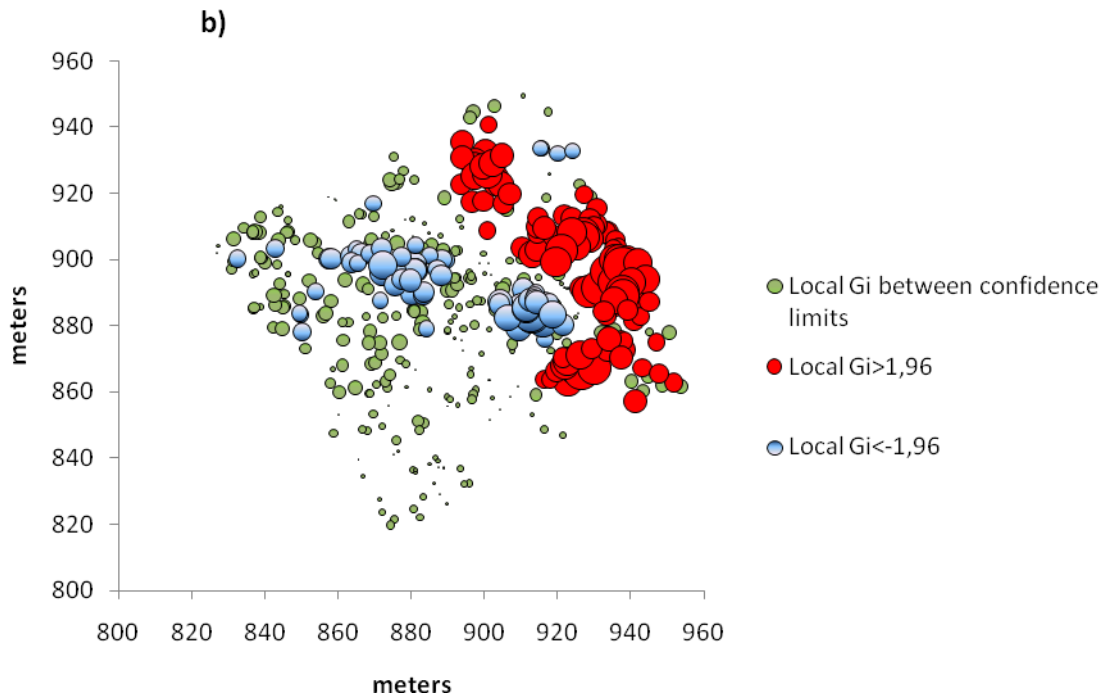
Fig.19: a)Moran's I:Global autocorrelation for the Age of all plants within the 1 ha plot. In red confidence limits. b)Local Gi*:Local autocorrelation for all plants: blue colours are the significant values among young individuals; red colours are the significant values among mature individuals. Lag distance:10 m.

To understand in more details how each specie contribute to the patterns, an analyses for fir, beech and spruce individuals will be performed. Of course, the same scale comparisons than above will be carried out as well.

Starting with fir, at 4 ha level the value of the global autocorrelation shows a similar trend compared to the global autocorrelation for the entire trees population. The value of Z(I) are positive from 10 m to 60 m (for a patch size of approximately 50 m) and are negative from 80 until 150 m (Fig. 20 a). The values above this distance are non significant apart a single and small positive peak at 180 m.

At the single hectare level (Fig.20 b), the pattern is different: it is indeed significntly positive from approximately 10 m up to 30 m. Afterwards is never significant, apart 2 significantly negative peaks at 50 and 70 m.

Fig.20: Comparison between the Moran's I for the DBH of Abies alba at the whole 4 ha plot level (a) and at 1 ha plot level (b). In red confidence limits. Lag distance: 10 m

In the figure 21, we can appreciate the contribution of each tree in clusters'formation thanks to the local Gi* index. The 2 big groups, with different diameter, detected by the Moran's index at the 4 ha scale can be easily recognized (a). The first is made by big diameters and it's located more towards the upper left corner of the plot, whereas the other is very close to the lower left corner of the area. Additionally, is possible to see a smaller cluster of big diameters close to the lower right corner of the area and, probably, it's the smallest patch detected by the Moran's index. Another reason to consider this latter as such is due to the positive values of the Z (I) shared

with the first group mentioned above. It means that the two groups are similar in the size of the diameters involved but different respect to the cluster in the middle (i.e. the group of the small trees in this case). This

interpretation is in accordance also with the double gradient shown by the pattern of the global index.

Lookin at the local Gi* related only to the hectare singularly considered (b) ,is very likely that the big group detected by the global index is the one located close to the lower right border made by small-sized diameters. Instead, the two peaks of different DBH respect to the previously mentioned cluster (but similars each other) are the remaining trees forming that small group of big-sixed DBH. It's clear that also in this case,both indexes are affected by the number of trees within the plot.

Fig.21: Comparison between the local Gi* for the DBH of Abies alba at the whole 4 ha plot level (a) and at 1 ha plot level (b). Blue colours are the significant values for small individuals;red colours are the significant values for big individuals. Dotted yellow line is the 1 ha plot location within the stand. Lag distance: 10 m.

Then, for the single hectare, the autorrelation analyses for the fir's age have been performed.

However, no one patch has been detected by the global Moran's index. Therefore, also the local Gi*plot doesn't reflect any cluster.
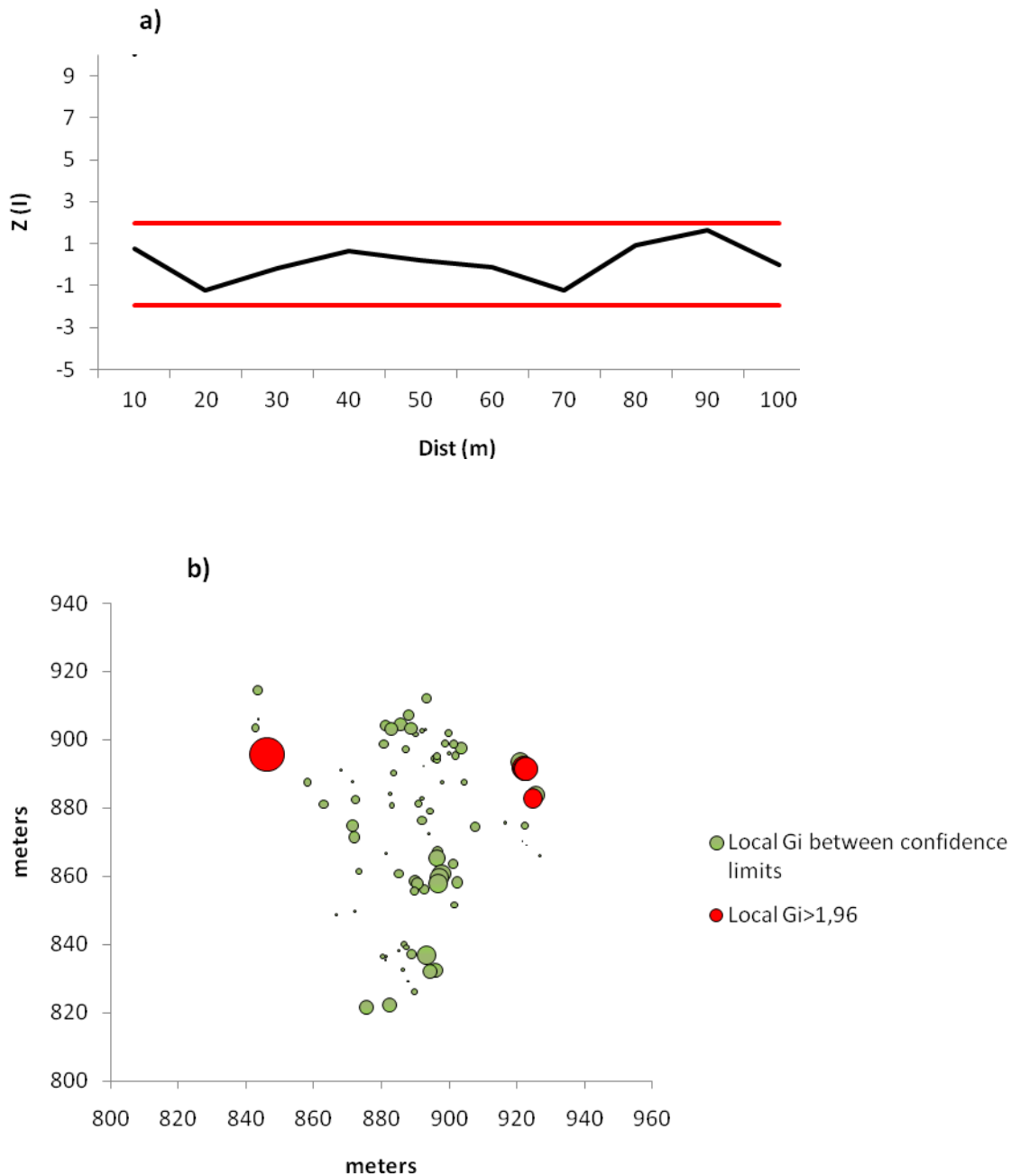
Fig.22: a)Moran's I: Global autocorrelation for the Age of Abies alba within the 1 ha plot. In red confidence limits. b)Local Gi*: Local autocorrelation for all plants: blue colours are the significant values among young individuals; red colours are the significant values among mature individuals. Lag distance: 10 m.

The population of beech is then evaluated (Fig. 23) and is immediately possible to notice that the value of the Z (I) global autocorrelation shows, at both the scales, an analogous trend similar to the entire tree population. This highlights the central role of the beech in shaping the spatial pattern of the Cansiglio permanent plot. As can be observed in the graph, at the largest scale (a) a mean groups' size with positive value of Z(I) is defined from 10 to 70 m (for approximately 60 m wide patch), negative value of the global autocorrelation index from 80 until 180 m detect a 100 m mean distance . A smaller, negative peak is present at the end of the graph.

Similarly, at the single hectare scale (b), the 2 groups are detected as well but, they are smaller. Indeed, the average size is approximately 30 meters big (from 10 meters to 40), the distance is about 30 meters long (from 60 to 90 m). Afterwards, the pattern is always within the confidence envelope.
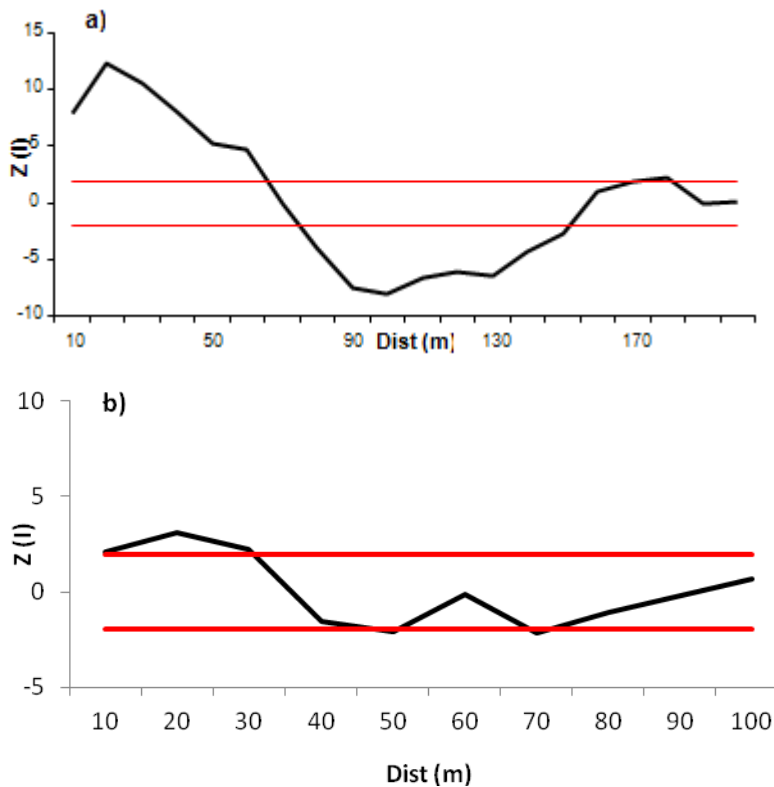

Fig.23: Comparison between the Moran's I for the DBH of Fagus sylvatica at the whole 4 ha plot level (a) and at 1 ha plot level (b). In red confidence limits. Lag distance: 10 m

With the Local autocorrelation index Local G*(Fig.24) we can evaluate the distribution of the groups in the whole 4 ha plot (a): a large patch characterized by big DBH is clearly visible from the lower left part of the plot until the upper central part. On the right part of the plot instead, 2 big patches with some additional smaller areas are made up of small DBH beeches.

Looking at the single ha scale (b) we can recognise the clusters's location like in the previous scale and is notably the fact that,in this case,the plot at the smaller scale is quite consistent with what observed at larger scale. The big DBH-sized group is indeed located in the same position as previously seen and all the trees contribute in the same way to form the cluster as remarked in the whole plot.
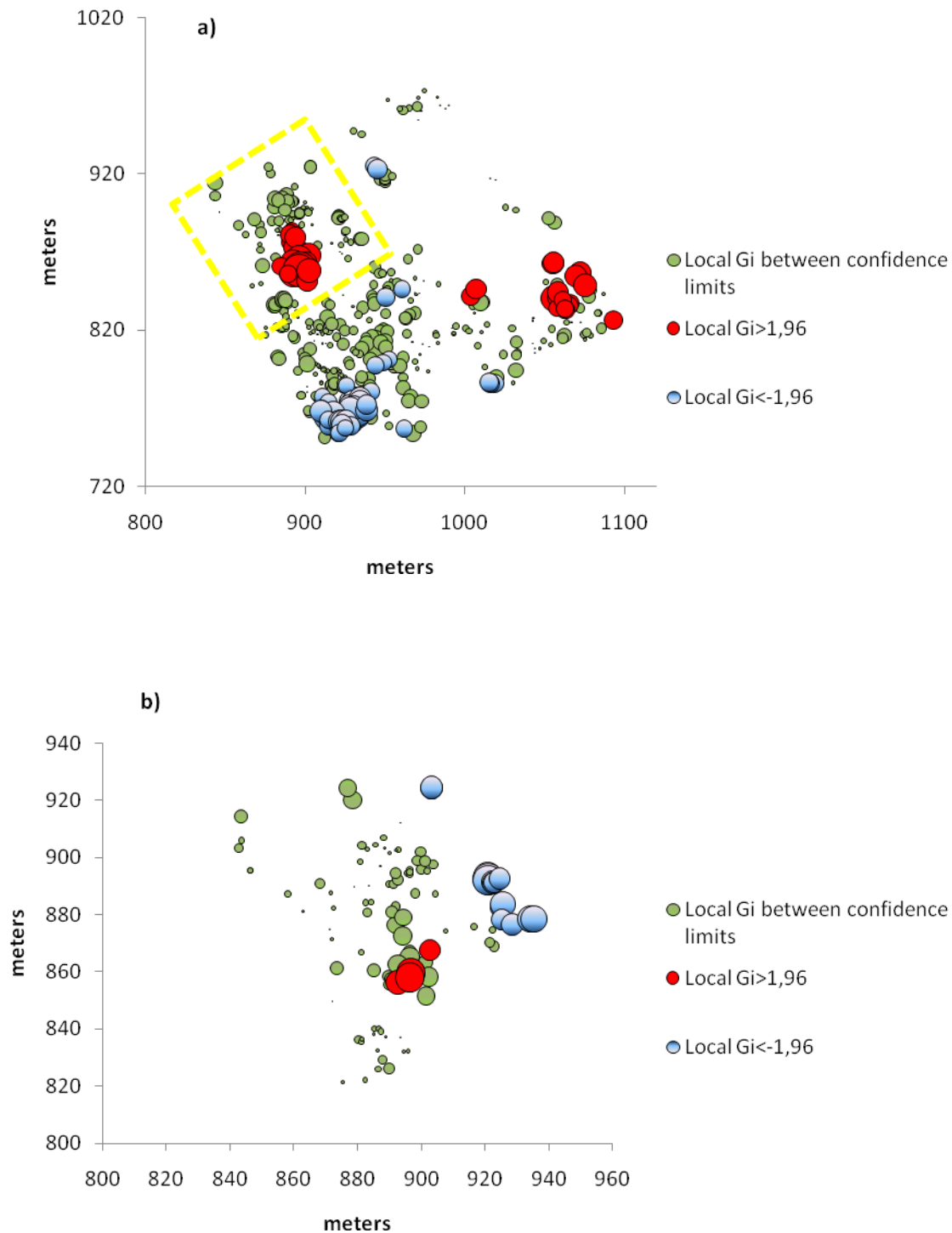
Fig.24: Comparison between the local Gi* for the DBH of Fagus sylvatica at the whole 4 ha plot level (a) and at 1 ha plot level (b). Blue colours are the significant values for small individuals; red colours are the significant values for big individuals. Dotted yellow line is the 1 ha plot location within the stand. Lag distance: 10 m.

Then, for the single hectare (Fig.25), global and local autocorrelation have been computed considering the age of the trees.

Even more than what has been seen for its DBH, beech is the most important species contributing in shaping the pattern of the Moran's index related to age. Indeed, it's almost the same of the one related to all trees: there are 2 big groups, approximately of 40 meters (a).

Local Gi*map (b) fits very well with the correlogram of the global index.We can recognize a big-sized group made up by old trees along the right border of the plot,whereas another cluster made up by young beeches is located along the diagonal of the area.

b)

Legend:
- Local Gi between confidence limits
- Local Gi>1,96
- Local Gi<-1,96
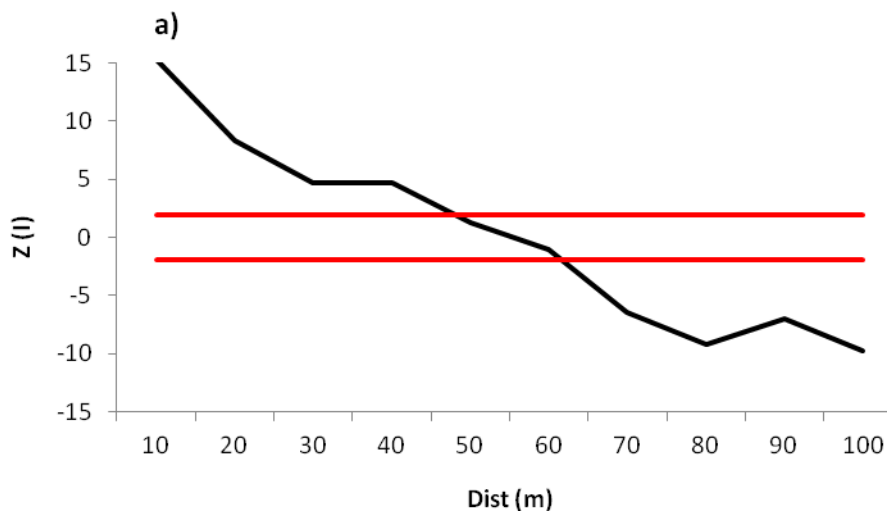
Fig.25: a)Moran's I:Global autocorrelation for the Age of Fagus sylvatica within the 1 ha plot. In red confidence limits. b)Local Gi*: Local autocorrelation for all plants: blue colours are the significant values among young individuals; red colours are the significant values among mature individuals. Lag distance: 10 m.

Finally, the global autocorrelation pattern for spruce is evaluated (fig.26).

If we look at the whole plot (a), the pattern is similar to the fir's one. The value of Z(I) from 10 to 60 m reveals a mean cluster size of approximately 50 m, whereas negative values of the Z(I) starting few after 60 m and ending at 130 m reveal a mean distance between them of approximately 70 m.

Then, if we look at the single hectare scale (b), we can see how such species shows just three significant peaks smaller than 10 meters.
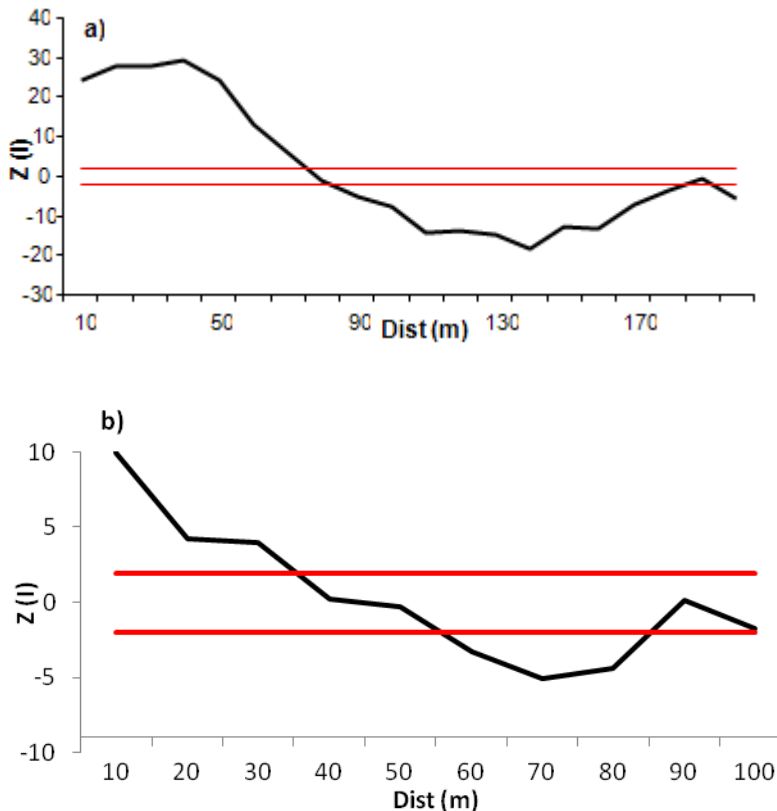

a)
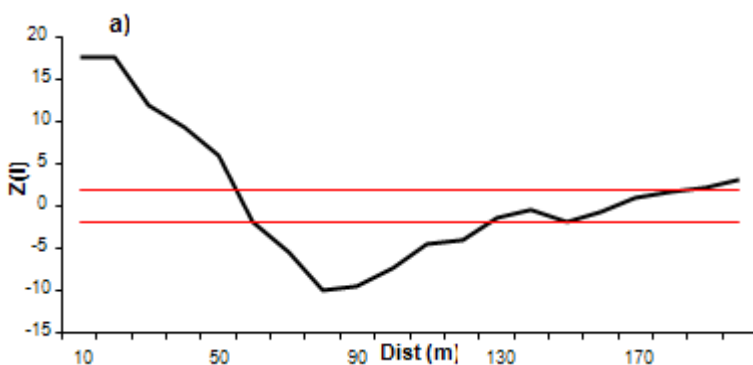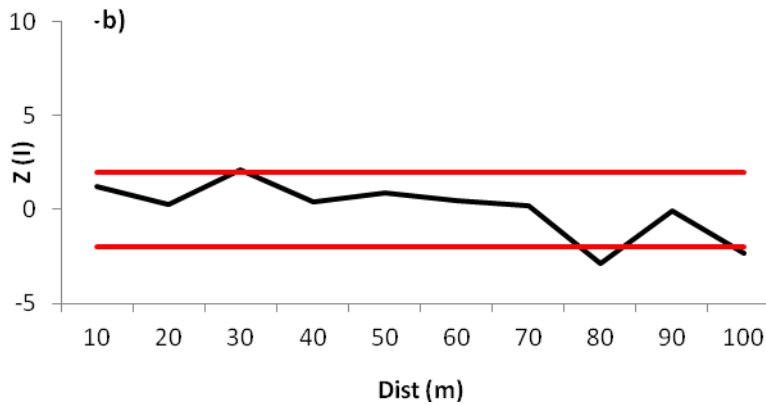
Fig.26: Comparison between the Moran's I for the DBH of Picea abies at the whole 4 ha plot level (a) and at 1 ha plot level (b). In red confidence limits. Lag distance: 10 m

The local autocorrelation index local G*(fig.27) identify many small patches with significant positive and negative values. Starting from the whole plot (a), in the right section is possible to see a big patch of large DBH trees , from the upper until the lower part of the permanent plot. By moving towards the left part of the plot a strip formed by small DBH trees is present. Finally, two patches, one in the upper left part and one in the lower right part are again characterized by large DBH.

On the other hand, if we look at the single hectare scale (b), is possible to see how the interpretation of the local Gi*map is difficult in seeking an accordance with the global index.This latter indeed shows that peaks we have already mentioned but, if we move to the local Gi* map, the groups visible are in average very far each other and this would seem to be in contrast with the pattern described by the Moran's I. Anyway, the only groups which is worth to mention are the ones located in the middle of the plot and to the lower right corner. They are all made up by small diameters.
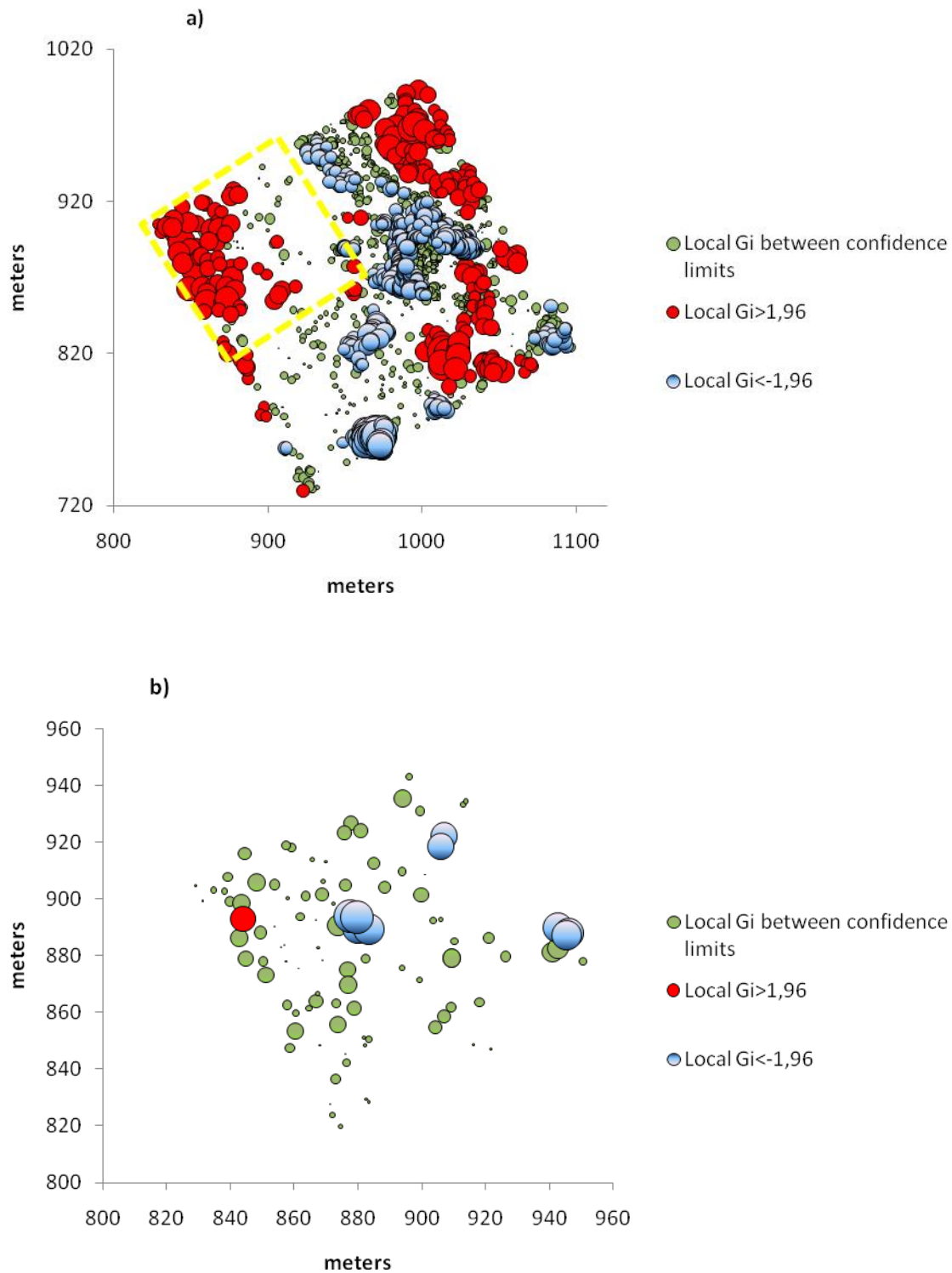
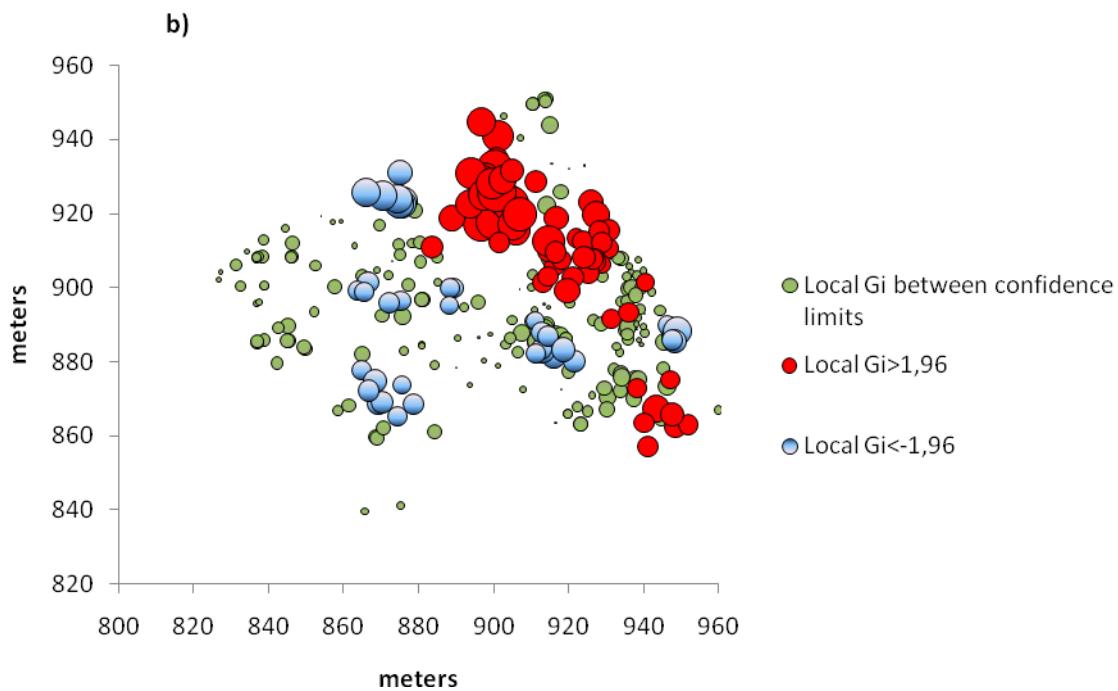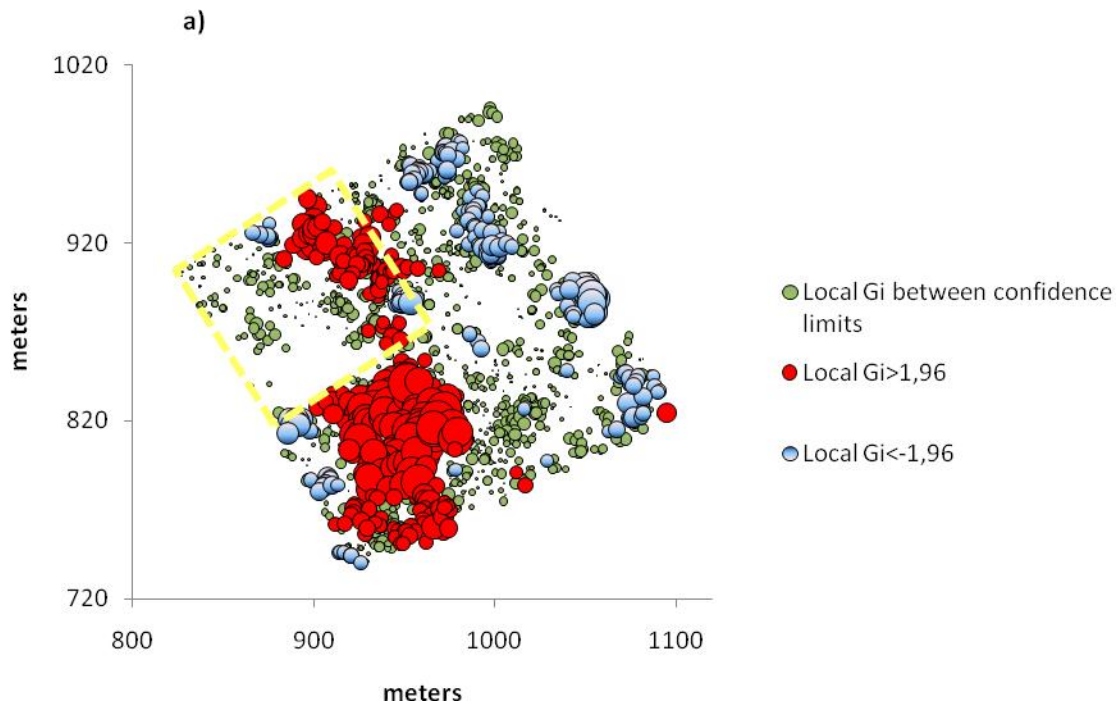**Fig. 27: Comparison between the local Gi* for the DBH of Picea abies at the whole 4 ha plot level (a) and at 1 ha plot level (b). Blue colours are the significant values for small individuals; red colours are the significant values for big individuals. Dotted yellow line is the 1 ha plot location within the stand. Lag distance: 10 m.**

Similarly to the autocorrelation related to DBH; for the age, at the single hectare scale, both indexes present difficult accordance as well (fig.28).

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Concerning the Moran's I (a),no significant values are found apart for the negative lag of approximately 20 m lenght. This one is difficult to be interpreted if we look at the local Gi* map (b). Indeed, there are at least 2-3 groups which would be worth to consider as such although they are very small: the first is located approximately in the middle of the upper border of the plot and the second one is close to the lower right corner. Both clusters are made up by old individuals. Additionally, there would be another small group made up by young individuals, located in the surroundings of the lower left corner.
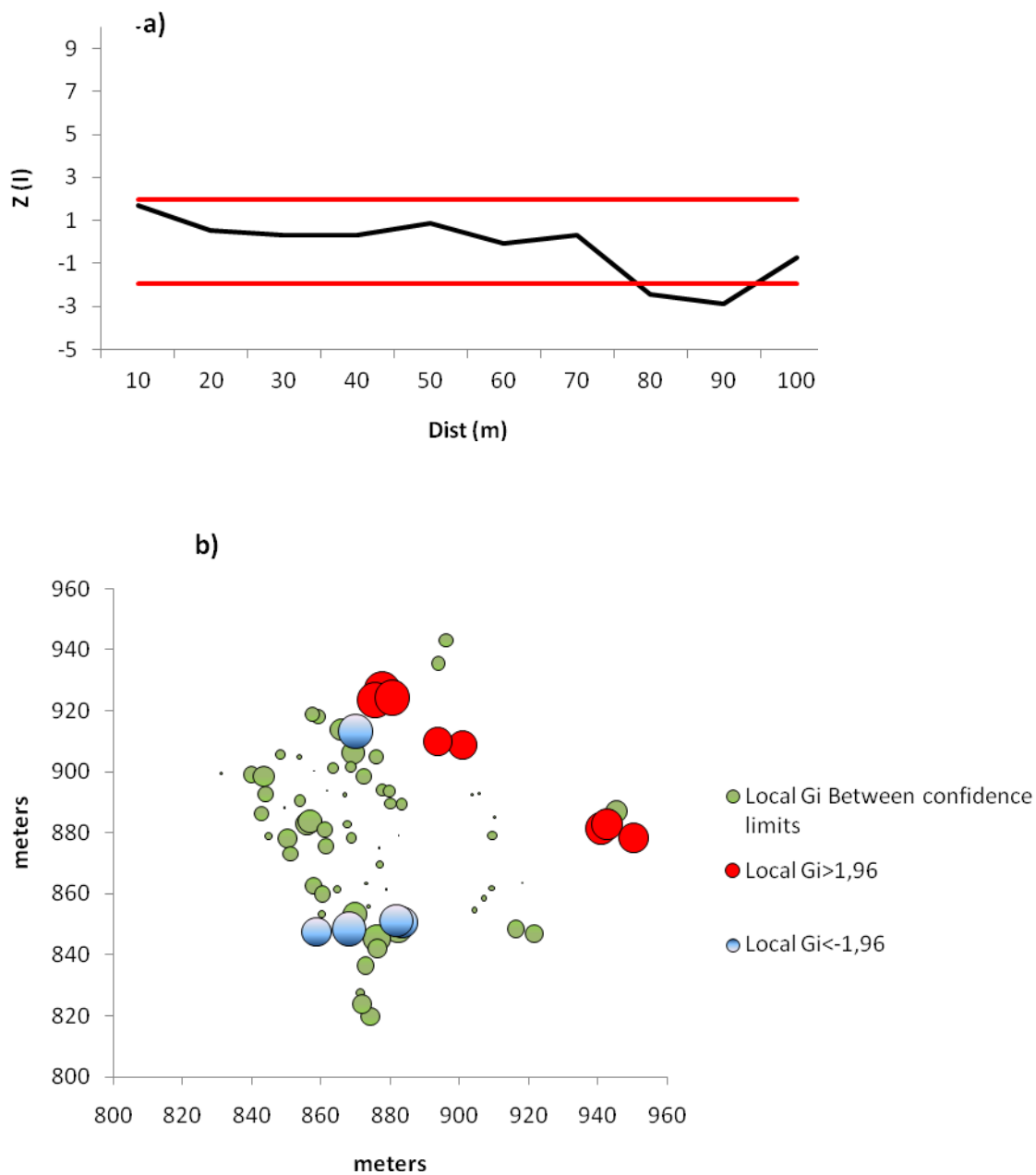
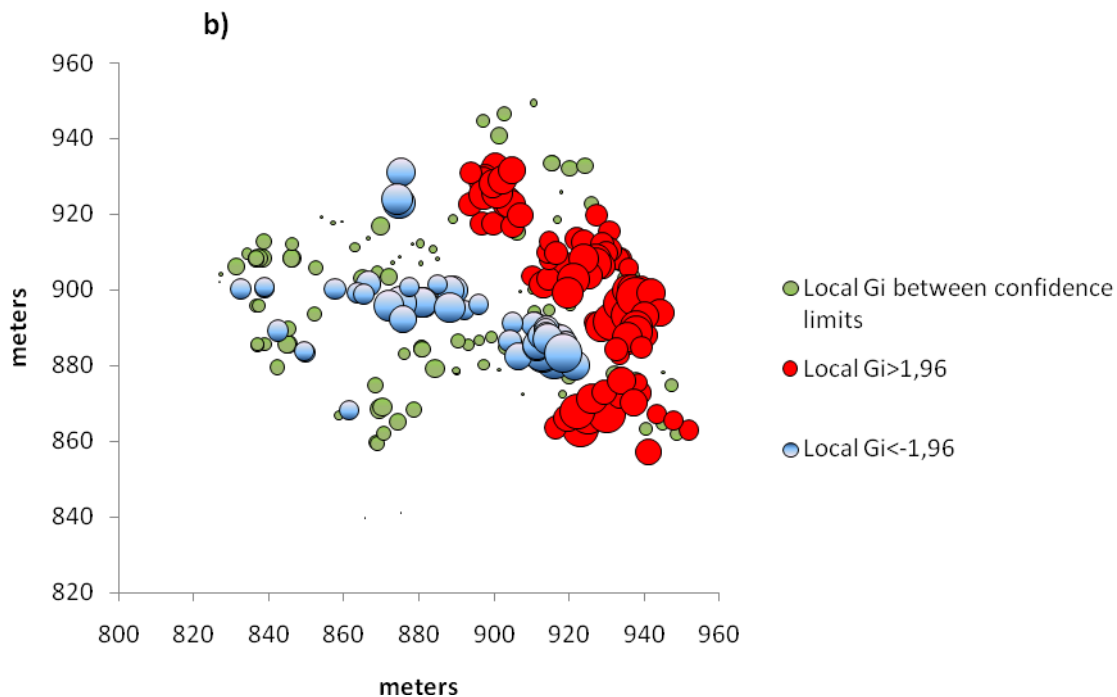**Fig.28: a)Moran's I:Global autocorrelation for the Age of Picea abies within the 1 ha plot.In red confidence limits. b)Local Gi*: Local autocorrelation for all plants: blue colours are the significant values among young individuals; red colours are the significant values among mature individuals. Lag distance: 10 m.**

4 DISCUSSION

4.1 STRUCTURAL CHARACTERISTICS

The Cansiglio forest can be classified as a multilayered mixed forest of fir, spruce and beech.

Concerning the parameters of the plot, considered at the 2 different scales, we'll firstly highlight the differences related to the mean DBH. Indeed, together with the obvious abundance of individuals, it's the parameter that mostly affect the spatial analyses, especially the autocorrelation ones.

Spruce is definitely the species with the highest difference in mean DBH if we consider the single hectare and the whole 4 ha plot.In this latter, the tree presents a mean DBH of 20 cm, whereas in the single ha the value is twice. Also fir shows a remarkable difference since is 28,5 cm if the whole area is considered and 35,6 in the other case.

Unlike the others, beech shows a very similar value in terms of mean DBH: 20 cm in the whole plot and 21,7 in the small one.

Also in terms of abundance, spruce shows the biggest difference: 340 individuals/ha if we average the total amount of individuals in the whole 4 ha but, if we consider the hectare alone there are actually 107 individuals.

Basal area instead, considering each species, is rather similar both in the whole plot and just in the single hectare. Fir, in this case, shows the biggest difference since it has an average of 9,8 m2/ha in the whole plot but an actual value of 13,9 meters in the hectare singularly considered. If we consider all the species involved, the value of basal area is very close at both scales (48,39 m2/ha for the whole plot and 46,9 in the hectare singularly considered).This similarity could reflect that in the hectare chosen occur the ecological conditions representative of the average ones of the stand.

Anyway,in both cases, the values are above the normally managed forests and are similar to what have been registered in other European mountain old-growth forest reserves.For instance,in a forest reserve of southern Slovenia, has been reported a total basal area of 41,6 m2/ha (Nagel et al., 2006),while Motta (2008) found values of 69,3 m2/ha in Lom forest reserve (Bosnia). Firm (2009) reported a value of 59,4 m2/ha for a mixed old growth forest of north eastern Slovenia.

Also concerning the composition percentage, basal area is rather well similar in both the scales considered. The differences are mainly concentered on fir, which is the species showing the biggest difference (33% of the total basal area composition in the whole plot against the 20% in the hectare singularly considered).

The specific composition is always beech-dominated. Beech, at the single hectare scale, shows a much more remarkable predominance (54% of the total) than in the whole plot (45%). However, in terms of basal area composition, the broadleaf present a smaller percentage respect the other

species (38% in the whole plot while spruce is 42%) and even the smallest (30% of the total) at the single hectare scale.

This is confirmed also by the DBH distribution where, at both scales, the pattern related to all trees is mainly shaped by beech from the smallest up to the intermediate age classes showing that distribution for the most similar to the reverse-J shaped one typical of shade tolerant species (Firm et al., 2009; Hao et al., 2007; Heiri et al., 2009; Motta et al., 2008; Standovár and Kenderes, 2003) Afterwards, the contribution of the conifers prevails more and more until the biggest classes where beech disappears.

This phenomenon, in the single hectare, is also confirmed by age distribution since the conifers have almost no one individual below 35 years old (actually, fir doesn't count any tree below such threshold).

This fact is related to the well known high recruitment skills shown by beech allowing seedlings to grow under the cover of older individuals thanks to its high shade-tolerance (Del Favero 2004; Heiri *et. al.* 2009).

However, if this capacity can be true compared with the spruce's one, the same cannot be said for fir. This latter indeed has a similar behavior of beech towards shade tolerance and therefore such big difference in seedlings' recruitment between them cannot be explained in these terms.

The most likely constraint affecting fir's recruitment is the browsing carried out by deers since such conifer is known to be the most palatable for them and Cansiglio forest is an area where these ungulates are definitively overabundant (Caudullo et al., 2003).

Although age structure has helped in the understanding of this process, we stress on the fact that it is very different respect to the DBH distribution. At least for beech, this latter is closer to a reverse J-shaped distribution but, if we look at the age, the distribution is closer to a Gauss normal distribution similar of light-demanding species (Heiri *et al.,* 2009). These differences are likely to be due to the intra-specific competition and to the past forest management. This was just to give the idea that if we want, for example, to know the recruitment's skills of a species we cannot rely just on diameter because it could drive to significant misinterpretations.

By the way, this issue is well described by the low correlation between DBH and age which has been found for all the species involved. This result, especially for fir and spruce, is consistent with other studies (Motta *et al.,*1999;Motta and Edouard,2005).

For what concerns the height distribution, considered the whole plot, is clear the strong direct dependence with the DBH whereas for all the species, at the single hectare level, is highlighted how such dependence is not the same respect to age. This low correlation, especially for the conifers, is consistent with other studies (Motta and Edouard,2005).

However, this could not be the case if we would consider the correlation with tree's height for each age class separately. In this sense it has been demonstrated , for instance, that in some fir dominated stands in Tuscany the seedlings reach a height of 0,5 m in 13- 15 years, disregarding other factors affecting the growth such as the covering of the older individuals (Di Filippo et al., 2004b).

This suggests that dendrochronological analyses are required in order to have a clearer picture of the relationships between height and age.

4.2 SPATIAL DISTRIBUTIONS-UNIVARIATE ANALYSIS

Making the comparisons between the 2 scales considered has been very useful to understand the importance of a 4 ha sized plot instead of a single ha-sized one.

Considering the whole plot, a strong clustering for all trees at all the distances is detected. This could be the result of past human management. As revealed by some authors in their study about the changes in spatial pattern following selective harvest (Meador et al., 2009), the consequences of human management seems to favour a stronger clustering of the remaining tree population once the tree recruitment starts. More in detail, the cutting of large trees leaves smaller and more uniform-sized trees (Sanchez Meador et al, 2008; Rozas, 2009) which increase the clustering of the whole tree population. At the single hectare scale, no significant difference is detected concerning this issue.

Subsequently, we evaluated how the strength and range of clustering evolved through the three DBH classes we previously selected: small, medium sized and mature. Both in the whole plot and in the single hectare we assist at a strong decline in the clustering at each DBH class. Small trees highlight the strongest clustering of regeneration which grows in dense patches between canopy gaps where enough light reach the ground. Medium sized phase is still highly clustered even if at a lower level compared to small individuals, while big-sized are regularly distributed in both the scales considered at short distances, than random and aggregated distribution are alternated along all the distance lags. Both in the case of all trees and in the one of medium sized trees, if we look at the single hectare scale, it's clear that such patterns tend to be more "hidden" and, approaching towards larger distances, falls within the non-significant area. Because of this, we stress once more on the importance of the big-size of the plot, which is able to guarantee the detection of patterns otherwise unseen.

  The reduction of the clumping strength as trees get larger has already been reported in the literature by various authors in different forests (Getzin et al., 2008; He and Duncan, 2000; Shackleton, 2002; Szewczyk and Szwagrzyk, 2010; Zhang et al., 2009). Our data suggest that competition is appreciable on trees between medium and big sized phases.

The overall clumped trend was evident also in the single species and at both the scales considered even if, once again, at smaller scale the detection of these pattern is weaker. By the way, at the single hectare level, spruce showed the biggest differences in terms of spatial distribution respect to the whole 4 ha plot and this is probably due to the high difference in terms of number of individuals found in the 2 areas considered.

A clustered distribution in all species, is known to favour the creation of more uniform monospecific patches of trees. This issue has been already described in the past by comparing a pristine Finnish spruce forest with a managed one: the spatial pattern of the latter was indeed more clumped compared to the former unmanaged stand (Kuuluvainen et al., 1996).

About the species-specific trends, spruce shows the highest clustering in the whole plot, followed by fir and finally by beech which seems the least clustered tree species, especially at medium to large distances considering both the whole area and the smaller scale. Nagel et al (2006) highlighted that clumping of beech seedlings at short to medium distances is probably linked with gap dynamics, a favourable microsite to beech regeneration.

 Considering the age distribution in the sinlge 1-ha plot, we can see that the trend detected for the DBH-univariate patterns is the opposite. It's indeed evident the increasing aggregation as long we move towards the older stages. By the way, the reason of the random distribution of young trees is possibly related to the small number of trees (Salas et al., 2006) rather than a different ecological process detectable by the age-related statistic. Indeed, young trees are made almost exclusively by young beeches and they count anyway for very few individuals (only 18 within the hectare). As we already said, the reason for such a low density is basically due to deers' browsing. Field evidences has shown that even young beeches are affected by this disturbance.

Moreover, considering that the mean age of the individuals is very low (62 years), it's likely that the distribution will be generally clumped. Indeed, although there is a big gap in literature concerning the spatial analyses of beech related to age, studies carried out both for tree line and Nordic conifers' stands highlight the fact that clumped spatial patterns can be detected even until 100 years old stands (Brumelis et al., 2005; Motta and Edouard, 2005). Once more, this fact highlight the well known rhole of competition which would acts, for all the species involved, in determining dominance relationships among even aged individuals whose, over the time, would be leaded to growth according to very different individual growth rate (D'APRILE et al., 2008; Di Filippo et al., 2004a; Ford, 1975).

All these considerations suggest that is likely that a clumped distribution could be occurred also for young individuals but 1-ha plot wasn't enough big to detect such pattern.

According with our results, we can therefore argue that, in contrast with the DBH spatial distribution, the trees are aggregated even at the older stages. This difference is well pointed out by the figure 11 (d-right side) and the figure 12 (c). Additionally, this fact makes stronger the consistence with Kuuluvainen's study (1996).

4.3 SPECIES TO SPECIES RELATIONSHIPS-BIVARIATE O-RING STATISTICS

Regarding the forest's history, our aim with the bivariate O-ring statistics is to evaluate the present spatial interactions between the species and to assess how this forest is evolving towards its potential vegetation.

According to the bivariate analyses, all species show a well defined relationship towards attraction/repulsion which is often maintained at all distances. Unfortunately, statistics are not available both for young spruce and for young fir versus the others, basically due to the absence of young individuals.

Notably, beech shows a strong repulsion towards its own big conspecifics at short distances and this is probably due to germination inhibition/lower success of seedling establishment under parent canopy trees rather than seed dispersal inabilities, since if for conifers having a wind dispersed seed we could consider a large seed shadow, on the contrary, beech has a heavy seed which falls nearby the parent trees. Therefore this can't explain the repulsion discovered between small trees and big ones. According to the literature, it has been observed that while fir can establish successfully under the canopy of old individuals, beech is a species which regenerate preferentially in canopy gaps (Nagel et al., 2006; Paluch, 2007). Paluch (2007), in particular, described the strong clustering of fir seedlings under close canopy because, he suggested, fir regeneration might be more associated to edaphic conditions rather than light availability, therefore concentrating not only in gaps but in all favourable niches.

We highlight that, considering the smaller scale, the bivariate analyses has shown an even stronger deficiency respect to the univariate one in detecting the patterns. Their identification was indeed possible only thanks to the 4 ha-sized plot.

The results seem to confirm the tendency of fir to grow under the canopy of beech. A shift between the two species, in the Alps, has been indeed suggested by different authors (Del Favero, 2004; Heiri, 2009).

Spruce instead, a less shade tolerant species compared to fir and beech, showed strong aggregation at all distances below its big conspecific whereas strong repulsion at all lags is detected towards big beeches. The behaviour of spruce differs from the one of the other two species, since it is positively aggregated only with its own conspecific.

In the contest of this forest type, a clear understanding of the reason which is below this behaviour is still far. This could be due to the plantation of spruce in the Cansiglio area after the first world-war even in locations potentially dominated exclusively by fir and beech (Del Favero, 2004).

Nevertheless, the only human intervention cannot explain entirely this issue. Other studies have indeed demonstrated that spruce seedlings rely on the presence of favourable microsites such as coarse woody debris and pit/mounds morphology following trees uprooting (Firm, 2009).

Anyway it can be argued that such conifer is a highly adaptable species compared to the others and that it can assumes different spatial patterns even within the same forest types according to very localized ecological conditions.

4.4 SPATIAL AUTOCORRELATION

The results of the entire tree population analyses for the two permanent plots show a general similar pattern with the presence of groups of trees with similar DBH. The groups of trees with homogeneous DBH have a patch size of approximately 70 meters in the whole plot and, of course, definitely smaller in the single hectare. It's worth to notice how the local $Gi*$ map shows evident differences at the smaller scale: clusters are seen as such within the 1 ha plot but they don't (or, at least some of them) if the same plot is considered together with the other 3 has. The reasons of this phenomenon has already been explained in the results' chapter regarding the formula which the statistic is based on but, during this discussion we'll have the possibility to go further in detail concerning this issue.

In the single hectare plot, we have evaluated the autocorrelation for age as well and it's evident the presence of 2 groups: one made by young trees and the other made by old trees. This cluster is made almost exclusively by beech. Evaluating the species-specific spatial autocorrelation values instead, the peculiarities of each single species behaviour are revealed.

The local $Gi*$ map highlights the little role of fir, with few areas of significant autocorrelation. This is due to the low number of trees rather than weak spatial aggregation.

Beech instead has a global index of autocorrelation at the single hectare scale which is comparable to the one observed in the whole forest and, moreover, it is the species showing the highest grade of accordance between the global index and the local one. Beech patches have a prominent role in shaping the entire tree population map in both the scales considered, especially for what concern small individuals and the age. Also the role of big individuals is however remarkable.

Another interesting pattern is revealed by comparing the fir Local $Gi*$ with the beech local $Gi*$. Considering the whole plot, the conifer lower right part is characterized by big DBH, while in beech is characterized by small DBH. On the contrary the lower left part of the conifer's map is characterized by small DBH while in beech the opposite. These findings confirm the bivariate O-

ring results previously discussed. This could be a sign of seedling preference for canopy gaps once large individuals fall or die, rather than diffuse regeneration under canopy trees. This regeneration preference indeed would imply a more sparse population less condensed in space. Therefore, it would hardly result in a strong and significant DBH autocorrelation.

For spruce, smaller patches of trees with homogeneous DBH have been highlighted in the whole plot, less connected with other species. However, this is consistent with its attitude to estabilish according to very localized ecological conditions, as well pointed out by Diaci (2002) and Firm (2009).

Those areas, together with the blue colours representative of small individuals, seem to be strongly segregated respect to fir's distribution in general and, definitely less strongly, respect to big beeches. Indeed, although the small spruces don't share the same space of the big broadleaf in most of the cases, in some others the opposite is true (between the central strip and the lower left part of the local *Gi** plot).

This result is consistent with the bivariate O-ring of small spruce vs big individuals where a clear repulsion is shown towards big firs but, regarding big beeches, the statistic is for its most not significant and even significative attraction is detected at larger distances.

Differently, it's interesting to note how small beeches tend clearly to grow under big spruce, like in the left sector and the upper right one. Like in the previous case, this result is in accordance with the bivariate O-ring analysis which showed strong attraction between small beech and big spruce.

According to Del Favero (2004), in the Alps, such dynamic seem to be much closer to a beech-spruce dominated stand rather than a mixed stand where fir is present too.

Moreover, the same author highlight how the 2 species tend to regenerate the one below the other but, in our case, this same true especially for beech and definitively less for spruce.

Therefore, we prefer to interpretate this fact under a different perspective than the forest type functioning, especially for such complex multilayered forest which is very difficult to standardize.

Looking at the local *Gi** map, and considering the bivariate pattern, it would seem indeed clear that spruce regenerate especially close to its own conspecifics. However, it must be kept in mind that these results are especially determined by that big cluster of small individuals located between the central strip of the plot and the upper right corner. Since that we know this big patch as being an artificial plantation (Piano di Gestione Riserve Naturali del Cansiglio(1986), it could be unreliable to trust at 100% the analyses related to it.

Therefore, we believe that the scarce and relatively unexpected attitude of small spruce to share the same space of big beeches can be determined by constraints related or to solar radiation asymmetries (Diaci, 2002) , possibly determined by the dolines orientations which in several cases

could be more likely to favour the regeneration of the most shade tolerant species like beech, or, more in general to the presence of favourable microsites such as coarse woody debris and pit/mounds morphology following trees uprooting (Firm, 2009).

Additionally, thanks to the local and global autocorrelation indexes, more information on the spatial structure can be revealed:

It is possible to see that in some areas big spruces seems to follow big beeches distribution.This relationship is the opposite respect to the repulsion shown by small spruces towards big firs and, in this sense, it would be very useful to get the data related to age to cope better with this issue.

While the two conifers seems to share several of the large DBH spatial patterns, beech is showing a completely reversed distribution map, where large trees are clumped in the middle of a fir and spruce patches. Also the small individuals of the three species seem to be segregated in space. Rather than considering this distribution a result of spatial heterogeneity inside the forest, apart probably for spruce naturally estabilished, we strongly believe that this is a clear sign of past human management, which have enhanced the tree spatial segregation through cuttings and plantings.

For what concerns the small hectare, for spruce in particular, we have to say something apart. We could wonder why, for instance,concerning the DBH of spruce, the global index has detected that small peaks despite, looking at the local Gi^*, there were 2 (at least)-3 little similar groups very far each other. On the other hand, it seems strange that the Moran's index, concerning the age, has detected just that relatively small negative lag despite the local Gi^* map showed at least 3 clusters.

Firstly is quite obvious that, since the statistic consider as being *neighbourhood* of the tree on which is applied the formula all the plants within a radius of 10 meters around, for the individuals belonging to the single hectare close to the corners whose are not shared with the whole plot, is likely that the value of Gi^* could be different respect to the one shown for the same individuals considered in the bigger scale. Indeed, for the plants located in such corners, the *neighbourhood* is "forced" to be different.

Nevertheless, especially if we focus on spruce, this cannot explain why, even in the close surroundings of the corner shared by the whole plot and the single hectare, occurs that big differences.

To explain better this issue it must be kept in mind that some authors (Anselin and Moreno, 2003) have put in evidence that the performances of the statistical tests depend on the nature of the spatial structure, i.e.by the weights' matrix properties involved in the analyses.

Then, for what concerns the power of all statistical tests, we highlight that they are all affected by the number of observations considered, i.e. the ability of the test to discriminate between the null hypothesis and the alternative one is as higher as the number of observations involved. This is of

course valid for point pattern analysis as well but for the local autocorrelation index is definitively more evident. Also Soraruf (2008), in a tree line environment within eastern Italian Alps, found very low significant values for age related to *Pinus cembra* both for spatial statistics using Ripley's K and for global autocorrelation. And also in that case, the local Gi* statistic has shown some difficulties with the global index. *Pinus cembra* was actually the far less represented species in terms of number of individuals within that tree-line stand.

Together with the other considerations, the latter could explain both the reason why in our study, at the smallest scale, the spruce autocorrelation is hardly significant and the difficulties to interpret the local index in accordance to the global one. Indeed, spruce has a significantly lower number of individuals respect to the other species in the plot and, on the other hand, beech is notably the species with the highest number of individuals both in the whole plot and in the hectare chosen within it. Moreover, it is the species with the most similar mean DBH between the 2 scales considered and, together with fir, has the most similar percentage of individuals at both the scales considered. However, fir has a remarkable difference in terms of mean DBH.

Spruce is instead the most un-even species if we consider the comparison between the parameters mentioned above and, in particular, is far less abundant respect to the others within the single hecatare plot.

All these considerations lead to the conclusion that the statistics, in particular related to autocorrelation, can differ greatly if different scales are considered. This situation could be avoided only in the case that the whole stand studied would be homogeneous in terms of DBH and age spatial distribution. However, this issue is clearly very difficult to understand on the field and, if we consider the age, it's impossible since the low correlation occurring between DBH and age; phenomenon which is by the way frequently observed in shade tolerant species (Motta and Edouard, 2005).

Secondly, especially for spruce and fir, the growth rate can vary widely as function of light and competition between individuals but, in any case, it depends on very localized conditions (Antos and Parish, 2002; Motta and Edouard, 2005).

This suggest that is very unlikely to find homogeneous spatial structures, especially if we look at mulilayered forest which, by the way, are mainly formed by fir, spruce and beech in northern Italian Alps (Del Favero, 2004).

Currently, most of spatial analyses in forest ecology are based upon not bigger than 1 ha-sized plots (Batllori et al.; Carrer and Urbinati, 2001; Hao et al., 2007; Lingua et al., 2008; Lopez et al.; Mason et al., 2007; Motta et al., 1999). Therefore, especially if the purpose is to define clusters' size and

location, but also to apply an efficient point pattern analysis, our results suggest that a 4 ha-sized plot could provide more useful and realistic informations.

5. CONCLUSIONS

The importance of long term ecological researches have been recognised since long time and many forest reserves have been established in the most peculiar and pristine forest ecosystems all around the world. The monitoring, repeated over the years, permits to gain important information about the dynamic of those ecosystems where a single research, as a snapshot, can not always capture. However, in Western Europe, the lack of pristine forests due to the diffuse direct or indirect human disturbances has limited the establishment of reserves in semi-natural ecosystems such as the one of our study.

Thanks both to the spatial analyses method applied and to repeating these analyses on the same plot at 2 different scales, our study have highlighted the importance of the scale of analyses and of the plot dimension.

It was clear indeed how spatial statistics are strongly affected by the overall number of individual considered in the point pattern but also by the nature of the spatial structure.

Therefore we conclude that, in order to obtain significant results by means of spatial analyses, at least a 4-ha permanent plot should be set-up instead of the single ha as usually done. In particular, if multilayered mixed forests, which are well known to be very heterogeneous in space, are considered. This is important especially in our forests whose still reflect the past silvicultural regime and therefore have a relatively low density of individuals per hectare.

Moreover, if we consider the statistics related to the spatial structure of beech age, the literature is very scarce. In this sense we advise to improve the efforts towards studies related to beech-fir-spruce dominated stands involving in the analyses local indexes of autocorrelation such as local $Gi*$ and the age parameter.

In particular, the local autocorrelation index can provide informations whose are unrevealed by the global Moran's I. This latter indeed tell us only the mean size of the clusters and the mean distance between clusters made by different values of DBH/age; but nothing is detected about their number, their location in space and, overall, whether they are made by individuals with low or high values of DBH or age. For this reason, the local $Gi*$ has proved to be a fundamental tool to made more robust the results obtained with the point pattern analysis.

Concerning the age, the needing of involving such parameter is evident due to the low correlation found between DBH size and age. In particular, in this study, it has been possible to highlight how

such parameter is lowly correlated with the DBH of all the species involved in the stand's community. This result is consistent also with other studies both for the more shade tolerant species like fir and beech (Motta and Edouard, 2005) and for spruce (Motta et al., 1999), which is less shade tolerant respect to the others in the stand.

For this reason, in this work, the data related to age, although available only for the single hectare, have allowed anyway to detect several useful results such as the evidence of a strong aggregation of all the plants up to the oldest stages. This confirm the well known role of competition which act, for all the species involved, in determining dominance relationships among even aged individuals whose, over the time, would growth according to very different individual growth rate (D'APRILE et al., 2008; Di Filippo et al., 2004a; Ford, 1975).

Unfortunately, the mentioned low correlation between the two parameters, the huge gap of young individuals for all the species and finally the low significance of autocorrelation statistics for the conifers, didn't allow to compare the spatial distributions of the species considering the age. Concerning this issue and according with literature (Caudullo et al., 2003Caudullo et al., 2003) and several field evidences we aware about deer browsing (especially for fir).

The analyses have then revealed how the past management footprint is still recognisable in the present forest structure, although it is untouched since 1971. The reverse J-shaped distribution typical of low-disturbance old-growth forest is substituted by an unimodal distribution skewed on the right which reveal the presence of a large number of trees with similar medium to large DBH. This, together with the lack of very large trees typical of old-growth stands and a low amount of large standing dead trees are the results of cuttings executed during the 1950s, which homogenized the forest structure over large areas. Additionally, the species-to-species relationships have revealed an high level of spatial segregation between the different tree species and a lack of repulsion between conspecific small and big individuals. Finally, thanks to the data available for age, we can surely state that the plants are generally aggregated up-to the oldest stages. Such high level of clustering is, likely, a heritage of the past forest management.

In addition, segregation between the tree species, imply less chances for fine-species mixture.

Global and local autocorrelation statistics revealed the presence of large and mainly monospecific groups of big trees. A different pattern instead has been detected for the small ones: the regeneration patches of different species seems to be overlapped, revealing the importance of intra-specific rather than inter-specific competition. This seems to confirm the spatial segregation hypothesis for plant coexistence in mixed forests.

Therefore, the overall conclusion of this work is that human management in Cansiglio forest has forced a coetanization and a simplification of the species mixture, which will take several decades

to evolve towards more natural condition. Within this context, we express concern about the lack of fir regeneration due to heavy browsing by ungulates, considering that it is a species which has a fundamental role in this kind of forest.

It will take many decades for this semi-natural forest to recover its natural structure but it's currently a good source for the understanding the natural dynamics that could be later applied in the close-to-nature silviculture. It's our hope that its evolution will be analysed and followed in the future.

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