Spatial structure: a way to understand the dynamics and to model the growth of mixed stands.

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Since a few years there has been a growing interest for uneven-aged or mixed forest stands. This interest is the result of both changing in demands from the society and also changing in forestry practices. Unfortunately, due to their high complexity, the dynamics of these stands is more difficult to understand than pure and even-aged stands, which rises new research questions in terms of stand description, stand dynamics and growth modelling. Existing management tools, such as stand level models, are not relevant for this kind of stands. The use of individual based models seems more appropriate, because of the individual variability within heterogeneous stands. However, this kind of models can not easily be used by forest managers, especially because they require to know the localisation of each tree in order to run simulations.

Spatial structure analysis can be used to have a better knowledge of these stands. Indeed, the observed spatial structure results from past biological processes (especially birth and mortality

of trees), and in return it defines the variety of local neighbourhoods of each tree, which influence future processes such as competition and mortality. Consequently, spatial structure analysis could be used in order to infer some information on the biological processes involved in the growth and the dynamics of heterogeneous stands.

The aim of this paper is to show how spatial structure analysis can be used to improve our knowledge of heterogeneous forest and to provide some perspectives for modelling them.

In order to answer this question, we applied an analysis of spatial structure to a mixed stand of Oak and Scots pine from French Centre area. We used the classical Ripley function L(r), and intertype function L12(r) to characterise the specific spatial structure of each population, and the structure of the interaction between populations. We then used the results of this analysis to build a typology of these stands. We identified four main types, and used the general observed spatial structures to make assumptions about ecological processes and historical factors influencing the dynamics of these stands.

In a second step, we used the typology in order to build a model of the spatial structure, that can simulate realistic virtuals stands from data at the stand scale classically used by forests managers.

We finally discuss the advantages of using such realistic virtual stands as initial states for distance dependant individual based models, when simulating the growth and the dynamic of mixed stands.

Keywords: Spatial structure; mixed stands; ripley’s functions; models; sessile oak (*Quercus petraea);* scots pine *(Pinus sylvestris)* ; Orleans forest ; management .

INTRODUCTION

Since a few years, there have been fundamental changes taking place in silviculture: Irregular or mixed forest stands are presently the subject of a renewed interest (Otto, 1991 ; Duchiron, 1994 ; Lanier, 1992, Hanewinkel, 2001). This interest comes from both changes in the need of the society and in the practices of forest's managers. Indeed, these stands could better correspond to objectives of ecological diversification and landscapes, but also appear more resistant with the climatic risks or other parasitic aggressions. forest's managers also find some interest in these stands : better development of stations, limitation of loss of commercial forest, better distribution of expenditure and receipts formerly. This interest is at last the consequence of a more general social demanding that environmental considerations be taken in account in forest management. It thus results a questioning of regular monospecific forest management, which was nevertheless in France, (and in several temperate countries), the type of forest management more widely used.

However, while they arouse a growing interest, forest's managers face a lack of management tools adapted to these heterogeneous stands. There is a need of specific new tools to manage those complex stands. Then, some new questions of research arise, as much in term of description that in term of dynamics stands and modelling of the growth, to manage, maintain or even set up such stands.

Particularly in term of modelling of the growth, the tools usually used, stand level models, are not relevant for this kind of stand. To take into account the strong individual variability inside heterogeneous stands, it seems to be more appropriate to use individual based models. Some forestry researchers sought to model the evolution of each individual tree according to his particular characteristics and its local environment. There are many models of this type, with a great diversity of indices of competition. (Botkin *et al.*, 1972; Ek and Dudek, 1980; Schütz, 1989; Gourlet-Fleury, 1992; Pukkala *et al.*, 1994; Murphy *and* Shelton, 1996; Moeur, 1997; Cescatti and Piutti, 1998; Nagel, 1999; Dubé *et al.*, 2001; Goreaud *et al.*, 2002; Ménard *et al.*, 2002; Chertov *et al.*, 2003. In France, we can also hold up as an example Courbaud *et al.*, 1993; Courbaud, 1997; Courbaud *et al.*, 2001, Prévosto *et al.*, 2000 for temperate forests , Robert 2003, Gourlet-Fleury 1997; Gourlet-Fleury and Houllier, 2000 for tropical forest. However, this kind of models can not easily be used by forest managers, especially because they require as initial state, the state and the localisation of each tree in order to run simulations. Even so, this kind of data are not available in common management.

In this context of need of informations about the functioning of heterogeneous stands, spatial structure analysis can help us to have a better knowledge of these stands, because spatial structure plays a crucial part in the operation of the ecosystem. The analysis of spatial structure is now commonly used in plant ecology (e.g. Tomppo 1986; Haase 1995; Pélissier & Goreaud 2001; Wiegand and Moloney 2004). Spatial structure represents, for a forest stand, the organization of the trees in space. It describes the neighbourhood relations between individuals, takes into account dimensions and the spatial relationship between the individuals (Bouchon, 1979). Dynamics of each individual being strongly influenced by the interactions between this individual and the others elements of the ecosystem (Begon et al., 1990), spatial arrangement thus influences the dynamics of the whole stand. Spatial structure of a stand thus results from history, past biological processes (birth, recruitment and mortality of trees), and past interactions between individuals. In return it defines the variety of local neighbourhoods of each tree, which influence future processes such as competition and mortality. Consequently, studying the spatial structure enables us not only to describe the stands, but moreover to establish some links with the various processes implied in their operation and their dynamics (see for examples Moeur, 1997 ; Batista and Maguire, 1998 ; Barot et al., 1999 ; Hoshino et al., 2001 and 2002 ; Goreaud et al., 2002 ; Park, 2003).

The aim of this paper is to show how spatial structure analysis can be used to improve our knowledge of heterogeneous forest and to provide some perspectives for modelling them.

Our study focuses on mixed stands Sessile oak- Scot pine of the Orleans forest in France, which is presented in the first section of this paper. Next, we will present the method used to analyse the spatial structure of our stands, and the results obtained in terms of main spatial types organized in a typology. In a fourth step, from the various spatial types, we will make assumptions about ecological processes and historical factors influencing the dynamics the studied stands.

Afterwards, we will show how to use the typology in order to build a model of the spatial structure, that can simulate realistic virtuals stands from data at the stand scale classically used by forests managers. We lastly discuss the advantages of using such realistic virtual stands as initial states for distance dependant individual based models, when simulating the growth and the dynamic of mixed stands.

STUDY AREA AND DATA COLLECTION

The study was conducted in Orleans forest, (France), where we are interested in mixed stand Sessile oak - Scots pine.

The Orleans state forest is one of the largest public woodlands in France (350 km^2). It is located a few kilometres north of the Loire river. It is a typical flat, lowland forest, stretching from Gien to Orléans (figure 1). Our experimental network was set up in the southern part of the forest, characterised by alluvial deposits of sand upon clay. The absence of natural drainage and the non permeable substratum both contribute to the development of groundwater tables. Soils are often acidic and characterised by successive water-logging and dry periods.

The ancient Oak forest was heavily over-harvested from the Middle Ages to 1850. By that time, the Oak stands had gone to pieces, gaps were very numerous and accounted for 30% of the whole surface. Between 1870 and 1890, the openings had been reforested by either seeding or planting Scots pine. In this way, the administration intended to reclaim soils and to restore the forest ecosystem. Scots pine found good growing conditions, and furthermore Oak was regaining its ecological and economic interest. Since that time, Oak and Pine have been managed together. Nowadays, foresters want to continue to manage the large area that originated from the second generation of Pine as mixed stands. These stands are the object of our surveys.

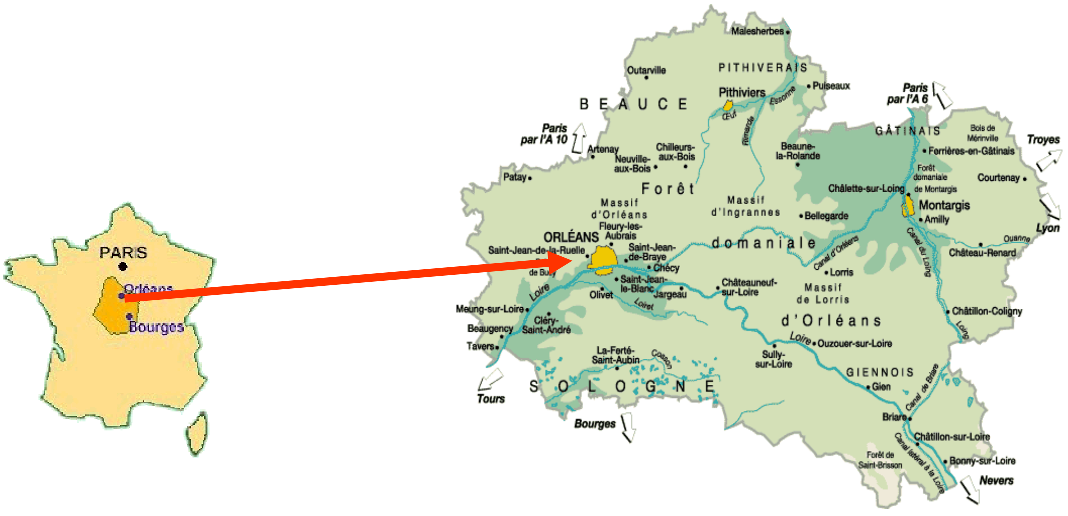


Figure 1 : Location of Orleans forest

In this study area, we set up 25 plots of 1ha with Sessile oak - Scots pine in the canopy.

We chose a pallet of plots representative of the various types of mixed stand of Sessile oaks and Scots pines (that we will call oak-pine mixed stands in the paper). We then have set up and mapped twenty six 1ha plots in order to study the spatial structure of these oak - pine mixed stands. Within each plot, we have measured the exact location of each tree (diameter>10cm) with a theodolite. For each tree located , we made a note of its species, circumference, and storey. Figure 2 illustrates one of our twenty eight cartography (plot 49), where we have the x, y coordinates of all the trees, and where different species are represented by different colours (oaks in green, Scots pines in red), and the size of the dots corresponds to different diameter classes.

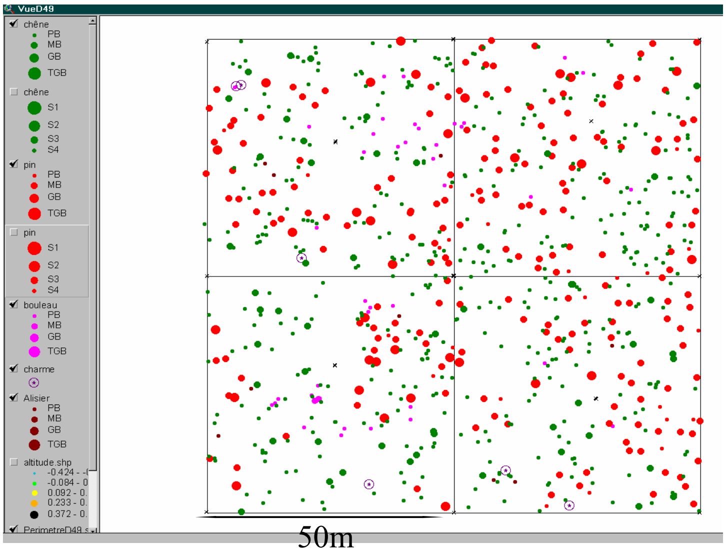


Figure 2 : Location of trees in plot 49 in Orleans forest. The different species are represented by different colours (oaks in green, Scots pines in red), and the size of the dots corresponds to different diameter classes.

In each plot we define sub-populations corresponding to trees with similar characteristics : same species same and similar layer.

This step is very important, specially in this kind of irregular and mixed stand, where individuals are so various. The aim here is to get characteristics within an homogeneous group of tree. We will illustrate this step latter, by one example (definition of sun-population in one plot).

ANALYSIS OF SPATIAL STRUCTURE

Spatial analysis

We used the classical *$K(r)$* function (Ripley 1977) to characterise the specific spatial structure of each population and *$K_{12}(r)$* intertype function (Lotwick & Silverman 1982) to characterise the structure of the interactions between populations (specially interaction between Oak and Pines). These statistical tools are powerful to characterise the spatial structure, but need to have the complete map of the area that we want to characterize. In return, these functions characterise the spatial structure of point patterns at different scales. *$K(r)$* and *$K_{12}(r)$* are more and more commonly used in ecological studies (see for summarize Batista and Maguire, 1998 and Goreaud, 2000)

The K*(r)* function is based on the average value of the number of neighbours at a distance r of any tree of the stand. This function measures tree abundance within a radius r from a focal tree, evaluated over all n trees in a plot of area A.

To determine the spatial pattern of a study region R , a circle of radius r is centered in each point (trees) of the study region and the number of points (trees) inside the circle is counted. For n points of the pattern distributed in a study region R with area A, the density $\lambda = n/A$ gives the mean number of points per unit area, assumed approximately constant through R (i.e., a homogeneous pattern). The function $\lambda K(r)$ gives the expected number of points (trees) within radius r of an arbitrary point of the pattern (trees):

λ = greek
capital L

$$\lambda K(r) = E(\text{the number of (within a circle of radius } r \text{ centered in each point))}$$

where $E()$ is the expectation operator. If the points are independent (which is the null assumption also called Completely Random Structure (CSR)), the expected value of $K(r)$ equals πr^2, i.e., the area of a circle of radius r. Thus, this null assumption depends on the spatial scale r. To remove this scale dependence of $K(r)$ and to stabilize the variance, a transformation called L-function, is used instead:

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

It follows $L(r) = 0$ for CSR, $L(r) > 0$ for clustering, whereas $L(r) < 0$ indicates regularity.

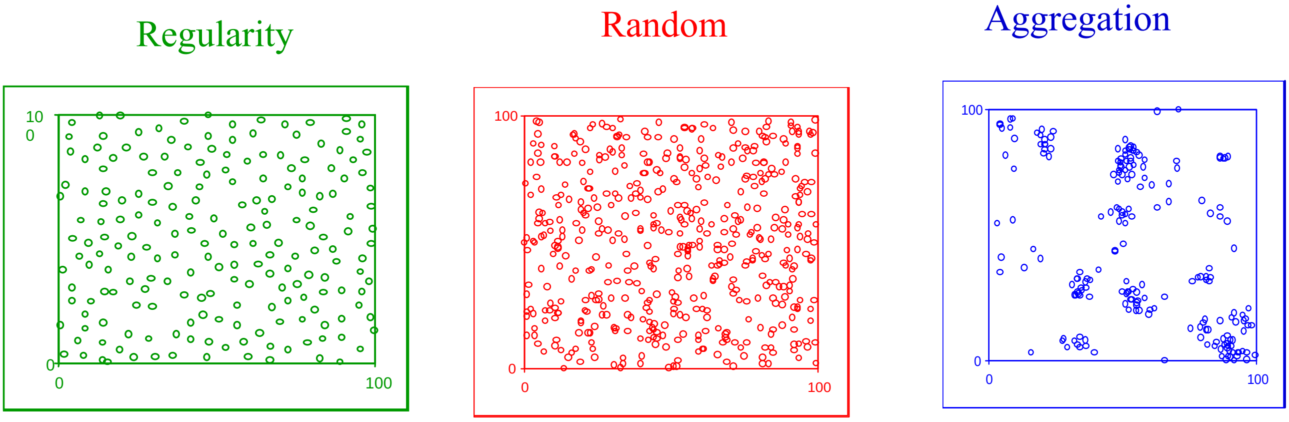
Since the classical null hypothesis is Complete Spatial Randomness (CSR) for *L(r)*, for each range r, we computed the corresponding confidence intervals with a risk α =1%, using Monte Carlo simulations. More details on the methods and programs used to estimate these functions and their confidence intervals can be found in (Goreaud & Pélissier 1999; Goreaud & Pélissier 2003).

Then, we will talk about aggregation (cluster or clump) for significant positive values (out of the confidence interval) of the *L(r)* function at different ranges *r*, regularity for significant negative values (out of the confidence interval) of the *L(r)* function at different ranges *r*. The more positive or negative (out of the confidence interval) are the values of *L(r)* , the more significant the resulting structure is. When the values of *L(r)* remain in the confidence interval, we will conclude that the structure is not differ significantly from CSR.

We also have to notice that, since the *L(r)* function characterize the spatial structure at different ranges *r*, we can emphasize the fact that the spatial structure is described at many scale or range: at small scale (range or distance) (for *r* < 10m), at medium scale (for 10m < *r* < 20m), at high scale (for *r* > 20m).

Those different spatial pattern and *L(r)* corresponding curve are illustrated in figure 3.

a



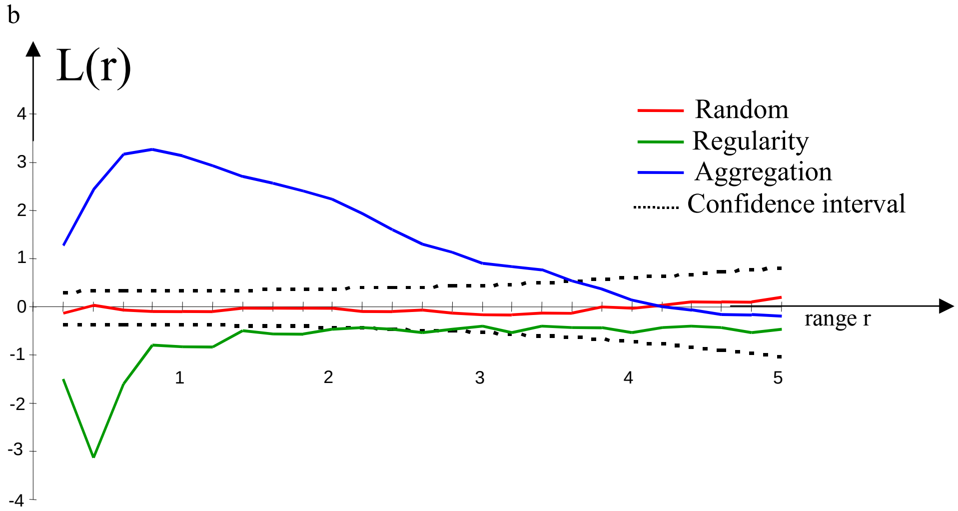


figure 3 : a : illustration of regular, random and aggegated distribution and b : corresponding *L(r)* (from Goreaud, 2000).

The $L_{12}(r)$ intertype function, which characterise the structure of the interactions between populations is based on the same principle than the *L(r)* function, for two patterns (1 and 2) occurring in a study region R. The function $L_{12}(r)$ gives the expected number of points of pattern 2 within radius *r* of an arbitrary point of pattern 1. The null hypothesis for $L_{12}(r)$ is population independence, because our three populations correspond to *a priori* different patterns. Then, for $L_{12}(r)=0$, we have an interspecific independence, for $L_{12}(r)>0$, we have an interspecific attraction, and for $L_{12}(r)<0$, we have an interspecific repulsion. The confidence interval is built the same way that previously; the spatial structure is also characterise at different range.

We then applied the *L(r)* function and $L_{12}(r)$ intertype function, for each one of our plot, to characterise the specific spatial structure of each population, and the structure of the interactions between populations, respectively. The results of this analysis will help us to define the main characteristics of the spatial structure of our mixed stand.

Developing a typology of stand spatial structure

We used a hierarchical cluster analysis (Tomassone et al 1993; Everitt 1974 in R development core team 2005) to define clusters of plots having a similar spatial structure. We focused on the structure of the trees from the canopy, which are known to play a major role in the dynamics of the stand. We considered more precisely two sub-populations : (i) oaks from the canopy, (ii) pines from the canopy.

For each plot, we considered the values of the L(r) function computed for these two sub-populations at ranges r=2,4,...,30m. We thus obtained 30 values characterising the specific spatial structure for oaks and pines in the canopy at short and long distances. We also considered the 15 values of the intertype function $L_{12}(r)$ between these two sub-populations, at ranges r=2,4,...,30m.

We then computed the matrix of spatial structure distances between all plots, using the classical Euclidean distance between the 45 values characterising the spatial structure of each plot : the square distance between two plots *i* and *j* was defined as the sum of the squares of the differences between the corresponding values of L(r) or $L_{12}(r)$ (equation 1).

$$(1) \qquad D_{i,j}^2 = \sum_{r=2}^{30}\left(L_{oak}^i(r) - L_{oak}^j(r)\right)^2 + \sum_{r=2}^{30}\left(L_{pine}^i(r) - L_{pine}^j(r)\right)^2 + \sum_{r=2}^{30}\left(L_{12}^i(r) - L_{12}^j(r)\right)^2$$

We finally applied the classical hierarchical clustering algorithm on this distance matrix, grouping together the plots whose spatial structure distances are the smallest. We therefore used the corresponding "hclust" function in R software (R development core team 2005). As the plots corresponding to one cluster have, by construction, a similar spatial structure, we interpreted the different clusters as different types in our typology.

RESULTS

spatial characteristic of oak- pine mixed stands of Orleans forest

We used the *L(r)* function and $L_{12}(r)$ to analyse the spatial structure of each sub-populations in each plot. We will first present the main results for one example (plot 12; figure 4), and after we will present the main spatial characteristics oak-pine mixed stands studied, in term of typology of spatial structure.

One example: plot 12

Plot n°12 (figure 4) corresponds to one case of mixed stand. We have in this plot mainly oak and pine.

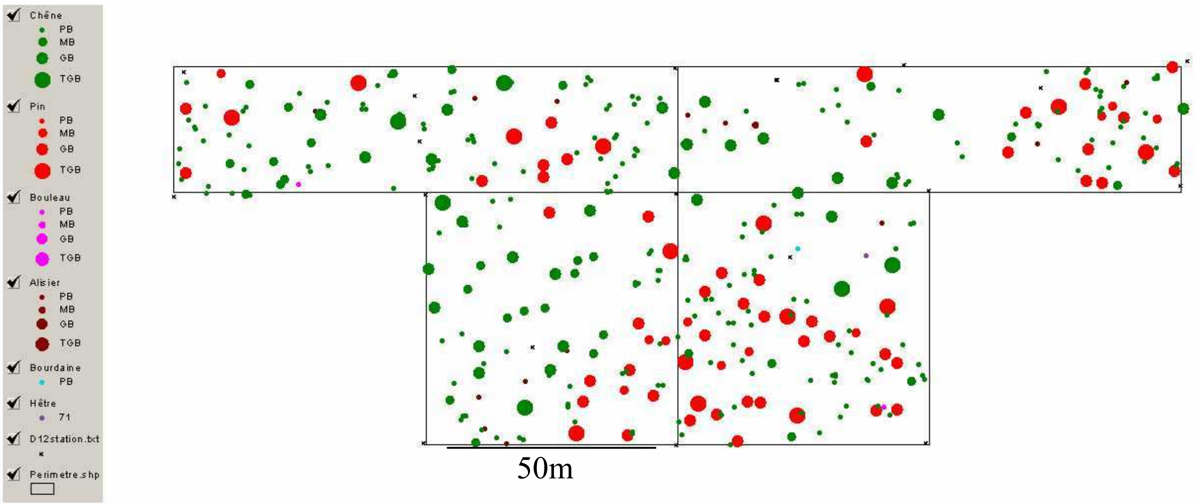


Figure 4 : Location of trees in plot 12 in Orléans forest. The different species are represented by different colours (oaks in green, Scots pines in red), and the size of the dots corresponds to different diameter classes.

Definition of sub-populations:

In this plot, we defined three sub-populations. First, as all Scots pines are in the canopy, they can be considered as one sub-population as a whole. Second, we have analysed precisely the spatial structure of oaks and have shown that it was possible to classify them in only two sub-populations, corresponding to oaks from the canopy, and oaks from the understorey, respectively. We considered that oaks from the canopy also correspond to older trees. There are very few trees of other species in this plot, so we decided to neglect them.

Spatial analysis:

we used the classical *L(r)* and *$L_{12}(r)$* function to characterise the specific spatial structure of each sub-population, and the structure of the interactions between sub-populations, respectively.

Spatial characteristics:

We present here presents the results of the analyses we made, only for oaks and pines of the canopy (Figure 5)

Scots pines and oaks of upper layers both have clumped spatial structures (significant positive values of the *L(r)* function at different ranges *r*), and present an interspecific repulsion (significant negative values of the *$L_{12}(r)$* function up to *r*=10m).

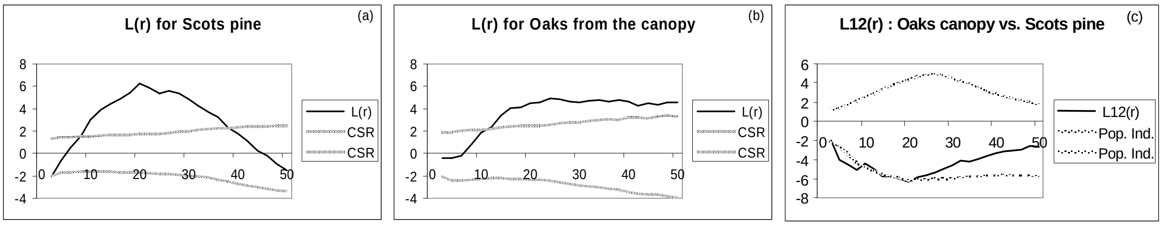


Figure 5 : Analysis of the spatial structure of plot 12 in Orléans forest : L(r) function (black line), and the corresponding confidence interval for the C.S.R. null hypothesis (grey line), for oak and pine of the canopy : (a) Scots pines, (b) oaks from the canopy. Intertype $L_{12}(r)$ function (black line), and the corresponding confidence interval for the Population Independence null hypothesis (grey line), for (c) oaks vs. Scots pines in the canopy.

Draft typology for spatial structure of our oak-pines mixed stands

We used these results of the spatial structure analysis of our 25 plots to define a typology of the spatial structure of oak-pine mixed stands. As explained in the method section, we more precisely considered the spatial structure of the sub-populations corresponding to oaks and pines in the canopy.

Figure 6 shows the dendrogram corresponding to the results of the hierarchical clustering applied to the corresponding L(r) and $L_{12}(r)$ values of our 25 plots. We can distinguish 4 very clear clusters, that we identified as 4 types for our typology. For each cluster, we analysed the

L(r) and L_{12}(r) functions of the corresponding plots, in order to characterise the spatial structure of each type. We first verified that the plots of a given cluster indeed have a similar spatial structure. When needed, we also used the dendrogram and the analysis of spatial structure to define sub-types, as detailed in the next section.

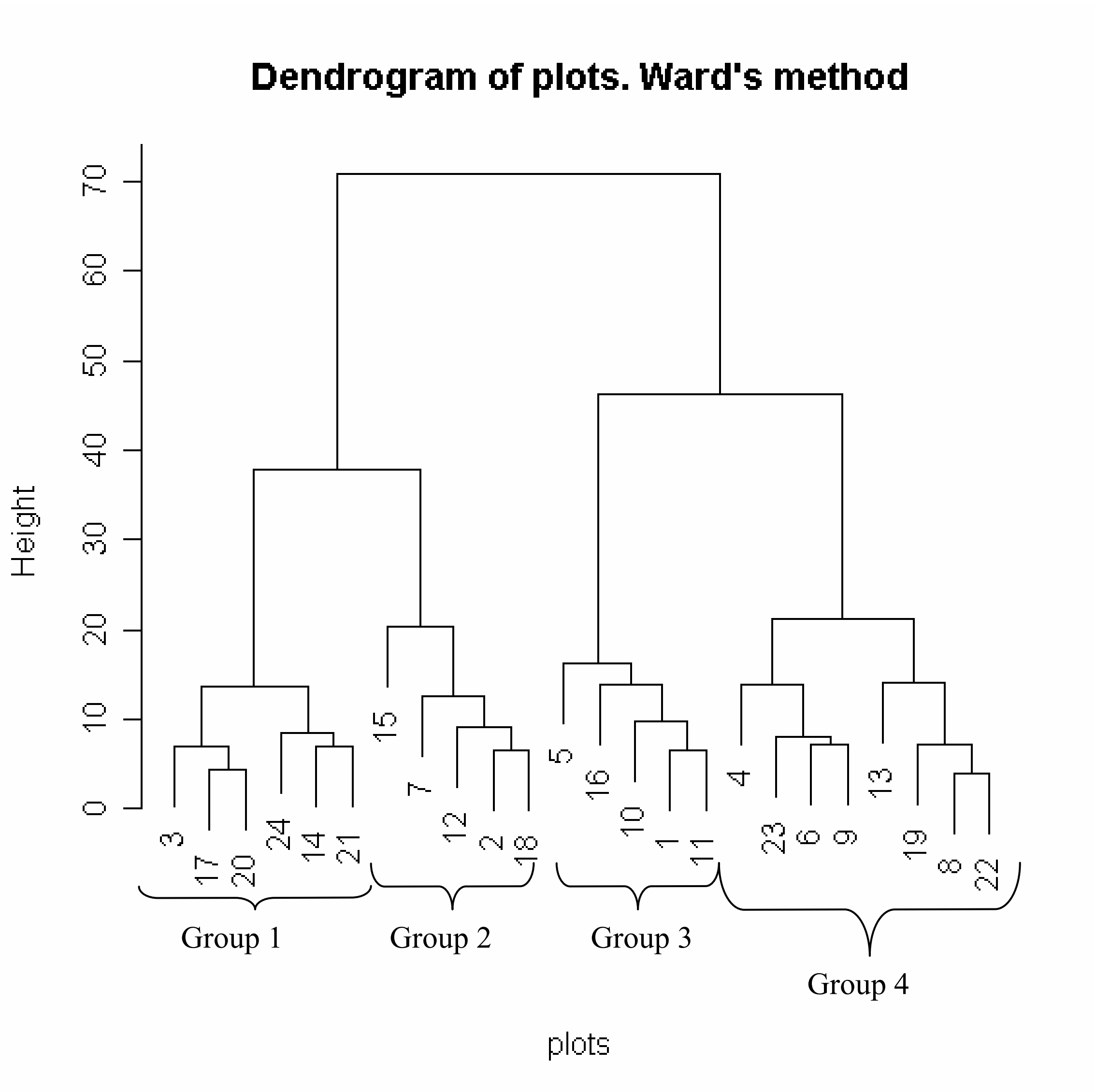


figure 6: dendrogram of plots, by ward's method. We can identify four main clusters of plots.

Spatial characteristics of the main groups of the typology

For the four group identified previously, i now present the spatial characteristics of each group. These various types highlight a kind of gradient, from random (type 1) towards strong aggregation (type 3), of the two main species, with the two others combination. The intertype structure also goes from independence (type 1) towards clear interspecific repulsion (type 3). Let us note that the spatial characteristics are only for the trees of the canopy (like in the example).

Type 1 :

The first type is characterised by a quiet similar structure for oak (figure 7a) and pines figure 7b): not differing significantly from random or slightly clustered. The two population have an intertype structure figure 7c) not different from interspecific independence, or slightly repulsive. In this type, we can subdivide the different plots into 2 sub-types; the first one where oaks and pines present a random spatial pattern , and the second one where oaks are slightly clustered, while pines have a random or a slightly clumped pattern (see the brackets in figure 7a).

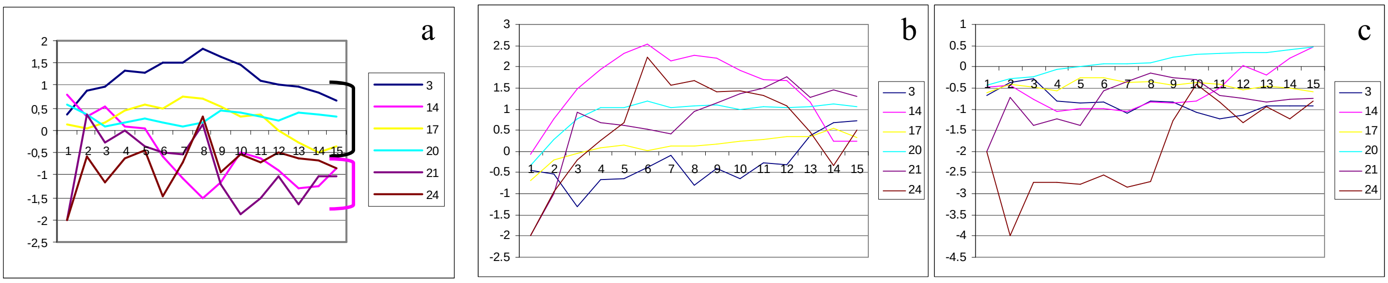


Figure 7: L(r) function for oak and pine of the canopy for type 1: (a) oaks, (b) Scots pines and (c) intertype $L_{12}(r)$ function. We can see in figure 7a the first subtype with a random structure of oaks (violet bracket) and the second type were oaks are slight clustered (black bracket).

Type 2 :

The second type is characterized by a spatial pattern more clumped than previously for oaks (figure 8a), and a slightly clumped spatial pattern for pines (figure 8b) and the two population present an interspecific repulsion (figure 8c), at small scale.

We notice that compared to the first type, oaks have a spatial pattern more significantly clustered.

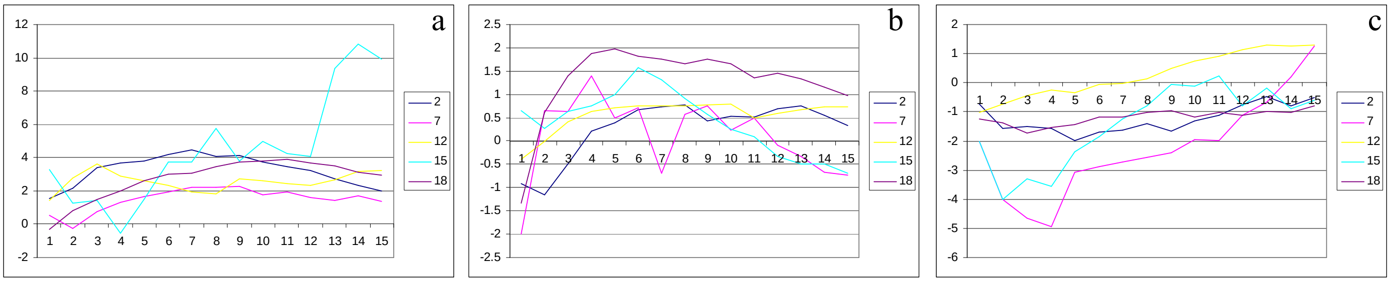


Figure 8: L(r) function for oak and pine of the canopy for type 2: (a) oaks, (b) Scots pines and (c) intertype $L_{12}(r)$ function.

Type 3 :

The third is characterized by clustered pattern of oaks (figure 9a) and pines (figure 9b), also more significantly than previously. The intertype structure is characterized by an interspecific repulsion, at small and middle scale (figure 9c). Compared to the two first types, we see a spatial structure more clustered, and a repulsion more significant.

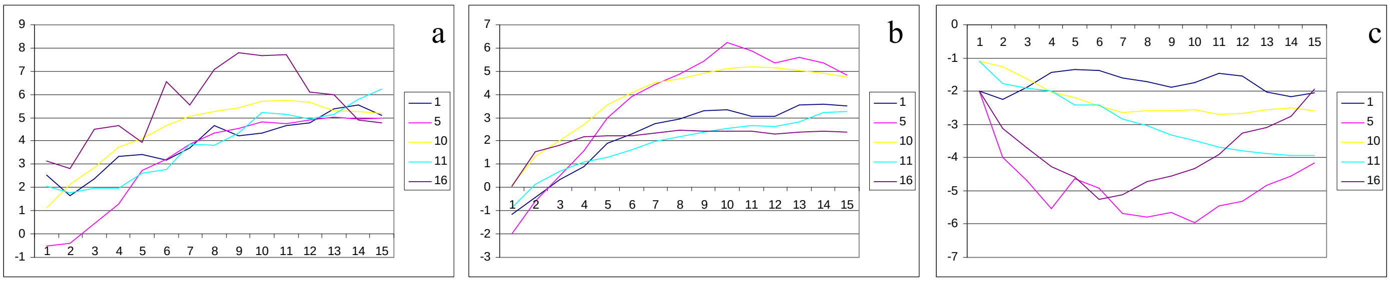


Figure 9: L(r) function for oak and pine of the canopy for type 3: (a) oaks, (b) Scots pines and (c) intertype $L_{12}(r)$ function.

Type 4 :

The fourth type is characterize by a slight aggregation of oak, and a strong aggregation of pines.The two population show an intertype structure of independence, or a tendency toward repulsion. In this type, we have a first sub-type of plot were oaks present an aggregated pattern at small scale, and are in an interspecific repulsion with pines; a second sub-type where oaks present an aggregated pattern also, but at larger scale and an interspecific repulsion more slight, an even independence.

The difference with the previous type is the slight aggregation of oak, while pines always have a significant aggregation.

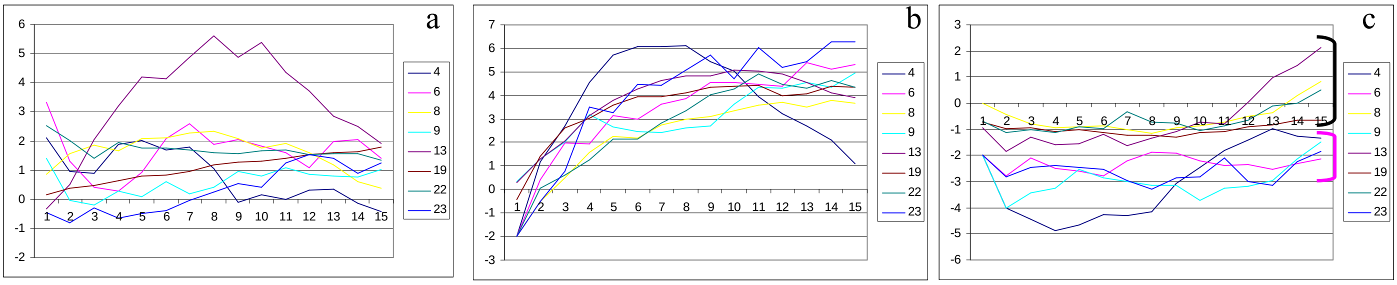


Figure 10: L(r) function for oak and pine of the canopy for type 4: (a) oaks, (b) Scots pines and (c) intertype $L_{12}(r)$ function. We can see in figure 10c the first subtype with independence or slight repulsion between oaks and pines (black bracket) and the second type were were the repulsion is more significative (violet bracket).

INTERPRETATIONS OF RESULTS

The analysis of spatial structure of oak-pine mixed stand leads us to reveal two main characteristics of these stand. First, aggregation is the most common structure. Second, there is a high variability in the spatial structure of our stand, and precisely a gradient from random structure (type 1) to strong aggregation.

These spatial characteristics of the stand can help us to better understand the processes ecological and anthropic that have influenced the dynamic of ecosystem. Many studies have been used spatial analyses in order to characterise the structure of different populations, and to infer from spatial patterns some information on ecological processes that play a part on the dynamic of studied stands. (for example Moeur 1993; Barot et al. 1999; Goreaud 2000, Moeur, 1997 ; Batista and Maguire, 1998 ; Barot et al., 1999 ; Hoshino et al., 2001 and 2002 ; Goreaud et al., 2002 ; Park, 2003, zenner et al., 2000, Szwagrzyk, 1991). Indeed, the present spatial structure of a stand is the result of different processes that lead to death of older trees and birth of regeneration at a given position. For instance, regeneration of species with heavy seeds is virtually considered to induce aggregates, whereas competition for light or soil nutriments is considered to induce regularity and interspecific repulsion (see goreaud et al., 2002.)

However, as we are in managed stands, we can hypothese that the main factor influencing the spatial structure is past management of the stand. Indeed, the Orleans forest is a former oak grove, deforested by excessive cutting at the end of the ten eighth century . Later (between 1870 and 1890), gaps were filled with Scots pine, owing to its adaptation to difficult climate and soil's conditions. Thus, at the end of this period, we can assumed that the spatial structure was mainly characterized by aggregates of oak and pine, in interspecific repulsion. This spatial structure can still be found in our actual mixed stand, specially on the third type.

For both oak and pine, the presence of more or less aggregated patterns, and the fact that regularity is rare, lead us to assume that intraspecific competition is not the main fator of the stand's dynamics; and that anthropic thinning are not too intense. This last point can be connected to the fact that there are nor clear guidelines for thinning in these mixed stand.

We can assume that these aggregated structures are also the results of a localized regeneration. Indeed, regeneration in our stand (and more generally in mixed stands broad-leaved / coniferous trees) is known to be widely influenced by quantity of light, which leads to installation of aggregate within gap (Mosandl et al., 1998; Hoshino et al., 2001, 2002 and 2003; Park, 2003; Paluch et al.,2004). Cluster may also be explained by the weak dispersion of seed for some species (Menaut et al., 1990; Collinet, 1997; barot et al.,1999) particularly in this case sessile oak. Thus, seedling are found in cluster around mother's tree.

The interspecific spatial structure is sometimes independence, and sometimes repulsion. We therefore make the hypothesis that the interspecific competition is high in some plots (type 2), and medium in others plots.

The interspecific interaction can have a high influence on regeneration. we can remark that: (i) we can found oak's regeneration under a canopy of pine, (ii) but very rarely the opposite (pine's regeneration is generally rare under shelter), (iii) in certains plots, no oak's regeneration is to be found under pines. These remarks are recurrent in many studies about mixed stands broad-leaved / coniferous trees (Mosandl and Kleinart, 1998; Hiura and Fujiwara, 1999; Lookingbill et al., 2000; Takahashi et al., 2003; Paluch et al., 2004).

We can therefore imagine that, when oak can regenerate under pines, the spatial structure will evolve towards less aggregation and less interspecific repulsion (types 1 and 4), whereas when no oak regeneration can occur under pines, the spatial structure will remain aggregate in repulsion.

This difference of spatial structure from a type to another could be explained by difference in soil conditions. Soil's heterogeneity have a great influence on regeneration and dynamics of stand, by creating area favourable or not at the growth of individuals. Soil's heterogeneity is often outcome of a spatial distribution of resources in soil. it thus results from it favourable zone, where we will find aggregates, and less or not favourable zone which will be more or less empty (Barot et al., 1999).

It happens also that one species use an environmental resources better than another one (ecological niche's theory, Hutchinson, 1957 in Begon et *al.*, 1990). This could be the case in our mixed stand, broad-leaved / coniferous trees not having the same requirements. It results from it a structure with aggregates which aggregates of the two species in repulsion.

DISCUSSION

In this paper, we show how spatial structure analysis can be used to improve our knowledge of heterogeneous stand; and more precisely of oak-pine mixed stands. We used spatial structure at two important steps. First, when we built a typology with four types of spatial structure, that helped us to describe these stands. Second, when we used the general observed spatial structure to link the present structure with the history of the stand, and to make hypotheses about ecological processes which influence the dynamics of these stands.

Our study is applied to a mixed Oak - Scots pine forest, but the method described in this paper can of course be used in any other context where a simulation of realistic point patterns is needed.

Interest and limit of such a typology

Such a typology appears to be very important, because a precise description allow forest manager to make some forestry guidelines, and to adjust it according to the different types identified. In the context of need of knowledge about heterogeneous stand, this approach, based on spatial structure, supply a clear description of mixed stand, which is a preliminary condition for an appropriate management.

This approach depends of course of the number of plots used to build the typology. We could ask our self some questions about the representative character of our typology. To evaluate it, we are thinking of doing some cartographies in other oak-pines mixed stand (and may be out of Orleans forest), to compare the found structure at our typology, and may be, to highlight another type.

This approach also depends on the variable that we used to build the typology. In our case, we used the spatial structure of oaks and pines of the canopy. It will be interesting to see the influence of the spatial structure of the understorey on our typology, and if necessary to give different importance to those two variables (and may be another) in the hierarchical clustering.

From typology to a model of spatial structure.

A typology based on spatial structure can be a first step to build a model of structure for each of our type, that can simulate virtual stand. A model of structure set of rule (about size structure, mixing, spatial structure…), that allow to build a virtual stand, from data at stand level. The method consist: (i)to characterize the spatial structure of real stand, (ii) to simulate a similar virtual stand, by expertise or by mimetic processes (using point process). Point process are statistical tools that allow to generate a point pattern. There is a lot of bibliography about characteristics and use of point pattern (for example Diggle, 1983, Goreaud et *al.*, 2004).

Forest modellers thought to use virtual stands, to replace these inaccessible data. The principle of virtual stands is: when we want to manipulate a forest stand, but we don't know with precision individual data about trees (species, position…), we can virtually estimate a list of trees, to which we allocate some individuals characteristics, by respecting some rule so that the virtual stand is closest to the real stand. Since we have individual data for each of our types, we will be able to simulate realistic complex patterns similar to real patterns measured in forest stands.

Use of such a model of spatial structure will consist to characterise at stand level a real oak-pine mixed stand, to link the real stand to one of our type, and to simulate the similar virtual stand, that could be manipulate instead of the real stand.

Interest of using realistic virtual stand.

Such a virtual stand could be used as initial state, for the use of an individual based model. Indeed, an accurate estimation of the evolution of these stands need the use of individual based models. But, this kind of models need as initial state of the simulation at the individual level, with the location and characteristics of all stems. However, such data are very expensive. Precise measurement of location of plants requires a huge amount of work, an is not always possible, especially when considering a large area. Then, it will be possible to use the realistic virtual stand, and to have the evolution of the corresponding real stand.

Work with realistic virtual stand is very important, because many studies have shown that the dynamics of a plant community can be very dependant on its spatial structure, especially in case of mixed species (e.g. Begon et al. 1990; Dieckmann et al. 2000; Goreaud et al., 2002). Thus, using unrealistic structure as initial state of a simulation with a spatially explicit individual based model can often bring to unrealistic simulation results. Which such a realistic model of spatial structure, it will be possible to have an accurate estimation of the evolution and the production of a forest stand, with the used of the appropriate individual based model.

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