SPATIAL PATTERN AND CONNECTION OF TREE DIAMETER CLASSES IN *PINUS HALEPENSIS* M. STANDS AFTER WILDFIRE

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EXTENDED ABSTRACT

Pinus halepensis M. is an exclusively Mediterranean species met in extensive stands in the evergreen-broadleaves zone where this species finds the optimum of its development. The regeneration and maintenance of these stands are influenced by the wildfires, which are a decisive factor for *P. halepensis* spread. The natural regeneration of the stands will be continuous and principally utilized for their renewal and improvement. The spatial pattern of the trees after the wildfire plays an important role to the structure and treatment of these stands. In this paper the methods for the estimation of spatial pattern and connection among diameter classes of *P.halepensis* trees are given.

The research was conducted in the forest area of the Kassandra Peninsula, Chalkidiki, and North Greece. The area is covered by the species *P. halepensis*. The trees had a diameter ranged from 4 to over 50 cm. The stands are mainly even-aged, whereas their management is based on a multiple uses frame. A representative sample of 49 plots of 0.05 ha was taken and the number and diameters of the trees in each plot were measured. The trees were then classified into five classes that could seem to be of interest for forest management.

The density and frequency of tree diameter classes, which provide the basic characteristics of spatial dispersion, were estimated. In studying spatial patterns, the plant ecologists have generally identified three distinct spatial patterns: random, aggregated and regular. For the characterisation of the spatial pattern of the trees in each diameter class, the Index of Dispersion (ID) was estimated and the null hypothesis of the spatial randomness was tested. Furthermore, the bootstrap distribution of the ID was estimated. The spatial dependence among the diameter classes was tested by the X^2 distribution. The test of the spatial randomness showed that the spatial pattern of the trees is aggregated. The findings show also that the *P. halepensis* like most trees after disturbance grows again in aggregated or clumped pattern. This initial, clumped pattern is caused by the seed dispersal, which results in a spatial pattern of advanced regeneration, suitable seedbeds for germination, competition from other plant species, mainly shrubs, and other factors. However, as the stands develop, a characteristic spatial pattern emerges as a result of intraspecies competition. Consequently, even though the stand begins in a strong clumped arrangement, later the component trees become more regularly spaced with age as the trees differentiate and as a consequence disturbances destroy some of them. By the time they reach the mature stage, the number of trees has become so reduced that they are relatively randomly or evenly distributed.

Key words: aggregated pattern, bootstrap estimate, index of dispersion, stand structure.

1. INTRODUCTION

Spatial patterns of trees are important characteristics of forests and can be used for estimating stand structure and the influence of silvicultural manipulation on the stand conditions, analyzing forest dynamics and identifying biological relationships between tree species such as competition [1],[2],[3]. Spatial tree pattern is also important for taking the appropriate management measures in each stand. The incorporation of spatial information into ecosystems analyses is a major challenge in the fields of forestry, ecology and forest management [4]. However, spatial studies of forest structure have focused on the descriptions of trees stems, which comprise with the dominant ecosystem element.

Spatial pattern does not remain constant but changes with the succession stage of the forest following a disturbance, which is a pervasive feature of forests. Natural disturbances are an integral part of ecosystems, and more often than not, are agents of renewal rather than destruction; thus, they comprise with an important factor of succession in forest ecosystems [5],[6]. Fire is the most common disturbance in a wide variety of forest ecosystem types and affects their dynamic and productivity [7], [8].

Generally, the vegetation of the Mediterranean forest ecosystems, after fire disturbance follows a secondary succession pattern [9],[10]. *P. halepensis* is Mediterranean conifer, with the above-mentioned attribute, which form extensive forests in the Mediterranean Basin. The investigation of the vegetation evolution and the postfire dynamics of Mediterranean forest ecosystems has been already studied in many cases [11] and it is usually focused on the early postfire regeneration; this happen because in this zone wildfires are an integral factor for these ecosystems and they make *P. halepensis* more competitive against the rich shrubby vegetation of exceptionally flammable species composing its understorey [7] So, the stand structure of the forest ecosystems in this region is affected by wildfire, but, only few data are available concerning this structure [12],[10]. Especially, there is still a scarcity of data concerning spatial pattern of these ecosystems.

The aim of this work is the study of the spatial pattern and the connection among diameter classes of trees in *P. halepensis* mature stands, naturally established after wildfires. The ultimate goal is the evaluation of current stand structure that can be used for taking the appropriate silvicultural measures according to the management purpose.

2. MATERIALS AND METHODS

2.1. Site description

The region of Kassandra Peninsula was selected for studying the *P. halepensis* tree spatial pattern because this species reaches its optimal growth in this region [7] and forms striking beauty forests which must be conserved.

The research was conducted at the state and community forests of the Kassandra Peninsula which locates 60 Km south-eastern of Thessaloniki and it occupies an area of about 35.000 ha. According to the climatic data of the meteorological station of the Forest Service in Kassandra (1978-1997) the mean annual rail fall is 581 mm while the mean annual temperature goes up to 16.3^{o} C (mean max. 30.1^{o} C, mean min 4.6^{o} C) [13]. The vegetation of the area consists of the characteristics Mediterranean florist components, where the *P. halepensis* dominates. It belongs to the Quercetalia ilicis zone.

Petrologically it shows a relative homogeneity since the dominant rocks are marls, cobble sand, and marl limestone.

2.2. Methods

A representative sample of 49 plots was taken and the number of trees X in each plot was counted and their diameter in b.h. was measured. The trees were classified into five classes assuming that this classification is interesting for the estimation of tree spatial pattern and the association of diameter classes in the plots. The density D, is set as the number of trees per plot unit and the frequency f as the proportion of the plots in which there is at least one tree.

A population is said to be distributed at random if the relative location of an individual object is independent of the location of any other object within an indefinitely large area [14]. Under the null hypothesis of the randomly distributed trees, the variable X has a Poisson distribution and the $Var(X)=E(X)$, where $E(X)$ the expected value of X. In the alternative cases when the trees are distributed in patches, it would be expected $Var(X)>E(X)$, while for a more uniform pattern $Var(X)<E(X)$ [15]. The index of dispersion ID is set as the quotient of the variance to the mean [14], [16] with a variance depend on the spatial distribution of trees and it may be used for the characterisation of the spatial pattern of trees. The estimator (n-1) ID under the null hypothesis, has an approximately chi-square distribution with n-1 degrees of freedom [17] and the confidence intervals for the ID can be constructed.

The test of the spatial association (dependence) between two diameter classes is based on the presence or absence of the classes in the plots and can be done by the chi-square distribution. The density, the frequency and the index of dispersion of diameter classes of trees were calculated. The null hypothesis of the spatial randomness and the independence among the diameter classes were also tested. Next, the plots were considered as a representative sample of the study area and the confidence intervals of ID were estimated with the bootstrap method [18], [19]. Non-parametric methods were used because the sampling pattern of ID is unknown.

3. RESULTS

A total number of 1412 trees was measured in the plots and classified in five diameter classes. Data analyses showed that the trees were widely distributed among the diameter classes (Table 1). However, the greater number of trees were concentrated in the classes of 21-35 cm (class III) followed by the class of 11-20 cm (class II), while in the V class (D over 50 cm) only a small number of trees was found. There is a great range of percentage variability; this was low in the crowded classes (III, IV and II) with values 56%, 79% and 95% respectively. On the contrary, it was very high in the class V (215%) and in the class I (164%).

Table 1: Summary statistics for the five diameter classes.

Diameter classes	Number of trees	Minimum of tree number per plot	1st Quartile	Mean	3rd Quartile	Maximum of tree number per plot	Standard Deviation
4-10	114	0	0	2.327	3	22	3.84
11-20	429	0	2	8.755	13	41	8.33
21-35	614	0	7	12.531	17	28	6.98
36-50	202	0	1	4.122	7	11	3.35
>50	53	0	0	1.082	1	10	2.32

Analyzing the values of index of dispersion (ID), as it is shown in Table 2, these are outside the confidence interval, which was computed as (0.6407, 1.4380, p=0.95). Thus, the null hypothesis of complete spatial randomness was rejected for all the five classes. The ID was in all cases over the upper limit (ID>1.4380), which means that the spatial pattern in the studied stands is aggregated or clumped, which ought to the postfire regeneration of *P. halepensis*. The index takes greater values in the small diameter classes and it decreased as the diameter increases except for the V class where its value is high meaning that there is a stronger trait for aggregation for the small diameter classes that the bigger ones. The strong aggregation of the young stands is reduced by the time because of the regular mortality appearing during the stand developmental stage due to intraspecies competition [7]. The exception of the high ID value in the V class is probably due to the fact that there are two district areas of forest stands in the study area. The first where large trees (d>50cm) appear covering a relatively small area (15 plots), and stands where not large trees exist (34 plots).

Table 2: Estimates of frequency, density and their standard errors, index of dispersion estimate and decision for null hypothesis.

Diameter classes	Frequency* *(f)*	Standard Error of *(f)*	Density *D*	Standard Error of *D*	Index of Dispersion**	Decision for null Hypothesis
4-10	0.571	0.010	2.327	0.548	6.329	reject
11-20	0.959	0.004	8.755	1.191	7.927	reject
21-35	0.980	0.003	12.531	0.997	3.888	reject
36-50	0.796	0.008	4.122	0.478	2.715	reject
>50	0.286	0.009	1.082	0.331	4.963	reject

* The proportion of the plots in which there is at least one tree
** ID>1 indicates an aggregated pattern, ID=1 indicates a random pattern and ID<1 indicates a regular pattern.

According to the statistics presented in Table 3, which shows the values of chi-square distribution with one degree of freedom, the diameter classes of trees were in general found to appear independently each other. However, this was not true for the classes II and III, which found to be closely connected. This connection can be explained by the strong relationship of the two classes in many forest stands. Usually, most of the trees of the two classes (II and III) are of the same age and the diameter differences between the trees are due to the trees differentiation as a result of the strong intraspecies competition, the microsites differences in soil fertility and the heredity of tree individual.

Table 3: Values of statistic X^2, for testing association between pairs of diameter classes[1]

Diameter classes	I	II	III	IV	V
I	-	0.8797	0.0213	3.5813	0.1021
II		-	5.4978*	0.0271	2.2024
III			-	0.5503	0.2297
IV				-	3.4210
V					-

[1] Classes: I=4-10 cm, II=11-20, III=21-35, IV=36-50 and V=>50 cm.
* There is a statistical dependence between the two diameter classes.

The bootstrap estimate of ID pattern is shown in Table 4. In all diameter classes the estimate of |bias/SE|<0.25; therefore, the bias estimate could be ignored [18]. The empirical percentiles are the ones of the bootstrap distribution. The BCa are bias-corrected and adjusted percentiles. Because the lower limits of bootstrap intervals are greater than the value 1.4380 the performance of chi-square test is good.

Table 4: Bootstrap* results for the estimate of Index of Dispersion.

Diameter classes	Observed value	Bias	Standard error (SE)	Bias/SE	Confidence intervals (95%)	
					Empirical	BCa
4-10	6.329	-0.406	2.266	0.179	2.686-10.372	3.072-12.495
11-20	7.926	-0.236	2.021	0.117	4.165-11.856	4.940-13.498
21-35	3.887	-0.065	0.638	0.102	2.633-5.109	2.807-5.384
36-50	2.715	-0.030	0.385	0.078	1.987-3.497	2.070-3.592
>50	4.963	-0.197	0.950	0.207	2.722-6.472	3.300-6.937

*B = 5,000 bootstrap replications.

4. DISCUSSION

From the findings of this study it seems that the *P. halepensis* like most trees after disturbance grows again in aggregated, or clumped, pattern with some areas containing no individuals [5]. This initial, clumped, pattern is caused by the seed dispersal, which results in a spatial pattern of advance regeneration, suitable seedbeds for germination, competition from other plant species, mainly shrubs, and other factors. In particular, non-uniform sites allow many stems to become established in an unevenly spatial pattern. However, as the stands develop, a characteristic spatial pattern emerges as a result of intraspecies competition. More soil area is encompassed by the roots as the seedlings grow and differences in very small-scale microsites become less important heredity [6]. Consequently, even though the stand begins in a strong clumped arrangement, later the component trees become more regularly spaced with age as the trees differentiate and as a consequence disturbances destroy some of them. By the time they reach the mature stage, the number of trees has become so reduced that they are relatively randomly or evenly distributed [6]. This pattern is precisely followed by all the *P. halepensis* stands in the study area with only one exception; this concerns the class with a diameter over 50 cm, which does not follow the above pattern as it exhibits a high dispersion index. This can be attributed mainly to the fact that there were two categories of plots; the first one, where some trees of the V class were recorded (15 plots) and plots where no trees of the above class were found (34 plots). Thus, the study area can be divided into areas where there were large trees, which means that in these areas the forest stands are quite old (over 100 years) and they have not been suffered from wildfires for a long time and comprise a relative small part of the area. While the remaining areas consist of younger *P. halepensis* stands as a result of wildfires.

Previous studies concerning other forest tree species have found that tree species were distributed randomly [20], [21] or aggregated [4],[3] depending on several factors as well as on the spatial scale.

Concerning the connection between the tree classes, it seems that trees of a class are usually aggregated rather than regularly distributed throughout the stand [6], but they are not strongly connected with the presence of the trees of a specific class. Actually, in many cases they are closely intermingled with the other classes but this happens probably in a random way, thus no connection between the classes was revealed. The only connection found was between classes II and III, and it can be attributed to the tree differentiation; both classes belong in the pole stand stage, according to silvicultural classification [11].

Implication to silviculture and management of the stands
This aggregated tree pattern is attributed to the way of *P. halepensis* postfire regeneration and affects stand structure. From the silvicultural point of view, the pattern of initiation has an effect on the stem quality of individuals despite the bad stem form by which the *P. halepensis* is usually characterized. The desirable structures in many pure stands have been caused by the wide range of tree ages and uneven spacing of stems while often a desirable spatial pattern can be created by manipulating conditions in the previous stand before it is removed.

Forest tending can use the above knowledge aiming at the creation of a more uniform tree spatial pattern in order to better exploit the site productivity. Otherwise, it has to be considered that this aggregation plays an important role in the high aesthetic values and scenic beauty of these forests. In the area of Kassandra, the young to middle-aged stands are not being cultivated. The cultivation should be included in the management plans, aiming for the creation of even- aged stands or group selective ones with regular succession of ages. Taking into account that the *P. halepensis* forests extend in Mediterranean areas with high touristic interesting this structure seems to be attractive to the people and contributes to its high value. So, a monitoring system for various important factors will be established including the evolution of forest ecosystems and their connection to the demands of people visiting the area. This stand structure with high spatial variability is also beneficial as habitats for wildlife. Thus, when a forest is burnt the natural process of regeneration should be enhanced since the anticipated future stand structure will satisfy the silvicultural and management goals. These goals are the development of a biological healthy forest, ecological exploited for multiple uses such as wood production, outdoor recreation, soil protection, improvement of hydrological cycle, resin production and apiculture [10], then this structure should be preferred.

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