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Natural regeneration, demographic and spatial structure of *Lophira lanceolata* (Ochnaceae) populations in Côte d'Ivoire

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Abstract

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The dynamics of particular woody species in the savannah zone of Côte d'Ivoire are strongly influenced by anthropogenic pressure, which compromises their sustainability. One such species is *Lophira lanceolata*, which has high socio-economic and ecological potential, but has received little research attention. This study aimed to analyse the demographic and spatial structure as well as the regeneration potential of *Lophira lanceolata* in three agro-ecological zones of the savannah in Côte d'Ivoire. The collected data included individual geographic coordinates, tree density, basal area and regeneration information. The results indicated that Kouassi-N'Dawa (87 ± 17 seedlings/ha) and Patizia (90 ± 19 seedlings/ha) exhibited higher levels of regeneration. The inverted J-shaped structure (decreasing distribution of diameter classes) observed in Kouassi-N'Dawa, and the right-skewed structure (predominance of small-diameter trees) observed in Patizia and Pouniakélé, suggest significant pressure on the populations under study. The spatial distribution pattern of this species varies considerably depending on the observation distance within and between sites. It has been demonstrated that human activities substantially impact the availability of tree resources and the planning of spatial areas. The findings of this study highlight the vulnerability of these resources and emphasise the need for appropriate management measures to be implemented.

Keywords: dwarf red ironwood, ecological characterisation, population dynamics, savannah.

INTRODUCTION

The tropical ecosystems of West Africa, particularly the savannahs, are characterised by high biodiversity and the provision of vital ecosystem services. They play a pivotal role in the survival of numerous human communities. Local communities rely on a variety of resources for their livelihoods, healthcare, materials for handicrafts, housing, and cultural practices. However, as a consequence of the exploitation of natural ecosystems, these environments are experiencing accelerated degradation due to various anthropogenic pressures, including agriculture, logging, mining and urbanisation. Natural phenomena such as floods and droughts also contribute to the degradation of these ecosystems. These factors compromise the natural regeneration of woody species and the sustainability of forest stands, thereby weakening the ecological resilience of these ecosystems (Huarez et al., 2024). In Côte d'Ivoire, savannahs are the most extensive terrestrial ecosystems, covering around two-thirds of the country (Sombo et al., 1995). These plant formations are distinguished by their endemic tree species, providing a scientific basis for specific conservation measures. One characteristic species of woody plant found in the savannahs is *Lophira lanceolata* (dwarf red ironwood or savannah azobé). Its wood is highly prized for use in construction, toolmaking and charcoal production, while its seeds are used in the production of traditional edible oil. Furthermore, it is utilised for its health, pharmacological and cosmetic value (Lotchio et al., 2022). This species, which is sometimes gregarious (Eyog-Matig et al., 2006), plays a crucial role in structuring stands and stabilising soils (Lankoandé et al., 2017).

Lophira lanceolata is overexploited due to its multiple uses, despite being classified as 'Least Concern' in the Red List of Threatened Species (IUCN, 2020). Although this species is important, knowledge of its regeneration processes and demographic structure remains limited, particularly in Côte d'Ivoire, where there is a lack of scientific data. This information is indispensable for evaluating the status of populations. Natural regeneration has been shown to reflect the balance between germination, growth, and recruitment phases (Hanbury-Brown et al., 2022), while demographic structure has been demonstrated to provide information on diameter or height class distribution (Abdourhamane et al., 2017). Ouédraogo et al. (2006) posit that demographic structure models (inverted J-shaped, right-skewed, left-skewed, exponentially increasing and normal) can be used to analyse rejuvenation or ageing dynamics in a population, as well as disturbances or insufficient recruitment. Studies in Côte d'Ivoire focusing on savannah species, including *Pterocarpus erinaceus* (Goba et al., 2019) and *Khaya senegalensis* (Taonda et al., 2023), have demonstrated the effectiveness of this method in assessing the state of natural regeneration and recruitment. Furthermore, the spatial distribution of individuals within a stand provides insight into ecological interactions, including intraspecific and interspecific competition as well as seed dispersal patterns (Goreaud, 2000). Several studies (Diouf et al., 2010; Fonton et al., 2012; Abdourhamane et al., 2017) have demonstrated the suitability of Ripley's method (1977) for characterising the spatial structure of woody stands. This method analyses the relationships between cohorts (young and adult), reflecting the biological interactions that determine the spatial organisation of a stand. However, these patterns can be significantly impacted by human disturbances and local environmental conditions (Abdourhamane et al., 2017; Ganka et al., 2023).

The lack of integrated studies on the regeneration, demography and spatial distribution of *Lophira lanceolata* hinders the implementation of recommendations. This study aimed to assess the regeneration, demographic and spatial structure of natural *Lophira lanceolata* populations in three locations in Côte d'Ivoire. Specifically, the study sought to answer the following questions: (a) What are the dendrometric parameters and state of regeneration of *Lophira lanceolata* in the different study areas? (b) How are diameter classes distributed within the population, and what are the resulting profiles? (c) What is the spatial configuration of individuals at different scales, and what are the resulting ecological implications?

MATERIALS AND METHODS

Study sites

The study was conducted at three savannah sites in Côte d'Ivoire, namely Patizia, Kouassi-N'Dawa and Pouniakélé, which are located from south to north (Fig. 1). All three sites are characterised by tropical ferruginous soils.

The Patizia site is situated in the Bouaflé department, in the Guinean savannah characterised by a Baoulean climate, which is typical of an attenuated transitional equatorial regime, with rainfall ranging from 1200 to 1600 mm (Kouassi et al., 2021). This climate is characterised by two rainy seasons and two dry seasons, with humidity levels ranging from 60% to 70% (Goula, 2007). The mean annual temperature in this region is 26°C (Assoko, 2022). The site is a community savannah that does not benefit from formal management and is subject to annual bushfires. The site is located on a range of hills where small streams are present. Anthropic activities in this locality include agriculture (cocoa, cashew nuts, palm, etc.) and gold panning.

The Kouassi-N'Dawa site, situated in the Bondoukou department of the sub-Sudanese savannah, is distinguished by an annual rainfall of less than

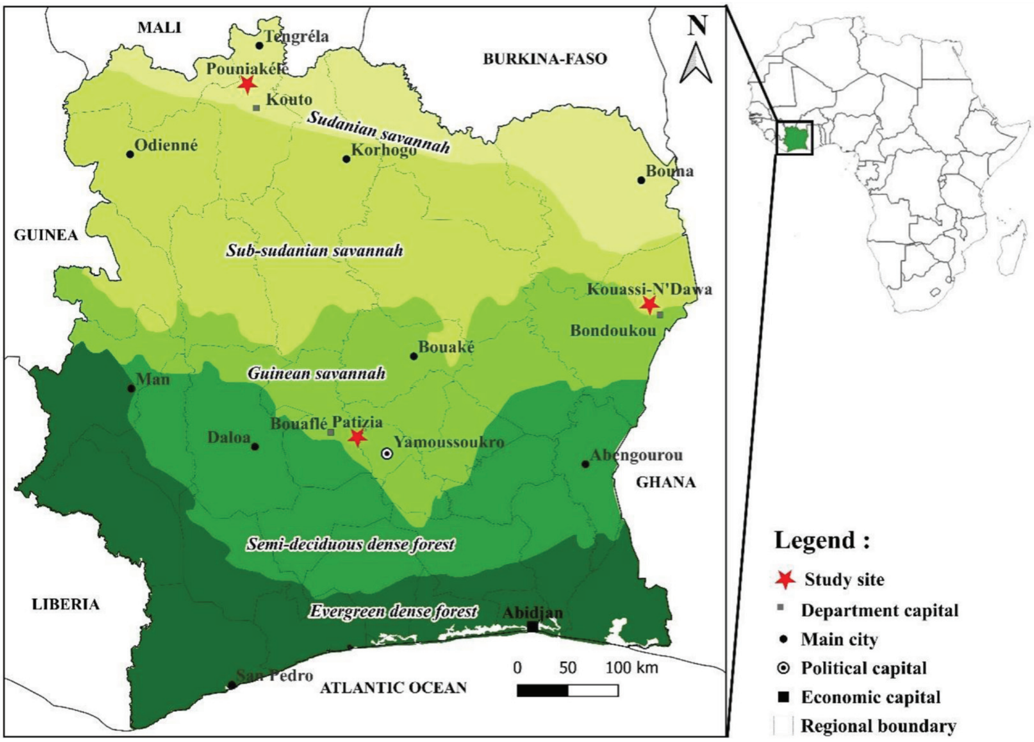

Fig. 1. The location of the three study sites in Côte d'Ivoire.

1300 mm (Kouassi et al., 2022) and an average temperature of 27°C (Ouattara et al., 2016). The site is characterised by an anthropomorphised community of the savannah. Agricultural exploitations, including the cultivation of cashew nuts and yams as well as gold panning, dominate the landscape. Annual bushfires are an occurrence. The topography of the Kouassi-N'Dawa site is characterised by a plateau.

The Pouniakélé site, located in the Kouto department of the Sudanese savannah, exhibits a bimodal climate, characterised by a protracted dry season and a brief rainy season, influenced by the harmattan phenomenon (Goula, 2007). The Sudanese climate is typified by an annual rainfall of less than 1200 mm (Kouassi et al., 2021) and temperatures of up to 36°C (N'Dri et al., 2018). The site has classified forest status, but is highly anthropised, with intensive cattle grazing and cotton and cashew tree farms. The site is situated on a hill and is prone to bushfires.

Data collection

Two complementary approaches were utilised to collect data for this study. Firstly, the delimitation of an identified population of *Lophira lanceolata* was undertaken. Secondly, elementary plots were installed within the delimited population to assess structural parameters. Plots measuring 100 × 100 m (10.000 m^2 or 1 ha) were established. The distance between plots was a minimum of 100 metres. Three elementary plots were established in Patizia and Pouniakélé, and four plots in Kouassi-N'Dawa. In each plot, the number of individuals of *Lophira lanceolata* was recorded. The subjects were divided into two distinct groups based on their DBH (diameter at breast height), which was 1.30 m. The first group was designated as regeneration or seedling: DBH < 5 cm; mature tree: It is evident that the diameter of the bone is greater than or equal to 5 centimetres. The 5 cm threshold was selected to exclude young individuals, who are still subject to high mortality, and to focus on the stable structural classes of the population. This method is commonly used in forestry studies in the African savannah. In addition to circumference, which is utilised for the estimation of diameter, measurements were also obtained of the total height of the tree. The circumference of the trees was measured using a tape measure, while their height was measured using a graduated pole.

To characterise the spatial distribution, all individuals present in the defined populations were sampled systematically using GPS coordinates. These individuals were classified into two groups. The first group comprised seedlings (DBH ≥ 15 cm, the minimum diameter observed for fruiting trees in the field), while the second group comprised young plants (DBH < 15 cm). The surface areas of the populations were 8.06 hectares at Patizia, 8.02 hectares at Pouniakélé, and 12.32 hectares at Kouassi-N'Dawa (split into two sub-populations).

Data analysis

Structural parameters

The structural parameters of *Lophira lanceolata* populations were characterised by assessing dendrometric characteristics, regeneration and demographic structure (diameter class).

Mature tree density (TD), defined as the number of trees per hectare, basal area (G), representing the sum of cross-sections of all mature trees in the population at 1.30 m above ground level, and regeneration density (DR), the number of seedlings per hectare, were the primary focus of the study. In terms of the regeneration process, a comprehensive enumeration and categorisation of all individuals was conducted. The categories employed for this purpose included natural seedlings (NS), defined as seedlings that have self-sown; suckers (SR), which are trees that have sprouted from the root of a mother plant; and stump sprouts (SS), denoting trees that have regenerated after the severing of a stem (Goba, 2020).

The number of adult trees was recorded as 139 in Kouassi-N'Dawa, 81 in Patizia, and 71 in Pouniakélé. The number of seedlings was recorded as 260, 268, and 151, respectively, in Kouassi-N'Dawa, Patizia and Pouniakélé.

The subsequent analysis of these data sets was undertaken to verify the normality of the data (Shapiro-Wilk test) and the homogeneity of variance (Levene test).

The variances were subjected to a series of statistical tests to ascertain the normality and homogeneity of the data. The data were then subjected to a one-way analysis of variance (ANOVA) to test the effect of site on the parameters. In instances where the ANOVA revealed a statistically significant result, subsequent pairwise comparisons were conducted utilising the Tukey post-hoc test. This analytical approach was employed to ascertain which pairs of sites exhibited significantly divergent means. When normality was not met, the non-parametric Kruskal-Wallis test and Dunn's post-hoc test were employed to compare the sites.

The demographic structure of *Lophira lanceolata* was analysed using diameter classes of 13, 12 and 9, with an amplitude of 5 cm, respectively, at Kouassi-N'Dawa, Patizia and Pouniakélé. The diameter classes were utilised in the construction of histograms and were fitted to Weibull-type structure models. The parameter c of the Weibull distribution is defined as its theoretical shape. Consequently, for $c < 1$, the distribution is inverted J-shaped, and the population is said to have high regeneration potential. For $1 < c < 3.6$, the distribution is positively skewed, indicating that young individuals with small diameters and low regeneration potential dominate the population. For $c > 3.6$, the distribution is negatively skewed, and the population is dominated by older individuals with very low regeneration potential. The Kolmogorov-Smirnov test was employed to verify that the observed structure conforms to the Weibull distribution. The discrepancy between the theoretical Weibull distribution and the observed distribution is represented by the parameter D, and the *p*-value indicates the statistical significance of this discrepancy.

The analyses were performed using XLSTAT software.

Spatial distribution

In this study, 83 seed trees and 630 young plants were identified at Kouassi-N'Dawa. A total of 134 seed trees and 494 young plants were categorised at Patizia, and 71 seed trees and 363 young plants were categorised at Pouniakélé. The GPS coordinates of the *Lophira lanceolata* individuals recorded were converted into metric coordinates for the analyses.

The spatial organisation of *Lophira lanceolata* trees in the population was visualised using Ripley's K(r) function through its derivative L(r) Besag (1977). The univariate $L_{11}(r)$ function was employed to detect the distribution patterns of seed trees in the population. The bivariate $L_{12}(r)$ function was used to analyse the type of spatial association between seed trees and juveniles. The position of the L(r) curve within the confidence intervals indicates that the spatial distribution of trees is not significantly different from a completely random distribution. When the L(r) curve lies above the upper confidence interval, the distribution of points is significantly aggregated at the corresponding distances (suggesting a facilitating interaction of one type on the other for two groups of plants). Conversely, a position of the L(r) curve below the confidence interval indicates a significantly regular distribution (implying a competitive relationship between two groups of individuals) of points.

The fixed distance intervals for the three sites were 150 metres at Kouassi-N'Dawa, 220 metres at Patizia, and 260 metres at Pouniakélé, for estimating the $L_{11}(r)$ and $L_{12}(r)$ functions. These intervals were chosen to estimate the $L_{11}(r)$ and $L_{12}(r)$ functions at the three sites. For the Kouassi N'Dawa population, both subpopulations were used. These analyses were conducted using the PROGRAMITA software developed by Wiegand & Moloney (2004).

RESULTS

Dendrometric parameters

Statistical analysis revealed no significant variation in tree density among the three study sites ($F = 0.72$; $p = 0.520$). The mean tree density was calculated to be 35 ± 18 trees/ha at Kouassi-N'Dawa, 27 ± 4 trees/ha at Patizia, and 24 ± 9 trees/ha at Pouniakélé (Table 1). The highest basal area was observed at Patizia (1.52 ± 0.52 m^2/ha), which is more than double that of the other two sites. The largest diameter (23.92 ± 12.03 cm) and tallest trees (12.45 ± 2.57 m) were also observed at Patizia. However, the diameter values obtained at Kouassi-N'Dawa (15.90 ± 10.24 cm) and Pouniakélé (14.87 ± 8.86 cm) were found to be statistically identical (Table 1).

Regeneration

The regeneration inventories revealed that the populations of Kouassi-N'Dawa (87 ± 17 seedlings/ha) and Patizia (90 ± 19 seedlings/ha) had the highest densities. These densities were approximately double those recorded in Pouniakélé (51 ± 12 seedlings/ha). Furthermore, these inventories revealed the presence of three distinct regeneration mechanisms– suckering, stump sprouting and natural seeding – at all three sites (Table 2). Furthermore, analysis of these mechanisms also revealed that natural seedlings accounted for more than 90% of the natural regeneration observed at the three sites (Fig. 2). The contribution of suckering and stump sprouts to total regeneration was found to be less than 5%.

Table 1. Dendrometric parameters of the three populations of *Lophira lanceolata*. Values are mean ± standard deviation. TD: tree density; G: basal area; DT: tree diameter at 1.30 m from the ground, TH: height of the tree. On a line, the means followed by the same letter are not significantly different at the 5% threshold

	Populations					
	Kouassi-N'Dawa	Patizia	Pouniakélé	F	KW	*p*
TD (trees/ha)	35 ± 18^a	27 ± 4^a	24 ± 9^a	0.72	–	0.520
G (m^2/ha)	0.74 ± 0.19^b	1.52 ± 0.52^a	0.55 ± 0.43^b	5.48	–	0.037
DT (cm)	15.90 ± 10.20^b	23.92 ± 12.03^a	14.87 ± 8.86^b	–	35.28	< 0.001
TH	6.00 ± 2.77^c	12.45 ± 2.57^a	7.79 ± 1.34^b	–	161.82	< 0.001

Table 2. Regeneration abundance through populations of *Lophira lanceolata*. Values are mean ± standard deviation. NS: natural seedlings; RD: regeneration density; SR: suckers; SS: stump sprouts. On a line, the means followed by the same letter are not significantly different at the 5% threshold

	Populations					
	Kouassi-N'Dawa	Patizia	Pouniakélé	F	KW	*p*
RD (seedlings/ha)	87 ± 17^a	90 ± 19^a	51± 12^b	5.57	–	0.041
NS (seedlings/ha)	80 ± 16^a	87 ± 19^{ab}	45 ± 12^b	6.12	–	0.035
SS (seedlings/ha)	4 ± 3^a	1 ± 0^a	4 ± 1^a	3.05	–	0.122
SR (seedlings/ha)	3 ±1^a	2 ± 1^a	2 ± 0^a	–	4.41	0.110

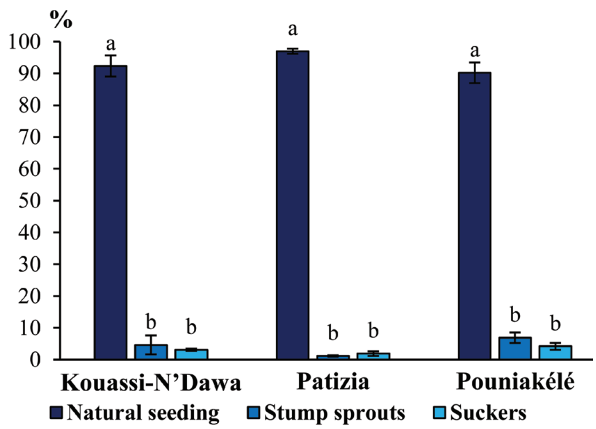

Fig. 2. Percentage of the three modes of regeneration (natural seeding, stump sprouting and suckering) of *Lophira lanceolata* in each population.

Demographic structure

The observed distribution exhibited a right-skewed shape, characterised by Weibull "c" shape parameters ranging from 1 to 3.6 for Patizia (c = 1.60; D = 0.137; p = 0.941) and Pouniakélé (c = 1.11; D = 0.348; p = 0.139) (Fig. 3). At Pouniakélé, this distribution, which resembles an inverted "J" structure, is characterised by a strong representation of young trees, i.e. individuals measuring between 5–10 cm, followed by a gradual decrease in the number of individuals in the higher classes. Trees with a diameter exceeding 25 cm are under-represented, with a paucity of trees measuring over 45 cm in diameter. Conversely, the Patizia site demonstrates a surge in the middle classes (15–20 cm and 20–25 cm), accompanied by a decline in the upper classes. However, this decline is less pronounced than observed at Pouniakélé. The distribution at Kouassi-N'Dawa (c = 0.92; D = 0.235; p = 0.364), with "c" < 1, presented an inverted "J" shape, characterised by a predominance of small-diameter classes (5–10 cm and 10–15 cm), which represented nearly 66% of the population. In comparison, trees with a diameter greater than 25 cm were poorly represented (less than 5% of the total number of trees) (Fig. 3).

In the Kouassi-N'Dawa and Patizia populations, trees with diameters greater than 50 cm were observed, in contrast to the Pouniakélé population.

Spatial distribution

A detailed analysis of the distribution of *Lophira lanceolata* individuals was conducted, revealing distinct patterns that varied according to the specific site and the distance scale employed. An analysis of the $L_{11}(r)$ curve at Kouassi-N'Dawa revealed that as the observation distance increased, the spatial distribution of seed trees underwent a transition from an aggregated tree structure to a random distribution. However, at short distances (1–7 m), the arrangement of the trees was random. Furthermore, analy-

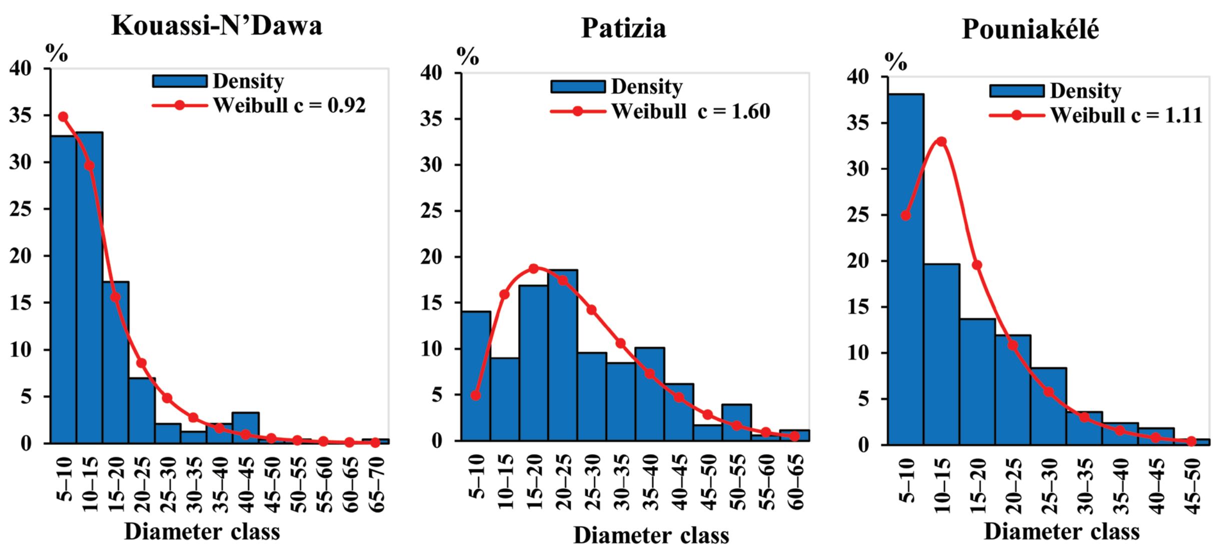

Fig. 3. The structure of *Lophira lanceolata* populations at three sites (Kouassi-N'Dawa, Patizia and Pouniakélé) according to diameter class.

sis of the $L_{12}(r)$ curve demonstrated that, within this population, young individuals were found in proximity to the seed trees (Fig. 4). At Patizia, analysis of the $L_{11}(r)$ curve indicated that the initial distribution of seed trees was random, subsequently evolving towards a regular pattern as the observation distance increases. The distribution of juvenile individuals in relation to seed trees was initially random, but as the distance increased, this distribution became regular between the two groups (Fig. 4). In the Pouniakélé population, *Lophira lanceolata* seedlings were dispersed randomly. The young individuals were aggregated with the seedlings up to an observation distance of 98 m; beyond this distance, the young individuals and seedlings were arranged randomly (Fig. 4). However, for distances of less than 6 m, the two types of plant were dispersed randomly.

DISCUSSION

The integration of native savannah trees into reforestation initiatives necessitates a thorough understanding of the ecological parameters that prevail within their natural habitats. The present study was

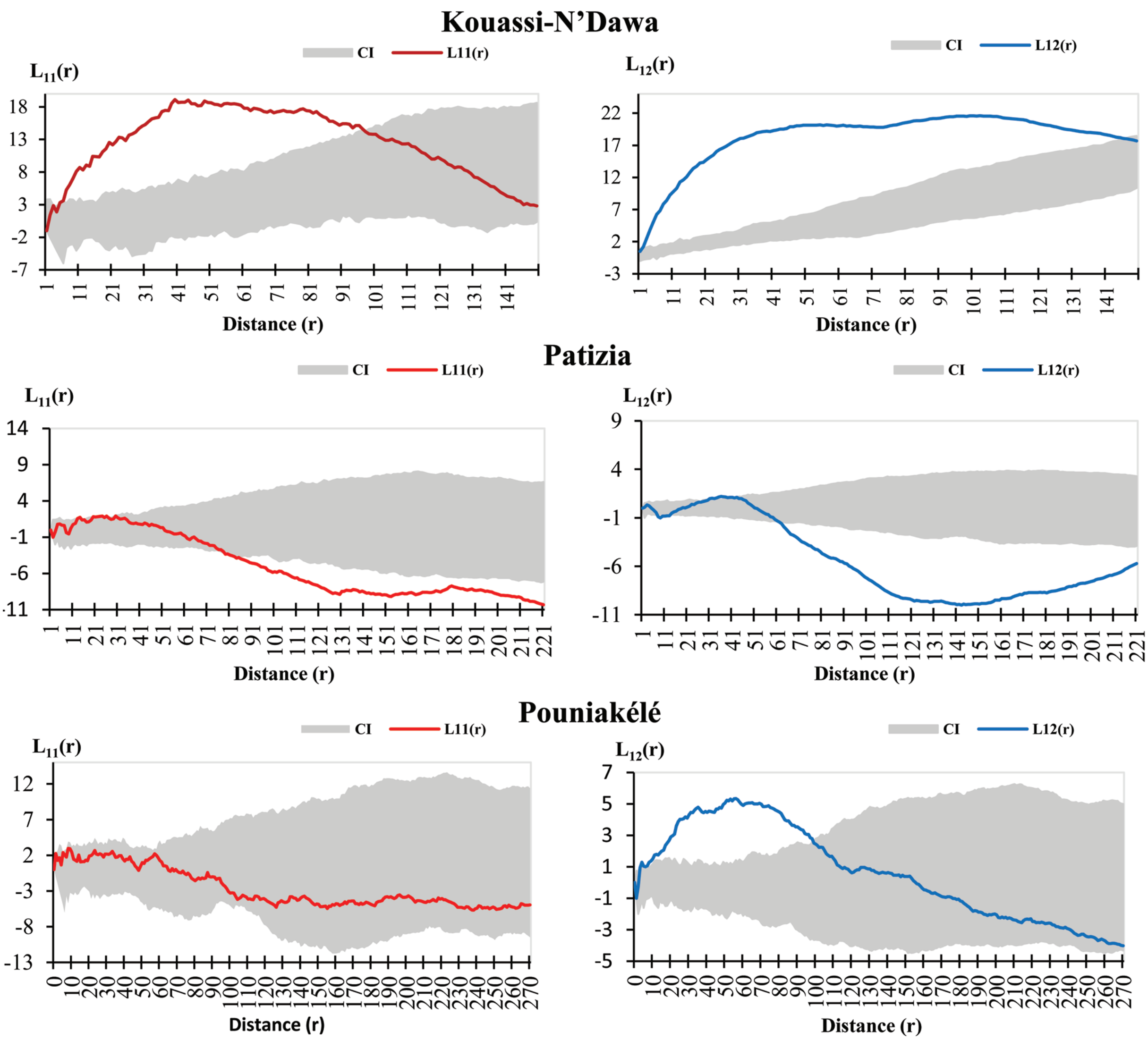

Fig. 4. Spatial arrangement function curves for all $L_{11}(r)$ trees (in red) and between adult and young $L_{12}(r)$ trees (in blue) of the spatial distribution of *Lophira lanceolata* individuals at Kouassi-N'Dawa, Patizia and Pouniakélé; CI: confidence interval limits.

conducted with the objective of investigating the regeneration, demographic, and spatial structure of dwarf red ironwood in three natural populations in Côte d'Ivoire.

Dendrometric parameters

The results of this study demonstrate that the density of adult trees is relatively homogeneous in the three populations. This finding may indicate stability in the structural characteristics of the species under investigation. However, this uniformity obscures the presence of contrasting dynamics within each population. These densities are considerably lower than those obtained in Burkina Faso by Lankoandé et al. (2017), who obtained densities of more than 135 trees/ha in different vegetation types (savannah and fallow), with a maximum of 280 ± 92.6 trees/ha in fallow. This discrepancy can be attributed to the elevated level of human activity observed, which included the utilisation of wood for charcoal production and agricultural purposes. Despite this homogeneity in density, variations in basal area are observed, reflecting differences in the populations. The Patizia forest, located within the Guinean savannah to the south, is distinguished by its trees, which possess a greater diameter, consequently resulting in a higher basal area. The region's climate is distinguished by elevated precipitation levels, ranging from 1200 to 1600 mm annually (Kouassi et al., 2021), and a pronounced seasonal precipitation pattern, categorised into two distinct rainy seasons (Goula, 2007). These conditions are considered conducive to the optimal growth of tree species. These results are analogous to those of Houetchegnon (2016) on *Prosopis africana* in the equivalent agroecological zones in Benin. The author posited that substantial precipitation would exert a favourable influence on diameter size.

Regeneration

The regeneration densities observed in this study demonstrate a pattern of increasing frequency from south to north. This finding aligns with the observations reported by Goba et al. (2019) in their study of rosewood (*Pterocarpus erinaceus*) in the same geographical regions of Côte d'Ivoire. The highest recorded densities were observed in Kouassi-N'Dawa and Patizia, which may be attributable to the environmental conditions in these regions that are more conducive to the proliferation of the species. The environmental conditions at the two sites are very similar (Ouattara et al., 2016; Assoko, 2022), while the low regeneration density observed at Pouniakélé in the drier savannah is noteworthy. The present findings are consistent with those of Ouédraogo et al. (2006), who demonstrated that wet savannahs exhibit a greater propensity for high regeneration density in comparison to less moist savannahs. At Pouniakélé, this low density may be indicative of anthropogenic pressures (e.g. felling of young trees to make enclosures and repeated bushfires, grazing) that have a detrimental effect on the development of young shoots (Goba et al., 2019). Dwarf red ironwood is a bushfire-tolerant tree (Mapongmetsem, 2007). Still, its natural regeneration, primarily through natural seeding, can be significantly disrupted by bushfires (Eyog-Matig et al., 2006), as it destroys the tops of young plants. According to Ouattara (2001), even the most vigorous species require a period without fire to become properly established. Furthermore, bushfires have been observed to impede the growth of plant species and to compromise the integrity of mature trees with delicate bark. The regeneration densities obtained in this study are considerably lower than those reported by Lankoandé et al. (2017) in Burkina Faso, where densities of over 3000 individuals/ha have been obtained in some savannah and fallow areas. This demonstrates the pressure on this resource in Côte d'Ivoire. The low densities observed in this study could be explained by the occurrence of bush fires during the flowering and fruiting of this species, which take place during dry periods in Côte d'Ivoire, i.e. from October to March in savannah areas (Lankoandé et al., 2017; N'Dri et al., 2018; Soro et al., 2020). The consequences of these fires can be considerable, impacting the plant's reproductive cycle by drying out or aborting inflorescences and dehydrating or burning fruits. However, natural regeneration is a phenomenon that has been observed to occur by various means, including natural seeding, stump sprouting and suckering. In particular, natural seeding has been found to account for over 90% of observed regeneration. This method of regeneration through seed has the potential to be employed on a large scale for reforestation purposes.

Demographic structure

The three populations under scrutiny exhibited heterogeneous distribution patterns, indicative of disparate dynamics. The Weibull shape indices "c" of the diameter classes of Kouassi-N'Dawa (sub-Sudanese) demonstrate an inverted J-shaped structure ($c < 1$), whilst those of Patizia in the Guinean savannah and Pouniakélé in the Sudanese savannah ($1 < c < 3.6$) correspond to a positive asymmetric structure.

The Kouassi-N'Dawa population is characterised by a significant presence of young trees, with limited representation of the adult classes. The preponderance of young individuals suggests that local ecological conditions are conducive to germination. Nevertheless, this overabundance of young trees does not guarantee population stability. Indeed, despite the fact that the inverted "J" structure is frequently associated with dynamic regeneration, it can also be indicative of low or absent recruitment, in circumstances where the young individuals fail to transition through the adult stages successfully. This phenomenon has been observed in several savannah line species (Houetchegnon, 2016). This result may also indicate that *Lophira lanceolata* populations are under strong anthropogenic pressure due to the scarcity of mature trees, as demonstrated by Dicko et al. (2017). This finding corroborates observations made during the course of the investigations, as it has been demonstrated that in this particular population, adult trees are felled for charcoal production. The low representation of mature trees may have a detrimental effect on the long-term survival of this population. It is therefore crucial to monitor growth, mortality and transition rates to assess whether current recruitment is enabling the population to be effectively renewed. At Pouniakélé, too, the distribution is characterised by a high density of young individuals, but with greater representation of adult classes than at Kouassi-N'Dawa. The underrepresentation of intermediate and adult classes suggests that young individuals encounter difficulties in ascending to the upper classes. In addition to anthropogenic pressures (selective tree felling), Houetchegnon (2016) suggests that the disruption and vulnerability of certain tree development stages could explain this distribution, since the individuals are neither all the same age nor young. This distribution pattern could also be explained by ecological pressures such as interspecific competition or microclimates, which could have an unfavourable effect on the development of young plants (Sankaran et al., 2008). The presence of adult trees has been demonstrated to impede the access of young plants to light, water and nutrients, thereby modulating the microclimate and compromising their growth and survival. In contrast, the Patizia population is characterised by a preponderance of young trees, accompanied by a notable presence of mature trees. This distribution indicates active regeneration in the population, with a moderate transition to adult classes. This structure, which is characterised by enhanced equilibrium in comparison to the other two, demonstrates a recruitment potential that is undoubtedly attributable to the ecological characteristics of the environment.

The structure observed at the three sites indicate that the presence of a high density of young individuals does not necessarily imply demographic viability of the populations in question. This observation is consistent with those made by Laris & Dembele (2012), who emphasise that savannah ecosystems in Africa are subject to intricate interactions between natural factors (e.g. drought, competition, facilitation) and anthropogenic pressures (e.g. fire, exploitation, grazing) that influence population structure. The observed distribution of demographics may also be influenced by the site's topography. As demonstrated by Zhang et al. (2024), micro-relief has been shown to influence on abiotic factors, including soil moisture, light availability and interspecific plant interactions. These factors have been found to be conducive to the growth of young plants.

Spatial distribution

The distribution patterns exhibited by the three populations under scrutiny manifested at diverse scales, encompassing random, aggregated or attractive, regular or repulsive configurations. These observations demonstrate a heterogeneous spatial distribution of *Lophira lanceolata* in the three populations. The results obtained provide valuable insights into the ecological dynamics and regeneration processes of this species. The observed phenomenon can be explained by the manner in which the seeds of *Lophira lanceolata*, a pterochorous species with anemochorous fruit dispersal, are disseminated. Research has demonstrated that the spatial distribution of a species is influenced by its mode of dispersal (Hubbell, 2011). At Kouassi-N'Dawa, the distribution of all individuals in the population (L_{11}(r)) and attraction at the level of interaction among seeders and juveniles (L_{12}(r)) show limited distribution of the latter. This phenomenon could be attributed to the impact of vegetation. The density of a stand of trees can impede the dispersal of seeds over long distances due to the effects of weak winds. A similar distribution pattern has been observed in *Pterocarpus erinaceus*, a tree that relies on anemochorous dispersal (Rabiou et al., 2015). In the Patizia population, a mixed trend was observed in both the seeders and the interactions among seeders and young trees. The random trend indicates that seeders exert minimal influence on seedling establishment in the early stages, subsequently giving way to a more selective establishment through a regular or repulsive pattern. This observation may be attributable to competition among individuals within and between populations for nutrients at the site. This configuration could be attributed to the topographical relief of the site, as the population under scrutiny is situated along a chain of hills. Miron et al. (2021) have also noted that the distribution of trees is influenced by the topography of the site. Furthermore, Ganka et al. (2023) have demonstrated that the separation of individuals can accentuate the irregularity of distribution. In the Pouniakélé population, the mixed pattern observed in the interaction between seed trees and juvenile plants may also be explained by the site's topography, as in Patizia, which is located on a hill. However, this phenomenon could be explained by the impact of strong or weak winds and surface water runoff on the fruits of large trees and those at the summit of the hill, which could favour the formation of granulates on the hillslopes or at the foot of the hill. Jesel (2005) has also demonstrated that variations in the environment over time have a significant impact on the capacity of seeds to thrive in a range of microsites. The divergent mixed distributions observed in the Patizia and Pouniakélé populations may be attributable to their evolutionary trajectory over time.

CONCLUSIONS

The objective of this study was to evaluate the regeneration, demographic structure and spatial structure of natural populations of *Lophira lanceolata* in three locations in Côte d'Ivoire. Of the three populations under consideration, Patizia exhibited the optimal dendrometric characteristics, although tree density was statistically equivalent in all three populations. As demonstrated in Patizia, within the Guinean savannah, and in Kouassi-N'Dawa, within the sub-Sudanese savannah, regeneration was found to be high. The observed regeneration mechanisms included natural seeding, stump sprouting and suckering. Natural seeding represents the most prevalent regeneration mechanism for this species, thus enabling the utilisation of seeds to produce large-scale seedlings for silvicultural purposes. The demographic structure observed in the three populations are characterised by imbalanced structure, dominated by small-diameter trees. The spatial distribution of the species is strongly influenced by site topography, stand density and human activities. Consequently, implementing protective measures is imperative to ensure the sustainability of this species. It would also be a worthwhile endeavour to introduce this species, which is indigenous to the savannahs, into the existing forestry programme, replacing the exotic species with this new variety. To achieve this objective, it is necessary to utilise regeneration or seedling production techniques based on identified genotypes. This process involves the identification and evaluation of species diversity through the utilisation of molecular tools.

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REFERENCES

Abdourhamane H., Rabiou H., Diouf A., Morou B., Mahamane A., Bellefontaine R., 2017: Structure démographique et répartition spatiale des populations de *Sclerocarya birrea* (A. Rich.) Hochst. du secteur sahélien du Niger. – Bois et Forêts des Tropiques, 333: 55–66. http://doi.org/10.19182/bft2017.333.a31468

Assoko A.V.S., 2022: Conception d'outils de prévision des extrêmes hydrologiques en région tropicale ouest africaine: Cas du bassin versant de la Marahoué en Côte d'Ivoire. A dissertation for a doctoral degree in Geoscience and the Environment.

Besag J., 1977: Contribution to the discussion of Dr Ripley's paper. – Journal of the Royal Statistical Society: Série B, 39: 193–195.

Dicko A., Natta A.K., Biaou H.S.S., Gouwakinnou G., Balagueman R., 2017: Typology and structural characterization of *Lophira lanceolata* populations in Bénin (West Africa). – Sciences de La Vie, de La Terre et Agronomie, 5(1): 36–43.

Diouf A., Barbier N., Mahamane A., Lejoly J., Saadou M., Bogaert J., 2010: Caractérisation de la structure spatiale des individus ligneux dans une "brousse tachetée" au sud-ouest du Niger. – Canadian Journal of Forest Research, 40(4): 827–835. https//doi.org/10.1139/X10-031

Eyog-Matig O., Ndoye O., Kengue J., Awono A., 2006: Les fruitiers forestiers comestibles du cameroun. Bureau régional de l'Institut international des ressources phytogénétiques (IPGRI) pour l'Afrique de l'Ouest et du Centre. Cotonou.

Fonton N.H., Atindogbe G., Fandohan B., Lejeune P., Ligot G., 2012: Structure spatiale des arbres des savanes boisées et forêts claires soudaniennes: implication pour les enrichissements forestiers. – Biotechnologie, Agronomie, Société et Environnement, 16(4): 429–440. https://hdl.handle.net/2268/144439

Ganka G., Salako K.V., Fandohan A.B., 2023: Impacts des tabous et des cérémonies rituelles sur la structure des peuplements de *Triplochiton scleroxylon* K. Schum., un arbre sacré au Bénin. – Bois et Forêts des Tropiques, 357: 57–70. https://doi.org/10.19182/bft2023.357.a36900

Goba A.E., 2020: Caractérisation structurale et variabilité génétique du vène [*Pterocarpus erinaceus* Poir. (Fabaceae)] pour une gestion durable de ses peuplements dans les savanes de Côte d'Ivoire. A dissertation for the degree of Biological Sciences Doctor. Nangui Abrogoua University. Abidjan.

Goba A.E., Koffi K.G., Sié R.S., Kouonon L.C., Koffi Y.A., 2019: Structure démographique et régénération naturelle des peuplements naturels de *Pterocarpus erinaceus* Poir. (Fabaceae) des savanes de Côte d'Ivoire. – Bois et Forêts des Tropiques, 341: 5–14. https://doi.org/10.19182/bft2019.341.a31750

Goreaud F., 2000: Apports de l'analyse de la structure spatiale en forêt tempérée à l'étude et la modélisation des peuplements complexes. A dissertation for the degree of Geosciences of Environment Doctor of forest sciences. ENGREF (AgroParisTech). Nancy.

Goula B.T.A., 2007: Évaluation du secteur de l'alimentation en eau potable et de l'assainissement en milieu rural et urbain. Rapport provisoire. Banque Africaine de Developement. Kinshasa.

Hanbury-Brown A.R., Ward R.E., Kueppers L.M., 2022: Forest regeneration within Earth system models: current process representations and ways forward. – New Phytologist, 235(1): 20–40. https://doi.org/10.1111/nph.18131

Haurez B., Languy M., de Wasseige C., Julve C., Vermeulen C., Bracke C., Nagalo Y.A., 2024: Forêts denses humides et aires protégées forestières d'Afrique de l'Ouest-État des lieux et perspectives. AGRECO G.E.I.E. Belgique. https://hdl.handle.net/2268/329178

Houetchegnon T.O., 2016: Études ethnobotanique, écologique et morphologique de *Prosopis africana* (Guill., Gerrott. et Rich.) Taubert au Benin et impacts des changements climatiques sur l'espèce. A dissertation for the degree of Agronomic Sciences Doctor. Parakou University. Parakou.

Hubbell S.P., 2011: The Unified Neutral Theory of Biodiversity and Biogeography (MPB-32). Princeton.

IUCN, 2020: *Lophira lanceolata*. The IUCN Red List of Threatened Species 2020: e.T156106640A156106642. – https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T156106640A156106642.en [accessed on 16 February 2025].

Jesel S., 2005: Ecologie et dynamique de la régénération de *Dicorynia guianensis* (Caesalpiniaceae) dans une forêt guyanaise. A dissertation for the degree of Forest ecology Doctor. INA-PG. Montpellier.

Kouassi A.M., Assoko A.V.S., Kouakou K.E., 2021:

Caractérisation hydrologique du bassin versant de la Marahoué (Bandama, Côte d'Ivoire). – Revue internationale d'innovation et d'études appliquées, 34(1): 91–101.

Kouassi A.M., Kouao J-M., Kouakou K.E., 2022: Caractérisation intra-annuelle de la variabilité climatique en Côte d'Ivoire. – Bulletin de l'association de Géographes Français. Géographies, 99(2): 289–306. https://doi.org/10.4000/bagf.9534

Lankoandé B., Ouédraogo A., Boussim J.I., Lykke A.M., 2017: Natural stands diversity and population structure of *Lophira lanceolata* Tiegh. ex Keay, a local oil tree species in Burkina Faso, West Africa. – Agroforestry Systems, 91(1): 85–96. https://doi.org/10.1007/s10457-016-9913-3

Laris P., Dembele F., 2012: Humanizing savanna models: integrating natural factors and anthropogenic disturbance regimes to determine tree–grass dynamics in savannas. – Journal of Land Use Science, 7(4): 459–482. https//doi.org//10.1080/1747423X.2011.597444

Lotchio A., Dicko A., Natta A.K., 2022: Impact de la provenance, de la morphologie et du stockage des graines de *Lophira lanceolata* sur leur germination au Bénin. – Bois et Forêts des Tropiques, 353: 3–16. https://doi.org/10.19182/bft2023.357.a36900

Mapongmetsem P.M., 2007: *Lophira lanceolata* Tiegh. ex Keay. – PROTA, 14: 115–118.

Miron A.C., Bezerra T.G., Nascimento R.G.M., Emmert F., Pereira R.S., Higuchi N., 2021: Spatial distribution of six managed tree species is influenced by topography conditions in the Central Amazon. – Journal of Environmental Management, 281: 11183. https://doi.org/10.1016/j.jenvman.2020.111835

N'Dri A.B., Fongbe M., Soro T.D., Gignoux J., Kone M., Dosso K., N'dri J.K., Barot S., 2018: Principaux indices de l'intensité du feu dans une savane Guinéenne d'Afrique de l'Ouest. – International Journal of Biological and Chemical Sciences, 12(1): 266–274. https://dx.doi.org/10.4314/ijbcs.v12i1.21

Ouattara N., 2001: Situation des ressources génétiques forestières de la Côte d'Ivoire (Zone de Savanes). l'Atelier sous-régional FAO/IPGRI/CIRAF sur la conservation, la gestion, l'utilisation durable et la mise en valeur des ressources génétiques forestières de la zone sahélienne (Ouagadougou, 22–24 September 1998). Rome.

Ouattara D., Kouamé D., Tiebre M-S., Kouadio Y.J-C., N'guessan K.E., 2016: Biodiversité végétale et valeur d'usage en zone soudanienne de la Côte d'Ivoire. – International Journal of Biological and Chemical Sciences, 10(3): 1122–1138. http://dx.doi.org/10.4314/ijbcs.v10i3.18

Ouédraogo A., Thiombiano A., Hahn-Hadjali K., Guinko S., 2006: Diagnostic de l'état de dégradation des peuplements de quatre espèces ligneuses en zone soudanienne du Burkina Faso. – Science et Changements Planétaires/Sécheresse, 17(4): 485–491.

Rabiou H., Diouf A., Bationo B.A., Mahamane A., Segla K.N., Radji R.D., Kokou K., Saadou M., 2015: Structure démographique de peuplement naturel et répartition spatiale des plantules de *Pterocarpus erinaceus* Poir. dans la forêt. – International Journal of Biological and Chemical Sciences, 9(1): 69–81. http://dx.doi.org/10.4314/ijbcs.v9i1.7

Ripley B.D., 1977: Modelling spatial patterns. – Journal of the Royal Statistical Society: Series B, 39(2): 172–192. https://doi.org/10.1111/j.2517-6161.1977.tb01615.x

Sankaran M., Ratnam J., Hanan N., 2008: Woody cover in African savannas: the role of resources, fire and herbivory. – Global Ecology and Biogeography, 17(2): 236–245. https//doi.org/ 10.1111/j.1466-8238.2007.00360.x

Sombo NC., Kouassi L., Koffi A.K., Schoemaker J., Barrère M., Barrère B., Poukouta P., 1995: Enquête Démographique et de Santé, Côte d'Ivoire 1994. Calverton.

Soro T.D., N'dri A.B., Dembele B.N., Kpre A.J-N., Kouassi K.V., Kpangba K.P., Kouamé Y.A.G., Moussa K., 2020: Périodes des feux de végétation en fonction des secteurs phytogéographiques de Côte d'Ivoire: approche par télédétection et perceptions des populations. – Quest Journal of Research in Environmental and Earth Sciences, 6(4): 08–17.

Taonda A., N'Guessan A.E., Kouakou A.B., Ouédeaogo H., Kassi N.J., 2023: Structure et potentiel de séquestration de carbone de la forêt classée de Foumbou à Korhogo au nord de la Côte d'Ivoire. Structure and potential carbon sequestration of theFoumbou classified forest (Korhogo) in northern ofCôte d'Ivoire – Revue Ecosystèmes et Paysages, 3(2): 1–12. https://doi.org/10.59384/recopays.tg3216

Wiegand T., Moloney K.A., 2004: Rings, circles, and null-models for point pattern analysis in ecology. – Oikos, 104(2): 209–229. https://doi.org/10.1111/j.0030-1299.2004.12497.x

Zhang D., Zhao Y., Qi H., Shan L., Chen G., Ning T., 2024: Effects of micro-topography and vegetation on soil moisture on fixed sand dunes in Tengger Desert, China. – Plants, 13(11): 1571. https://doi.org/10.3390/plants13111571

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