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Spatial Pattern Analysis of *Tarenna Rwandensis* (Rubiaceae), an Endemic Tree Species of Nyungwe National Park (Rwanda)

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Abstract

The spatial pattern of individuals of *T. rwandensis*, an endemic ligneous species of Nyungwe National Park was analyzed. Individual was classified into three age-based categories: seedlings, saplings and adults to detect intraspecific interactions. Three rectangular plots of 21×9m each were made at Uwinka and each individual *T. rwandensis* identified was mapped using cartesian coordinates (x,y). The point pattern generated was analyzed by means of Ripley's K function for univariate analysis and O-ring statistics for bivariate analysis to compare observed sets of values from the data.

Our study revealed that *T. rwandensis* doesn't regenerate adequately; we observed a very low number of seedlings compared to other age categories. The univariate analysis of the observed individuals showed that seedlings are clumped from the scale of 0.5 m up to 4m. Saplings and adults show contrasting spatial patterns in different plots due to competition and environmental heterogeneity. Concerning bivariate analysis, the study showed neutral interactions between adults and seedlings for all considered scales in plot 1 whereas saplings exhibit neutral interactions around adults only at the scale of 0.5 up to 1.5m. In this plot 1, we found that seedlings and saplings have clear spatial neutral interactions for the scale of 0.5 up to 2.5m scale. In plot 1, seedlings show neutral interactions around adults for all considered whereas saplings exhibit neutral interactions around adults only at the scale of 0.5 up to 1.5m. Seedlings exhibit a clear spatial neutral interaction around saplings from 0.5 up to 2.5m scale in this plot 1. In the plots 2 and 3, spatial neutral interactions have been observed between adults and saplings for all scales considered.

Key words: Spatial pattern, *Tarenna rwandensis*, regeneration, spatial interactions and Nyungwe National Park

1. Introduction

Plants, especially terrestrial long-lived perennials such as trees, do not usually move once established. This has always attracted many scientists who have shown that plant survival and growth depend on local environments within a habitat. In addition, plants do not spatially respond to the patchiness of environments randomly (Antonovics *et al.* 1980; Stratton *et al.* 1998). Therefore, the spatial configuration, of the individual trees in a forest stand can provide information about the underlying ecological processes at a site, such as competition among the trees, growth, death and regeneration (Malkinson *et al.* 2003).

In natural systems, the patterns result from processes that occur in ecological space and time (Fortin *et al.* 2005). Space and pattern can be defined respectively as the 'final frontier' (Liebhold et al. 1993) and 'distinctive form' or opposite of 'random' (Webster 1989; Fowler and Fowler 1976), implying that a pattern can be detected and describe. Moreover, there is an implication that the pattern in ecological system is dynamic, evolving and changing. Indeed, a spatial pattern is usually 'a single realization' or 'snapshot' of a process or of a combination of processes at one given time (Fortin *et al.* 2003). Three basic models of population distribution within an area are used : random in which the position of each individual is independent of the others, regular where the distance between neighboring individuals is maximized and clumped when the distance between neighboring individuals is minimized.

Spatial patterns of organisms help in identifying particular mechanisms, in explaining the ecosystem functioning and stability, and in designing adequate management, recovery, or restoration actions (Miller *et al.* 2002, Maestre *et al.* 2005). Spatial structure influences the dynamics, composition and biodiversity of community

(Tilman, 1994) and it is a result of natural processes occurring in ecosystems. The spatial patterns of plant species depend on a set of processes, including dispersal patterns, germination and emergence responses, and seedling growth and survival (Herrera *et al.* 1994, Jordano and Herrera 1995). They depend on a mixture of both exogenous and endogenous processes and the results are referred to as spatial dependence among individual organisms (Marie-José *et al.* 2005). Through the quantification of spatial pattern, the underlying ecological processes are revealed (Marie-José *et al.* 2005).

A number of works have been done in Nyungwe forest (Rwanda) in order to provide a building block to the conservation of its biodiversity but the spatial pattern of ligneous species of the forest seem to be left behind. The current work will provide spatial pattern of *T. rwandensis* (Rubiaceae), one of the five endemic ligneous species of Nyungwe forest which are *Oricia renieri, Pentadesma reyndersii, Pavetta troupinii, Psychotria palustris* and *Tarenna rwandensis*. The study analyzed the spatial pattern of *T. rwandensis* and provided information about the regeneration state of *T. rwandensis* and the underlying process governing its spatial pattern. Our study aims to identify spatial distribution of seedlings, saplings and adults and to determine intraspecific interactions between these different age-based categories.

2. Methods

2.1 Study site

This research was conducted in 2013 in Nyungwe forest located in Southwestern Rwanda at Uwinka site covering an area of 5.67 Ares. The forest has 1013 km^2 and is adjacent to Kibira National Park, Burundi, and together form one of the largest contiguous blocks of lower mountain forests in Africa (Vedder et al. 1988).

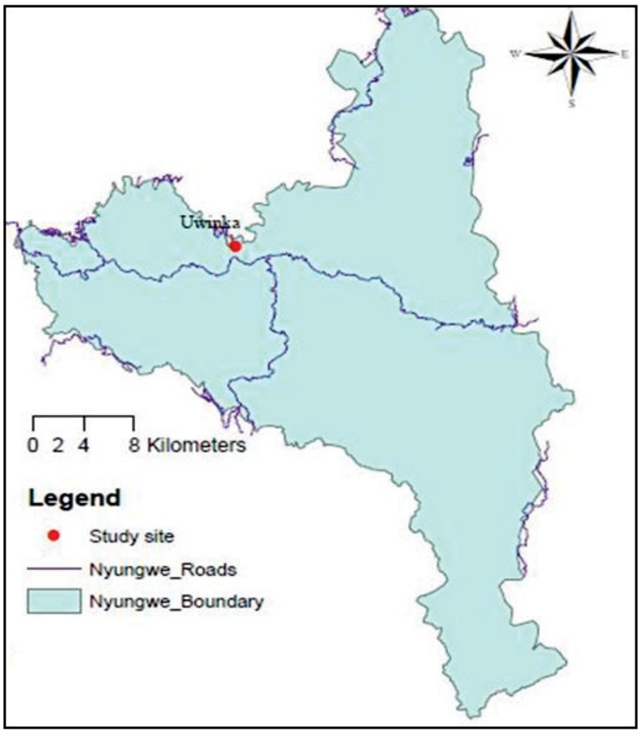

Figure 1: Study Site in Nyungwe National Park

Temperatures at NNP are generally cool with an average minimum temperature of 10.9°C and an average maximum temperature of 19.6° C (Sun *et al.* 1996). The mean annual rainfall of 1,744 mm (Sun *et al.* 1996) is typical for an African rainforest. A major dry season occurs between July and August and a minor dry season takes place between December and January. The bedrock of Nyungwe rainforest is mainly composed of very old Precambrian rocks differentiated in three geological parts (Storz 1983). The substratum is derived from granites and granitic rock usually poor in nutrients in the eastern part of the forest (Sorg 1978). Schist, quartzite and dolerite are the main parent rocks in the western part of the forest, and derive fertile soils (Sorg 1978).

2.2 Study species

T. rwandensis is a tree that can reach 19 m of high and possesses Saplings branches with red brown peel and the recent ones have square-shaped section. The leaves have leafstalks of 0.7 - 1.8 cm long and their limbs are closely elliptic with a pointed summit of 1.5 cm long. The leaves are also sharp at the base of 4 to 11 cm long and 1.4 to 3 cm large. The species have got triangular stipulates of 2 to 4 mm long with winged extremity. The terminal inflorescences with more 1 to 2 pairs are born from the lower node. The flower has got too short peduncles of 2 to 5 mm long. The perianth possesses tubular calyx of 1to 1.2 mm long with very short lobes and a corolla which has a tube of approximately 2 mm long. The globular fruit of 4 to 6 mm of diameter has a summit persistent calyx and possesses 6 to 10 seeds. *T. rwandensis* lives between 2000-2400m and is rarely found (Troupin 1978).

2.3 Data collection

We have made three rectangular plots of 21×9 m each at Uwinka where the species of interest was numerously found. After delimitation each plot was subdivided into 3×3 m quadrates to enhance the accuracy of the coordinates. Every individual of *T. rwandensis* was mapped using cartesian coordinates (x,y) preceded by individual categorization. Categories considered are: seedlings, Saplings individuals and adults.

2.4 Data analysis

Two kinds of analyses were performed: univariate and bivariate analyses. For the univariate spatial analysis of *T. rwandensis* spatial pattern, Repley's K-function was used to compare all observed sets of values from the data, with the values of complete spatial randomness (CSR) using the same shape and the same number of events in order to determine at which scales the points of *T. rwandensis* point pattern tend to be regular, clumped or under (CSR). To do this, Repley K-function for a certain distance r is defined as $K(r) = \lambda^{-1} E(r)$ where E(r) is the expected number of points within a distance r from an arbitrary point of the study region, and λ is the density of points inside this area estimated as:

$$\lambda = \frac{n}{A}$$ (Ripley, 1977). (1)

(n and A are the number of points inside and the area of the study region respectively). Given that the interpretation of the K- function $K_{11}(r)$ is difficult visually, a modified function called L-function which is a square root transformation of $K_{11}(r)$ was used. This function is estimated as following

$$L_{11} = \sqrt{\frac{K(r)}{\pi}} - r$$ (Besag, 1977) (2)

Values of $L_{11}(r)$ at any distance were compared to those observed from a randomly distributed set of individuals within the same area. The expected value of the univariate L-function under CSR is 0 for all r, positive where the pattern tends to be clustered and negative when the patterns tends to be regular. Moreover a Monte Carlo test has been used to test the significance of the results by running 99 simulations which correspond to 99 % confidence envelope. The L- function was computed using Programita 2010 software as well as the Monte Carlo test. For the bivariate analysis we used O-ring statistics in order to avoid the cumulative effect of K-function. The O- ring statistcs $O_{12}(r) = \lambda_2 g_{12}(r)$ is obtained by relating the correlation function $g_{12}(r)$ to Repley's K-function.

$$g_{12}(r) = \frac{\frac{dk_{12}}{dr}}{2\pi r}$$ (Stoyan nd Stoyan 1994) (3)

The O-ring statistics $O_{12}(r) = \lambda_2 g_{12}(r)$ gives the expected number of point of pattern 2 at distance r from an arbitrary point of pattern 1. Again a Monte Carlo test has been used to test the significance of the results. $O_{12}(r) = \lambda$ for CSR, $O_{12}(r) > \lambda$ indicate an aggregation of individuals at distance r, and $O_{12}(r) < \lambda$ indicates regularity (Wiegand *et al.* 1999).

3. Results

A total of 68 individual stems of *T. rwandensis* were mapped in the three plots surveyed at the site of Uwinka. The individuals include 7.35% of seedlings, 52.94% of saplings and 39.70% of adults.

Table 1. The number of individuals recorded within the 3 plots

Age category	Plot 1	Plot 2	Plot 3	Total
Seedlings	5	0	0	5
Saplings	12	4	20	36
Adults	5	11	11	27

The three age categories of the study tree species are not all present neither similarly abundant in the plots considered in the three studied plots. Although the observed variation of number of individual in different plots, we analyzed spatial pattern.

3.1 Spatial pattern of *T. rwandensis* individuals

Seedlings showed contrasting spatial distributions. For example, seedlings in the plot 1, for the scales of 1 m to 4m, the spatial pattern is clustered but beyond 4m the spatial pattern becomes random (Table 2).

Table 2. Spatial patterns of *T. rwandensis* individuals at scales of 1 to 5m

Scale (m)						

+: aggregation or clumping; r: random

Saplings of *T. rwandensis* also showed a contrasting spatial distribution. Plot 1 exhibit a clumped spatial distribution along the scale of 1 up to 5 m. In plot 2 the spatial pattern of saplings seems random up the scale of 4.5 m. In plot 3, saplings are randomly distributed along the whole scale considered. Only adult individuals exhibit distinct spatial patterns in the study area. Adults in plot 1 are clumped along the all considered scales but in plot 2, they are clumped from 0.5 up to 2.7m beyond which there randomly distributed until 5m. Adults in plot 3 exhibit a random distribution for all considered scales.

3.2 Spatial interactions of *T. rwandensis* individuals

In addition to the univariate analysis of individual of *T. rwandensis*, here below are the results of the bivariate analysis. In plot 1, seedlings show neutral interactions around adults for all considered scales whereas saplings exhibit neutral interactions around adults only at the scale of 0.5 up to 1.5m. In this plot 1, seedlings exhibit clear spatial neutral interactions around saplings from 0.5 up to 2.5m scale.

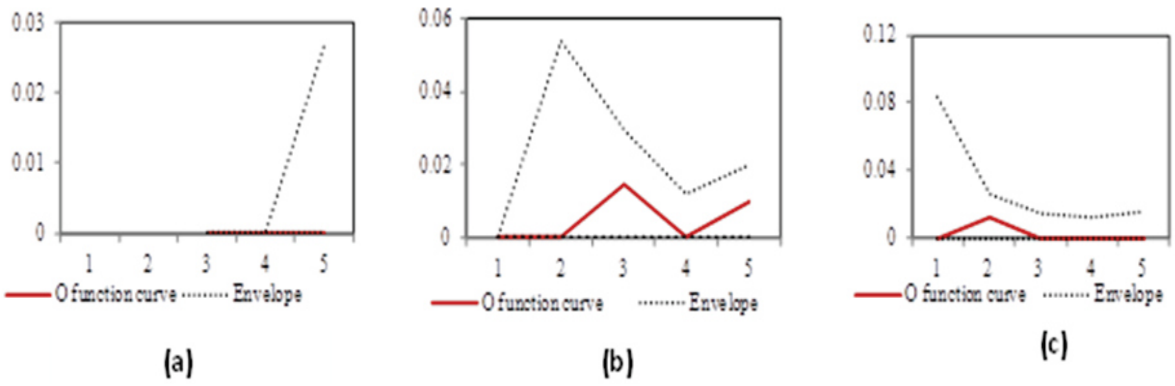

Figure 2. Spatial interactions exhibited among different categories of *T. rwandensis* individuals in plot 1: (a) interactions adults-seedlings, (b) interactions adults–saplings and (c) interactions saplings–seedlings

Spatial neutral interactions of saplings have been also observed in plots 2 and 3 around adults for all scales considered. These neutral interactions have also been observed between adults and saplings in plot3 for the scales from 2.5 up 5m.

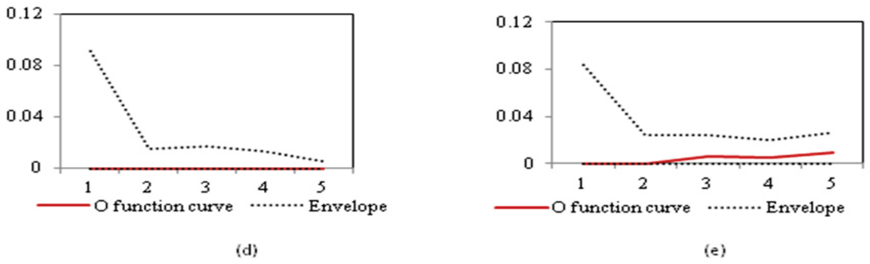

Figure 3. Spatial interactions exhibited among adult and Saplings individuals of *T. rwandensis* in plots 2 and 3: (d) interactions adult – saplings in plot 2 and (e) interactions adults – saplings in plot 3

4. Discussion

A very low number of *T. rwandensis* seedlings were observed in the study area in comparison to other age categories. Moreover *T. rwandensis* regeneration status marches with the information got from our field assistant from Nyungwe National Park conservation project who have been working in the field of forest conservation for several years, confirming that *T. rwandensis* has got a low density seedlings in these days. This constitutes an indicator of a problem that constitutes a barrier for this species to successfully generate. Owing to the fact that the analysis of seedling spatial distribution can reveal information on the species-specific constraints on successful regeneration (Hubbell *et al.* 1999), several causes could be suggested about this situation but the most probable one might be based in flower pollination and in fruit maturation of *T. rwandensis.* Post seed predation might also be the cause of this handicap of successful regeneration (Diaci 2002) of *T. rwandensis*. Even if fruit of *T. rwandensis* are small, they may probably constitute a source of food for small mammals like rodents or other invertebrates. On the other hand, probably there is a problem of suitable condition for *T. rwandensis* seeds germination and adult trees may have produced modification that hinder successful establishment of seedlings; they die Saplingser. Plants that surround seedlings could affect their survival by interfering with them through competition for water, nutrients, light or other mechanisms (Guérard *et al.* 2001). The mortality of seedlings may also result from an attack of infectious parasites that have found favorable conditions in the site. Further researches are indispensable to check if this species does not contract infections affecting its regeneration.

The surviving seedlings were found in some plots to be clustered for the all scales considered. The most probable cause of this pattern may be the limited seed dispersal or short distance seed dispersal of this species as it is the most cause of clumped distribution of seedlings in tropical forests (Forget *et al.* 1999). Moreover we may also add the fact of human disturbance. And when we consider for example the seedlings spatial distribution in the plot 1, we noticed that their clumping is along the human path that could have caused some disturbance. It is well known that some species may specifically need the perturbation of the soil in combination with light availability for successful regeneration and these conditions are gathered in disturbed area (van Dam 2001).

Saplings and adults within the three studied plots revealed distinct contrasting spatial patterns. This could be linked to many factors, the most important ones being competition and environmental heterogeneity. Due to various light intensity of a heterogeneous forest canopy cover of the site, competition for light may have induced different mortality intensity of old seedlings across the site resulting in different spatial patterns of saplings throughout the site. The fact that light is the crucial factor controlling survival of saplings was also discussed in Duchesneau *et al.* (2001). The clumped pattern exhibited by saplings may be due to the patchy distribution of biological, chemical and physical properties of the soils (Simard *et al.* 1998).

Regarding bivariate analysis, the neutral interaction between seedlings and adults may result in the mortality of seedlings due to aboveground competition. Light availability is the probable cause associated to this random distribution of seedlings. Change in physical environmental factors due to difference in humidity, thickness of litter and soil nutrients that may be patchily distributed may also be the cause of lack of significant interaction between adults and seedlings because for example, the excessive humidity doesn't allow the germination since it forms a barrier from oxygen absorption (Mayer *et al.* 1982) and the high thickness of litter (30-40cm) could disturb the plant regeneration in Nyungwe rainforest. The lack of significant spatial interaction has been documented by Wiegand *et al.* (2000). In the case of *T. rwandensis*, more detailed research that takes the above environmental factors into accounts should be conducted to reveal the underlying process of observed neutral interactions between individuals.

Seedlings and saplings and their patchy clumped distribution around adults may result from environmental modification from adult trees which in turn result in handicapping seed germination and seedlings successful establishment elsewhere except this small area around the path which may possess favorable condition (Staelens *et al*. 2006). It seems logical that trees exert their influence not only on the ground floor vegetation but also to the distribution of saplings, hence competition for light should be the probable cause of this random pattern as light is the among determinant factor of survival of saplings, a fact well documented by (Pukkala *et al.* 1993).

Spatial pattern is a single realization or snapshot of a process or of a combination of process at one given time (Fortin *et al.* 2003). For this reason, we may suggest that positive interaction among adults has been the common process governing spatial pattern of adults on this site from past years but as time goes on trees growing up and their density increases with an increased competition for resources so that spatial pattern begins to change from aggregation to complete spatial randomness. This population dynamics is well documented in literature where positive interaction leads to aggregation of individuals and clumped (or under-dispersed) patterns (Callaway and Walker 1997), while random patterns of uncorrelated plant distribution indicate either an absence of significant spatial interaction or a temporal transition from negative to positive interaction or vice versa (Wiegand *et al.* 2000). Repulsion is mainly caused by competition and leads to regular spatial distribution via mortality in a resource-limited and competition-dominated system (Stoyan and Penttinent 2000).

5. Conclusion

The low seedling density of *T. rwandensis* confirmed a problem in its regeneration in Nyungwe National Park. The spatial pattern of individuals of this native tree species is essentially clumped. The random pattern exhibited by seedling around adults and saplings on one hand and saplings around adults on other hand in different plots reveals less important seed dispersion and the role of biotic factors (fruitage, post seed and predation) in *T. rwandensis* regeneration.. For this reason, further research on the role of these biotic interactions on *T. rwandensis* regeneration and its influence on microhabitat structure and functioning are recommended.

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