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Spatial Distribution Patterns of the Populations of Two Subterranean Termites (Blattodea: Termitidae) In *Eucalyptus* (Myrtales: Myrtaceae) Plantations

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Abstract

The study was conducted in Afaka, Northern Guinea Savanna of Nigeria to determine the spatial distribution patterns of the populations of *Ancistrotermes* sp. and *Microtermes* sp. in *Eucalyptus camaldulensis* Dehnh, *Eucalyptus citriodora* Hook, *Eucalyptus cloeziana* F. and *Eucalyptus tereticornis* Muell plantations. Spatial distributions patterns of the two termite species populations were determined using indices such as ratios of population variance to mean, Lloyd's index, Green coefficient, Taylor power and Iwao's regression models. The values of variance to mean ratios, Lloyd's index and Green coefficient showed that the populations of both termite species had aggregated distribution pattern in all the *Eucalyptus* species plantations. The distribution patterns of *Ancistrotermes* and *Microtermes* differed using Taylor's and Iwao regression models. The values of R^2 in Taylor's model ranged from 0.02 to 0.99 for *Ancistrotermes* sp. and 0.29 to 0.99 for *Microtermes* sp., while in Iwao's model, R^2 ranged from 0.10 to 0.96 for *Ancistrotermes* sp. and 0.08 to 0.98 for *Microtermes* sp. The information provided is vital to develop a sound pest management protocol for these termite species.

Keywords: Spatial distribution, *Ancistrotermes* sp., *Microtermes* sp., Aggregated, Taylor's model, Iwao's model

Introduction

Eucalyptus, a genus of more than 500 species, belongs to the family Myrtaceae. It is one of the most valuable and widely planted hardwoods in the world (Demel 2000). More than 300 species contain volatile essential oils in their leaves, out of which about 20 species have been reported to contain high contents of 1,8-cineole used commercially for the production of essential oils in the pharmaceutical and cosmetic industries (Dhakad et al. 2018). Leaves and stem barks of different *Eucalyptus* species are used for the treatments of several diseases such as typhoid fever, ulcers, malarial fever, cough, stomach upset, blood sugar and skin infections in Markurdi, Nigeria (Ekhuemelo et al. 2017). Essential oils of the leaves of *E. camaldulensis* were used in the treatment of lung diseases, while the volatile oils were used as expectorants (Adeniyi et al. 2006).

Termites' attacks have serious negative impacts on the successful establishment of tree plantations; and are recognized as a major limiting factor in *Eucalyptus* plantation establishment in the tropics (Nair 2007). Great losses of *Eucalyptus* seedlings and saplings due to termites' infestations have been reported in India (Rajagopal 1982, Nair and Varma 1985, Thakur et al. 1989, Patel and Sahu 1995), China (Wylie and Floyd 1992), Malawi (Chilima 1991) and Nigeria (Alamu 2017). Generally, members of the family Termitidae, especially the subterranean foragers have been reported to cause serious damage to the roots of young *Eucalyptus* plants (Wilcken et al. 2002). The occurrence of different species of subterranean termites has been reported in *Eucalyptus* plantations in Nigeria where the foraging populations of *Ancistrotermes* and *Microtermes* species were very prominent (Alamu et al. 2018).

Throughout Africa, members of the family Termitidae to which *Ancistrotermes* and *Microtermes* species belong are considered as serious pests to crops, rangeland and forestry. Different species of *Microtermes* and *Ancistrotermes* were reported to be responsible for the destruction of range and crops in Sudan (Pearce et al. 1995), Ethiopia (Abdurahman 1990), Ghana (UNESCO 1997) and Nigeria (Wood et al. 1980, Umeh and Ivbijaro 1997). Damage caused by *Ancistrotermes* and *Microtermes* species to plants is mostly internal or subterranean (Mugerwa et al. 2014). These subterranean termites do not build epigeal mounds, and consequently, most farmers considered them not important. However, they attack plants through the roots and advances into the stem causing wilting and eventual death (Mugerwa et al. 2014).

Integrated pest management as an alternative to absolute reliance on chemical pesticides in the control of termites to reduce damage to *Eucalyptus* seedlings require a good knowledge of the spatial distribution of termites (dos Santos et al. 2011). Spatial distribution has been described as one of the important characteristic properties of insect population and adequate knowledge of it is required in effective sampling plan for decision making in pest management programmes (Binns et al. 2000, Khaing et al. 2002). Sampling programmes is an important ecological tool that can be employed in population dynamics study of pests (Wilson 1994, Jarosik et al. 2003), evaluation of the pest infestation status (Arnaldo and Torres 2005) and crop loss assessment (Hughes 1996). Some of the important parameters required for the estimation of pest density for a reliable sampling procedure have been identified as the sampling unit, sampling time and sampling size (Boeve and Weiss 1998, Southwood and Henderson 2000). Despite the fact that the objectives of population sampling may differ, the development of a sampling procedure requires adequate knowledge of the spatial distribution of the populations (Binns et al. 2000, Liu et al. 2002). The use of dispersion indices for insect pests has been described to be convenient in decision making plans for insect management programme because of their easy calculation procedure and simple results provided (Darbemamieh et al. 2011).

Spatial distribution patterns of foraging populations of termites have been studied using various methods such as the nearest-neighbour technique for distance index (Korb and Linsenmair 2001), geostatistical techniques, Ripley's K function and pair correlation function for epigeal mound and subterranean population distributions (Crist 1998, Grohmann et al. 2010, Lima et al. 2015). Arifin et al (2014) reported in South Sumatra Palembang, Indonesia, the randomly distribution of epigeal mounds built by *Macrotermes* spp. in different landscapes. Additionally, subterranean termites have been described to exhibit aggregated spatial distribution in *Eucalyptus* plantations (Bezerra and Wilcken 1998, Zanetti et al. 2005) in Brazil. However, information on the spatial distribution patterns of *Ancistrotermes* and *Microtermes* species with high prevalence in *Eucalyptus* plantations in Nigeria (Alamu et al. 2018) are inadequate. Therefore, as a guide to embark on meaningful sampling procedure for effective management of these two subterranean termites, their spatial distribution patterns need to be properly documented. This study therefore, aimed to determine the spatial distribution patterns of the populations of *Ancistrotermes* and *Microtermes* species in *Eucalyptus* plantations in Afaka, Kaduna State, Nigeria to provide useful information on the development of effective sampling programme as a basis for their management.

Materials and Methods

Termite population sampling

The study was conducted in *Eucalyptus* plantations in Trial Afforestation Research Station experimental plots in Afaka, Kaduna State (Longitude 10° 39' 59" North and Latitude 7° 23' 16" East), Nigeria. Populations of *Ancistrotermes* sp. and *Microtermes* sp. were sampled in four *Eucalyptus* species (*E. camaldulensis, E. cloeziana, E. citriodora* and *E. tereticornis*) plantations using wood boards (30 x 20 x 1 cm) prepared from *Terminalia ivorensis* as bait. *Terminalia ivorensis* has been classified as a low density wood species and very susceptible to termite infestations (Owoyemi and Olaniran 2014). In each plantation, 20 *T. ivorensis* wood boards were arranged along each of the two diagonal axes of 100 x 100 m^2 sampled plot at a distance of 6 m apart. The experiment was replicated four times in each plantation.

Each wood board was gently lifted up at 15 days after installation, and transferred separately into a polythene bag together with the termites attached to it and the soil excavated underneath the board up to a depth of 5 cm with the aid of a spade and a hand trowel. All the polythene bags with the contents were carried to the laboratory where termite species were sorted out and counted. The termite samples were preserved in 70% ethanol and identified in Entomology laboratories of National Horticultural Research Institute, Ibadan and Forestry Research Institute of Nigeria, Ibadan using identification keys according to Webb (1961). Identification was based on the morphology of soldier caste using a stereo binocular microscope.

Determination of the spatial distribution patterns of *Ancistrotermes* and *Microtermes* species populations

Spatial distribution patterns of the populations of *Ancistrotermes* and *Microtermes* species were classified using dispersion indices such as variance to mean ratio (S^2/m), Lloyd's index, Green coefficient, Taylor model and Iwao's model. When the ratio of population variance to mean population density (S^2/m) is equal to 1.0, < 1 or >1, the distribution is random, uniform or aggregated, respectively (Feng and Nowierski 1992). A chi-square ($\chi 2$) test was performed for the S^2/m to determine its significant departure from 1.0 by the following equations:

$$\chi^2 = (n-1)\, S^2/m \ldots\ldots\ldots\ldots\ldots(1)$$

$$Z = \sqrt{2\chi^2} - \sqrt{(2n-1)} \ldots\ldots\ldots (2)$$

Where; n = number of samples, S^2 = mean population variance and m = mean population density.

When $|Z| < 1.96$, agreement with a random dispersion was accepted;

when $|Z| < -1.96$, a uniform dispersion was suspected; and

when $|Z| > 1.96$, a clumped or aggregated dispersion was accepted following the study of Elliott (1973).

Determination of patchiness

Patchiness was determined using Lloyd's index. The index was calculated as a ratio of mean population crowding (m^*) to mean population density (m). The mean population crowding (m^*) was determined using the formula described by Southwood (1978):

$m^* = m + [(S^2/m) - 1]$

Where; m = mean density and S^2 = variance.

When Lloyd's index = 1, it indicated a random dispersion; when it was > 1, it indicated an aggregated dispersion; and when it was < 1, it indicated uniform dispersion (Lloyd 1967).

Determination of the degree of aggregation

The degree of aggregation was measured by the Green coefficient (Cx) (Green 1966), Taylor's power law (Taylor et al. 1978) and Iwao's patchiness regression (Iwao 1968).

Green Coefficient–The Green coefficient (Cx) was determined using the following formula described by Green (1966):

$$\frac{(S^2/m) - 1}{\sum x - 1}$$

Where; S^2 = population variance, m = mean number of termites per sample and Σx = total number of termites. When Cx = 0, the coefficient indicated a random dispersion; and when Cx = >0 – 1, it indicated an aggregated dispersion. Taylor's power law was used to model the relationship between mean and variance as:

$$S^2 = am^b.$$

The coefficients *a* and *b* were estimated from the regression model: log S^2 = log a + b log m, where, the slope *b* is an index of aggregation. When b < 1, it indicated a uniform distribution; when b = 1, it indicated a random dispersion; and when b > 1, it indicated aggregated distribution. Iwao's patchiness regression was used to quantify the relationship between the mean population crowding index (*m**) and mean density (*m*) using the following equation:

$$m^* = \alpha + \beta m$$

where the value of *m** was derived from formula: $m^* = m + (S^2/m - 1)$.

The intercept *α* is the index of basic contagion and *β* is the density contagiousness coefficient, a measure of aggregation.

Results

Spatial distribution patterns of *Ancistrotermes* and *Microtermes* species populations

The values of variance to mean ratios and Lloyd's patchiness index for *Ancistrotermes* and *Microtermes* species in the four *Eucalyptus* species plantations were greater than 1. The values of Z statistic (deviation from randomness) and Green coefficient were greater than 1.96 and zero, respectively for the two termite species in each of the *Eucalyptus* species plantations (Table 1). In Table 2, Taylor's power law regression analysis showed positively significant relationships between variance (S^2) and mean population of *Ancistrotermes* sp. in *E. camaldulensis* (R^2 = 0.98; p = 0.01), *E. citriodora* (R^2 = 0.96; p = 0.02) and *E. cloeziana* (R^2 = 0.99; p = 0.05) plantations. There was a weak relationship between log S^2 and log m of *Ancistrotermes* sp. population in *E. tereticornis* (R^2 = 0.02; p = 0.87) plantation. The values of the slopes (b) for the relationships between log S^2 and log *m* of *Ancistrotermes* sp. populations were significantly greater than 1 in *E. camaldulensis* (b = 2.21; t (cal) > t(tab)), *E. citriodora* (b = 1.95; t (cal.) > t (tab)) and *E .cloeziana* (b = 2.11; t (cal) > t (tab)) plantations but less than 1 in *E. tereticornis* (b = 0.18; t (cal) < t (tab)) plantation (Table 2).

Similarly, using Iwao's model regression analysis, there was a positive but non-significant (p < 0.05) relationship between the mean crowding and mean population of *Ancistrotermes* in *E. camaldulensis* (R^2 = 0.78; p = 0.11) and *E. tereticornis* (R^2 = 0.01; p = 0.68) plantations. However, the regression analysis of the population parameters showed a significant relationship in *E. citriodora* (R^2 = 0.91; p = 0.04) and *E. cloeziana* (R^2 = 0.96; p = 0.02) plantations. The values of slope (β), 4.56, 6.28 and 9.34 recorded for *Ancistrotermes* in *E.camaldulensis*, *E. citriodora* and *E. cloeziana* plantations, respectively were significantly greater than 1 (t cal > t tab). However, the value of slope, 1.42 in *E. tereticornis* was not significantly different from 1 (t cal < t tab) (Table 2).

Table 3 shows that the relationships between log S^2 and log m of *Microtermes* sp. were positively and significantly correlated in *E. camaldulensis* (R^2 = 0.99; p = 0.01) and *E. citriodora* (R^2 = 0.90; p = 0.05) plantations using Taylor's model. The relationship between the two parameters were not significantly correlated in *E. cloeziana* (R^2 = 0.29; p = 0.46) and *E. tereticornis* (R^2 = 0.77; p= 0.12) plantations. Furthermore, the values of slopes (b) observed in *E. camaldulensis*, *E. citriodora* and *E. cloeziana* were significantly greater than 1 (t cal > t tab) but did not differ significantly from 1 in *E. tereticornis* plantation (t cal < t tab).

Table 1: Dispersion parameters of *Ancistrotermes* and *Microtermes* species in different *Eucalyptus* plantations

Eucalyptus Plantations	Dispersion parameters							
	Ancistrotermes sp.				*Microtermes* sp.			
	Variance : mean ratio (S^2/m)	Deviation from randomness (Z)	Lloyd's Index (m*/m)	Green coefficient (Cx)	Variance : mean ratio (S^2/m)	Deviation from randomness (Z)	Lloyd's Index (m*/m)	Green coefficient (Cx)
E. camaldulensis	944.50	111.85	3.87	0.09	1488.85	290.75	5.69	0.06
E. citriodora	648.52	72.44	7.93	0.02	672.10	190.87	8.31	0.10
E. cloeziana	650.49	147.4	8.54	0.10	1815.24	292.51	7.44	0.20
E. tereticornis	858.65	182.24	4.71	0.10	1344.90	159.60	7.47	0.04

Table 2: Taylor's power law and Iwao's regression analysis for the dispersion of A*ncistrotermes* sp. in different E*ucalyptus* species plantation

Eucalyptus Plantations	Taylor power law						Iwao's regression					
	Log a	b	R^2	t (cal)	t (tab)	p-value	α	β	R^2	t (cal)	t (tab)	p-value
E. camaldulensis	-0.06	2.21	0.98	5.36	4.30	0.01	-0.66	4.56	0.78	5.11	4.30	0.11
E. citriodora	0.89	1.95	0.96	4.39	4.30	0.02	93.63	6.28	0.91	4.53	4.30	0.04
E. cloeziana	0.68	2.11	0.99	13.88	4.30	0.05	-19.31	9.34	0.96	6.61	4.30	0.02
E. tereticornis	4.87	0.18	0.02	0.92	4.30	0.87	1494.89	1.42	0.10	0.81	4.30	0.68

Table 3: Taylor's power law and Iwao's regression analysis for the dispersion of *Microtermes* sp. in E*ucalyptus* plantations

Plantation	Taylor power law						Iwao's regression					
	Log a	B	R^2	t (cal)	t (tab)	p–value	α	β	R^2	t (cal)	t (tab)	p-value
E. camaldulensis	1.27	1.73	0.99	5.21	4.30	0.01	413.32	3.18	0.98	6.72	4.30	0.01
E. citriodora	1.93	1.41	0.90	4.89	4.30	0.05	335.28	3.12	0.91	4.92	4.30	0.04
E. cloeziana	- 1.49	2.92	0.29	5.59	4.30	0.46	155.18	1.01	0.08	0.36	4.30	0.71
E. tereticornis	2.92	1.08	0.77	3.18	4.30	0.12	1380.13	0.86	0.11	0.08	4.30	0.66

Using Iwao's regression model for the relationship between the mean crowding and mean density of *Microtermes* sp., there were significantly positive relationships between the two population parameters in *E. camaldulensis* (R^2 = 0.98; p = 0.01) and *E. citriodora* (R^2 = 0.04) plantations. However, in *E. cloeziana* (R^2 = 0.08; p = 0.71) and *E. tereticornis* (R^2 = 0.11; p = 0.66) plantations the relationships between mean crowding and mean density of *Microtermes* were not significant (Table 3). The regression also showed that values of slopes in *E. camaldulensis* and *E. citriodora* plantations were significantly greater than 1 (t cal > t tab). The slope values in *E. cloeziana* and *E. tereticornis* were not significantly different from 1 (t cal < t tab).

Discussion

The results of variance to mean ratio, Lloyd's index and Green coefficient provided in this study indicated that *Ancistrotermes* and *Microtermes* species had aggregated dispersion in all the *Eucalyptus* plantations. This is similar to the reports of Bezerra and Wilcken (1998) and dos Santos et al (2011) that subterranean termites exhibited aggregated dispersion in *Eucalyptus* plantations. This aggregated dispersion suggests that the presence of a termite at one point leads to an increased probability of another individual termite being nearby. Termites aggregated dispersion could also be due to the release of aggregation and trail pheromones that attract other individual termites toward sources of food. Termites lay recruitment trail from the food source to the nest in a continuous manner (Reinhard and Kaib 2001). The recruitment trail is followed by more workers as well as by single soldiers. Following the course of this trail, termites build a non-branched subterranean tunnel or a gallery above ground leading to the source of food (Reinhard et al. 1997). The sternal gland is the only known source of trail pheromones in termites, and secretions of this gland are considered to function in the recruitment of nest mates from nest to feeding sites (Arab et al. 2012). Aggregated distribution had been reported in other soil insects such as wireworms, leatherjackets, Sciaridae, *Bibio johannis* and *D. febrilis* (Benefer et al. 2010).

The results of spatial distribution of *Ancistrotermes* and *Microtermes* species using Taylor's and Iwao's regression analyses showed different patterns of dispersion in different *Eucalyptus* plantations. This explains the reason why the use of one index is not sufficient for the determination of spatial dispersion of an organism. The uniform distribution pattern of *Ancistrotermes* and *Microtermes* species in *E. tereticornis* plantation using Taylor's power law and Iwao's regression models confirmed that different statistical methods produce varied results and accuracy in calculating the spatial distribution of an organism (Sedaratian et al. 2010). Taylor's power law and Iwao's regression have been widely used for evaluation of dispersion and sampling protocols for many insects (Deligeorgidis 2002). The correlation coefficient (R^2) in Taylor's model was always higher than in Iwao's model. This suggests that the data demonstrated better fitness in Taylor's model than Iwao's model. This has been noted for many other insects and mites (Geiger and Daane 2001, Hamilton and Hepworth 2004, Sedaratian et al. 2010, Darbemamieh et al. 2011). The coefficients *a* and *b* derived from the Taylor's power law have been described as sources of information for the calculation of sampling size in the development of management strategies for insect pests (Buntin 1994, Young and Young 1998, Moradi-Vajargah et al. 2011).

Conclusion

The spatial distribution of the foraging populations of *Ancistrotermes* and *Microtermes* exhibited aggregated dispersion using ratios of variance to mean, Lloyd index and Green coefficient in *Eucalyptus* plantation. However, the Taylor's and Iwao's model displayed different population spatial distributions (aggregated and uniform). Therefore, it could be concluded that the spatial distributions of the population of *Ancistrotermes* and *Microtermes* species is not influenced by the species of *Eucalyptus* but on the dispersion index employed. This important ecological information about *Ancistrotermes* and *Microtermes* can be useful in the determination of optimal sample size for effective management programme.

Conflict of interest

The authors declare that they have no conflicts of interest.

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