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Seasonal variation of litter arthropods in some Eucalyptus plantations at the Arboretum of Ruhande in Rwanda

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Abstract
The main objective of this study was to assess the seasonal variation of litter arthropods in seven *Eucalyptus* plantation types and native *Entandrophragma excelsum* stands at the Arboretum of Ruhande, Rwanda. Arthropods were collected using the 1m^2 square pick–up point technique, killed using 10% formalin solution, and transported to the laboratory for identification to the class level. The results indicate that the collected arthropod individuals belong to five classes. Seasonality exerted a strong effect on the abundance and diversity of litter arthropods. In total, 2828 arthropod individuals were collected in September 2012, 3458 individuals in January 2013 and 4005 individuals in April 2013. The Class of insects was the most abundant with relative frequency of 54.8%, 77.3% and 76.6% in September 2012, January 2013, and April 2013 sampling periods. The negative effect of *Eucalyptus* plantations on arthropods abundance was not exclusively confirmed by the results as some stands of *Eucalyptus* species had arthropod abundance comparable to those under native *Entandrophragma excelsum* stands. It is recommended to replicate this study under forest plantations located in other ecological zones in Rwanda, which will generate general information for better conservation of arthropod diversity in Rwanda. It is also recommended to continue arthropod classification at family, genus and species levels.
Keywords: Litter arthropods; Arthropod abundance; Arthropod diversity.

1. Introduction

Phylum Arthropoda is the largest in the animal kingdom, including more than one million species classified in more than nine classes (McGavin, 2002). Arthropods are highly represented in all habitats (Duelli *et al*., 1999) and may thus be used as indicators of environmental changes caused by land use changes, disturbance and pollution (Rocha *et al*., 2010).

Soil and litter arthropods are important decomposers of organic matter, recycling nutrients and releasing the energy locked in plant tissues (Petersen and Luxton, 1982; Kremen et al., 1993; Bardgett *et al*., 2005a; Bardgett *et al*., 2005b; Coleman and Rieske, 2006) which are vital processes for the sustainability of nature and unmanaged ecosystem (Lavelle *et al*., 2006). The breakdown of organic matter by arthropods is essential for the production of minute organic matter consumable by fungi and bacteria and thus, minerals and nutrients of dead organisms become readily available in the soil for plant uptake (FAO, 2013).

Variability in climatic variables such as temperature, humidity, rainfall, litter amount and slope of the terrain and elevation, and soil nutrients influence the abundance and diversity of the Arthropods (Samson *et al*., 1997; Townsend *et al*., 2008). Arthropod diversity is also dependent on habitat heterogeneity expressed as differences in litter pool and food (e.g., palatable leaf litter, fruits, seeds, and herbivore frass), toxins, (e.g., phenols and tannins) and structural complexity that creates habitat (e.g. branches and leaf litter depth) (William *et al.*, 2000; Dominy *et al*., 2003; Kaspari *et al*., 2003).

In Rwanda, forest plantations cover 10% of national territory, of which *Eucalyptus* plantatio*n* covers 65% (Nsabimana *et al*., 2008). Thought it is know that forest ecosystems conserve largest biodiversity, arthropod diversity has never been studied in Rwanda, suggesting a need for studying litter arthropods under these plantation species. In spite of the generalized use of *Eucalyptus* in forestry in many parts of the World, there is little information on its impact on the invertebrate fauna (Florence, 1985; Da Silva *et al*., 2008). In addition, the results of previous studies carried out throughout the World, were not conclusive about the influence *Eucalyptus* plantations on the abundance of invertebrates (Chander and Goyal, 1995).

This study aimed to test the hypothesis that *Eucalyptus* plantations may negatively affect the arthropod communities, although most studies reported a negative influence on invertebrates (Ratsirarson *et al*., 2002) resulting from the fact that *Eucalyptus* leaves have oil glands (Penfold and Willis, 1961) and other secondary compounds such as tannins, phenols and surface waxes which avoid consumption by leaf-eating arthropods (Ohmart *et al*., 1987; Larsson and Ohmart, 1988; Edwards and Wanjura, 1990).

The objectives of this study were to study the seasonal variation of litter arthropods under seven *Eucalyptus* plantation types and a native *Entandrophragma excelsum* stand, established at one climatic zone at the Arboretum of Ruhande in Rwanda, and thus document on ecological influence of these stands on arthropod diversity. Specifically: (1) to investigate seasonal variation of litter Arthropods under some *Eucalyptus* plantations; (2) to compare the abundance and diversity of litter arthropods in *Eucalyptus* and *Entendrophragma excelsum* stands and (3) verify the hypothesis that *Eucalyptus* plantations reduce or increase inhabiting arthropod diversity.

2. Materials and Methods

2.1 Study area

The Arboretum of Ruhande is situated at latitude 2°36´S and long. 29°44´E, in Southern Rwanda, nearby the National University of Rwanda with an altitude ranging between 1,638 and 1,737 m (Nsabimana *et al*., 2009). The climate in the region is characterized by a long-term average annual rainfall of 1246.4 mm with a bimodal rainfall pattern, two rainfall seasons alternating with two dry seasons. The short wet season extends from mid-September to December, a short dry season from January to February, a long wet season from March to May, and a long dry season from June to the mid-September. The relative humidity has the minimum of 59% during dry seasons and the maximum of 86% in wet seasons (Nsabimana *et al*., 2009).

The arboretum of Ruhande has the total area of about 200ha (Stanga, 1991) split up into 504 numbered plots. Each plot has 50 x 50m of size, with 207 native and exotic tree species of which 69 are *Eucalyptus species* (Nsabimana *et al*., 2008). Many plantation species are replicated, which offer opportunity to study effects of plantation species on different variables, including soil and biodiversity. The Arboretum of Ruhande houses a diversity of vertebrates including small mammals, Monkeys (*Chlorocebus aethiops, B*lue monkeys), gazelles (*Gazella dama),* birds, and bats which feed on a diversity of arthropods, including insects. Beside seeds production and biodiversity conservation, the Arboretum of Ruhande is used for teaching and research purpose by national teachers and students and those from foreign learning institutions (ISAR, 1987). The arboretum of Ruhande was historically managed by catting herbaceous plants and shrubs and leaving them on the ground (Nsabimana *et al*., 2009).

Seven *Eucalyptus* plantation types and one *Entandrophragma excelsum* stand were selected for the study. Each plantation type was replicated three times, making 24 plots in total. Selected stand types and plot numbers at the Arboretum of Ruhande are the following: *Eucalyptus citriodora* (plots 58, 211, 456), *Eucalyptus grandis* (plots 218, 220, 265)*, Eucalyptus maculata* (plots 6, 446, 458)*, Eucalyptus maidenii* (179, 377, 452)*, Eucalyptus microcorys* (plots 77, 367, 448)*, Eucalyptus saligna* (plots 20, 375, 442)*,* and *Eucalyptus tereticornis* (plots 109, 110, 540) and a stand which is native to Rwanda, *Entandrophragma excelsum* (plots 44, 54, 78). Three subplots of $1m^2$ were selected randomly in each plot leaving 5m at the edge.

2.2 Arthropods data collection and identification and litter pH measurement

Litter arthropods were collected using the square pick-up point technique (Lamotte, 1969) during three seasons: September 2012, January 2013 and April 2013. Aboveground litter was removed from the soil in a thin layer of about 6cm depth (Jovon, 2011) and targeted arthropods were visually recognized and pulled out with sharp-pointed forceps and fingers (Martin, 1977). Arthropods were collected into bottles containing a killing agent, 10% formalin solution (Steyskal et al., 1986). The samples were then transported to the laboratory for further identification using dichotomous keys in the literature (Scudder, 1993; Choate, 2003). Litter samples were also collected on the date of arthropods sampling, and were oven- dried at 70°C for 48h. Thereafter they were milled in a ball mill (Model: MM200, Retsch, Germany) for subsequent measurement of pH using litter powder water suspension in the ratio 1:2.5, and the mixture was left to settle for one hour and then read pH using a glass electrode.

2.3 Data analysis

Numbers of arthropod individuals per Class, were organized into excel sheets and analyzed using the Biodiversity professional software (McAleece *et al*., 1997). Diversity indices such as Shannon and evenness indices were calculated to determine the diversity of arthropods in different plantation types and to determine the similarity of different plantation types respectively. Biodiversity Professional software calculates the Shannon-weaver index H´ (Weaver and Shannon, 1949) using the following formula:

$$H' = -\sum_{i=1}^{S}(p_i \ln p_i) \qquad p_i = \frac{n_i}{N}$$

Where: n_i is the number of individuals in a species, *i* (the abundance of species *i*), S is the number of species, ***N*** is the total number of individuals in a community (here N is the number of arthropods in each Class), p_i is the relative abundance of each species, calculated as the proportion of individuals of a given species *i* to the total number of individuals in a community. A rich ecosystem with high species diversity has a large H´ value, while an ecosystem with little diversity has a low H´ (Weaver and Shannon, 1949).

3. Results

In total, 2828 arthropod individuals were collected in September 2012 at the end of short dry season. The Class of insects was the most abundant (54.8%) followed by the Class of Diplopoda (Table 1). Arthropod individuals were the highest in the litter of *Entandrophragma excelsum* stand (24.6%) followed by *Eucalyptus grandis* and *Eucalyptus tereticornis* stands (Table 1). The Class of insects was the most abundant in the litter of Arboretum plantations, with 77.3% of all arthropods sampled in January 2013, and the Chilopoda were the least sampled. The proportions of Arachnida, Crustacea and Diplopoda were almost comparable (Table 2). Arthropods individuals were the highest in the litter of *Eucalyptus saligna* stand (19.5%) followed by *Eucalyptus maidenii* stand (16.8%), while the arthropod individuals were the least abundant under *Eucalyptus maculata* stand (Table 2). A total of 4005 arthropod individuals were collected in April 2013, and the Class of insects was the most dominant (76.6%), while Chilopoda were the least abundant among other arthropod classes (Table 3). The arthropod individuals were the most dominant in the litter of *Eucalyptus tereticornis* stand followed by *E. saligna* stand (Table 3).

In total, 10291 arthropod individuals were collected during 3 seasons, of which 27.5% were collected in shot dry season (September 2012), 33.6% in shot wet season (January 2013), and 38.9% in long wet season (April 2013) (Fig. 1). The Class of insects dominated other Classes in all seasons. The Diplopoda were more abundant in dry season than in wet seasons (Fig. 1), and were not captured in *Eucalyptus microcorys* stand in all seasons. The Arachnida abundance did not change significantly following the seasons (Fig. 1).

Table 1. Abundance of arthropod individuals as sampled in September 2012 in the litter of 8 plantation types in the Arboretum of Ruhande and classified in their classes. *Entandrophragma exc = Entandrophragma excelsum.*

Plantation type	Arachnida	Chilopoda	Crustacea	Diplopoda	Insecta	Total Individuals	%
Entandrophragma exc.	61	15	13	349	259	697	24.65
Eucalyptus citriodora	22	6	4	37	131	200	7.07
Eucalyptus grandis	11	8	32	177	290	518	18.32
Eucalyptus maculata	19	3	8	19	104	153	5.41
Eucalyptus maidenii	54	0	40	16	206	316	11.17
Eucalyptus microcorys	24	4	24	0	101	153	5.41
Eucalyptus saligna	36	0	48	37	156	277	9.79
Eucalyptus tereticornis	73	1	57	80	303	514	18.18
Total individuals	300	37	226	715	1550	2828	
Frequency (%)	10.6	1.3	8.0	25.3	**54.8**		

Table 2. Abundance of arthropod individuals as sampled in January 2013 in the litter of 8 plantation types in the Arboretum of Ruhande and classified in their classes. *Entandrophragma exc = Entandrophragma excelsum.*

Plantation type	Arachnida	Chilopoda	Crustacea	Diplopoda	Insecta	Total Individuals	%
Entandrophragma exc.	55	7	15	80	234	391	11.3
Eucalyptus citriodora	18	11	12	28	212	281	8.13
Eucalyptus grandis	23	0	20	47	383	473	13.7
Eucalyptus maculata	11	3	11	22	108	155	4.48
Eucalyptus maidenii	27	1	47	7	498	580	16.8
Eucalyptus microcorys	36	6	41	0	347	430	12.4
Eucalyptus saligna	22	5	29	38	581	675	19.5
Eucalyptus tereticornis	53	2	101	8	309	473	13.7
Total individuals	245	35	276	230	2672	3458	
Frequency (%)	7.08	1.01	7.98	6.65	**77.27**		

Table 3. Abundance of arthropod individuals as sampled in April 2013 in the litter of 8 plantation types in the Arboretum of Ruhande and classified in their classes. *Entandrophragma exc* = *Entandrophragma excelsum.*

Plantation type	Arachnida	Chilopoda	Crustacea	Diplopoda	Insecta	Total Individuals	%
Entandrophragma exc.	52	6	4	76	82	220	5.49
Eucalyptus citriodora	32	11	12	27	202	284	7.09
Eucalyptus grandis	37	10	34	101	403	585	14.6
Eucalyptus maculata	22	11	23	58	262	376	9.38
Eucalyptus maidenii	37	2	35	13	351	438	10.93
Eucalyptus microcorys	22	15	12		198	247	6.16
Eucalyptus saligna	34	4	50	21	671	780	19.47
Eucalyptus tereticornis	43	7	110	16	899	1075	26.84
Total individuals	279	66	280	312	3068	4005	
Frequency (%)	6.96	1.64	6.99	7.79	**76.60**		

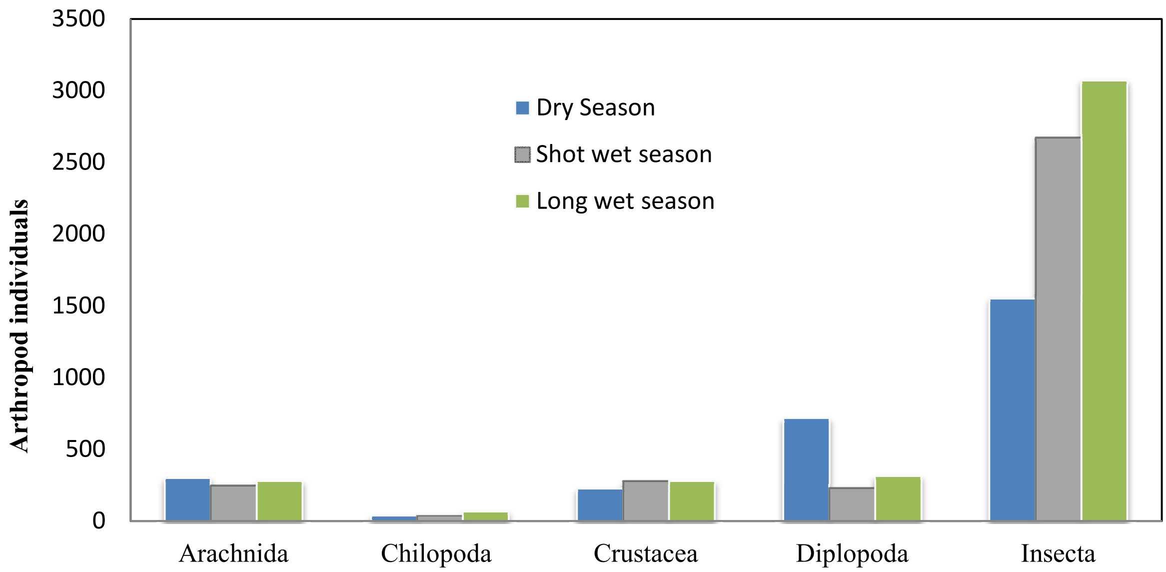

Figure 1. Seasonal variation of litter arthropods abundance in the Arboretum of Ruhande.

The Shannon diversity indices H′ of litter arthropods sampled in September 2012 (end of shot dry season) was the highest in the stand of *Eucalyptus saligna* followed by *E. tereticornis* and *Entandrophragma excelsum* stands (Table 4). The Shannon indices of the arthropods sampled in January 2013 are highest in *Entandrophragma excelsum* stand followed by *Eucalyptus maculata* stand (Table 4). Biodiversity analysis of litter arthropods sampled in April 2013 resulted in Shannon diversity indices that were highest in *Entandrophragma excelsum* stand followed by *Eucalyptus maculata* stand (Table 4). Considering the Shannon diversity indices for all seasons, it can be suggested that on the average, *Eucalyptus* plantations had less litter arthropod diversity in comparison to that of *Entendrophragma excelsum* stand (Table 4). Shannon diversity indices of litter arthropods sampled in September 2012 were higher than those in wet seasons (Table 4). The Shannon diversity indices correlated with litter pH ($R^2 = 0.66$; $p < 0.05$; Fig. 2).

Table 4. Shannon diversity indices for litter arthropods sampled in September 2012, January 2013 and April 2013.

Plantation type	September 2012		January 2013		April 2013	
	Shannon index	Eveness	Shannon index	Eveness	Shannon index	Eveness
Entandrophragma excelsum	0.471	0.292	0.48	0.298	0.542	0.337
Eucaltypus citriodora	0.441	0.275	0.382	0.298	0.422	0.337
Eucalytpus grandis	0.439	0.273	0.296	0.214	0.421	0.337
Eucalyptus maculata	0.439	0.273	0.426	0.298	0.426	0.337
Eucalytpus maidenii	0.431	0.311	0.235	0.298	0.311	0.337
Eucalyptus microcorys	0.413	0.298	0.289	0.208	0.308	0.222
Eucalyptus saligna	0.504	0.364	0.249	0.298	0.246	0.337
Eucalyptus tereticornis	0.493	0.306	0.41	0.298	0.264	0.337

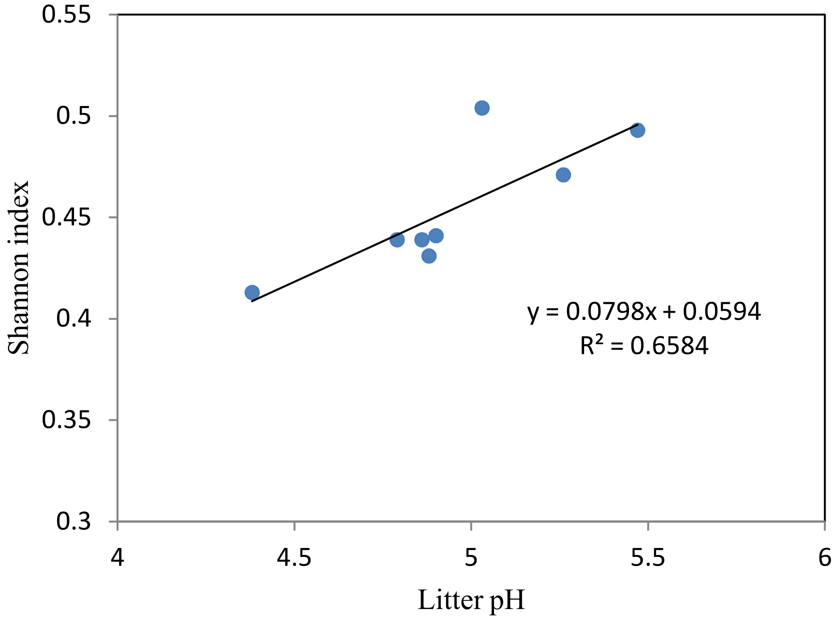

Figure 2. Positive relationship between litter pH and Shannon diversity indices for the arthropods sampled in September 2012.

4. Discussion

This study is the first that has examined the likely impact of wet and dry seasons on leaf litter arthropods in a number of *Eucalyptus* plantation types and *Entendrophragma excelsum* stands at the Arboretum of Ruhande, Rwanda. Seasonality has affected the abundance and diversity of litter arthropods, with wet seasons having the higher number of arthropods (Fig. 1). This may be explained by the fact that the litter biomass was greater in wet seasons than in dry season (Pearson *et al*., 1986). It may also result from the development of understory vegetation that could be eaten by the arthropods during wet seasons (Pereira *et al*., 2001). Seasonal variability is also linked to temperature change, which determines the growth rate of arthropods (Wolda, 1988).

Seasonality of litter arthropods has been studied by many authors. For instance, most arthropod groups had high number of individuals during wet seasons but declined during dry month in an Australian rain forest (Frith and Frith, 1990). Similar finding was observed in Amazonian forest, Brasir (Silveira *et al*., 2009). Arthropod abundance in wet season was of 2.3 times higher than that in dry season as observed in a tropical oceanic island (Tanaka and Tanaka, 1982). The abundance of arthropods in wet seasons were very high comparable to those in dry seasons in a lowland forest in Southern Peru (Pearson *et al*., 1986). It was noted that climatic seasons tend to translate into seasonal activity patterns in living organisms including arthropods which became active only at certain times of the year (Wolda, 1988).

In this study, the abundance of litter arthropods increased from 27.5% in September 2012, to 33.6% in January 2013 (shot wet season) and 38.9% in April 2013 (long wet season) (Fig. 1). These figures indicate that the litter invertebrates increase with the precipitation, but heavy rainfall tends to decrease litter amount and soil invertebrate densities (Chiba *et al.,* 1975). Shannon indices of arthropods sampled in September 2012 were higher than those in other seasons (Table 4), indicating that the heavy rain tends to decrease arthropods diversity as it was also noted by Chiba *et al.* (1975).

The *Eucalyptus* plantations have been more blamed worldwide to affect negatively litter arthropods (Zahn *et al*., 2009) suggesting that some *Eucalyptus* species do not allow development of understory vegetation which may be feed by arthropods (Pereira *et al*., 2001). The *Eucalyptus* species are also blamed for having poor organic carbon (Signihal *et al*., 1975; Balagopalan and Jose, 1995; Animon *et al*., 1999). It has also been suggested that some *Eucalyptus* species are efficient competitors for water from soil (Poore and Fries, 1985). Having oil glands in their leaves (Penfold and Wills, 1961) and tough leathery leaves (Edward and Wanjura, 1990) have been also included among reasons to blame *Eucalyptus* plantations to limit development of litter arthropods.

However, the results of this study show that the stands of *E. tereticornis, E. saligna,* and *E. grandis* have a greater abundance of arthropods than the litter of *Entendrophragma excelsum* stand that has been used for comparison (Tables 1–3). These *Eucalyptus* stands allow the growth of herbs and shrubs of various types, which serve as food to inhabiting arthropods (Pereira *et al*., 2001). It was noted that high vegetation diversity supports in turn a high invertebrate diversity (Teodorescu and Cogalniceanu, 2002) and the poor undergrowth of herbaceous plants result in reduced arthropods abundance (Mallick and Pati, 1996).

The Class of insects has remained most dominant among arthropods collected in all seasons (Tables 1–3; Fig. 1), this may be explained by the fact that the Class of insects has Hymenoptera order which is worldwide abundant (Chavhan *et al*., 2011), including Formicidae (ants) which prefer wet litter habitat conditions and deep litter depth (Sabu, 2005) and increasing with the increase of their specific food resources such as larva and other arthropods (Samson *et al*., 1997; Shattock and Barnet, 2001). Insects are also able to adapt to the extreme environmental conditions such as rain, high humidity and low litter temperature (Stork, 1988; Basu, 1997).

The Centipedes remained the fewest in all seasons that we sampled (Fig. 1) and under all plantation types. This may be because they do not eat litter; they are primarily carnivorous, eating marine insects (Chamberlin, 1920). On the other hand, Millipedes were higher in dry season (Fig. 1) and it was contrary to previous finding that they usually have their highest activity in spring and autumn (Voigtländer, 1996; Tajovsky, 2000). This high number may support the note by Berg and Hemerik (2004) that some millipedes do not have ecological preference.

On the average, the arthropods diversity (Shannon index) in *Eucalyptus* stands was lower than that in *Entendrophragma excelsum* stands (Table 4). This may result from multiple reasons: *Eucalyptus* stands have less understory vegetation types (Pereira *et al*., 2001); they are poor in organic carbon (Animon *et al*., 1999); their effectiveness in competition for water (Poore and Fries, 1985); having leaves that leachate directly on certain species of arthropods (Canhoto and Laranjeira, 2007; Zahn *et al*., 2009) and their influence on soil and litter pH which has shown correlation with diversity indices (Fig. 2). All these conditions can unfavour the establishment of certain species of arthropods in *Eucalyptus* stands.

5. Conclusions

The present results provide an overview on the seasonal variation of litter arthropods in some *Eucalyptus* plantations at the Arboretum of Ruhande. The study confirms that the seasonality has an effect on the abundance and diversity of arthropods, with highest figures in wet seasons. The negative effect of *Eucalyptus* plantations on arthropods abundance was not exclusively confirmed as some stands of *Eucalyptus* species had arthropod abundance comparable to those under native *Entandrophragma excelsum* stands. The Class of insects was the most abundant in all seasons with relative frequency of 54.8%, 77.3% and 76.6% in September 2012, January 2013, and April 2013 sampling periods respectively. This study need to be repeated under forest plantations located in different ecological zones in Rwanda.

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