BIODIVERSITAS
Volume 26, Number 4, April 2025
Pages: 1618-1629

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d260413

Impact of planting rotations and tree age on insect pests and weeds in balsa plantations of East New Britain, Papua New Guinea

MALAGAT BOAS[1], JOSHUA URIM[2], KARI SOGERA IAMBA[3,4,♥]

[1]Department of Fisheries, Papua New Guinea University of Natural Resources and Environment. Vudal 613, East New Britain, Papua New Guinea
[2]Department of Forestry, 3A Composites PNG Balsa. Kokopo 611, East New Britain, Papua New Guinea
[3]Department of Agriculture, Papua New Guinea University of Natural Resources and Environment. Vudal 613, East New Britain, Papua New Guinea
[4]Department of Zoology, Faculty of Science, University of South Bohemia. Branišovská 1760, 370 05 České Budějovice, Czech Republic.
Tel./fax.: +420-775-368233, ♥email: kari.iamba@gmail.com

Manuscript received: 23 June 2024. Revision accepted: 28 March 2025.

Abstract. *Boas M, Urim J, Iamba KS. 2025. Impact of planting rotations and tree age on insect pests and weeds in balsa plantations of East New Britain, Papua New Guinea. Biodiversitas 26: 1618-1629.* Balsa (*Ochroma pyramidale*) is an income-generating tree crop in East New Britain Province (ENB) of Papua New Guinea, and repetitive planting (rotations) on the same piece of land can result in pest and weed incursions. We sampled insects and weeds from three planting rotations: rotation 1, 2, and 3, and across two age groups: 1-9 months and 10-18 months old trees within each rotation. We found that the age of trees did not strongly affect pest abundance. The reason is that most of the pests associated with balsa trees are cocoa pests and were present in the soil before the blocks were cleared for the first planting. However, the planting rotations had a strong effect, suggesting how harvesting and clearing can affect the colonization and establishment of insects. The abundance of insects increased with planting rotations, with most individuals participating in the third rotation. In contrast, the diversity of pests between young trees (1-9 months) did not differ significantly from older trees (10-18 months). Since the plantations studied are generally young (<2 years), leaves are less lignified; therefore, there is lower attractiveness and colonization by insect pests. Weed abundance was strongly associated with planting rotations and tree age. However, neither factor affected the species richness of weeds, hence the diversity. This can be explained by the exotic status of weed species and supported by the Enemy Release Hypothesis (ERH). Many weed species sampled are invasive and are free from natural enemies. We assume that high pest diversity in rotation two directly responds to the availability of natural vegetation near balsa plantations that provide refugia for insects. This study emphasizes the importance of land use history and how past host plants such as cocoa or coconut can sustain pest load and affect balsa trees. It also provides information on intercrop systems and their impact on pest and weed infestation in balsa plantations. Overall, the findings are relevant to plant protection management.

Keywords: Balsa, insect pests, planting rotations, tree age, weeds

INTRODUCTION

Balsa (*Ochroma pyramidale*) is becoming a potential income-generating tree crop in East New Britain Province (ENB) of Papua New Guinea. However, more information is needed on the dynamics of pest and weed incursions resulting from repetitive planting on the same block of land for over 2 to 3 or even four rotations, totaling 10 to 15 or 20 years, respectively, which are growing concerns. According to Howcroft (2002), most balsa trees were mainly damaged by cocoa pests. A healthy forest is not free of insects, diseases, disturbances, and tree defects. The impact of pest occurrence on tree mortality, losses, and damage to large volumes of forest trees every year is significant (Pautasso et al. 2015; Balla et al. 2021). Pests affect crop productivity and include pathogens, weeds, nematodes, mollusks, arthropods, and vertebrates (Culliney 2014). The status of an insect pest develops when there is an increase in their population, resulting from unlimited food supplies, less competition, and favorable climatic conditions. Climatic change is already influencing agriculture and crop production in the Pacific Island Countries (Georgeou et al. 2022). Changes in environmental conditions, such as a rise in temperature, can affect the reproduction, survival, spread, and population dynamics of pests (Skendžić et al. 2021).

Several types of insects, including bark beetles, may attack stressed trees or large-size trees (Stephenson et al. 2019; Tai et al. 2019; Koontz et al. 2021). Insects and pathogens can have short-term and long-term impacts on forest ecosystem services (Seidl et al. 2018; Guo et al. 2023). The disturbances or damage caused by these pests can be either direct or indirect. Direct damage includes boring, piercing, and sucking into the trunk or spreading toxic substances, pathogens, or exudates, which cause plant mortality resulting in loss of production. Several insect and fungal pests have been recorded on balsa in ENBP, although none has threatened the industry so far (Midgley et al. 2010). Howcroft (2002) observed that the incidence of insect problems was higher on sites close to old cocoa blocks or land previously planted with cocoa. Most of the species were cocoa-related pests, like *Pantorhytes plutus* (cocoa weevil), *Glenea lefebvrei*, *G. aluensis* (longicorn beetle), and *Sylepta derogata* (leaf roller) causing damage to the balsa trees. *Zeuzera coffeae*, a coffee pest, seriously

damaged most 18-month-old balsa trees in Java (Nair 2000).

Weeds are also considered pests as they interfere with man's agricultural, horticultural, and pastoral activities (Gullino et al. 2022; Haq et al. 2023). Perennial weed species are a significant problem in agriculture and forestry since they have well-developed underground systems (Monteiro and Santos 2022; Zimdahl and Basinger 2024). Native weeds pose a low threat to production since the bush fallow system allows the forest system to regenerate during fallow, hence avoiding heavy weed infestation. Weeds, mainly grasses and herbs, also compete with young woody saplings for sunlight, thus slowing down the growth of trees. The increase in light availability after forest clearing promotes the growth of grasses, herbs, ferns, and vines (Chazdon 2014) that can significantly inhibit forest regeneration through competition (Elgar et al. 2014; Knoke et al. 2014; Catterall 2016). There is a shift from non-native to native plants over time (Shoo et al. 2016). Weeds can also become hosts to insect pests when there are no weed management strategies (Kumar et al. 2021).

This study was carried out to assess the temporal change in species composition of insect pests and weed species at different planting rotations. The cocoa industry in East New Britain was ravaged by a serious pest called cocoa pod borer (*Conopomorpha cramerella*) in 2006 and thousands of small farmers were affected. Since then, more research focused on the management of pests not only on cocoa but other commodity crops such as balsa, coconut and galip. Since there is little or no information on the impact of insect pests and weeds in balsa, we did the study in a scientific approach to provide this baseline information that can be useful for future research dealing with plant protection strategies. We expect the species richness of insects to decrease and weeds to increase with increasing rotation. The decrease in soil nutrients over time and fast growth rate will favor the growth of weeds, hence their richness and abundance. On the other hand, the removal of trees during harvesting will affect species richness and abundance of insects; therefore, they will decrease with increasing rotation. We also predict that younger trees will host fewer insects than older trees due to their temporal proximity to disturbance.

MATERIALS AND METHODS

Study sites

Six (6) plots from three different balsa plantations, namely Veranulla, Gilalum, and Lakunda plantations in the Gazelle Peninsula, were selected for this study (Figure 1). These plots consisted of different aged groups of balsa trees and were undergoing three different rotations of planting. Plot 1 and Plot 2 were both first Rotation plantings with ages 1-9 months and 10-18 months, respectively, and both were at Veranulla Plantation. Plot 3 and Plot 4 were second rotation plantings. Plot 3 was 1-9 months old, and Plot 4 was 10-18 months old, respectively, and were from Gilalum Plantation. Plot 5 and Plot 6 were third rotation blocks. Plot 5 was 1-9 months old located in Lakunda Plantation, and Plot 6 was 10-18 months old located in Veranulla Plantation. The total area of each sample plot was 24x24 m (576m²) at a planting space of 3x3 m totaling 81 trees per plot.

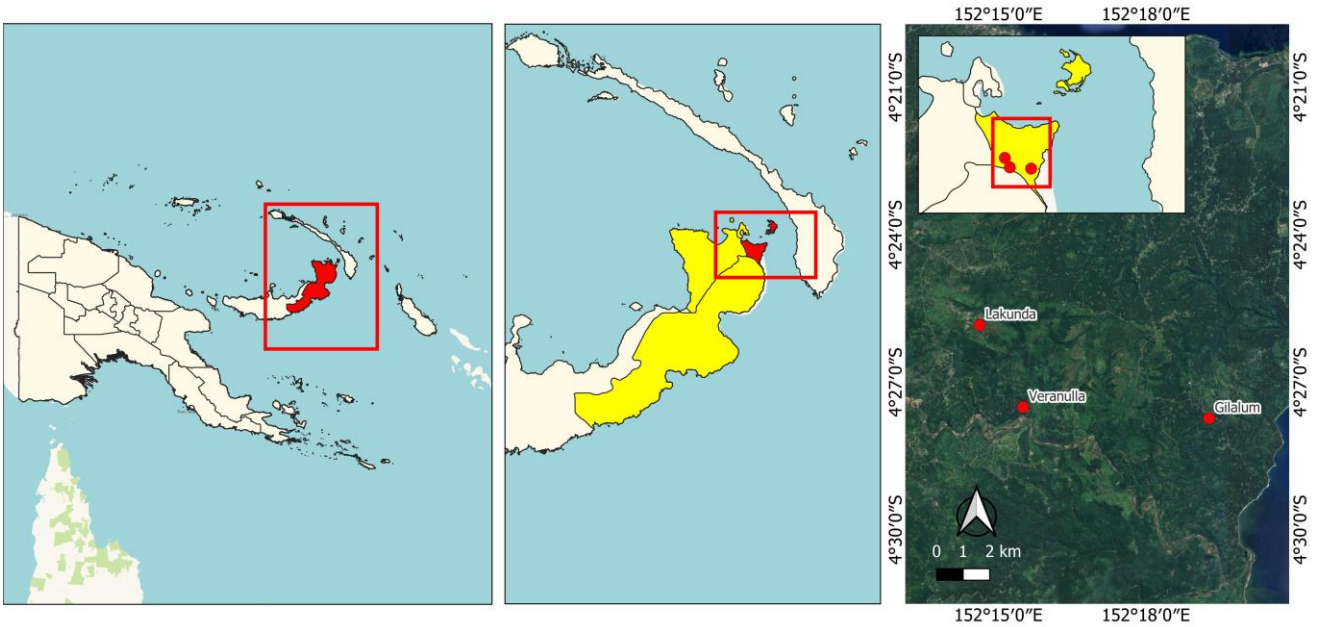

Figure 1. Map of the three balsa plantations in which the study was carried out. The three study sites are at least 3 km apart and located in East New Britain Province of Papua New Guinea

Plot 1 was previously intercropped with cassava (*Manihot esculenta*), kaukau (*Ipomoea batatas*), taro (*Colocasia esculenta*), tobacco (*Nicotiana tabacum*), and tomato (*Solanum lycopersicum*) during the first four (4) months after field planting. Prior to balsa, this plot was planted with cocoa and intercropped with coconut, but later cleared, paving the way for balsa except for the coconut trees. Plot 2 was under first rotation and consisted of trees of age 10-18 months. This plot was also previously planted with cocoa and intercropped with coconut trees.

Plot 3 was planted with second rotation trees at 1-9 months. Previously, it was planted with cocoa and coconut, but cocoa was removed except coconut trees. In Plot 4 balsa was also intercropped with coconut trees after cutting down the cocoa trees. These plots have now been used for two consecutive plantings. The first four months of planting of both plots were intercropped with ground nuts (*Arachis hypogaea*), kaukau, tomatoes, pumpkin (*Cucurbita* sp.), cabbages (*Brassica* sp.), and tobacco. Plot 5 was previously planted with the second rotation of balsa planting, likewise, Plot 6. Both plots were now going through the third rotation of planting with a period of five (5) years per rotation. However, more than ten (10) years ago, both plots were planted with cocoa trees which were cut down to make way for balsa planting while leaving the coconut trees standing. Up to four (4) months after field planting, gardens were ceased to avoid disturbing root development. Graphical description of the land use history of the plots is shown in Figure 2.

Insect identification and collection method

Monitoring of insects and sampling was done very early in the morning, between 5:30 am and 6:00 am, for six days in each of the six (6) plots. The first two weeks were carried out on first (1st) rotation plots at 1-9 months and 10-18 months, respectively. In the following two weeks, monitoring and sampling were done on the second (2nd) rotation plots at 1-9 months and 10-18 months. In the fifth (5th) and sixth (6th) week, monitoring and sampling were done on the third (3rd) rotation plots aged 1-9 months and 10-18 months, respectively. Insect counts were done on their presence on each of the young balsa trees in each plot. The population of each pest on the balsa leaves, stems, branches and weeds in each plot was recorded. A sampling of insects of economic importance was also collected and placed in collecting bottles with 70% alcohol, then later dried, identified, and pinned up in the insect boxes. We used the Pacific Pests, Pathogens and Weeds Introduction website (https://apps.lucidcentral.org/pppw_v12/text/intro/index.html) to aid in identifying insect pests and weeds. This website gives helpful interactive keys and has an application that is accessible via smart phone.

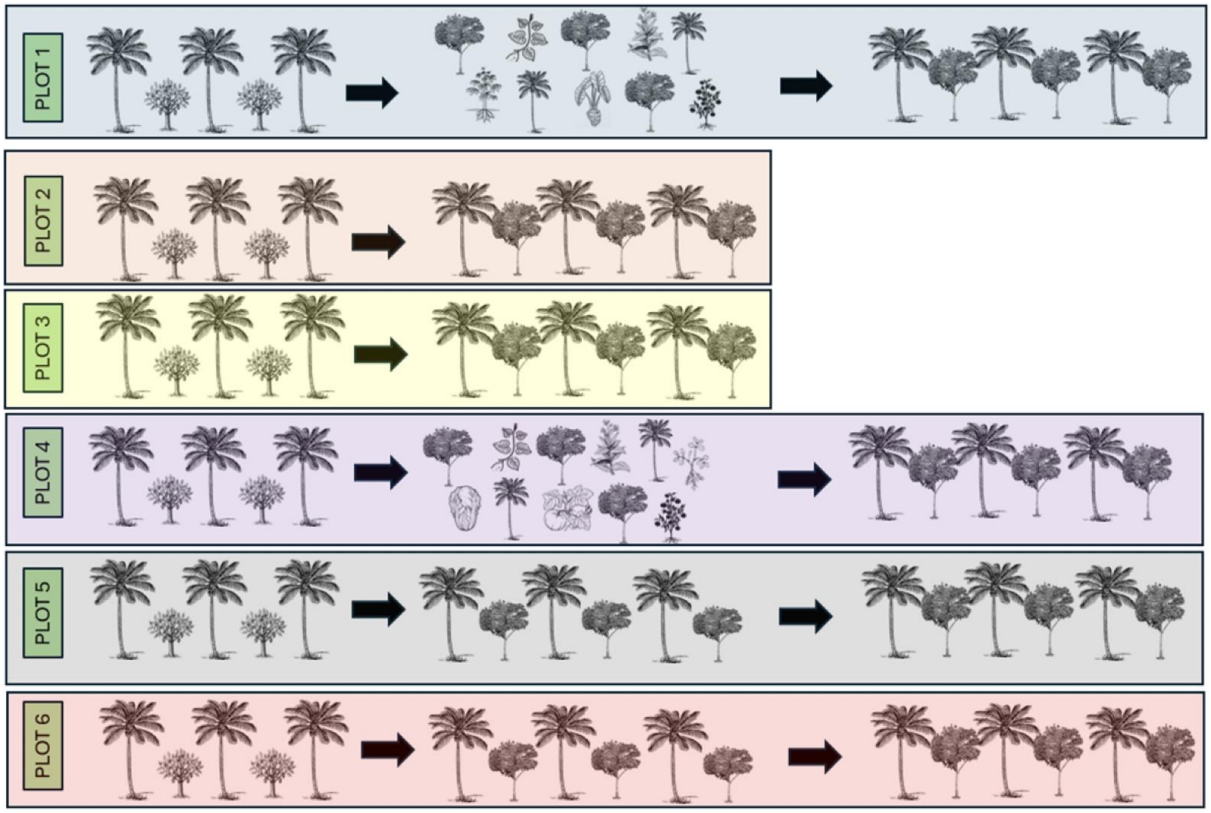

Figure 2. Graphical description of the land use history of the plantations. Plot 1 was previously planted with cocoa-coconut intercrop system then cocoa was replaced by balsa-coconut-vegetable system and eventually balsa-coconut system. Plot 2 was previously occupied by cocoa-coconut intercrop system followed by balsa-coconut system. Plot 3 was previously planted with cocoa-coconut system then replaced by balsa-coconut system. Plot 4 was initially planted with cocoa-coconut system followed by removal of cocoa paving way for balsa-coconut-vegetable system and eventually replaced by balsa-coconut system. Plot 5 and Plot 6 was previously occupied by cocoa-coconut system then followed by balsa-coconut system after which the harvested balsa was replaced with new balsa trees

Weed identification method

Weed sampling was carried out using a 1x1 m quadrat. In each of the six plots, a starting point was selected in the center of each plot, and then 10 m was measured from this starting point to where the first throw was taken. The quadrant was thrown 5 meters away from where it previously landed. This was done on a random basis up until five (5) consecutive throws were made for each plot. Where each quadrat landed, a careful identification and count of each weed's species population was recorded for each quadrat. On the field, weed identification was done using reference material (Weeds of New Guinea and their control) by Henty and Pritchard (1988).

Data analysis

All analyses were performed in R version 4.4.0. (R Core Team 2024). We used planting rotations and tree age as predictors, and abundance and species richness as responses. Firstly, the abundance was summed and pooled according to planting rotations, tree age, and species. This procedure is applied to both insect pests and weed species. After that, we used the VEGAN package to determine the total number of species and their diversity (Shannon index) in each planting rotation and tree age group. The effects of the predictors (rotation, age) were predicted using a Generalized Linear Model (GLM) with Poisson error distribution to account for species counts and abundances. We ran separate analyses for each predictor with species richness and abundance, respectively. We used a simple Linear Model (LM) to test the effect of rotation and tree age on the diversity of pests and weeds. All models were tested for significance using ANOVA from the CAR package, followed by post-hoc pairwise tests. We calculated the estimated marginal means using the EMMEANS package to do a pairwise comparison of means. To determine the species composition, we pooled the abundance of each species together for the three planting rotations (rotation 1, 2, 3) and two tree age groups (1-9 months, 10-18 months). Then, we calculated the percentage of each species across rotations and ages. This provided information on the presence and absence of each species, and their composition (%). For multivariate analysis, we used Redundancy Analysis (RDA) as a method to extract and summarize the variation in our response variable (species richness). We explained them using our explanatory variables (planting rotations, tree age). RDA assumes a linear relationship among variables (Wildi 2017).

Therefore, to do that, we modeled the species matrix as response and rotation and the age matrix as explanatory variables. Two RDA analyses were done, each for insects and weed complexes. RDA constrained ordination method was performed using VEGAN package. The species data matrix was log-transformed using the Hellinger method. The RDA did the partitioning of variances for both the constrained and unconstrained ordination. We selected species that explain at least 80% of the variation. Each axis was explained by the eigenvalues along with their explained variation (proportion). The test of significance was done by running ANOVA of each model with permutations: 999 using the CCA package. All graphical representations of the analyses were done using the GGPLOT2 package.

RESULTS AND DISCUSSION

A total of 35 insect pest species, with 2,838 individuals, were sampled during the study. We sampled 46 species in rotation 1, 53 in rotation 2, and 50 in rotation 3. Across the tree age groups, we collected 78 species in 1-9 months trees and 71 species in 10-18 months. A total of 24 weed species, with 3,237 individuals, were sampled during the study. We sampled 32 species in rotation 1, 21 in rotation 2, and 19 in rotation 3. For the tree age groups, we collected 38 species in 1-9 months and 34 species in 10-18 months of trees.

The species richness of pests did not change across the planting rotations ($\chi 2$: 0.49, df: 2, p: 0.78). There was no change between rotation 1 vs. rotation 2, rotation 1 vs. rotation 3, and rotation 2 vs. rotation 3 (Table 1). In contrast, the abundance of pests changed significantly across the planting rotations ($\chi 2$: 86.311, df: 2, $p<0.001$). Pest abundance in rotation 2 was higher than rotation 1 (z: -3.47, p: 0.002), and rotation 3 was higher than rotation 2 (z: -5.67, $p<0.001$). Similar to pest richness, the number of weed species did not change across planting rotations ($\chi 2$: 3.926, df: 2, p: 0.1404) (Table 2). The weed's abundance followed a similar pattern as pests with significant change across planting rotations ($\chi 2$: 959.05, df: 2, $p<0.001$).

Table 1. Pairwise comparisons of pest richness and abundance between planting rotations and tree age groups, respectively. The contrasts are based on separate models for pest richness and pest abundance. Each contrast is quantified by estimate, Standard Error (SE), z-value, and p-value. The z-value measures whether the standard deviations are above or below the mean of each model

Contrast	Pest species richness				Pest abundance			
	Estimate	SE	z-value	p-value	Estimate	SE	z-value	p-value
Rotation 1 - Rotation 2	-0.1417	0.202	-0.703	0.7617	-0.170	0.0491	-3.469	0.0015
Rotation 1 - Rotation 3	-0.0834	0.204	-0.408	0.9123	-0.421	0.0465	-9.058	< 0.001
Rotation 2 - Rotation 3	0.0583	0.197	0.296	0.9530	-0.251	0.0443	-5.674	< 0.001
1-9months - 10-18months	0.094	0.164	0.573	0.5665	-0.004	0.0375	-0.113	0.9103

Table 2. Pairwise comparisons of weed richness and abundance between planting rotations and tree age groups, respectively. The contrasts are based on separate models for pest richness and pest abundance. Each contrast is quantified by estimate, Standard Error (SE), z-value, and p-value. The z-value measures whether the standard deviations are above or below the mean of each model

Contrast	Weeds species richness				Weeds abundance			
	Estimate	SE	z-value	p-value	Estimate	SE	z-value	p-value
Rotation 1 - Rotation 2	0.421	0.281	1.500	0.2910	-0.626	0.0396	-15.808	< 0.001
Rotation 1 - Rotation 3	0.521	0.290	1.800	0.1696	0.835	0.0581	14.385	< 0.001
Rotation 2 - Rotation 3	0.100	0.317	0.316	0.9464	1.461	0.0538	27.137	< 0.001
1-9 months - 10-18 months	0.111	0.236	0.471	0.6375	0.776	0.0378	20.520	< 0.001

The species richness of pests did not change with the tree age (χ2: 0.33, df: 1, p: 0.57). There was no change in the first 9 months of growth and also in the successive 9 months (Table 1). Also, the pest abundance did not change dynamically with tree age (χ2: 0.012, df: 1, p: 0.91). The number of weed species did not change during the 18 months of tree growth (χ2: 0.22, df: 1, p: 0.64). In contrast, their abundance changed significantly during the 18 months of growth (χ2: 453.32, df: 1, p<0.001) (Table 2). Weed abundance increased significantly in the first 9 months of growth and decreased in the successive 9 months (z: 20.52, p<0.001).

We used both the planting rotations and tree age in a single RDA model to determine the linear relationship among pest species. Overall, the RDA model with permutations = 999 was not significant (F: 0.94, df: 3, p: 0.65). Most of the variation was explained by the first axis (33%, F: 1.59, df: 1, p: 0.8) and the second axis (16%, F: 0.77, df: 1, p: 0.78). Pest species that explain at least 80% of variation are *Aulacophora flavomarginata*, *Aulacophora foveicollis*, *Halyomorpha halys*, *Helopeltis clavifer*, *Nezara viridula*, *Oecophylla smaragdina*, *Phyllophaga* sp., *Planococcus lilacinus*, *Sexava* sp., *Spilosoma virginica* and *S. derogata* (Figure 3). Rotation and age explained 49% of the total variation in pest species composition. *Halyomorpha halys*, *O. smaragdina*, and *S. derogata* are associated with rotation 2 and older trees. *Helopeltis clavifer* and *Sexava* sp. are associated with rotation 1, rotation 3, and older trees. *Aulacophora flavomarginata*, *P. lilacinus*, and *N. viridula* are associated with rotation 3 and younger trees. *Spilosoma virginica* and *Phyllophaga* sp. do not have any strong association with planting rotation and tree age.

We used both the planting rotations and tree age in a single RDA model to determine the linear relationship among weed species. Overall, the RDA model with permutations: 999 was significant (F: 1.89, df: 3, p: 0.03). Most of the variation was explained by the first axis (49.1%, F: 3.78, df: 1, p: 0.02) and the second axis (14.6%, F: 1.12, df: 1, p: 0.66). Weed species that explain at least 80% of variation are *Crassocephalum crepidioides*, *Imperata cylindrica*, *Paspalum conjugatum*, *Peperomia pellucida* and *Sorghum halepense* (Figure 4). Rotation and Age explained 63.7% of the total variation in weed species composition. *P. pellucida* is closely associated with rotation 2 and older trees. *Paspalum conjugatum* is associated with young trees of rotation 2, and *C. crepidioides* is associated with young trees of rotation 3. Both *I. cylindrica* and *S. halepense* are closely associated with older trees of rotation 3.

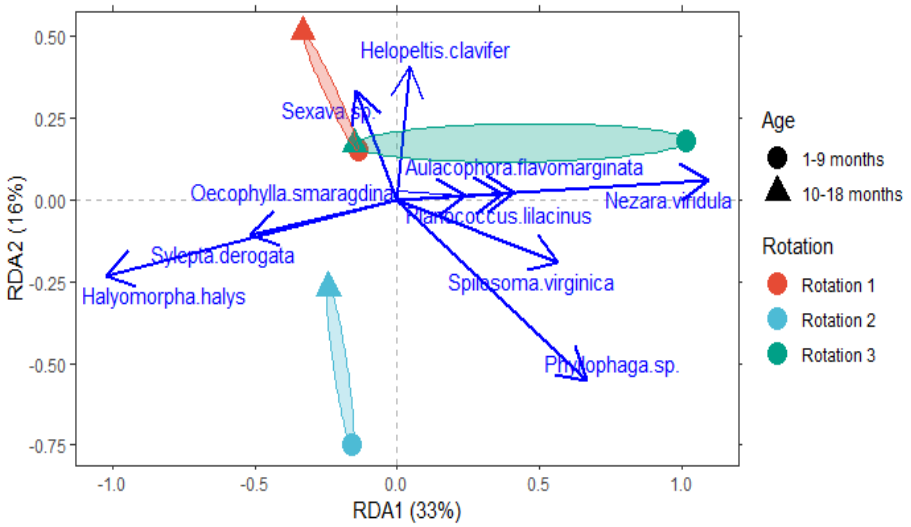

Figure 3. Only pest species that explain at least 80% of variation are shown. This ordination plot is based on the RDA model of the pest species matrix and two explanatory variables: tree age and planting rotation. The pest species matrix was transformed using the Hellinger distance to quantify the similarity between species and explanatory variables

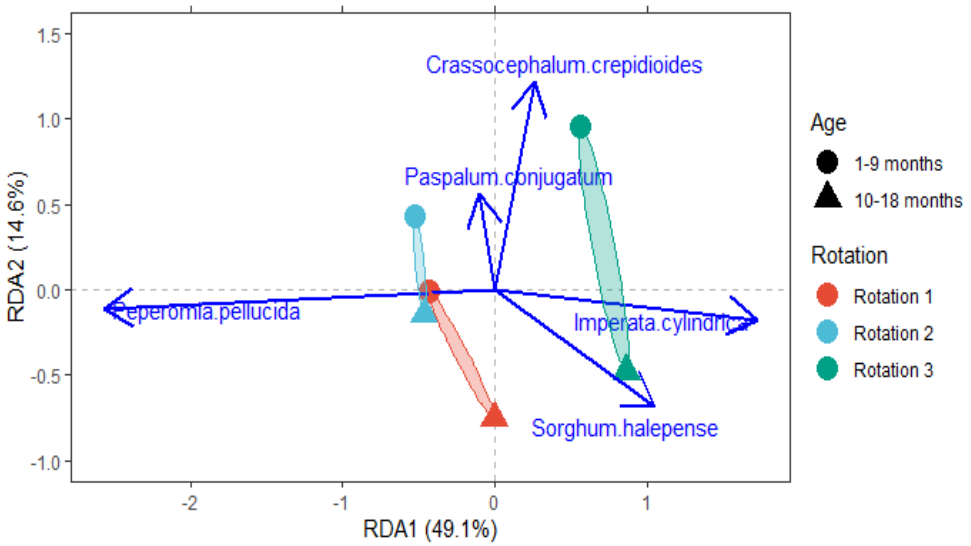

Figure 4. Only weed species that explain at least 80% of variation are shown. This ordination plot is based on the RDA model of the weed species matrix and two explanatory variables: tree age and planting rotation. The weed species matrix was transformed using the Hellinger distance to quantify the similarity between species and explanatory variables

According to the pest species that explained 80% of the variation, *A. flavomarginata*, *N. viridula*, *O. smaragdina*, and *P. lilacinus* were only present in rotation 3. These four pest species were unique to rotation 3 and were not found in the other two rotations. *Phyllophaga* sp. was present in rotation 2 and rotation 3 but not in rotation 1 (Figure 5). While *A. foveicollis*, *H. halys*, *H. clavifer*, *Sexava* sp., *S. virginica*, and *S. derogata* were present across all three rotations. These six pest species were common across all three rotations. Rotation 1 and rotation 2 had a single unique species each: *Valanga* sp. and *Xenococcus annandalei*, respectively. Most insect pest species were unique and common in rotation 3, while Rotation 1 and rotation 2 had a shared number of species.

The common pest species that were unique to young trees include *A. flavomarginata*, *N. viridula*, *O. smaragdina*, *P. lilacinus*, and *X. annandalei* (Figure 6). Only *Valanga* sp. was unique to older trees, while *A. foveicollis*, *H. halys*, *H. clavifer*, *Phyllophaga* sp., *Sexava* sp., *S. virginica* and *S. derogata* were present in both the young and old balsa trees. Most pest species were unique and common in plantations with younger trees, while older balsa trees shared a number of pest species.

The common weed species that are unique to rotation 1 include *Elephantopus mollis* and *Euphorbia geniculata* (Figure 7). Rotation 2 was only dominated by *Ageratum conyzoides*. *Sorghum halepense* is present in rotation 1 and rotation 3, *I. cylindrica* in rotation 1 and rotation 3, *P. pellucida* in rotation 1 and rotation 2, *C. crepidioides* in rotation 2 and rotation 3, and finally, *P. conjugatum* is present across all three rotations. Most weed species are unique and common in rotation 1, while rotation 2 and rotation 3 had a shared number of species.

The common weed species that are unique to young balsa trees include *A. conyzoides*, *C. crepidioides*, *Cyperus brevifolius*, *E. mollis*, *E. geniculata* and *Solanum torvum* (Figure 8). Others like *S. halepense*, *I. cylindrica*, *P. pellucida*, and *P. conjugatum* are present in both young and old balsa plantations. Most weed species were unique and common to younger balsa trees, while older balsa trees shared a number of species.

The diversity of insect pests, as measured by the Shannon index, was significant across planting rotations (F: 21.81, df: 2, p: 0.02). Pest diversity in rotation 1 was significantly lower than in rotation 2 (t: -6.60, df: 3, p: 0.01). There was no difference in pest diversity between rotations 1 and 3 and rotations 2 and 3 (Figure 9.A). In contrast, tree age did not have any significant effect on pest diversity (F: 0.06, df: 1, p: 0.82; Figure 9.B). Both planting rotations (Figure 9.C) and tree age (Figure 9.D) did not have any significant effect on weed diversity.

Discussion

From this study, we found that the effect of planting rotations on insect pest abundance was significant. However, the planting rotations did not affect the species richness of pests. A recent study showed that low species richness directly responds to environmental disturbances such as harvesting, planting, oil palm development, and subsistence gardening (Iamba et al. 2021). Pest abundance generally increased with planting rotations and peaked on the third rotation. This can be due to a lack of good harvesting practices that fail to leave very short stumps as a preventive measure to minimize breeding grounds of wood-boring insects such as longicorn beetles and inoculum of root-rotting (Koski et al. 2024). However, the pest abundance was similar between younger trees (1-9 months) and older trees (10-18 months). Castro et al. (2019) reported that there was no significant effect of study site, plantation age, or their interaction on the total abundance of *Coptoborus ochromactonus* (ambrosia beetle) caught in traps (Martínez et al. 2020).

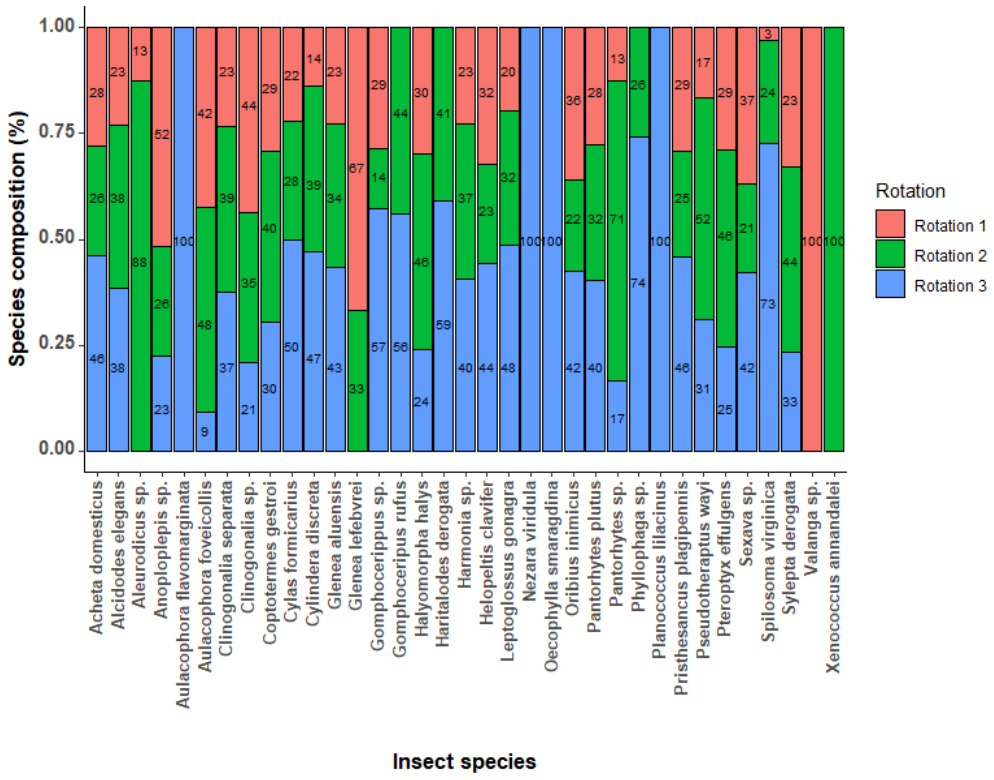

Figure 5. Composition of insect pest species across three planting rotations. The number within the column bars represents the composition (%) of each species across planting rotations. Bars having a single-color means that the species is unique to that rotation and is dominant. Bars having two colors mean the species is shared between two rotations, and those having three colors mean it is shared across all three rotations

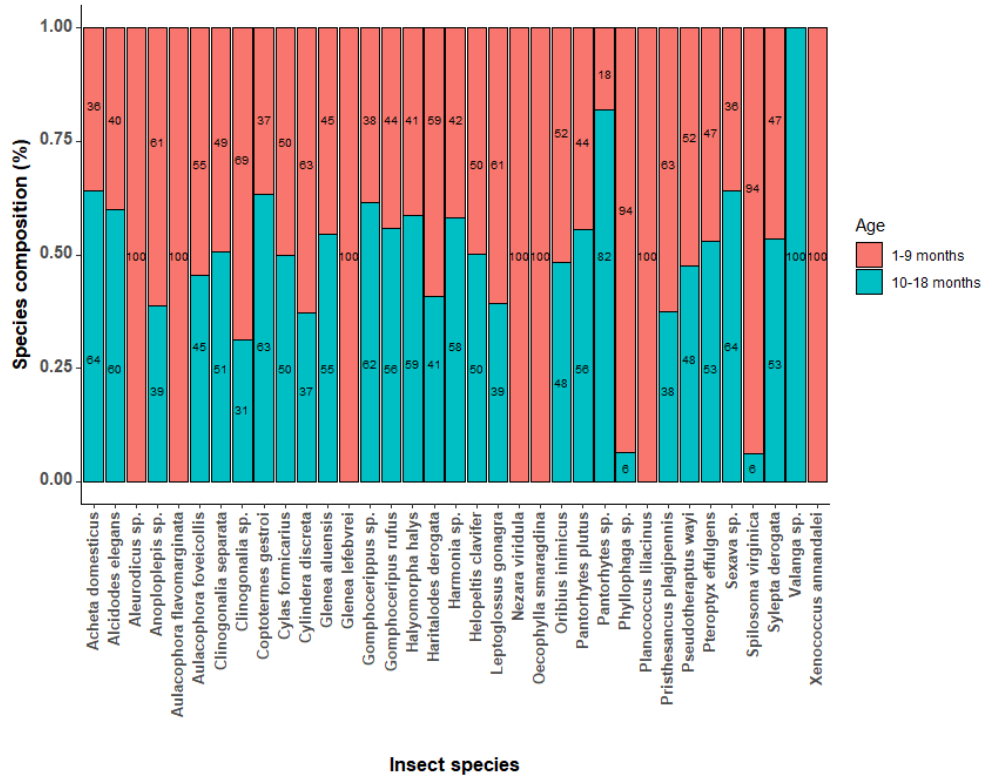

Figure 6. Composition of insect pest species across tree age. The number within the column bars represents the composition (%) of each species in young and old balsa trees. Bars having a single-color means that the species is unique to that rotation and is dominant. Bars having two colors means the species is shared between the two age groups

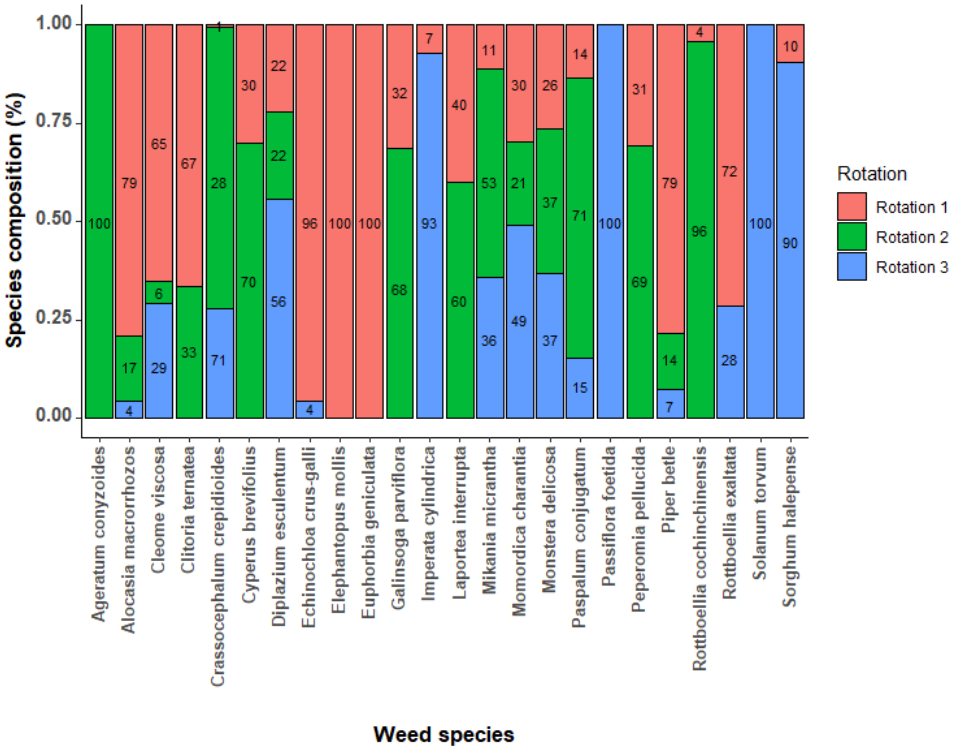

Figure 7. Composition of weed species across three planting rotations. The number within the column bars represents the composition (%) of each species across planting rotations. Bars having a single-color means that the species is unique to a single rotation and is dominant. Bars having two colors mean the species is shared between two rotations, and those having three colors mean it is shared across all three rotations

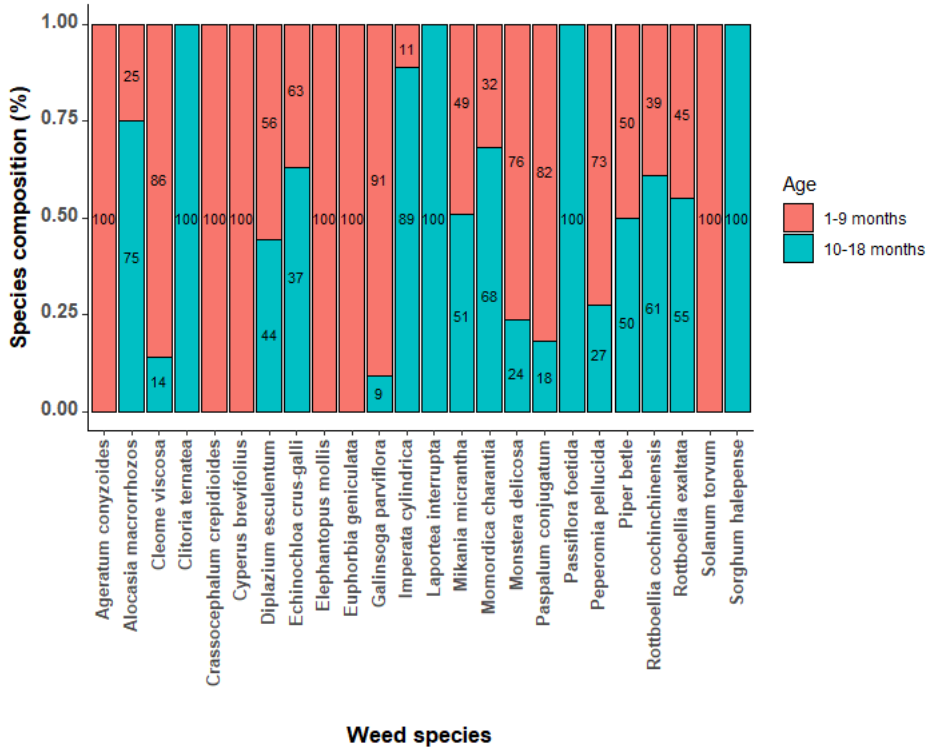

Figure 8. Composition of weed species across tree age. The number within the column bars represents the composition (%) of each species in young and old balsa trees. Bars having a single-color means that the species is unique to a single rotation and is dominant. Bars having two colors means the species is shared between two tree age groups

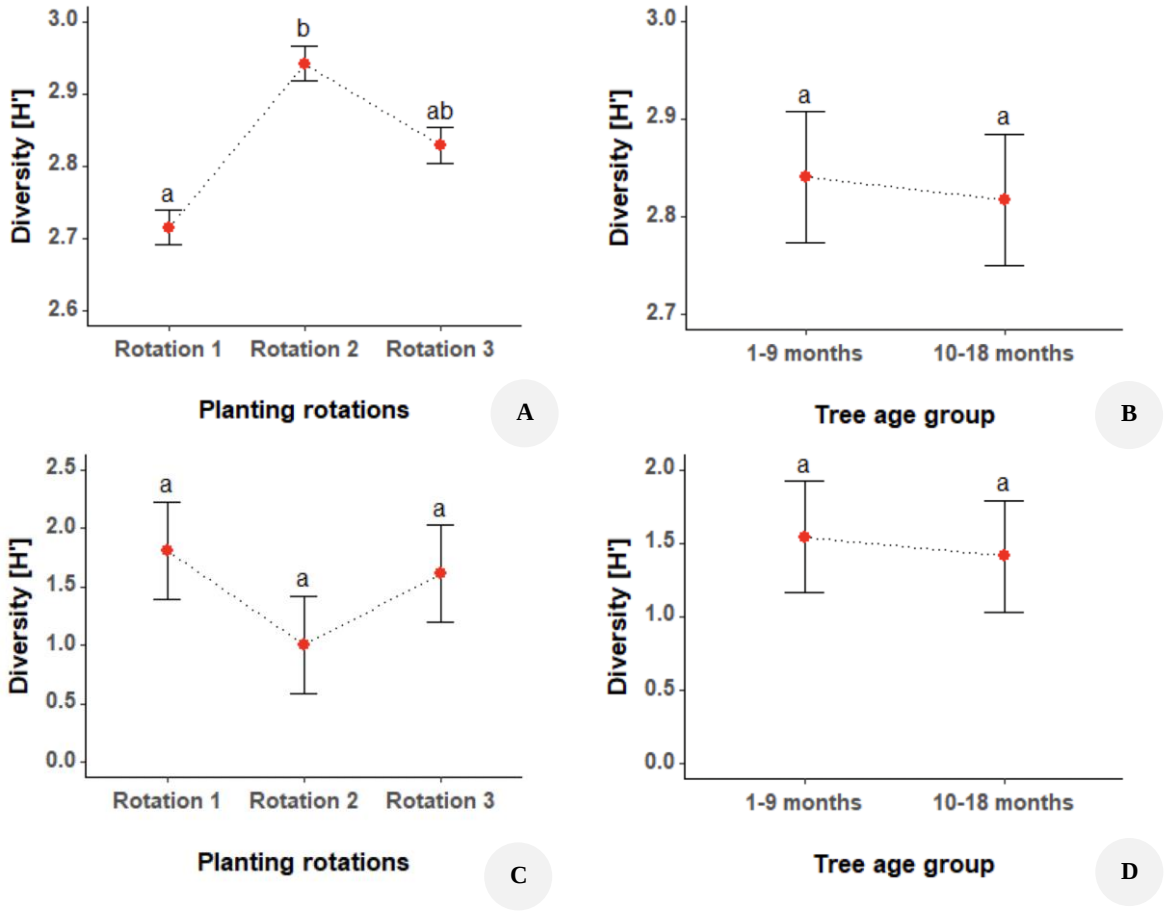

Figure 9. A. Diversity plot using Shannon index (H) for pests across planting rotations; B. Pests across a tree age group; C. Weeds across planting rotations; D. Weeds across a tree age group

Another explanation of similar abundances can be attributed to our studied plantations being generally young and not totally lignified; therefore, insect colonization may be delayed due to the lower attractiveness of newly planted trees (Martínez et al. 2020). Our study showed that species composition of pests differs across planting rotations and plantation age (Figures 3 and 4). A study on scolytine communities showed that species are likely to differ in their composition than in their cumulated species richness between natural forests and in plantations (Martínez et al. 2019). The difference in pest species composition (Figure 4) can be due to differences in compositional traits as younger leaves are acquisitive, softer, have high assimilation rates, and are more nutritive than old tough leaves (Marsh et al. 2018) so pests should feed more in younger trees. The attributes of acquisitive leaves are long petioles (Filartiga et al. 2022), large leaf laminas (Box et al. 2022), high Specific Leaf Area (SLA) (Liu et al. 2016), and compound leaves (Sun et al. 2022). Contrarily, older leaves are conservative, characterized by high leaf dry matter contents, leaf density, and leaf thickness (Ribeiro et al. 2022; Xu et al. 2023). Height, canopy structure, architecture, and age of vegetation can also affect the refugium of insects, hence their composition and distribution (Iamba and Yoba 2020). These findings have important implications for pest management strategies, particularly in the context of planting rotations and the age of the plantation.

Balsa resembles pioneer and early successional species that are usually short-lived, fast resource acquisitionists and cheap low-density wood investors that provide quick (Levy-Tacher et al. 2015; Cañadas-López et al. 2019). Balsa is an example of a fast-growing soft-wood tree that invests most of its resources in growth rather than building up wood density. Ecology theory embraces that organisms differ in their use of shared, limiting resources in order to coexist (Bloxham et al. 2024), and they do that through niche partitioning (Ceia et al. 2023). Coleopteran species such as *Cylas formicarius* (sweet potato weevil), *G. aluensis* (longhorn beetle), and *P. plutus* (cocoa weevil) are wood borers while *A. foveicollis* (pumpkin beetle) and *A. flavomarginata* (cucumber beetle) are folivores. Fast-growing trees such as balsa have high Specific Leaf Area (SLA) that enables them to maximize sunlight (Cañadas-López et al. 2019). In most tropical plant species, young leaves suffer more damage from herbivores and pathogens than mature leaves (Pablo-Rodríguez et al. 2023). Young leaves, being less tough and fibrous, are palatable to chew and easier to digest (Bumb et al. 2018; Schön et al. 2023). The recruitment of herbivores to feed on plants and their

preference for specific tissues are often influenced by nutrient content. Fast-expanding young leaves also experience higher herbivory damage than slow-expanding species since they are less tough and have higher nitrogen content that makes them more attractive to herbivores (Stiegel et al. 2017; Zettlemoyer 2022). The diversity of the insect pest complex was relatively low in rotation 1 (H: 2.72) and high in rotation 2 (H: 2.94) while being moderate in rotation 3 (H: 2.83). Generally, monoculture forests are known to host a lower diversity of bio-indicators, such as invertebrates, birds, mammals, and vascular plants (Zhu et al. 2023). A long-standing forest plantation with rich undergrowth is able to harbor higher moth diversity (Manwei et al. 2023). This phenomenon is evident for rotation 2 and rotation 3 but not rotation 1. The age of trees did not have any significant effect on the diversity of insect pests. Since the plantations studied are generally young, leaves are less lignified; therefore, there is lower attractiveness and colonization by insect pests (Alhousari and Greger 2018).

Weeds can serve as alternative hosts and provide refugia for insect pests and other pathogens (Kumar et al. 2021). The competitive ability of weeds reduces plant crop germination, growth, and development parameters (Korav et al. 2018). Although rotation 1 had a high weed abundance (n: 1832), the diversity was low (H: 1.007). Moreover, as planting rotation increases, weeds' abundance and species richness generally decrease. The decrease in weed abundance across planting rotations and tree age is notable. This can be due to balsa (*O. pyramidale*, syn. *O. lagopus*) being a fast-growing pioneer tropical tree with very low wood density (Howcroft 2002; Midgley et al. 2010) and its invasiveness in the Pacific Islands (Teasdale et al. 2018). Balsa is also considered a weed due to its rapid growth and competitive capability to shade out other species, competitiveness for water and sunlight, and suppression of undergrowth (Midgley et al. 2010). It can out-compete other weed species; therefore, planting rotations and tree age had no significant effect on weed diversity. The weed species that were present across all three planting rotations is *P. conjugatum* (Figure 5). The carabao grass (*P. conjugatum*) is invasive in New Guinea (Kew Gardens 2024). Its spread can be explained by three invasion mechanisms: (i) Adaptation to The Physical Environment (ATE); (ii) Resource Competition And/Or Utilization (RCU), and Enemy Release (ER) (Rhodes et al. 2021). According to the Enemy Release Hypothesis (ERH), many invasive species are successful because they escape the control of natural enemies when introduced (Schulz et al. 2019; Brian and Catford 2023). ERH can also explain why other invasive weed species were common across planting rotations and tree age. Other common invasive weed species found in at least two rotations and across tree age groups include *A. conyzoides, S. halepense, I. cylindrica, P. pellucida,* and *C. crepidioides,* and they are all invasive (Kew Gardens 2024). We assumed that the high pest diversity in rotation two directly responds to natural or mixed vegetation availability along the plantation edges. The second rotation also produced higher insect richness and high weed richness. Natural vegetation near forest plantations provides a habitat for wildlife and insects (Tolkkinen et al. 2021; Randriamananjara et al. 2024). While weeds are generally considered a threat to plant growth, the importance of nitrophilous weeds cannot be ignored (Gannett et al. 2024). The intensification of weed management in organic farms hurts species diversity and insect-pollinated weeds (Benvenuti 2024; Boinot et al. 2024).

Several species that breed in rotting wood include *Phalacrognathus muelleri* and *Oryctes rhinoceros* (Fu et al. 2024). Excessive burning of waste logs, including stumps, prior to third rotation planting helped reduce the initial pest pool. One of the reasons for the significant difference between the pest abundance in rotation 1 and rotation 3 is good harvesting techniques where trees were cut right down to the top of buttress roots, leaving less dead matter for pests to thrive. Burning of waste logs before planting third rotation was also evident at rotation 1 which rid out the breeding ground of pests (Deguine et al. 2021). Burning also delays weed colonization of the plots at the time of planting until the development of a full canopy (Gonzalez-Andujar 2023). A closed canopy allows less sunlight to penetrate, thus preventing late-blooming weed species. As far as weed diversity is concerned, there were no significant differences across planting rotations. The close proximity of rotations to each other (~7 kilometers) could be a contributing factor in the non-significant difference in their diversity. The low species diversity between sites thus supports the findings of Novotny et al. (2007), as similar richness can spread across 75,000 km^2 of contiguous habitat.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the contributions of the following people whose efforts were instrumental in facilitating the collection of Data used to produce this document. The Manager Silvicultural Department for the advice on tree phenology, weeds species, and pest management; the Manager-GIS Mapping for the maps and demarcations of different plots used in the experiment; Manager-Plantation and Development for the expert advice on field planting and weed management; Nursery Staff, Spray team and Field officers who devoted their time and effort in assisting to make this document available to the public. We value your contributions and hope that this document will assist in further bridging gaps in understanding pests and weed management in balsa tree production. The authors declare no potential conflict of interest. BM planned the research, collected data, and wrote the introduction, methods, and discussion. JU collected the field data and compiled them. KSI did all the analyses, wrote the results and also wrote the discussion. All authors reviewed and approved the final version to be published.

REFERENCES

Alhousari F, Greger M. 2018. Silicon and mechanisms of plant resistance to insect pests. Plants 7 (2): 1-11. DOI: 10.3390/plants7020033.

Balla A, Silini A, Cherif-Silini H, Chenari BA, Moser WK, Nowakowska JA, Oszako T, Benia F, Belbahri L. 2021. The threat of pests and pathogens and the potential for biological control in forest ecosystems. Forests 12 (11): 1-34. DOI: 10.3390/f12111579.

Benvenuti S. 2024. Weed role for pollinator in the agroecosystem: Plant–insect interactions and agronomic strategies for biodiversity conservation. Plants 13 (16): 1-23. DOI: 10.3390/plants13162249.

Bloxham B, Lee H, Gore J. 2024. Biodiversity is enhanced by sequential resource utilization and environmental fluctuations via emergent temporal niches. Plos Comput Biol 20 (5): 1-22. DOI: 10.1371/journal.pcbi.1012049.

Boinot S, Alignier A, Storkey J. 2024. Landscape perspectives for agroecological weed management: A review. Agron Sustain Dev 44 (1): 1-29. DOI: 10.1007/s13593-023-00941-5.

Box F, Erlich A, Guan JH, Thorogood C. 2022. Gigantic floating leaves occupy a large surface area at an economical material cost. Sci Adv 8 (6): 1-7. DOI: 10.1126/sciadv.abg3790.

Brian JI, Catford JA. 2023. A mechanistic framework of enemy release. Ecol Lett 26 (12): 2147-2166. DOI: 10.1111/ele.14329.

Bumb I, Garnier E, Coq S, Nahmani J, Granado DRM, Gimenez O, Kazakou E. 2018. Traits determining the digestibility-decomposability relationships in species from Mediterranean rangelands. Ann Bot 121 (3): 459-469. DOI: 10.1093/aob/mcx175.

Cañadas-López Á, Rade-Loor D, Siegmund-Schultze M, Moreira-Muñoz G, Vargas-Hernández JJ, Wehenkel C. 2019. Growth and yield models for balsa wood plantations in the coastal lowlands of Ecuador. Forests 10 (9): 1-16. DOI: 10.3390/f10090733.

Castro J, Smith SM, Cognato AI, Lanfranco D, Martinez M, Guachambala M. 2019. Life cycle and development of *Coptoborus ochromactonus* (Coleoptera: Curculionidae: Scolytinae), a pest of balsa. J Econ Entomol 112 (2): 729-735. DOI: 10.1093/jee/toy403.

Catterall CP. 2016. Roles of non-native species in large-scale regeneration of moist tropical forests on anthropogenic grassland. Biotropica 48 (6): 809-824. DOI: 10.1111/btp.12384.

Ceia FR, Cherel Y, Silva AV, Garrido S, Angélico MM, da Silva JM, Laranjeiro MI, Ramos JA. 2023. Drivers of niche partitioning in a community of mid-trophic level epipelagic species in the North Atlantic. Hydrobiologia 850 (7): 1583-1599. DOI: 10.1007/s10750-023-05160-3.

Chazdon RL. 2014. Second Growth: The Promise of Tropical Forest Regeneration in an Age of Deforestation. University of Chicago Press, Chicago. DOI: 10.7208/chicago/9780226118109.001.0001.

Culliney TW. 2014. Crop losses to arthropods. In: Pimentel D, Peshin R (eds). Integrated Pest Management: Pesticide Problems. Springer, Dordrecht. DOI: 10.1007/978-94-007-7796-5_8.

Deguine JP, Aubertot JN, Flor RJ, Lescourret F, Wyckhuys KAG, Ratnadass A. 2021. Integrated pest management: Good intentions, hard realities: A review. Agron Sustain Dev 41 (3): 1-35. DOI: 10.1007/s13593-021-00689-w.

Elgar AT, Freebody K, Pohlman CL, Shoo LP, Catterall CP. 2014. Overcoming barriers to seedling regeneration during forest restoration on tropical pasture land and the potential value of woody weeds. Front Plant Sci 5 (200): 1-10. DOI: 10.3389/fpls.2014.00200.

Filartiga AL, Klimeš A, Altman J, Nobis MP, Crivellaro A, Schweingruber F, Doležal J. 2022. Comparative anatomy of leaf petioles in temperate trees and shrubs: The role of plant size, environment and phylogeny. Ann Bot 129 (5): 567-582. DOI: 10.1093/aob/mcac014.

Fu C, Qian Q, Deng X, Zhuo Z, Xu D. 2024. Prediction and analysis of the global suitable habitat of the *Oryctes rhinoceros* (Linnaeus, 1758) (Coleoptera: Scarabaeidae) based on the maxent model. Insects 15 (10): 1-15. DOI: 10.3390/insects15100774.

Gannett MA, Butler-Jones AL, DiTommaso A, Sparks JP, Kao-Kniffin J. 2024. Soil C:N impacts on soil biological health and consequences on weed control in soybean and corn systems. Weed Sci 72 (4): 402-421. DOI: 10.1017/wsc.2024.17.

Georgeou N, Hawksley C, Wali N, Lountain S, Rowe E, West C, Barratt L. 2022. Food security and small holder farming in Pacific Island countries and territories: A scoping review. Plos Sustain Transform 1 (4): 1-22. DOI: 10.1371/journal.pstr.0000009.

Gonzalez-Andujar JL. 2023. Integrated weed management: A shift towards more sustainable and holistic practices. Agronomy 13 (10): 1-3. DOI: 10.3390/agronomy13102646.

Gullino ML, Albajes R, Al-Jboory I, Angelotti F, Chakraborty S, Garrett KA, Hurley BP, Juroszek P, Lopian R, Makkouk, K. 2022. Climate change and pathways used by pests as challenges to plant health in agriculture and forestry. Sustainability 14 (19): 1-22. DOI: 10.3390/su141912421.

Guo Q, Potter KM, Ren H, Zhang P. 2023. Impacts of exotic pests on forest ecosystems: An update. Forests 14 (3): 1-13. DOI: 10.3390/f14030605.

Haq SM, Lone FA, Kumar M, Calixto ES, Waheed M, Casini R, Mahmoud EA, Elansary HO. 2023. Phenology and diversity of weeds in the agriculture and horticulture cropping systems of Indian Western Himalayas: Understanding implications for agro-ecosystems. Plants 12 (6): 1-16. DOI: 10.3390/plants12061222.

Henty E, Pritchard G. 1988. Weeds of New Guinea and Their Control. Department of Forests Papua New Guinea, Lae, Papua New Guinea.

Howcroft N. 2002. The Balsa Manual: Techniques for Establishment and the Management of Balsa (*Ochroma lagopus*) Plantations in Papua New Guinea. ITTO East New Britain Balsa Industry Strengthening Project. Papua New Guinea Forest Service, East New Britain.

Iamba K, Waldi D, Kumawayo I, Elias M. 2021. A rapid assessment of insect communities in balsa plantations of East New Britain Province, Papua New Guinea. Intl J Entomol Res 6 (2): 109-115.

Iamba K, Yoba S. 2020. Spatio-temporal dispersion patterns of *Bactrocera musae* Tryon (Diptera: Tephritidae: Dacinae) in Vudal agroecosystem, East New Britain. Intl J Entomol Res 5 (6): 78-84.

Kew Gardens. 2024. Plants of the World Online: The International Plant Names Index and World Checklist of Vascular Plants. https://powo.science.kew.org.

Knoke T, Bendix J, Pohle P, Hamer U, Hildebrandt P, Roos K, Gerique A, Sandoval ML, Breuer L, Tischer A. 2014. Afforestation or intense pasturing improve the ecological and economic value of abandoned tropical farmlands. Nat Commun 5 (1): 1-12. DOI: 10.1038/ncomms6612.

Koontz MJ, Latimer AM, Mortenson LA, Fettig CJ, North MP. 2021. Cross-scale interaction of host tree size and climatic water deficit governs bark beetle-induced tree mortality. Nat Commun 12 (1): 1-13. DOI: 10.1038/s41467-020-20455-y.

Korav S, Dhaka AK, Singh R, Premaradhya N, Reddy GC. 2018. A study on crop weed competition in field crops. J Pharmacogn Phytochem 7 (4): 3235-3240.

Koski TM, Zhang B, Wickham JD, Bushley KE, Blanchette RA, Kang L, Sun J. 2024. Chemical interactions under the bark: Bark-, ambrosia-, and wood-boring beetles and their microbial associates. Rev Environ Sci Biol Technol 23 (3): 255-273. DOI: 10.1007/s11157-024-09709-z.

Kumar S, Bhowmick MK, Ray P. 2021. Weeds as alternate and alternative hosts of crop pests. Indian J Weed Sci 53 (1): 14-29. DOI: 10.5958/0974-8164.2021.00002.2.

Levy-Tacher SI, Vleut I, Román-Dañobeytia F, Aronson J. 2015. Natural regeneration after long-term bracken fern control with Balsa (*Ochroma pyramidale*) in the Neotropics. Forests 6 (6): 2163-2177. DOI: 10.3390/f6062163.

Liu Y, Dawson W, Prati D, Haeuser E, Feng Y, van Kleunen M. 2016. Does greater specific leaf area plasticity help plants to maintain a high performance when shaded? Ann Bot 118 (7): 1329-1336. DOI: 10.1093/aob/mcw180.

Manwei DXL, Yang Z, Minxin Z, Xiuling S, Bing H, Gang Z, Zihao Q, Kai L. 2023. Edge effect in plantation patches based on moth diversity. Biodivers Sci 31 (5): 1-11. DOI: 10.17520/biods.2023074.

Marsh KJ, Ward J, Wallis IR, Foley WJ. 2018. Intraspecific variation in nutritional composition affects the leaf age preferences of a mammalian herbivore. J Chem Ecol 44 (1): 62-71. DOI: 10.1007/s10886-017-0911-3.

Martínez M, Cognato AI, Guachambala M, Boivin T. 2019. Bark and ambrosia beetle (Coleoptera: Curculionidae: Scolytinae) diversity in natural and plantation forests in Ecuador. Environ Entomol 48 (3): 603-613. DOI: 10.1093/ee/nvz037.

Martínez M, Cognato AI, Guachambala M, Urdanigo JP, Boivin T. 2020. Effects of climate and host age on flight activity, infestation percentage, and intensity by *Coptoborus ochromactonus* (Coleoptera: Curculionidae: Scolytinae) in commercial balsa plantations of Ecuador. J Econ Entomol 113 (2): 824-831. DOI: 10.1093/jee/toz303.

Midgley S, Blyth M, Howcroft N, Midgley D, Brown A. 2010. Balsa: Biology, Production and Economics in Papua New Guinea. [Report]. Australian Centre for International Agricultural Research, Australia.

Monteiro A, Santos S. 2022. Sustainable approach to weed management: The role of precision weed management. Agronomy 12 (1): 1-14. DOI: 10.3390/agronomy12010118.

Nair KSS. 2000. Insect Pests and Diseases in Indonesian Forest: An Assessment of the Major Threats, Research Efforts and Literature. CIFOR, Bogor.

Novotny V, Miller SE, Hulcr J, Drew RA, Basset Y, Janda M, Setliff GP, Darrow K, Stewart AJ, Auga J, Isua B, Molem K, Manumbor M, Tamtiai E, Mogia M, Weiblen GD. 2007. Low beta diversity of herbivorous insects in tropical forests. Nature 448 (7154): 692-695. DOI: 10.1038/nature06021.

Pablo-Rodríguez JL, Bravo-Monzón ÁE, Montiel-González C, Benítez-Malvido J, Álvarez-Betancourt S, Ramírez-Sánchez O, Oyama K, Arena-Ortiz ML, Alvarez-Añorve MY, Avila-Cabadilla LD. 2023. Linking anthropogenic landscape perturbation to herbivory and pathogen leaf damage in tropical tree communities. Plants 12 (22): 1-29. DOI: 10.3390/plants12223839.

Pautasso M, Schlegel M, Holdenrieder O. 2015. Forest health in a changing world. Microb Ecol 69: 826-842. DOI: 10.1007/s00248-014-0545-8.

R Core Team. 2024. A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna. https://www.R-project.org/.

Randriamananjara MA, Fenton NJ, DesRochers A. 2024. Understory vegetation diversity and composition in intensively managed plantations compared to extensively managed forests. New For 56 (1): 1-22. DOI: 10.1007/s11056-024-10071-9.

Rhodes AC, Plowes RM, Goolsby JA, Gaskin JF, Musyoka B, Calatayud PA, Cristofaro M, Grahmann ED, Martins DJ, Gilbert LE. 2021. The dilemma of Guinea grass (*Megathyrsus maximus*): A valued pasture grass and a highly invasive species. Biol Invasions 23 (12): 3653-3669. DOI: 10.1007/s10530-021-02607-3.

Ribeiro DR, Silva JLA, do Nascimento MT, Vitória AP. 2022. Leaf habits and their relationship with leaf and wood traits in tropical dry forests. Trees 36 (1): 7-24. DOI: 10.1007/s00468-021-02200-0.

Schön JE, Tiede Y, Becker M, Donoso DA, Homeier J, Limberger O, Bendix J, Farwig N, Brandl R. 2023. Effects of leaf traits of tropical trees on the abundance and body mass of herbivorous arthropod communities. Plos One 18 (11): 0288276. DOI: 10.1371/journal.pone.0288276.

Schulz AN, Lucardi RD, Marsico TD. 2019. Successful invasions and failed biocontrol: The role of antagonistic species interactions. BioScience 69 (9): 711-724. DOI: 10.1093/biosci/biz075.

Seidl R, Klonner G, Rammer W, Essl F, Moreno A, Neumann M, Dullinger S. 2018. Invasive alien pests threaten the carbon stored in Europe's forests. Nat Commun 9 (1): 1-10. DOI: 10.1038/s41467-018-04096-w.

Shoo LP, Freebody K, Kanowski J, Catterall CP. 2016. Slow recovery of tropical old-field rainforest regrowth and the value and limitations of active restoration. Conserv Biol 30 (1): 121-132. DOI: 10.1111/cobi.12606.

Skendžić S, Zovko M, Živković IP, Lešić V, Lemić D. 2021. The impact of climate change on agricultural insect pests. Insects 12 (5): 1-31. DOI: 10.3390/insects12050440.

Stephenson NL, Das AJ, Ampersee NJ, Bulaon BM, Yee JL. 2019. Which trees die during drought? The key role of insect host-tree selection. J Ecol 107 (5): 2383-2401. DOI: 10.1111/1365-2745.13176.

Stiegel S, Entling MH, Mantilla-Contreras J. 2017. Reading the leaves' palm: Leaf traits and herbivory along the microclimatic gradient of forest layers. Plos One 12 (1): 1-17. DOI: 10.1371/journal.pone.0169741.

Sun R, Peng Z, Li S, Mei H, Xu Y, Yang W, Zhichao L, Wang H, Zhang J, Zhou C. 2022. Developmental analysis of compound leaf development in *Arachis hypogaea*. Front Plant Sci 13 (749809): 1-10. DOI: 10.3389/fpls.2022.749809.

Tai XN, Mackay DS, Ewers BE, Parsekian AD, Beverly D, Speckman H, Brooks PD, Anderegg WRL. 2019. Plant hydraulic stress explained tree mortality and tree size explained beetle attack in a mixed conifer forest. J Geophys Res Biogeosci 124 (11): 3555-3568. DOI: 10.1029/2019jg005272.

Teasdale JR, Mirsky SB, Cavigelli MA. 2018. Meteorological and management factors influencing weed abundance during 18 years of organic crop rotations. Weed Sci 66 (4): 477-484. DOI: 10.1017/wsc.2018.15.

Tolkkinen M, Vaarala S, Aroviita J. 2021. The importance of riparian forest cover to the ecological status of agricultural streams in a nationwide assessment. Water Resour Manag 35 (12): 4009-4020. DOI: 10.1007/s11269-021-02923-2.

Wildi O. 2017. Data Analysis in Vegetation Ecology. Wiley-Blackwell, Birmensdorf, Switzerland. DOI: 10.1079/9781786394224.0000.

Xu L, Zhan, N, Wei T, Liu B, Shen L, Liu Y, Liu D. 2023. Adaptation strategies of leaf traits and leaf economic spectrum of two urban garden plants in China. BMC Plant Biol 23 (1): 1-12. DOI: 10.1186/s12870-023-04301-z.

Zettlemoyer MA. 2022. Leaf traits mediate herbivory across a nitrogen gradient differently in extirpated vs. extant prairie species. Oecologia 198 (3): 711-720. DOI: 10.1007/s00442-022-05130-x.

Zhu H, Zhang J, Cheuk ML, Hau BCH, Fischer GA, Gale SW. 2023. Monoculture plantations impede forest recovery: Evidence from the regeneration of lowland subtropical forest in Hong Kong. Front For Glob Change 6: 1-14. DOI: 10.3389/ffgc.2023.1098666.

Zimdahl R, Basinger NT. 2024. Fundamentals of Weed Science. Elsevier, USA.