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Original Article

Distribution and Abundance of Pine Needle Aphids (*Eulachnus rileyi Williams*) and Their Potential Natural Enemies on Pine Tree Species (*Pinus patula and Pinus elliottii*) at Sao Hill Forest Plantation, Iringa-Tanzania

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ABSTRACT

Tanzania's forest plantations are predominantly composed of pine trees, which are essential for timber and pulpwood industries. However, these plantations face a significant threat from the Pine Needle Aphid (*Eulachnus rileyi*), which is spreading rapidly. This rapid spread is attributed to the wide distribution of its host tree species across the country. This study assessed the distribution and abundance of PNA and their natural enemies and examined the relationship between their populations. Systematic sampling was used, whereby every 5th tree along the row of the particular compartment was considered as a candidate. Five shoots in lower, middle and upper crown part of selected tree were randomly cut and put in labeled zipped plastic bags for laboratory assessment of the aphids and natural enemies. Results from this study indicated that PNA was un-equally distributed throughout the divisions, trees species and age classes at Sao Hill Forest Plantation. The mean abundance of adult aphid was significant different between pine tree species and the two divisions ($p < 0.05$). Nymphs were more abundant than eggs and adults. For *P. elliottii* where only middle and old age classes were observed the mean abundance of aphids were higher than *P. patula* of the same age class. The middle crown part had the highest mean aphid abundance for both tree species and age classes. Three natural enemies namely Coccinellid beetles, Spiders and Stink bugs were detected on the affected twigs but they were very low in numbers. The correlation between PNA and natural enemies' abundance was weakly positive (Rho = 0.0859). Therefore, this study recommends implementing various tending operations i.e. thinning, weeding and pruning, along with regular insect surveys and monitoring programs to mitigate favorable conditions for the growth of aphids. Additionally, it suggests the introduction or release of natural predators like *Tetraphleps raoi* over a large area to increase the current stock of the natural enemies to enhance biological control.

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INTRODUCTION

The genus *Eulachnus* possesses 12-18 morphologically described species which regularly feed in small groups of several individuals (Kanturski *et al.*, 2015). Aphids from genus *Eulachnus* are recognized as Pine pests and may cause damage in Pines Forest plantations. *Eulachnus* species are characterized by a small, narrow, spindle-shaped body and are hidden while feeding and become very active when disturbed (Branco, *et al.*, 2023; Kanturski & Wieczorek, 2014; Kanturski *et al.*, 2015). Naturally, this aphid causes only minor damage where it has been introduced, however, it has the potential to cause serious damage. Heavy infestations cause needles to turn yellow and drop prematurely, resulting in growth reduction (FAO, 2007). *Eulachnus rileyi* (Lachnidae: Homoptera), PNA, originates from Europe and North America and was first discovered in Zambia, Zimbabwe and South Africa in the late 1970s but the species has later spread to Tanzania, Kenya and Malawi where Pines are grown (Katerere, 1984). In Zambia, Zimbabwe and Malawi this aphid attacks *P. caribaea, P. chiapensis, P. elliottii, P. kesiya, P. merkusii, P. michoacana, P. oocarpa, P. patula, P. roxburgii* and *P. taeda* (Katerere, 1984). In Tanzania, the aphid is found in most Pines growing plantations and SHFP has the most serious attacks *(Nshubemuki, et al.,* 2011). In spite that there is no available information about the abundance, quantitative effects and distribution of the PNA on its Pine host species in Tanzania, though the actual damage to Pines is slight than that caused by the Pine Woolly Aphid (Murphy *et al.*, 1991). Mazodze *et al* (1990) reported in Zimbabwe that the Pine plantations were very safe from serious damage of PNA and no economic loss was reported. The combined attack of PNA and PWA toward the dry season may cause more severe damage, as these exotic pests are widespread in exotic pine plantation in Tanzania (Petro, & Madoffe, 2011).

Extensive exotic tree planting in Tanzania started in the 1960s. The exotic species commonly planted are *P. patula, P. elliottii, P. caribaea, P. kesiya, Cupressus lusitanica, Eucalyptus* species, *Acacia mearnsii, Cedrela Mexicana, Tectona* *grandis*, and *Terminalia* species *(Nshubemuki, et al.*, 2011). In spite being free from insect attack at the establishment phase, to date most Pines, Eucalyptus and Cypress are attacked by several exotic insects at different levels of severity. The planting of these species in Tanzania led to the outbreak of Cypress aphid (*Cinara cupressivora*), Leucaena Psyllid (*Heteropsylla cubana*), PWA (*Pineus boerneri*), and Blue gum chalicid (*Leptocybe invasa*) which attack Cypress, Leucaena, Pines and Eucalyptus respectively (Lyimo, 2016; Madoffe & Austra, 1990; Madoffe & Austra, 1993; Petro & Madoffe, 2011; Yakuti, 2015). For more than decades now insect pests have been known on forest plantations, affecting tree species at different age classes and sites and potentially important commercial trees in Tanzania, however, the intensity of attacks varies (Lyimo, 2017; Petro & Madoffe, 2011; Yakuti, 2015).

The exotic insect pests have been introduced to foreign countries accidentally through global trade flow of forest commodities. The importation of wood packaging materials and living plants has facilitated the unintended transport of forest insect pests and pathogens (Brockerhoff & Liebhold, 2017; Meurisse *et al.*, 2019). They can also spread locally within a country from one location to another during the movement of site preparation equipment and repetitive silvicultural activities, such as pruning and thinning (Brockerhoff & Liebhold, 2017). The introduced exotic insect pests caused extensive damage to large areas of forests in different parts of Tanzania. Example, over 15 000 hectares (ha) in Tanzania were infested by *C. cuppressivora* to variable damage levels ranging from minor to severe damage (Nshubemuki *et al.*, 2011). It was estimated that *C. cuppressivora* caused an annual loss of growth increment worth USD 13.5 million and killed USD 41 million worth of trees in Africa (Murphy, 1996). On other hand, PWA caused growth loss and even death of Pinus species particularly at SHFP in Iringa Region, Tanzania (Petro & Madoffe, 2011). Similarly, *L. invasa* was recorded to cause growth reduction of infested Eucalyptus due to the fact that it perpetrates severe damage by inducing galls mainly on rapidly growing parts like shoots, young stems, petioles or midribs of leaves which form an ideal breeding site for the gall wasp (Petro *et al.*, 2015).

The distribution, abundance and outbreak of insect pests are influenced more by biotic and abiotic factors such as food quality and quantity, natural enemies, age of trees, temperature, humidity and precipitation (Flinte *et al.*, 2011). Tree age can affect aphids by influencing their growth rates, survival, and fertility. When trees are attacked by aphids, they react by producing allelochemicals that have adverse effects on the aphids. The susceptibility of a stand to insect pest outbreaks can also be influenced by the landscape pattern of host tree composition, stand structure, and density (Ferrenberg, 2016). Menéndez, (2007) reported that climate particularly temperature and precipitation have a very strong impact on the development, reproduction, survival and geographical distribution of insect pests; as a result, it is highly possible that these organisms will be affected by any changes in climate. Since they are cold-blooded organisms, aphids can respond quickly to their climatic

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environment affecting directly on their development, survival, and spread. With their short generation times, high reproductive rates, and high mobility it is also possible that they will respond more quickly to climate change than long-lived organisms, such as mammals and plants. Studies have shown that aphid activities increase on stressed trees or trees grown on site of poor quality which are deficient in NPK, boron, and other trace elements which may result in increased aphid populations (Madoffe & Austra, 1993; Madoffe, 2006). There is some reduction in aphid populations and its damage intensity in some areas, which is attributed to the climate change and natural enemies attacking the aphids (Kanturski *et al*,. 2016). Implying that climatic conditions and natural enemies do influence the spread and damage intensity of aphids as an issue that has not been given attention. The same case could be applied in PNA distribution and its abundance.

Recently, an outbreak of PNA (*Eulachnus rileyi Williams*) was reported in pine plantation in Tanzania like Kiwira, Iyondo Mswimwa, and Sao Hill Forest Plantation. A survey conducted by TAFORI in 2020 on forest plantations and woodlots of Tanzania, has reported that in SHFP 65% (severe) incidence of the infestation due to defoliation especially of the main growing tip leading to death of trees aged 3-5 years. Hence, there is a high risk of the spread of PNA in SHFP due to the wide distribution of host trees species. Therefore, this study aimed at collecting information on the distribution and abundance of PNA so as to determine its potential threat to the forest plantation. The findings from this study are useful to present the baseline and important data for effective management and the development of appropriate strategies for monitoring the forest plantation health against infestations by PNA and its effect on the growth and production of the forest plantation.

Methodology

Description of Study Area

This study was conducted at SHFP which is in Mufindi District, Iringa Region within the Southern Highland of Tanzania. The SHFP consist of four divisions with different sizes, these includes Irundi (Division I), Ihefu (Division II), Ihalimba (Division III) and Mgololo (Division IV) (Figure 1). SHFP is situated 100 km south of Iringa town and 15 km from Mafinga town on the Tanzania-Zambia (TANZAM) high way which cuts through the southwestern part of the plantation. The plantation covers a total area of 135 903 ha, out of which 54 070 ha are planted with Pines, and 3500 ha with Cyprus and Eucalyptus spp. This makes the SHFP to be the largest in Tanzania. Also 48 200 ha are natural forests and 1700 ha are areas for other uses including residential. The plantation lies between 8^0 18'S to 8^0 35'S and 35^0 6'E to 35^0 20'E. It has an average elevation of 1634 m asl. The altitudes range from 1400 m asl to 2000 m asl (Nguyeje *et al.*, 2022). The rainfall at SHFP is unimodal with single rainy season from November through May and a dry season during the rest of the year. The area receives between 600 mm to 1300 mm of rainfall annually. Temperatures are fairly cool, reaching close to freezing point between June and August. The mean monthly minimum and

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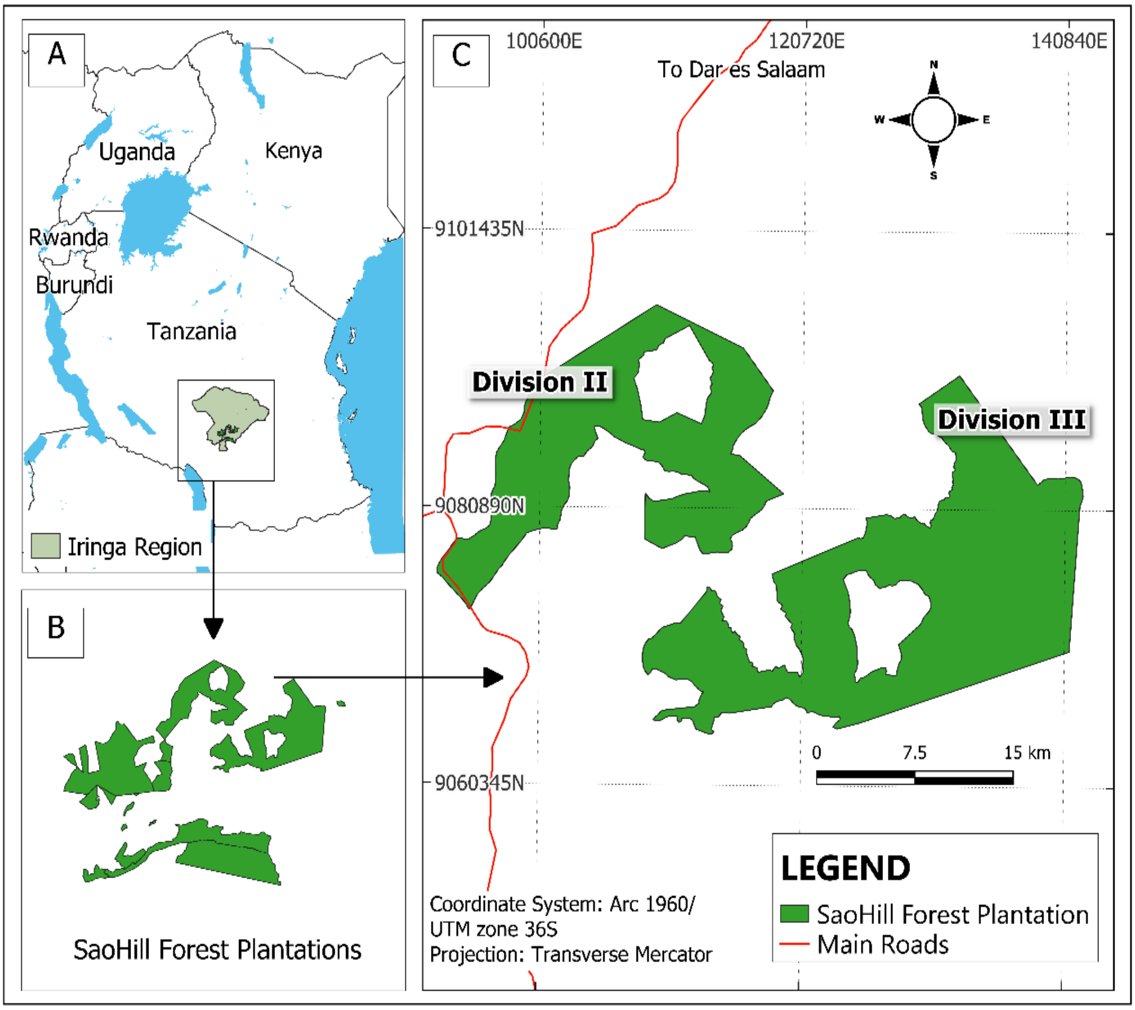
maximum temperatures are 10^{0}C and 23^{0}C respectively (Mauya, 2022). The natural vegetation is characterized by mosaic of open grassland with scattered trees and shrubs dominated by species such as *Brachystegia* and *Jubernadia*. Other species include *Erythrina, Parinari cussonia, Apodytes,* and *Albizia*. The exotic species planted in the area include *Pinus patula, Pinus ellioti, Eucalyptus maedenii, Eucalyptus saligina* and at small scale *Cupressus lusitanica* (Mauya,2022).

Figure 1: Map showing study area (Sao Hill Forest Plantation, Iringa Tanzania)



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Sampling design

Stratified sampling was adopted whereby two divisions with Pine tree species at different age classes were selected to ensure heterogeneity. In each division, compartments with different age classes were selected for each tree species. Before embarking in the field for data collection, a reconnaissance survey was conducted to capture the general distribution of PNA at SHFP. In each selected compartment, 60 trees were selected systematically whereby every 5th tree along the row was considered as a candidate. The first tree was established randomly at any of the corner of the compartment at least 100 m from the boundary. The distance between transects were at every 10th row from the starting point. A total of 10 transects were considered in each compartment, distributed systematically. It should be noted that each division originally intended to include six compartments with varying age classes and tree species (three compartments per each tree species). However, the young age class of *P. elliottii* was not observed, resulting in five compartments (2 for *P. elliottii* and 3 for *P. patula)* per division, making a total of 10 compartment for this study.

Data collection

Data were collected from two main plantation species, *P. patula and P. elliottii*. Three age classes, young trees (0-8 years), middle trees (9-16 years), and old trees (>16 years) were considered in each division. Tree age was obtained from the forest compartment register. The crown of the selected trees was divided into three crown levels (lower, middle and upper) and five twigs/shoots of 15 cm in each crown level were randomly cut and quickly put in a labelled plastic bags to avoid insect jumps for laboratory insect counting. The plastic bags containing sampled twigs were put in a refrigerator to avoid insect decomposition. Each shoot was then carefully (with a help of fine brush) washed with alcohol (70% ethanol) in a Petri dish to remove the aphids (eggs, nymphs and adults). The separate aphid morphs (eggs, nymphs and adults) were counted and recorded accordingly. At the same time diversity and abundance of natural enemies were assessed and counted from the same twig used for PNA assessment. Identification of the natural enemies was done either in-situ or collected for laboratory identification using reference resources at the Department of Ecosystems and Conservation laboratory, College of Forestry, Wildlife and Tourism, Sokoine University of Agriculture.

Data analysis

Data for this study were checked for normality using the Shapiro-Wilk normality test (Shapiro test function) and homogeneity of variances using Levene’s test (Levene test function) across the data sets before choosing the appropriate analysis. Descriptive statistics were used to determine mean abundance of PNA and their potential natural enemies using R version 4.4.0 and Microsoft excel computer software programs. Mann-Whitney U Test at 5% level of significance was conducted to compare the abundance of PNA between divisions and also between tree species. At the same time Kruskal-Wallis Test at 5% level of significance was used to statistically test the equality of mean abundance differences in PNA between crown levels and age classes. Furthermore, Spearman’s Rank Correlation was run to determine the relationship between abundance of natural enemies and that of aphids.

Results

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Distribution and Abundance of Pine Needle Aphid at Sao Hill Forest Plantation

The results revealed that mean abundance of adult PNA was 10.8 aphids per twig distributed un-equally throughout the two divisions and age classes of SHFP. The mean abundance of adult aphids per twig was 7.6 and 12.9 for Division II and Division III, respectively (Table 1). The mean abundance of eggs and nymphs per 15cm twig followed similar trend as adults with 5.5 and 12.2 in Division II and 9.2 and 21.1 in Division III respectively (Table 1). Division III had more aphids (eggs, nymphs and adults) than Division II. The Mann-Whitney U test revealed a significance difference between the two divisions at SHFP (W= 26 622, p = 0.000001, effect size r = 0.111). The mean abundance of nymphs was higher than other PNA growth stages. The mean abundance of eggs was lowest for both divisions and tree species (Table 1 and 2).

The mean total abundance of adult aphid attacking Pine tree species at SHFP were 19.6 and 7.0 for *P. elliottii* and *P. patula* respectively (Table 2). The Mann-Whitney U test showed that the mean abundance of aphids between Pine tree species was significantly different (W = 57 001, p = 0.000001, effect size r = 0.171). The mean abundance of adult aphid was 7.3, 8.5 and 5.1 for *P. patula* for young, middle and old age classes respectively. *P. elliottii* which was observed only in middle and old classes was significantly more attacked by aphids than *P. patula* having the mean abundance of 23.2 and 17.9 comparing to 8.5 and
5.1 of *P. patula* of same age classes (Figure 2). Kruskal Wallis test show that there are significant differences in the mean abundance and distribution of adults PNA across *P. patula* age classes (X^2 = 17.0, df = 2, p = 0.000208). The result indicated that middle age trees were more preferred by adult aphid than other tree age classes for *P. patula*. The preference was significantly different between young and old and middle and old age classes but not between young and middle age classes (Table 3, 4 and 5).

Table 2: Mean abundance of eggs, nymphs and adults PNA per twigs between Pinus tree species at SHFP

Species	Mean abundance		
	Eggs	Nymphs	Adults
Pinus elliottii	14±1.9 (0.97)	28±2.8 (1.44)	19.6±2.4 (1.21)
Pinus patula	5±0.7 (0.33)	13±1.5 (0.74)	7±0.9 (0.44)
Overall Mean	7.7±0.8 (0.41)	17.5±1.4 (0.73)	10.8±1 (0.53)

Mean±Confidence Level (95%) and (Standard error)

Table 3: Pairwise comparisons using Wilcoxon rank sum test with continuity correction to compare population density of adult PNA across *P. patula* age classes at SHFP

Source of variation (Age class)	df	Chi-squared (X^2)	P-value
Between young, middle and old trees	2	17.0	0.000208b
Between young and middle trees	1	6672	0.312a
Between young and old trees	1	8698	0.002b
Between middle and old trees	1	9211	0.000069b

df= Degree of freedom, a= statistically Insignificant (p>0.05), and b= statistically significant (p<0.05) at 5% level of significance

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Table 4: Mean abundance of eggs, nymphs and adults PNA per twigs at different age classes of *P. patula* at SHFP

Age classes in years	Mean abundance		
	Eggs	Nymphs	Adults
Young (0-8)	5.4±1.2 (0.59)	13.5±2.5 (1.27)	7.3±1.5 (0.76)
Middle (9-16)	5.1±1.4 (0.51)	16.9±3.4 (2.8)	8.5±1.8 (0.97)
Old (>16)	4.3±0.8 (0.41)	8.4±1.6 (0.9)	5.1±0.9 (0.45)
Overall mean	5±0.6 (0.21)	13±1.1 (0.93)	7±0.6 (0.22)

Mean±Confidence Level (95%) and (Standard error)

Table 5: Mean abundance of eggs, nymphs and adults PNA per twigs at different age classes of *P. elliottii* at SHFP

Age classes in years	Mean abundance		
	Eggs	Nymphs	Adults
Young (0-8)	0	0	0
Middle (9-16)	16.8±2.4 (0.73)	32.9±5.4 (3.8)	23.2±2.8 (2.3)
Old (>16)	12.6±1.4 (0.71)	25.6±3.6 (1.3)	17.9±2.4 (1.2)
Overall mean	14.6±0.9 (0.41)	28.6±2.6 (0.7)	19.6±1.2 (0.5)

Mean±Confidence Level (95%) and (Standard error)

Figure 2: Mean abundance of PNA population per twig for various growth stages in all age classes in SHFP

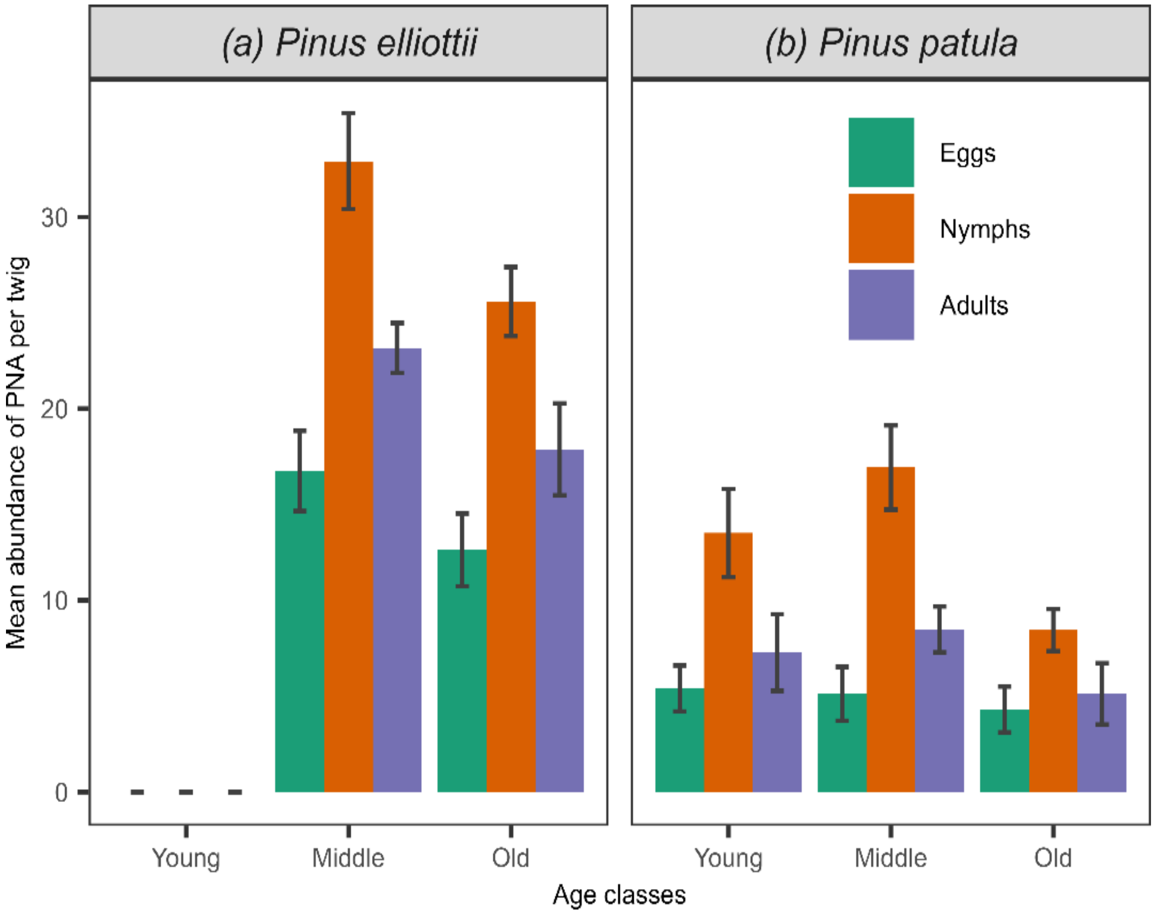

Table 6 and 7 shows that the mean abundance of adult aphids recorded were 6.5, 8.8 and 4.4 for *P. elliottii* and 2.5, 3.1 and 1.5 for *P. patula* for lower, middle and upper crown, respectively. The middle crown part for both tree species and age classes had higher mean abundance of aphids, followed by lower crown part and upper crown

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part the least. The mean abundance of adult PNA between crown parts was statistically significant (X^2= 96.2, df= 2, p = 0.000001) for *P. elliottii* and (X^2= 60.9, df= 2, p = 0.000001) for *P. patula*. The middle crown part hosts more PNA than lower and upper crown and the abundance was statistically significant (Table 8 and 9)

Table 7: The Mean number of adult PNA in three crown parts of *P. elliottii* at SHFP

Age classes in years	Mean abundance of PNA in crown parts		
	Lower	Middle	Upper
Middle (9-16)	7.4±1.5 (0.76)	10.8±1.9 (0.95)	4.9±1.1 (0.57)
Old (>16)	6±1 (0.51)	7.7±1.2 (0.62)	4.2±0.7 (0.38)
Overall Mean	6.5±0.8 (0.43)	8.8±1.1 (0.53)	4.4±0.6 (0.31)

Mean±Confidence Level (95%) and (Standard error)

Table 7: The Mean number of adult PNA in three crown parts of *P. patula* at SHFP

Age classes in years	Mean abundance of PNA in crown parts		
	Lower	Middle	Upper
Middle (0-8)	3±0.5 (0.25)	3.7±0.6 (0.3)	1.8±0.4 (0.2)
Old (9-16)	2±0.8 (0.42)	2.3±0.6 (0.31)	0.9±0.3 (0.13)
Young (>16)	2.5±0.5 (0.27)	3.1±0.6 (0.32)	1.7±0.4 (0.22)
Overall Mean	2.5±0.4 (0.18)	3.1±0.4 (0.19)	1.5±0.2 (0.12)

Mean±Confidence Level (95%) and (Standard error)

Table 8: Pairwise comparisons of adult PNA attacking *P. elliottii* by crown parts at SHFP

Source of variation (Tree crown parts)	df	Chi-squared (X^2)	P-value
Between lower, middle and upper tree crown parts	2	96.2	0.000001b
Between lower and middle tree crown parts	1	1223	0.145a
Between lower and upper tree crown parts	1	1723	0.001b
Between middle and upper tree crown parts	1	1957	0.000001b

df= Degree of freedom, a= statistically Insignificant (p>0.05), and b= statistically significant (p<0.05) at 5% level of significance

Table 9: Pairwise comparisons of adult PNA attacking *P. patula* by crown levels at SHFP

Source of variation (Tree crown parts)	df	Chi-squared (X^2)	P-value
Between lower, middle and upper tree crown parts	2	60.9	0.000001b
Between lower and middle tree crown parts	1	7305	0.0002b
Between lower and upper tree crown parts	1	8683	0.00009b
Between middle and upper tree crown parts	1	9228	0.000001b

df= Degree of freedom, a= statistically Insignificant (p>0.05), and b= statistically significant (p<0.05) at 5% level of significance

Distribution and abundance of natural enemies of Pine Needle Aphid at Sao Hill Forest Plantation

The main natural enemies for PNA detected in affected twigs of Pine tree species (*P. patula* and *P. elliottii*) at SHFP were; Coccinellid beetles (Coleoptera: Coccinellidae), Spiders (Arachnida) and Stink bugs (Pentatomidae). The mean abundance of natural enemies was 5.4, 5.3 and 4.4 per 15 cm twig for Coccinellid beetles, Spiders and Stink bugs respectively (Figure 3). Two species of coccinellid beetles identified were *Adalia bipuncta* (two-spotted ladybugs) and *Harmonia axyridis* (halloween beetles). The abundance of natural enemies was lower compared with the abundance of PNA found at SHFP. The mean abundance of natural enemies was 3.0 and 4.0 per 15 cm twig for Division II and Division III respectively.

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Division III appear to have supported higher mean abundance of natural enemies compared to Division II. The total mean abundance of natural enemies was 3.1 and 3.8 per twig for *P. elliottii* and *P. patula* respectively. In

P. elliottii tree species Coccinellid predator beetles were not seen (Figure 4). Furthermore, the mean abundance of natural enemies was 4.2, 3.4 and 3.3 for young, middle and old age classes (Figure 5). The young age class appears to have supported higher number of natural enemies than middle and old age classes. In spite that, in young age trees only Coccinellid predator beetles were observed at SHFP (Figure 5).

Figure 3: Mean abundance of Potential Natural enemies for PNA attacking Pine trees at SHFP

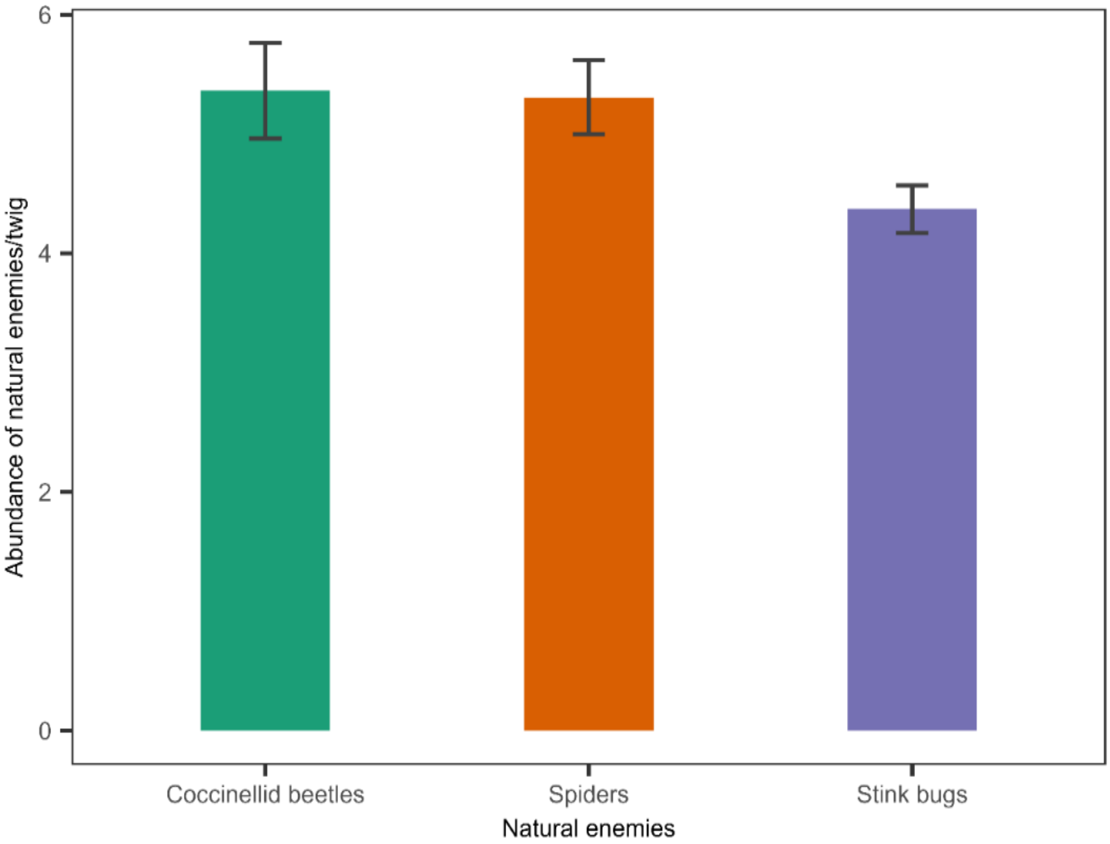

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Figure 4: Mean abundance of Natural enemies between Pine tree species at SHFP

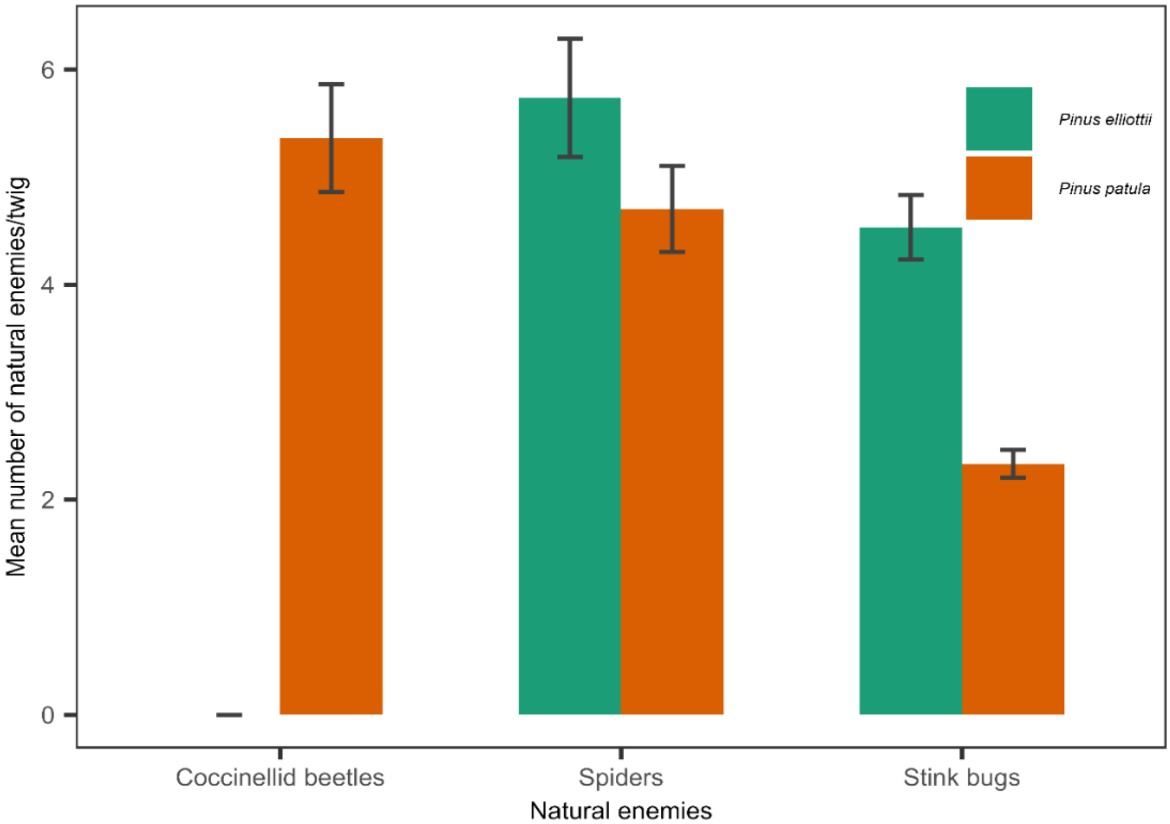
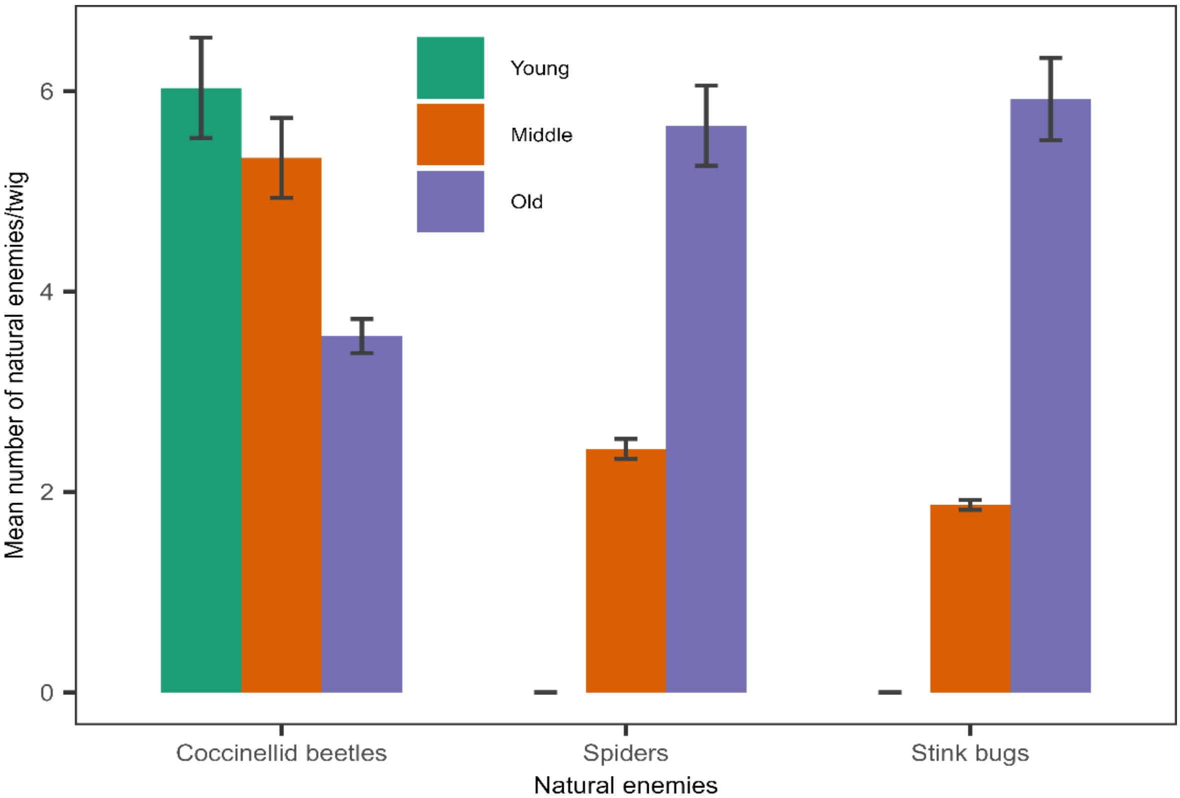


Figure 5: Mean abundance of natura enemies in different age classes of Pine trees at SHFP



Relationship between Pine Needle Aphid and Natural enemies' populations

The result revealed that the relationship between the abundance of natural enemies and PNA was very

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weak (rho = 0.0859), which indicate a weak positive correlation between the abundance of natural enemies and that of PNA. This suggests that as the number of PNA increases, there is a slight tendency for the natural enemies to also increase, although the relationship was weak. In spite that, the correlation was statistically significance (p = 0. 035), which mean that the presence of these three indigenous natural enemies had mild/very little contribution in keeping the population of PNA low, even though they are few in in number compared to the abundance of PNA attacking Pine tree species at SHFP.

Discussion

The abundance of PNA recorded in this study was lower compared to what was reported in other studies of aphids in forest plantations. In the same plantation, Madoffe & Austra, (1993) and Petro and Madoffe, (2011) reported higher number of PWA per twigs attacking *P. patula* and *P. elliottii* compared to what was found in this study. In Arusha, it was reported that 25.8 adult Cypress aphids per twig was observed in SUA training forest-Olomotonyi attacking *Cupressus Lusitanica* (Yakuti, 2015), which was very high compared to the current study found. The population decrease recorded during this study might have been caused by availability of predators like spiders, coccinellid beetles and stink bugs which were seen visiting shoots affected by PNA. In spite of these indigenous natural enemies living in association with aphids, there was no clear evidence that they were feeding on aphids, therefore contributing to the decreasing aphid population. The results are similar to that of Solangi *et al.,* (2008); and Mirmoayedi and Maniee (2009), who reported that the sucking insect pests were below the economic injury level at all phonological stages of the cotton plant due to regular rise in predator population. Kanturski *et al.*, (2016) reported that the most important factor in the decrease in population density of PNA is the rainy season and, on a small scale, the presence of their natural enemies.

In SHFP, management practices like, weeding, seed source and pruning are done equally throughout the plantation (Kingazi, 2020). The difference in number of aphids between the two divisions might have been caused by micro climatic variations, there were slightly differences in temperature and humidity between the divisions i.e. Division III had average daily temperature and humidity of 18.5 ^{0}C and 18.5% respectively while Division II had average temperature and humidity of 13.7 ^{0}C and 20.8% respectively. This result was similar to that of (Rachmatsyah *et al.*, 2012) in Java, Indonesia who found that Pine Woolly Adelgids require low temperature ranging from 16-22 ^{0}C to survive, which was consistent with their original distribution. Another probable reason for significant different in numbers of PNA between the two divisions might be due to natural enemies/predators present within the divisions, it was observed that Division III had more numbers of natural enemies per twigs compared to Division II. The significance difference in aphid infestation between Division II and III might be due to previous history of infestations. Division III, particularly the Nundwe and Itimbo Western ranges, has been identified as a hotspot for PNA infestations. Moreover, a severe PNA outbreak was recorded in Itimbo West (Sao Hill) in 2005, affecting approximately 288.8 ha of *P. patula* with an estimated volume of 98 411 m^3 (Nshubemuki *et al.,* 2011). This suggest that Division III has been more prone to aphid infestations compared to

Division II. The results further showed that nymph was found in highest numbers for both divisions, tree species and age classes, followed by adults and eggs the least. The abundance difference of the three growth stages recorded might have been caused by predators present at the study site. Some aphid's predators like coccinellid beetles, spiders and stink bugs were observed in the study site. They typically prefer adults, but may feed on eggs and so rarely on nymphs. Likewise, the abundance of nymphs was high possibly because the nymph life span is longer than adult life span which continuously makes the abundance of nymphs higher than that of adults and eggs (Mailu *et al.*, 1980). The results are similar to that of Petro and Madoffe, (2011) who found that PWA nymphs were highest, followed by adults and eggs the least among the three aphid growth stages. However, the results differ with that of Yakuti, (2015) who found that adult Cypress aphid were more abundant than nymphs and eggs because immature stages of Cypress aphids are more sensitive to abiotic factors changes than adults. In addition, the results of this study are contrary to that of Madoffe and Austra, (1993) in the same plantation who reported that eggs of PWA were more abundant compared to other aphid growth stages.

The mean abundance of adult PNA were significantly difference between tree species as adult aphid feeding preference appears to be *P. elliottii* than *P. patula*. This shows that *P. elliottii* tree is more suitable host for PNA probably due to composition and quality of volatile substances in the tree that attract and orient the aphids towards attacking *P. elliottii* than *P. patula*. Likely, some trees emit repellent compounds, which could deter insects, or contain compounds in the bark that could kill aphids if consumed, making them relatively resistant to attack (Petro & Madoffe, 2011). Probably this could be the reason as to why *P. elliottii* was found more attacked by PNA than *P. patula*. Similarly, Petro and Madoffe, (2011) reported that *P. patula* were more resistance to attack by PWA and had fewer mean abundance of adult aphids than *P. elliottii*, although the difference was not statistically significant. The same results was reported in Kenya by Mailu *et al.* (1980) that *P.patula* was found to be relatively more resistant to PWA attack in the highland plantations than other Pine species. In contrary, Katerere, (1982; 1984) reported that *P. patula* and *P. taeda* were most severely attacked and damaged by PNA compared to *P. elliottii* in Zimbabwe. Observations show that high numbers of adult PNA were found to attack middle age class for both divisions and tree species. The results were similar to Petro and Madoffe (2011) who reported that middle age *P. patula* were vulnerable to PWA infestation than old and young trees. Adult aphids possibly preferred to damage/attack middle age trees because of high foliage quality they have compared to other age classes, which constantly create decent places for aphid survival. In earlier studies, Klemola *et al.*, (2003); and Ruohomäki *et al.*, (2000) found that *Epirrita autumnata* outbreaks took place mostly in mature birth trees because of low parasitism or high foliage quality and availability of more suitable oviposition sites in mature trees. This contrast with Madoffe and Massawe, (1989); Yakuti, (2015); and Petro *et al.*, (2015) whose results indicated that young trees were more vulnerable to aphid infestation than old and middle aged trees and were highly killed. This is because the phloem sap of the young age trees is rich in sugars that is why aphids were more in young age classes. Furthermore, the

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results of the current study are contrary to that of Lyimo, (2016) who reported that the mean total numbers of *H. cubana* were not significantly different among DBH classes. This is because *H. cubana* prefer new growing shoots and new growing shoots were available at each DBH classes. The possible reason of preference in attack between PNA and *H. cubana* could be due to difference mode of attack by PNA and H. cubana is highly seasonal in its occurrence (Ahmed *et al.,* 2014).

The mean abundance of adult PNA per twig at SHFP for lower, middle and upper crown part were statistically significant which is contrary to that of Chilima, (2001); and Petro and Madoffe, (2011) which reported that the infestation by PWA between crown parts was not significant for *P. patula, P. elliottii* and *P. kesiya.* Despite this contradiction, the middle crown part of *P. patula* and *P. elliottii* had higher total mean number of PWA followed by lower crown part and upper crown part the least, which is similar to this study found. The differences in total number of aphids observed in tree crown parts might be possibly due to the fact that PNA are positively phototactic, but do not settle onto surface exposed to strong light (Katerere, 1982; Thomas, 2014). They appear negatively to phototactic response and strong light and therefore tend to settle in hidden and light fissures. The undersides of lateral branches, which obtain only moderate light, tend to support a higher concentration of aphids than the upper surfaces (Katerere, 1982). The middle crown part of *P. patula* and *P. elliottii* receives less light from the sun due to shade of branches above it. This would tend to boost accumulation of aphids in the middle crown part where there is less strong direct light therefore contributing to high infestation of aphid (Petro & Madoffe, 2011). Similarly, Yakuti, (2015); and Kebede and Mulugeta, (2021) found that the total mean number of Cypress aphid was higher in middle crown part, followed by lower crown part and upper crown part had the least total mean numbers. Moreover, the results agree with Madoffe and Massawe, (1989), who reported that the mode of insect distribution on the tree is mainly affected by light, wind, and temperature and so the insects could attain the favorable microclimatic sites. Therefore, there is a considerable variation in severity of attack on individual tree within crown parts of affected Pine trees for the reason that it creates microclimate variation within crown parts of the trees by making shelter against light, wind, temperature, humidity and other environmental factors affecting PNA development, distribution and performance. The result is contrary to that of (Lyimo, 2016) who reported that the mean number of H. cubana per 15 cm terminal shoot in both Morogoro and Tanga region were statistically insignificant for lower, middle and upper crown parts, despite this, there was a slightly high population density in lower crowns. On top of that, Petro *et al.,* (2015) reported that the lower crown parts for both *Eucalyptus camaldulensis* and *Eucalyptus tereticornis* in the Coast had higher total number of galls, followed by middle crown parts while the upper parts had the lowest total mean number of galls. Despite this, there was no significance difference in mean total numbers of galls per twig due to the open structure of the eucalyptus tree crowns as they receive light, moisture, and wind fairly equally in all parts, hence equally distributed within the tree crown. Additionally, McClure, (1982) found that *P. boerneri* and *P. coloradensis* are selectively fed more on the lower crown of the Pine tree species which is contrary to the finding of this study. The

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study revealed unequal distribution of natural enemies across divisions, age classes and tree species. All three detected natural enemies in the study area were native species, with no introduced natural enemies found in the study area. This contrasts with the situation in SHFP, where introduced natural enemies like *Tetraphleps raoi*, specifically introduced to control PWA at SHFP were effective against PNA (Petro & Madoffe, 2011). The absence of introduced natural enemies might be due to climate change and the role played by indigenous natural enemies against the introduced predators (*Tetraphleps raoi)*. The abundance of natural enemies was lower than the abundance of PNA found at SHFP. Nevertheless, the presence of these natural enemies likely contributed to controlling PNA. This aligns with previous reports, such as those by Hosseini and Poorjavad, (2020), which reported a low number of natural enemies associated with *Eulachnus* aphids. Field observations by Katerere, (1982) in Zimbabwe showed that an average of one Coccinellid predator beetle per 1000 aphids in study area were recorded. The result from this study clearly demonstrates that there is quite very weak positive relationship between the abundance of natural enemies and that of aphids. This suggests that as the abundance of aphid increases, there is a slight tendency for the natural enemies to also increase. This weak positive relationship is attributed to the presence of other food sources in the study area, which means that these natural enemies did not rely solely on aphids for their sustenance. In spite that, these natural enemies play a role in reducing aphid populations attacking Pine tree species at SHFP. The results from this study are contrary to that of Yakuti, (2015) who found that the number of Cypress aphid decreased as the number of natural enemies increased at SUA Training Forest, Arusha. The current study revealed that indigenous natural enemies associated with PNA are similar with previous studies reported. In contrast to other study, stink bugs (Pentatomidae) were found in association with PNA attacking Pine tree species at SHFP. Certainly, the study did not prove that these indigenous natural enemies were feeding on the PNA, therefore contributing to the declining aphid population. Furthermore, the found indigenous natural enemies in this study were reported as important predators for PNA in Zimbabwe, Iran and Poland (Hosseini & Poorjavad, 2020); (Katerere, 1982); and (Kanturski *et al.*, 2016).

Conclusion

The study investigated low population of PNA in all growth stages including eggs, nymphs and adults compared to previous studies of aphids attacking forest plantations in Tanzania. This could be due to climate change and role played by natural enemies (stink bugs, coccinellid beetles, and spiders). The abundance of aphids was unequally distributed thought the divisions, age classes and pine tree species at SHFP. The study revealed that both divisions studied exhibited presence of PNA. There was significant difference in abundance of PNA between divisions, tree species, age classes and crown parts for both tree species ($p < 0.05$). The study found that there are no introduced natural enemies (biological control) at SHFP. The abundance of natural enemies was lower compared with the abundance of PNA found at SHFP. There was a weak positive relationship between the abundance of natural enemies and aphid. Therefore, from these findings it is evidently shown that the distribution and abundance of PNA appear to be

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attributed to location (division), tree species and age classes.

Recommendations

Based on the results from this study and understandings from other studies, it is recommended that tending operation i.e. thinning, weeding and pruning must be intensified in order to reduce favorable environmental conditions for aphid performance (reproduction/growth/survival
). The SHFP management team should reconsider the introduction and release of *Tetraphleps raoi* or other predators as biological control agents over large area to increase the current stock of the natural enemies. The government should also intensify classical biological control as it has good prospects in Tanzania, by final goal for an Integrated Pest Management. Further studies should be conducted on the status of PNA to other forest plantations. In addition, other studies should investigate on the effect of abiotic factors such as rainfall, humidity, temperature and wind velocity and also should be carried in all seasons in order to assess the seasonal abundance of PNA.

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Data availability statement

The data that support the findings of this study are available upon reasonable request from the corresponding author.

Conflict of interests

The authors declare no conflicts of interest.

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