Tanzania Journal of Forestry and Nature Conservation, Vol 93, No. 1 (2024) pp34-50

Impact of *Heteropsylla cubana* infestation on *Leucaena leucocephala* in Morogoro and Tanga regions, Tanzania

Lyimo, P.J.

Department of Ecosystems and Conservation,
College of Forestry, Wildlife and Tourism, Sokoine University of Agriculture,
P.O. Box 3010, Chuo Kikuu, Morogoro. Tanzania
Corresponding: paulo.lyimo@sua.ac.tz

ABSTRACT

Heteropsylla cubana has damaged *Leucaena leucocephala* in Tanzania since its 1992 outbreak while its impacts remain unclear to date. This study aimed to assess the impact of *Heteropsylla cubana* on *L. leucocephala*, a valuable multi-purpose tree in Tanzania. Using the Point Centre Quarter method, the study observed *L. leucocephala* in Morogoro and Tanga regions to determine the population density of *H. cubana*, infestation density, and shoot health. Descriptive statistics were used to calculate the frequency and mean population density of *H. cubana*, infestation density, and shoot health. Analysis of Variance was used to compare the mean population density of *H. cubana* among different diameter at breast height (dbh) classes and crown parts. The findings show that the population density of eggs of *H. cubana* differed significantly among crown levels in Morogoro, but not in Tanga. There was no significant difference in nymph and adult population density among crown levels or dbh classes in both regions. The infestation density and shoot damage were slightly higher in Morogoro than in Tanga, but both regions had good shoot health. Farmers can safely plant *L. leucocephala* without fear of *H. cubana*, as its population is below injury level in the study areas.

Key Words: *Heteropsylla cubana*-*Leucaena leucocephala*-Infestation density-Shoot health.

INTRODUCTION

Background information

Leucaena leucocephala is a versatile tree that is extensively cultivated in tropical regions for its multiple benefits including fodder, fuelwood, reforestation, shade, erosion control, and nitrogen fixation (Ahmed *et al.* 2014, Nair 2007). However, the invasion of the Leucaena psyllid, *Heteropsylla cubana* Crawford, has significantly limited the benefits of *L. leucocephala*, reducing its production by 50-70% in humid regions and 20-50% in sub-humid environments (Mullen and Shelton 2003).

The Leucaena psyllid (*Heteropsylla cubana*) is a small yellow-green insect belonging to the family Psyllidae of the order Homoptera. It feeds on the young growing shoots of several plant species related to the genera Mimosa, Piptadenia, and Leucaena. The insect is native to Central and South America, and its spread beyond its natural habitat was recorded in Hawaii in 1984, Asia in 1985, and East Africa in 1992 (Ahmed *et al.* 2014, Madoffe and Petro 2011, Nair 2007). The heavy infestations of *H. cubana* defoliate the plant, stop growth, and limit photosynthesis due to the sticky fluid exudates promoting the growth of sooty mold on leaves (Shelton 2008).

The economic loss due to *H. cubana* attacks was estimated to be more than 316 million USD in Indonesia in 1986, while Malaysia had to import over 48,000 tons of leaf meal at a cost of over 20 million USD for pig and poultry feeds due to the attack on Leucaena fodders (CABI 2013). In India, over 200,000 seedlings were destroyed due to psyllid invasion in 1988 (CABI 2013, Napompeth 1994). The socio-ecological and economic impacts of *H. cubana* in Tropical America are negligible because *L. leucocephala* is not cultivated with the same intensity as in Asia, and natural enemies have co-evolved with the psyllid and kept its populations in check (CABI 2013).

In East Africa, *H. cubana* arrived in August 1992 and restricted the utilization of the important multi-purpose tree *L. leucocephala*, which is found in many parts of Tanzania and usually planted along farm boundaries and in homesteads for fodder, soil fertility improvement, and fuelwood (Madoffe and Petro 2011, Msangi *et al.* 2002). Most Leucaena stands were lowered after the invasion of *H. cubana* (Madoffe *et al.* 2000). To control the *H. cubana* in Kenya and Tanzania, the Asia-Pacific experience was considered the best option (Ciesla and Nshubemuki 1995, Madoffe and Petro 2011). Biological control using two hymenopterous parasitoids, *Tamarixia leucaenae* and *Psyllaephagus yaseeni*, introduced from Trinidad and Tobago and released in Tanzania and Kenya, appears to be effective against the psyllid, as evidenced by a reduction in its population and Leucaena shoot damage in some areas (Madoffe *et al.* 2000, Madoffe and Petro 2011, Lyimo and Mwatawala 2022). Also, during the reconnaissance survey, it was found that the biological control of psyllids *T. leucaenae* and *P. yaseeni* as well as its mummies was well established in the study area (Lyimo and Mwatawala 2022. However, the current occurrence of *H. cubana*, infestation density, and shoot health of *L. leucocephala* since the release of *T. leucaenae* and *P. yaseeni* in 1995 in the Morogoro and Tanga regions of Tanzania remains largely unclear. Therefore, this study aimed to assess the population density of *H. cubana*, infestation density and shoot health of the *L. leucocephala* in Morogoro and Tanga regions.

MATERIALS AND METHODS

Description of study area

The study was conducted in Morogoro and Tanga regions on the same sites as described by Lyimo and Mwatawala (2022) (Figure 1, Table 1).

Table 1: Description of study areas

Region	Location name	Latitude	Longitude	Altitude (ft)
Morogoro	SUA farm	6°.822097	37°.661160	1669.0
	Melela A	6°54'53.6"	37°26'0.61"	1627.3
	Melele B	6°55'84.6"	37°19'.61"	1623.0
Tanga	Mlingano	5°.06667	38°.91667	290.4
	Tanga dairy farm	5°15'S	39°15	217.8
	Ziwani	5°.3354	38°.5494	788.1

The recent statistics show that Morogoro region has a population of 3 197 104 people whereas the population in Tanga region is 2 615 597 people (URT 2022). The pre-dominantly vegetation type in Morogoro region is Miombo woodland and mountainous vegetation while Tanga region is characterized by bushland, palm gardens, village cultivations and estates (mainly sisal), natural forest and shrub thickets and open savannah grassland with scattered trees and scrub thickets (Lyimo 2016, Lyimo and Mwatawala 2022).

Morogoro region receives an annual average rainfall of 600-1200 mm and average annual temperature varies between 18°C on the mountains to 30°C in river valleys whereas Tanga region is characterized by mean annual rainfall of 1200 mm and mean monthly temperatures range between 19°C and 33°C (MRSEP 2006, Lyimo and Mwatawala 2022). In regards to the soil type, Morogoro region has mostly sandy clay loams in the topsoils and clays in subsoils whereas Tanga soils are sandy in the coastal belt, clay to loamy in the hinterland, and leached mineral laterite in the highlands (Swai 2005, Lyimo and Mwatawala 2022).

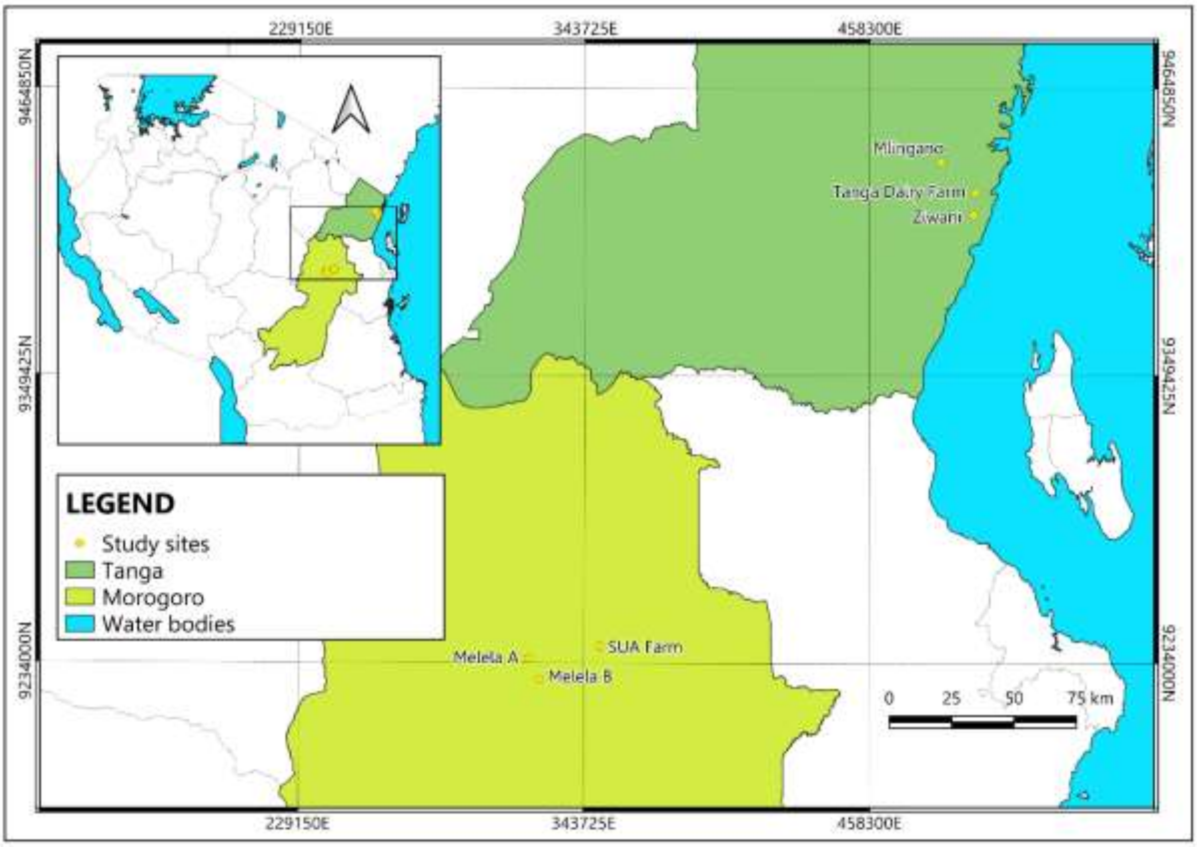

Figure 1. Map showing study sites in Morogoro and Tanga regions in Tanzania

Sampling design

The same sampling design described by Lyimo and Mwatawala (2022) was applied in this study. The Point-Center Quarter (PCQ) method was used to assess the population of *Heteropsylla cubana*, along with the incidence and extent of damage (Marisa, 2015). Five systematically placed sampling points were established at each site, including one at the center and four at each corner (Figure 2). At each sampling point, four quadrants were created. In each quadrant, nearby *Leucaena leucocephala* trees (dbh ≥ 1 cm) and regenerants (dbh < 1 cm) were sampled and recorded.

All trees with dbh ≥ 1 cm (Adult trees) were further categorized into three dbh classes: 1-5 cm, 6-15 cm, and >15 cm (Lyimo and Mwatawala 2022). Trees in each dbh class were then grouped by crown level (upper, middle, and lower). For each dbh class, two trees and two regenerants were sampled in each quadrant, resulting in 20 samples per quadrant, 100 samples per site, and a total of 600 samples across all sites (Lyimo 2016).

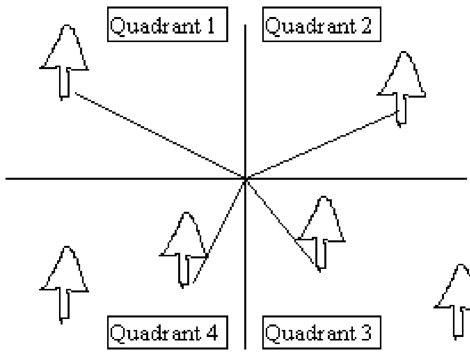

Figure 2: The layout of sampling point on the study area (Marisa 2015).

Data collection

Data were collected between April and July 2021, from 5:30 am to 10:00 am, when adult psyllids were less active. For adult trees (dbh ≥ 1 cm), one 15 cm growing shoot was randomly selected from each crown level; for regenerants (dbh < 1 cm), two 15 cm growing shoots were sampled per quadrant. The shoots were cut, placed in polythene bags, and stored overnight in a refrigerator to immobilize nymphs and adults (Lyimo 2016, Lyimo and Mwatawala 2022).

The collected shoots were washed with ethanol (70%) in a Petri dish and examined under a dissecting microscope to identify and count eggs, nymphs, and adult insects. Nymphs were classified by developmental stage: small (yellow, 1st and 2nd instars), medium (blackish, 3rd and 4th instars), and large (greenish, 5th instar) (Lyimo and Mwatawala 2022). Infestation density and shoot health were recorded using an empirical score modified from Bray and Woodroffe (1988) (Table 2).

Data Analysis

Descriptive statistics were used to report the frequency, mean population density, infestation density, and shoot health across sites and dbh classes as described by Lyimo and Mwatawala (2022). Analysis of Variance was applied to compare mean population densities of *H. cubana* among dbh classes and crown levels, as the data met assumptions of normality and homogeneity of variance. The main focus was to compare the population density within each site, rather than between sites, in order to have a clear view of intra-site variability and the influence of site-specific characteristics on pest density. Additionally, a Chi-Square (χ^2) test was used to assess significant differences in infestation density and shoot health among dbh classes. Data was analysed using R version 3.2.3, with Excel spreadsheets used to generate graphs.

RESULTS

Population density of *H. cubana* in adults' trees of *L. leucocephala*

The mean counts of *H. cubana* individuals across all life stages (eggs, nymphs and adults) and three crown levels (lower, middle and upper) observed in adults' trees (dbh ≥ 1 cm) of *L. leucocephala* in Morogoro and Tanga regions are presented in Figures 3 and 4 respectively. Results showed that in Morogoro site number of eggs differed significantly among crown levels (F = 5.768, df = 2, p = 0.003) but not among dbh classes (F = 2.872, df = 2, p = 0.057) while in Tanga site no significant differences were observed both in crown levels (F = 0.061, df = 2, p = 0.941) and in dbh classes (F = 0.816, df = 2, p = 0.443). The results also showed no significant differences in number of small nymphs among crown levels and dbh classes in both sites: Morogoro (F = 0.367, df = 2, p = 0.693; F = 2.317, df = 2, p = 0.100) and Tanga (F = 0.005, df = 2, p = 0.995; F = 0.813, df = 2, p = 0.444) respectively.

Further, in Morogoro site the results showed no significant differences on number of adults *H. cubana* among crown levels (F = 0.235, df = 2, p = 0.156) while a significant effect were observed in dbh classes (F = 3.379, df = 2, p = 0.035), Whereas in Tanga region, there was no significant difference in the number of adults *H. cubana* among crown levels (F = 0.235, df = 2, P = 0.790) and among dbh classes (F = 0.813, df = 2, p = 0.727). The interaction between DBH and crown levels were not significantly different in both Morogoro (F = 0.484, df = 4, p =.748) and Tanga (F = 0.612, df = 4, p = 0.654) regions. Mean numbers of eggs and small nymphs were consistently higher than larger nymphs and adults in all studied dbh classes. The mean trend of *H. cubana* life stages in Morogoro and Tanga decreased from one stage to another (Figure 5).

Table 2: Mean scores for damage ratings shoot health and nymph population counts

Tree infestation ratings	Nymph population score	Shoot health score
1 - No infestation	0- None	1-No damage
2 - Light infestation	1 - 1-5 nymphs	2- Slight damage
(Loss of < 25% of young Leaves)	2 - 6-30 nymphs	3 - Heavy damage
3 - Moderate infestation	3 - 31-100 nymphs	4 - Dead
(Loss of 26 to 50% of young Leaves)	4 - >100 nymphs	
4 - Heavy infestation	5 - >100 nymphs extend to stem	
(Loss of >75% of young Leaves)		
5 - Severe infestation		
(Blackening stem with total leaves loss)		

Source: (Modified from Bray and Woodroffe 1988)

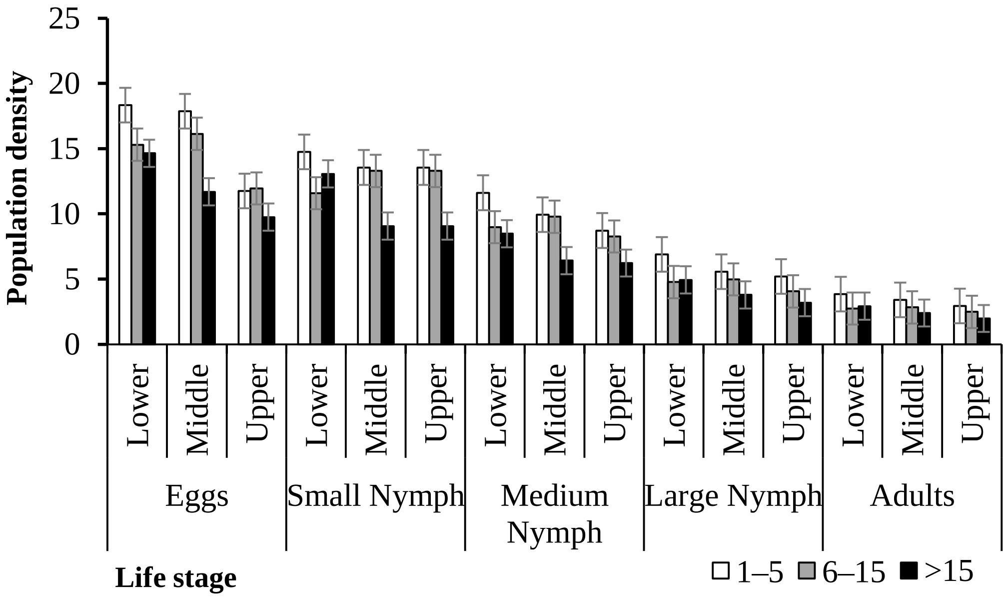

Figure 3. Mean number of three life stages of *H. cubana* across three crown levels and three dbh classes of adults *L. leucocephala* observed in Morogoro region

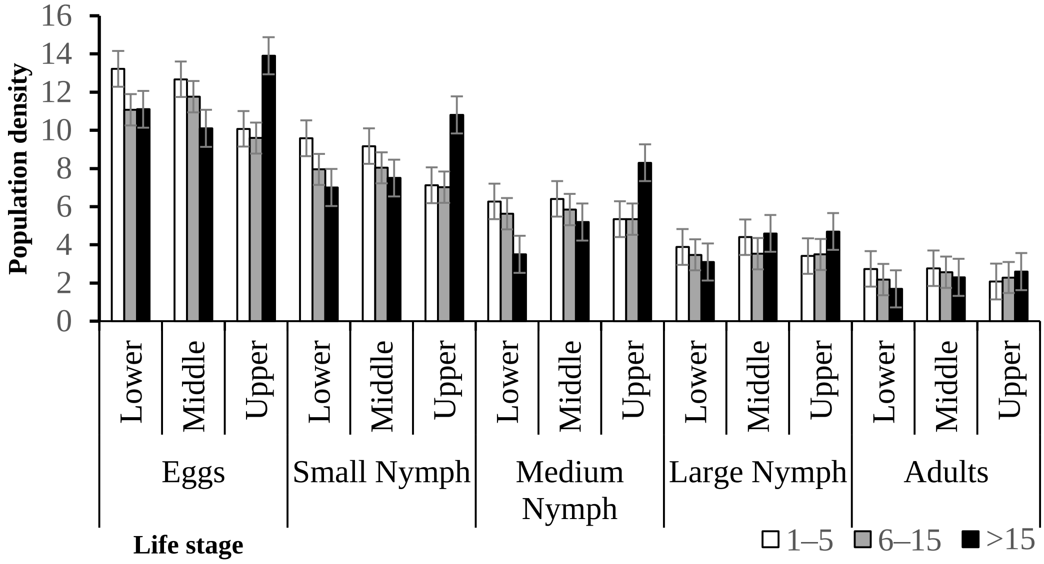

Figure 4. Mean number of three life stages of *H. cubana* across three crown levels and three dbh classes of adults *L. leucocephala* observed in Tanga region

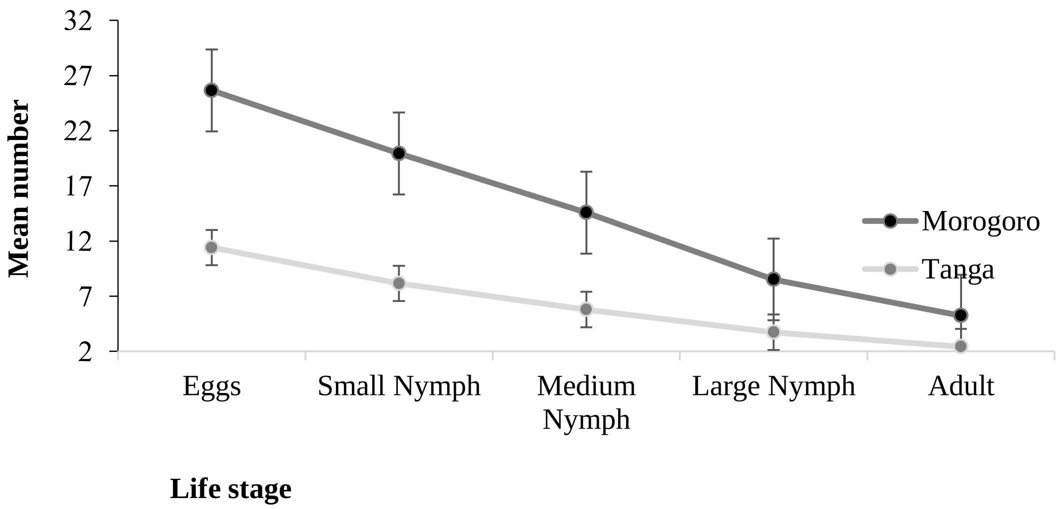

Figure 5. Mean trend of *H. cubana* life stages observed in adults' trees of *L. leucocephala* found in Morogoro and Tanga regions

Population density of *H. cubana* in regenerants of *L. leucocephala*

The population density of eggs and small nymphs are relatively low, with averages of 8 and 10, respectively in Morogoro region. Medium nymphs and large nymphs are even less common, averaging 7 and 3, respectively while adults have the lowest population density in Morogoro region (Figure 6). Conversely, in the Tanga region, population density is higher across all life stages, with eggs being the most abundant (average of 35) and adults the least abundant (average of 10). The t-statistics and p-values show that the differences in mean population densities between the two regions are statistically significant for all life stages of *H. cubana*.

The nymph population counted through subjective ratings showed most growing shoots of adult *L. leucocephala* had 6–30 nymphs followed by adults with 1–5 nymphs (Figure 7 and 8). Regenerants *L. leucocephala* had 1–5 nymphs in Morogoro and 6–30 nymphs in Tanga region (Figure 9).

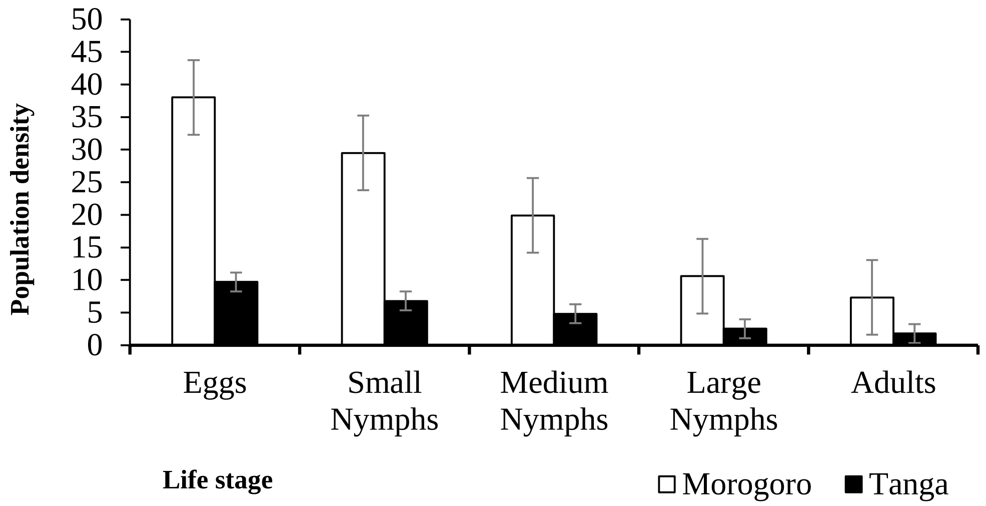

Figure 6. Mean number of eggs, nymphs and adults of *H. cubana* for regenerants *L. leucocephala* observed in Morogoro and Tanga region

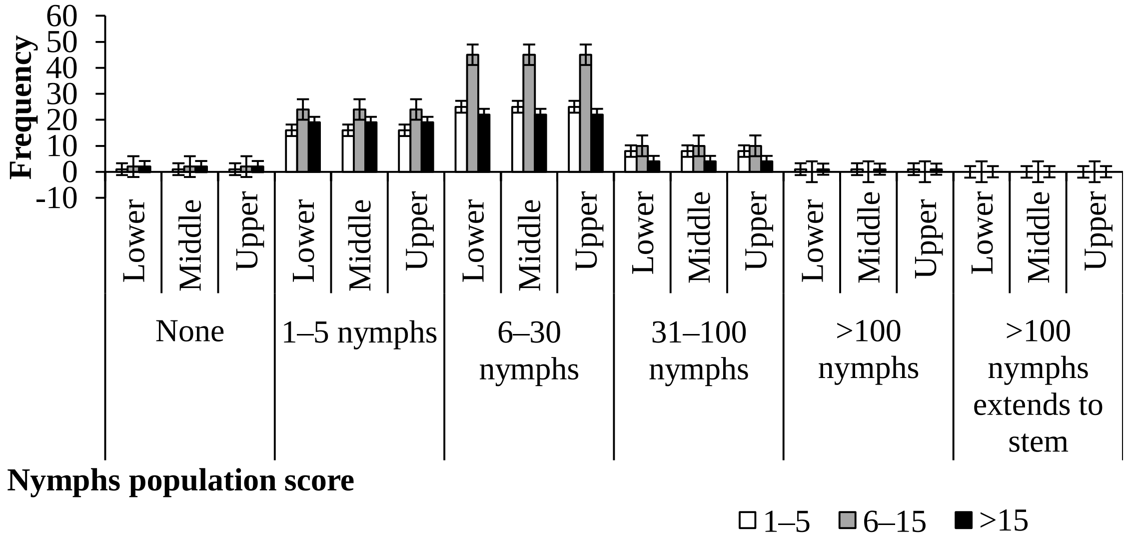

Figure 7. The nymph population counts through subjective ratings for adults *L. leucocephala* in Morogoro region

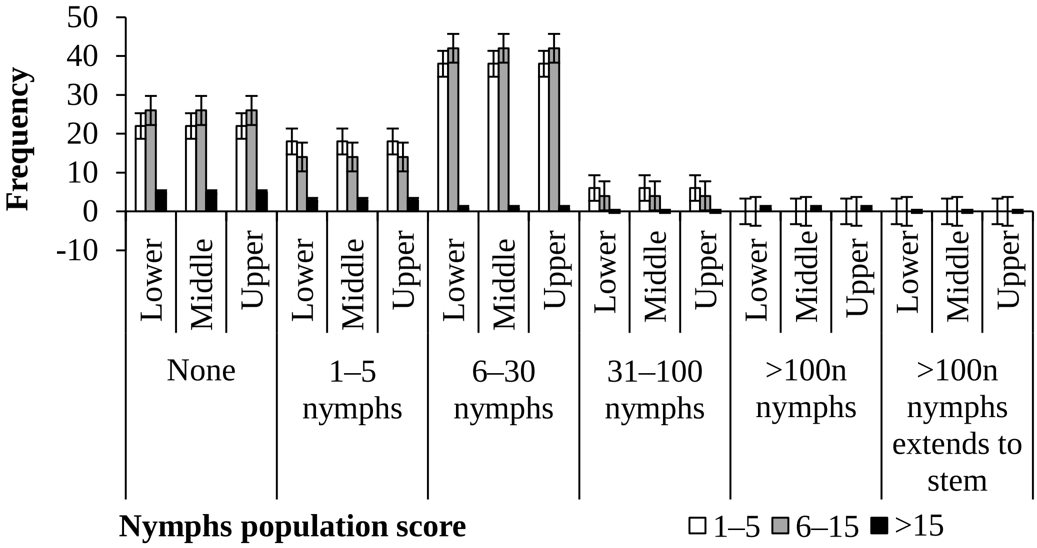

Figure 8. The nymph population counts through subjective ratings for adults *L. leucocephala* in Tanga region

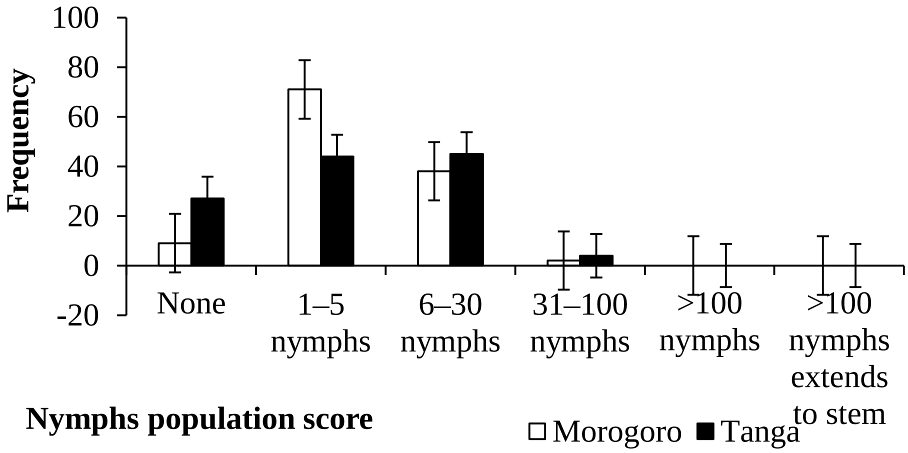

Figure 9. The nymph population counts through subjective ratings for regenerants *L. leucocephala* in Morogoro and Tanga region

Infestation density of *H. cubana* on adults' trees of *Leucaena leucocephala*

The results of the rate of infestation of adults' trees of *L. leucocephala* found in the two regions of Morogoro and Tanga across the three dbh classes are presented in Figure 10. The results showed that there was no significant relationship between dbh classes and infestation density in both sites of Morogoro and Tanga regions. Chi- square results for association between dbh classes and infestation density were (χ^2 = 20.0; df = 16; p = 0.220) for 1–5 and >15 and (χ^2 = 15.0; df = 12; p = 0.241) for 6–15 dbh class in Morogoro while (χ^2 = 15.0; df = 12; p = 0.241) for 1–5 and >15 and (χ^2 = 10.0; df = 8; p = 0.265) for 6–15 dbh class in Tanga. The results revealed that there was generally slightly high incidence in Morogoro compared to Tanga. A high proportion of adults *L. leucocephala* were lightly infested in all three dbh classes in Morogoro and Tanga.

For the regenerants, the rate of infestation of *L. leucocephala* found in the two regions of Morogoro and Tanga are presented in Figure 11. The results showed that the incidence of *L. leucocephala* infestation did not differ significantly in both Morogoro (χ^2 = 20.0; df = 16; p = 0.220) and Tanga (χ^2 = 15.0; df = 12; p = 0.241). The results revealed that like in the adults' trees, there was also slightly high incidence in Morogoro compared to Tanga. A high proportion of regenerants of *L. leucocephala* were lightly and moderately infested in Morogoro. Regenerants *L. leucocephala* were lightly and moderately infested in Tanga.

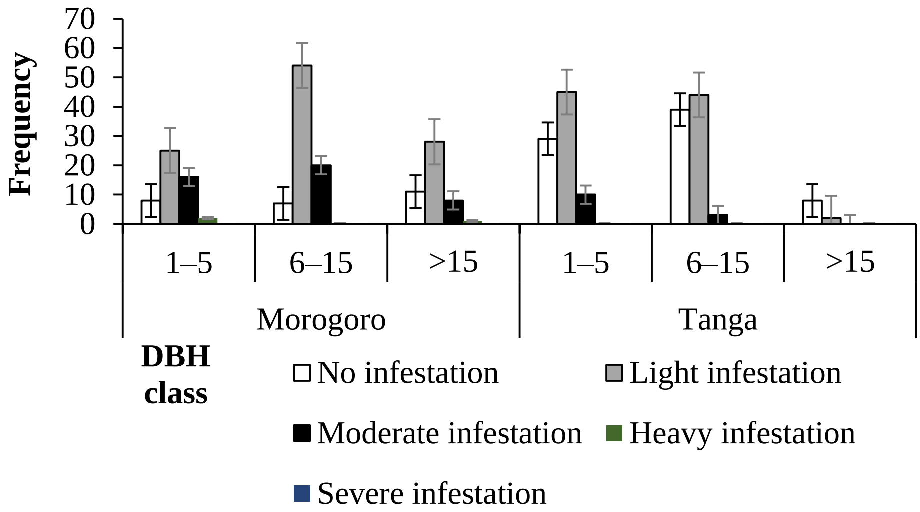

Figure 10. Infestation frequency of *H. cubana* on adults' trees of *L. leucocephala* in three dbh classes found in Morogoro and Tanga regions

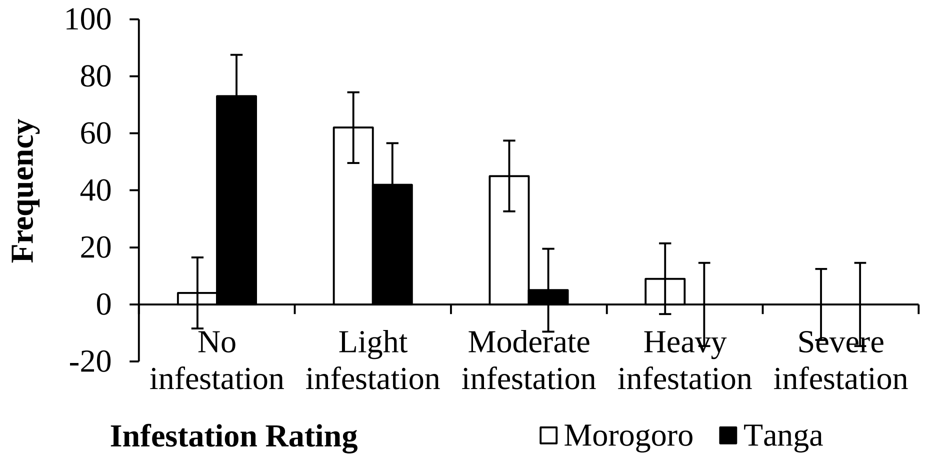

Figure 11. Infestation frequency of *H. cubana* on regenerants of *L. leucocephala* found in Morogoro and Tanga regions

Shoot damage of *Leucaena leucocephala*

The results of shoot health for adults' trees of *L. leucocephala* across three dbh classes and three crown classes found in the two regions of Morogoro and Tanga are presented in Figure 12 and 13 respectively. The Chi- square test results show a significant difference between dbh classes of shoot health for 1–5 dbh class ($\chi2$ = 24 .0; df = 6; p = 0.001), for 6–15 ($\chi2$ = 36.0; df = 9; p = 0.0001) and for >15 dbh class in Morogoro while ($\chi2$ = 36.0; df = 9; p =0.0001) for all three dbh classes in Tanga. The results showed that a high proportion of shoots of adults *L. leucocephala* were slightly damaged in all three dbh classes in Morogoro and Tanga (Figures 12 and 13).

Most of the shoots of the regenerants of the *L. leucocephala* in both Morogoro and Tanga regions were characterized with slight damage (Figure 14). Both regions experienced varying levels of damage. There were no reported deaths, with Tanga having fewer cases of heavy damage compared to Morogoro region. The shoot health of *L. leucocephala* trees of the regenerants was significant different (χ^2 = 54.0; df = 2; p < 0.05) in both Morogoro and Tanga regions.

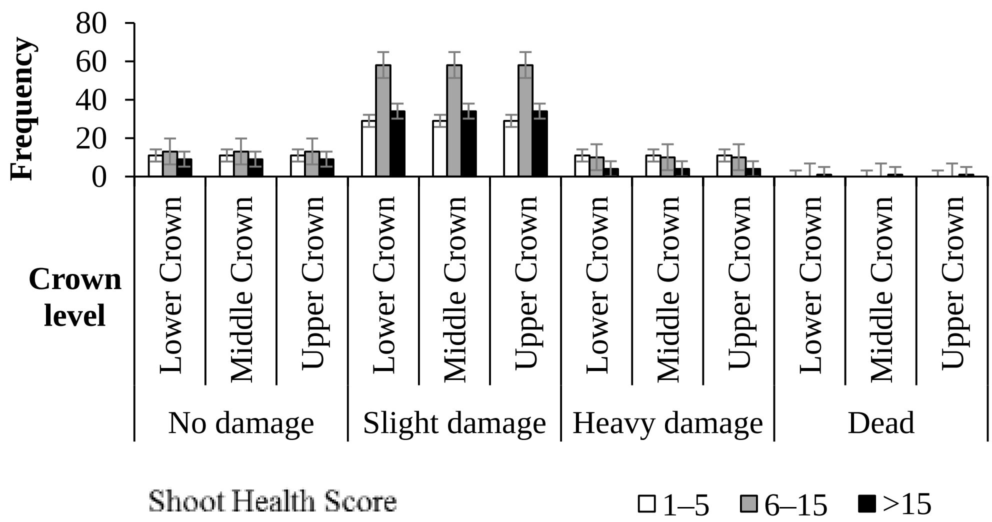

Figure 12. Shoot health frequency in three dbh classes and three crown parts for adults *L. leucocephala* found in Morogoro region

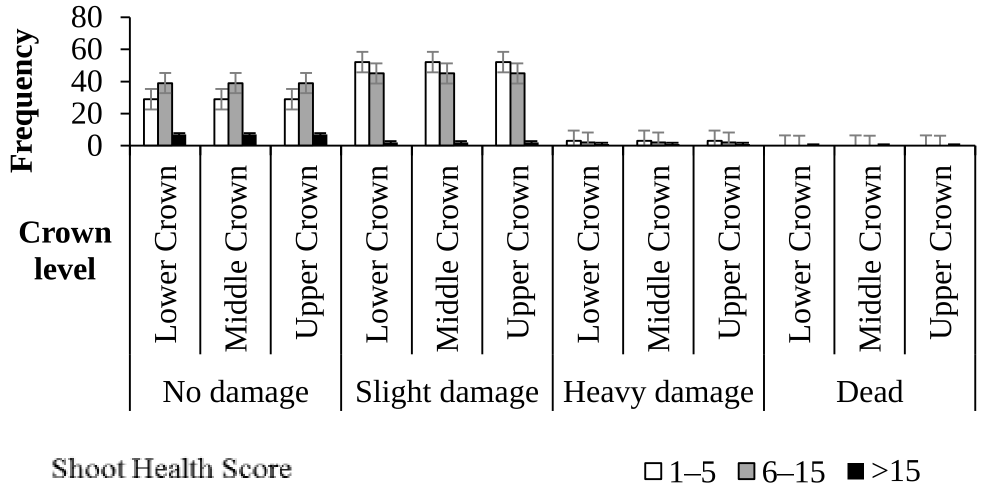

Figure 13. Shoot health frequency in three dbh classes and three crown parts for adults *L. leucocephala* found in Tanga region

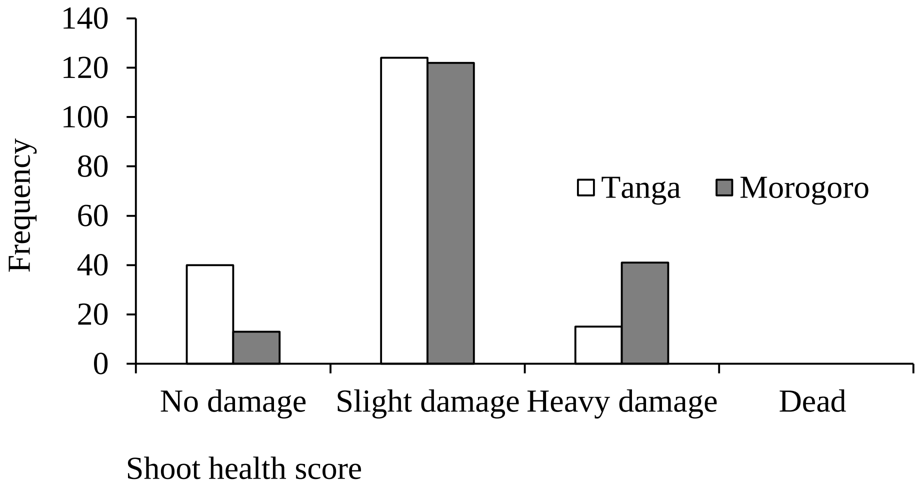

Figure 14. Shoot health frequency for regenerants *L. leucocephala* found in Tanga and Morogoro regions

DISCUSSION

Population density

The findings of this study show a low population density of *H. cubana* compared to other studies reported elsewhere. In India, the new shoots were heavily infested with up to 3000 nymphs and adults per 15 cm of terminal shoot (Nair 2007), which is very high compared to this study. Shelton (2008) reported field collected stem tips from all *L. leucocephala* individuals had psyllid eggs (average 234 ± 58 eggs/shoot). Over 90% of samples also had approximately 75-80 younger (instars 1-2) and older (instars 3-5) nymphs/shoot. However, the present studies (in contrast to above reported studies) were carried out in sites where *T. leucaenae* and *P. yaseeni* were introduced in 1995/1996 (Madoffe *et al.* 2000, Madoffe and Petro 2011). Several authors such Ahmed *et al.* (2014), Geiger and Andrew (2000), Shivankar *et al.* (2010) and Lyimo and Mwatawala (2022) reported that *T. leucaenae* and *P. yaseeni* are one of successful biological control agents against *H. cubana* in native and exotic locations.

The results showed that *H. cubana* prefers cooler climates. During the data collection, Morogoro had cooler climate with the mean temperature of 19.46°C than 30.2°C found in Tanga. Austin *et al.* (1996) and Castillo *et al.* (1997) reported high psyllid numbers throughout the year at Southeast Queensland and upland regions in Hawaii due to cooler climates. The current study found a high number of eggs and small nymphs compared with medium nymphs, large nymphs and adults. Similarly, Madoffe *et al.* (2000) found that small nymph populations were consistently higher than the other two instars and larger nymphs had the lowest populations in the same studied localities. This study found a decline in the number at each life stage of *H. cubana* from eggs to adults which resembles the same trend reported by Madoffe *et al.* (2000). The lower mean number of adult psyllids could be due to escaping during cutting of the growing shoot and put into the polythene bags for laboratory observation. The study done by Bruzas (1983) in South Africa, whose study took one-year, experienced higher number of eggs than nymph or adult *Pineus boerneri.*

The mean total numbers of *H. cubana* were not significantly different among dbh classes. This is because *H. cubana* prefers new growing shoots and new shoots were available at each dbh class. The result slightly differed from that of Madoffe and Petro (2011) which reported a significant difference in numbers of *H. cubana* between middle and old age classes but not between middle and old age class. The difference is due to difference mode of attack by *P. boerneri* and *H. cubana* is highly seasonal in its occurrence (Ahmed *et al.* 2014) and if food is available, cool temperatures could increase the psyllid populations (Bray 1992, Madoffe and Massawe 1994, Napompeth 1994). Additionally, dry season leads to tree stress, consequently making them susceptible to even moderate psyllid population (Larsson 1989). Other studies showed that psyllid population was affected by temperature, moisture, humidity and exposure to wind (Ahmed *et al.* 2014, Geiger and Andrew 2000, McAuliffe 2008) and the ups and downs of the psyllid populations were related to an optimum cooler temperature range and the availability of tender shoots in Hawaii (Ahmed *et al.* 2014).

Generally, the mean number of *H. cubana* per 15cm terminal shoot in Morogoro and Tanga regions for lower, middle and upper crown parts were statistically insignificant which is similar to that reported by Madoffe and Petro (2011) who found that the infestation by *P. boerneri* between crown parts was not significant for *Pinus patula* and *Pinus elliottii*. Despite of this, this study found a slightly high population density in the lower crown parts. These results are differently from that of Madoffe and Petro (2011) who reported that middle crown part had higher total mean number of *P. boerneri* followed by lower crown part, and upper crown part had lowest total mean number of aphids which implies that middle crown part was more damaged than lower crown and upper crown parts.

Infestation density

The higher infestation density of *L. leucocephala* in Morogoro region compared to Tanga region can be attributed to the increased population density of the insect *H. cubana* in Morogoro region. This species of psyllid, known to affect *L. leucocephala*, shows infestation through the presence of nymphs and adults feeding on the growing shoots of the plant, as highlighted by CABI (2013). The slightly elevated infestation densities in both regions, however, were also mitigated by natural control agents such as the parasitoids *Tamarixia leucaenae* and *Psyllaephagus yaseeni*, along with indigenous predators, which played a significant role in limiting the spread of *H. cubana* (Lyimo and Mwatawala 2022).

The decline in *H. cubana* populations has also been documented in previous studies. Madoffe *et al.* (2000) and Madoffe and Petro (2011) reported that hymenopterous parasitoids like *T. leucaenae* and *P. yaseeni* were likely to be responsible for reducing psyllid populations. This trend is consistent with findings from the Asia-Pacific Region, where the introduction of *T. leucaenae* and *P. yaseeni* successfully reduced *H. cubana* populations to lower levels (Ahmed *et al.* 2014, Nair 2007).

The insignificant difference in infestation density across different dbh classes in both Morogoro and Tanga regions indicates that psyllid feeding was not heavily influenced by the size of the plants. Instead, the availability of growing shoots, which are the primary feeding sites for *H. cubana*, was consistent across the various dbh classes, leading to similar infestation levels. However, Morogoro experienced more severe shoot damage than Tanga, which suggests that the population of *H. cubana* fluctuated over time, leading to varying degrees of impact on *L. leucocephala* in the two regions.

Shoot health

The observed reduction in shoot damage in Morogoro and Tanga regions following the release of parasitoids highlights the effectiveness of biological control measures in managing *H. cubana*. This pest, which predominantly targets young shoots of *Leucaena leucocephala*, has shown a preference for laying eggs in the delicate folds of developing leaflets. According to reports by CABI (2013) and Shelton (2008), this behavior underscores the susceptibility of new shoots to infestation, making them a critical focus for pest management strategies.

Interestingly, regenerating *L. leucocephala* appears to possess a greater number of suitable young shoots compared to fully grown adults. This distinction likely explains why the health of regenerating shoots in Morogoro and Tanga regions did not exhibit significant differences, despite the presence of *H. cubana*. The regenerants offer more opportunities for the pest to target, leading to consistent levels of shoot damage across these regions. The findings align with earlier studies by Geiger and Andrew (2000) and Chazeau *et al.* (1989), who observed that *H. cubana* populations tend to flourish in the presence of young *L. leucocephala* leaves and actively growing shoots. These results underscore the importance of continuous monitoring of young plant growth stages and emphasize the role of parasitoids in reducing pest populations and mitigating shoot damage in affected regions.

CONCLUSIONS AND RECOMMENDATIONS

This study found Morogoro region exhibited slightly higher infestation density and shoot damage in comparison to Tanga region. Despite this, both regions demonstrated good shoot health and minimal infestation to *L. leucocephala*, attributed to the low population density of *H. cubana*. Based on the results from this study and experiences from other studies, it is recommended that farmers are advised to plant *L. leucocephala* for various uses as the *H. cubana* population is below economic injury level in both sites of Morogoro and Tanga regions. Further studies should be conducted to assess the status of *H. cubana* in other localities where the hymenopterous parasitoids were not released. In addition, studies to assess the seasonal population density of *H. cubana* and the investigation of the effect of abiotic factors such as rainfall, temperature, wind velocity and others on *H. cubana* are suggested.

ACKNOWLEDGMENTS

The author would like to acknowledge the financial support from the Doreen Samwel Mvungi Foundation which supported this research to its completion. The great contribution of the Department of Ecosystems and Conservation Laboratory for the specimens processing is also highly acknowledged.

REFERENCES

Ahmed, A.M.M., Avilés1, L.R., Sánchez, F.J.S., Al-Zyoud, F. & Barros-Rodriguez, M. 2014. An Overview on some biotic and abiotic factors affecting the population dynamics of leucaena psyllid, Heteropsylla cubana Crawford (Homoptera: Psyllidae): Contributory factors for pest management. *Tropical and Subtropical Agroecosystems* 17: 437 – 446.

Alao, J.S., Sale, F.A. & Ojo, A.S. 2011. Problems and management of insect pests in social forestry in Nigeria. *African Journal of Agricultural Research* 6 (33): 6755 - 6758. DOI:10.5897/AJARX11.019.

Austin, M.T., Williams, M.J., Hammond, A.C., Frank, J.H. & Chambliss, G.G. 1996. Psyllid population dynamics and plant resistance of leucaena selections in Florida. *Tropical Grasslands* 30: 223-228.

Bray, R.A. 1994. The *Heteropsylla cubana*. In: Gutteridge R.C. & Shelton, H. M. (Eds.). Forage Tree legumes in Tropical Agriculture. CAB International, Oxford. pp. 283 -291.

Bray, R.A. & Woodroffe, T.D. 1988. Resistance of some leucaena species to leucaena psyllid. *Tropical Grasslands Journal* 22(1): 11-16.

Brewbaker, J.L. & Sorensson, C.T. 1990. New tree crops from interspecific Leucaena hybrids. In: Janick, J. and Simon, J.E. (Eds), Advances in New Crops, Timber Press, Portland, Oregon. pp. 283 - 289.

Burkhardt, D. 1986. Nomenclatural note on Heteropsylla cubana Crawford (Homoptera: Psylloidea), a new pest in Pacific Countries. *Revue suisse de Zoologie* 93(4): 1023 -1024.

Bruzas, W.A. 1983. The Pine Woolly Aphid (Pineus pini) and Associated Insects in Pine Plantations. Internal Report. PPRI, Department of Agriculture and Water Supply, Pretoria. 37pp.

Castillo, A.E., Cuyagan, O.E., Fogarty, S. & Shelton, H.M. 1997. Growth, psyllid resistance and forage quality of *Leucaena leucocephala*, *L. pallida*, *L. diversifolia* and the Fl hybrid of *L. leucocephala* x *L. pallida*. *Tropical Grasslands* 31(3): 188-200.

Ciesla, W.M. & Nshubemuki, L. 1995. *Heteropsylla cubana*: A threat to agroforestry in Africa. A Proceeding of a workshop held in Dar-es-Salaam, Tanzania, 10-14 October 1994, Rome FAO. 237pp.

Chazeau, J., Bouye, E. & Lydia, B.L. 1989. Lutte biologique contre le psylle *Heteropsylla cubana* ravageur du faux mimosa *Leucaena leucocephala* en Nouvelle Calédonie. Orstom, Nouméa.82pp.

Edward, E., Chamshama, S.A.O. & Mugasha, A.G. 2006. Growth performance of Lesser-known Leucaena species/provenances at Gairo inland plateau, Morogoro, Tanzania. *Southern African Forestry Journal* 208: 53 - 62.

FAO. 2001. Protecting plantations from pests and diseases. Report based on the work of W.M. Ciesla. Forest Plantation Thematic Papers, Working Paper 10. Forest Resources Development Service, Forest Resources Division. FAO, Rome.

FAO. 2007. Overview of forest pests Kenya. Forest Health & Biosecurity Working Papers. Rome, Italy. 26pp.

Krishnamurthy, K., Munegowda, M.R. & Rajagopal, D. 1989. Outbreak of psyllid, *Heteropsylla cubana* Crawford, on Leucaena and its outlook in alley cropping in India.

Proceedings of an international workshop held January 16-21, 1989 in Ogor, Indonesia. 17 – 24pp.

Geiger, C.A. & Andrew, P.G. 2000. Ecology of *Heteropsylla cubana* (Homoptera: Psyllidae): Psyllid Damage, Tree Phenology, Thermal Relations, and Parasitism in the Field. *Environmental Entomology* 29(1): 76 - 86. DOI:org/10.1603/0046-225X-29.1.76.

Geiger, C.A., Napompeth, B. & Van Den Beldt, R.J. 1995. An update on the status of the *H. cubana* in Southeast Asia. In: Shelton H.M., Piggin, C.M. and Brewbaker, J.L. (Eds.). Leucaena: Opportunities and Limitations. Canberra: Australian Centre for Agricultural Research. pp. 8-125.

Hughes, C.E. 1998. Leucaena - A genetic resources handbook. Oxford Forestry Institute, Tropical Forestry Paper No. 37. Oxford, UK. 274pp.

Larsson, S. 1989. Stressful times for the plant stress insect performance hypothesis. *Oikos* 56: 2, 277-283.

Lulandala, L.L. & Hall, J.B. 1987. Fodder and wood production from *Leucaena Leucocephala* intercropped with maize and beans at Mafiga, Morogoro, Tanzania. *Forest Ecology and Management* 21: 109 - 117.

Lyimo, P.J. 2016. Pest Status of Leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae) and Biological Control agent in Eastern Tanzania. Unpublished Master's Thesis at the Sokoine University of Agriculture, Morogoro, Tanzania. 81pp.

Lyimo, P.J. & Mwatawala, M.W. 2022. Status of Biological Control as a Management Tool for Leucaena psyllid, *Heteropsylla cubana*, Crawford (Homoptera: Psyllidae) in Eastern Tanzania. *Tanzania Journal of Forestry and Nature Conservation* 91(1): 58-69.

Johansson, A. 1994. Effect of *H. cubana* on women's enterprises. A case of Morogoro In: Sub Regional Workshop on *H. cubana*: a threat to agroforestry in Africa. (Edited by Ciesla, M. and L. Nshubemuki), 10-14 October 1994, Dar es Salaam, Tanzania. 40 - 47pp.

Kisaka, E.Z. 1994. Incidence of forest pest in Tanzania a special reference to the *H. cubana*. In: Sub-Regional Workshop on *H. cubana*: a threat to agroforestry in Africa (Edited by Ciesla, W. and L. Nshubemuki), 10-14 October 1994. Dar es Salaam, Tanzania. 236pp.

Madoffe, S.S. & Massawe, A. 1994. Periodicity of *H. cubana* infestation on *Leucaena leucocephala* growing in Morogoro: Preliminary observations. pp 155-161 in W.Ciesla and L.Nshubemuki (eds) H. cubana "A threat to Agroforestry in Africa", Dar-es-Salaam, Tanzania.

Madoffe, S.S., Muhundo, L., Day, R.K. & Nshubemuki, L. 2000. The pontential of Classical biological control against Leucaena psyllid (*Heteropsylla cubana* Crawford) in Eastern Tanzania. *Tanzania Journal of Agricultural Science* 3: 113 - 122.

Madoffe, S.S., Ngoo, A.G. & Tarimo, J. 2001. The influence of induced shading in *Leucaena leucocephala* seedlings on *Heteropsylla cubana*. *Tanzania Journal of Forestry and Nature Conservation* 74: 39-51.

Madoffe, S.S. & Petro, R. 2011. Status of forest insect pests in Tanzania: Introduction, Spread, Damage and Management Options. In: L. Nshubemuki, S.S. Madoffe, S.A.O. Chamshama, S. Bakengesa and C. Balama. (eds). Preceedings of the Workshop on Insect pests, Diseases and Soil Problems in Forest Plantation held at the Kibaha

Conference Centre, Kibaha, Tanzania, 3 to 4 February, 2011. Tanzania Forest Research Institute, Tanzania. 2-16pp.

Marisa, H. 2015. Application of Point-Centered Quarter Method for Measurement the Beach Crab (Ocypode spp) Density. *Biological Research Journal* 1: 1-6.

Ministry of Planning, Economy and Empowerment. 2006. Morogoro Region Socio Economic Profile (MRSEP). Ministry of planning, economy and empowerment. Dar es Salaam, Tanzania 122pp.

McAuliffe, M. 2008. Investment Opportunity: New PBR Leucaena variety. Full information package is available from Melissa McAuliffe. [Accessed 9 March 2021.] Available from URL: http://www.leucaena.net/pr_info_pack.pdf.

Msangi, R.B., Otsyina, R. & Kusekwa, M.L. 2002. Evaluation of lesser known Leucaena Species/Provenances and hybrids for fodder production and psyllid tolerance at Tabora and Shinyanga, Tanzania. In: Proceedings of the Regional Agroforestry Conference on Agroforestry Impacts on livelihoods in Southern Africa: Putting Research into Practices. (Edited by Rao, M.R. and Kwesiga, F.R). 20 – 24 May 2002, Aventura Resorts, Warmbaths South Africa. 181- 187pp.

Mullen, B.F., Gabunada, F., Shelton, H M, Stur, W.W. & Napompeth, B. 1998. Psyllid resistance in Leucaena. In: Australian Centre for International Agricultural Research Proceedings. (Edited by Shelton, H.M., Gutteridge, R.C., Mullen, B.F. and RA Bray, R.A.). Adaptation, Quality and Farming Systems Workshop 9 – 14 February, pp. 51 – 60.

Mullen, B.F. & Shelton, H.M. 2003. Psyllid resistance in Leucaena. Part 2. Quantification of production losses from psyllid damage. *Agroforestry Systems* 58:163 - 171.

Nair, K.S.S. 2007. Tropical Forest Insect Pests. The United States of America by Cambridge University Press, New York. 263pp.

Napompeth, B. 1994. *H. cubana* in the Asia-Pacific region: implications for its management in Africa. In: *H. cubana*: a Threat to Agroforestry in Africa. FAO Corporate Document Repository Food and Agriculture Organization of the United Nations, Rome, Italy. pp. 1–15.

NFTA. 1988. *H. cubanas* - A Review of the Problem and its Solutions. [http://factnet.winrock.org/fnrm/factnet/factpub/FACTSH/L_psyllids.html]. Site visited on 15/07/2021.

Ogol, C.K.P.O. & Spence, J.R. 1997. Abundance, population dynamics and impact of the leucaena psyllid *Heteropsylla cubana* Crawford in a maize-leucaena agroforestry system in Kenya. *Insect Science and its Application* 17: 183 - 192.

San Valentin, H. 1988. Seasonal population density, distribution and host range of psyllid infesting Ipil-ipil. [http://erdb.denr.gov.ph/enr/i4d/i4d_fo_psy.pdf.]. Site visited on 15/04/2021.

Sharma, J.K. & Sankaran, K.V. 1988. Incidence and severity of Botryodiplodia die-back in plantations of *Albizia falcataria* in Kerera, India. *Forest Ecology and Management* 24(1):43 - 58.

Shelton, H.M. 2008. Psyllid-resistant Leucaena hybrid for northern Australia. Meat and Livestock Australia Limited, Austaralia. 1 – 40pp.

Shivankar, V.J. & Rao, C.N. 2010. Psyllids and Their Management. *Pest*

Management in Horticultural Ecosystems 16: 1 - 4.

Showler, A.T. & Melcher, J. 1995. Environmental assessment for implementation of biological control for the H. cubana in Asia and Africa. Washington, D.C.: U.S. Agency for International Development.

Soon, U., Lin, T. & Chee, W. 1989. Studies on *H. cubana* in Malaysia. Proceedings of an international workshop held January 16-21, 1989 in Ogor, Indonesia. 28 – 39pp.

Sorensson, C. & Brewbaker, I.L. 1987. Psyllid resistance of Leucaena hybrids and Species in Leucaena. *Research Report* 7 (2):29 - 31.

Speight, M.R. & Wainhouse, D. 1989. Ecology and Management of Forest insects. Clarendon Press. Oxford, 373pp.

Swai, E., Karimuribo, E., Schoonman, L., French, N., Fitzpatrick, J., Kambarage, D. & Bryant, M. 2005. Description, socio-economic characteristics, disease managements and mortality dynamics in smallholder's dairy production system in coastal humid region of Tanga, Tanzania. *Livestock Research for Rural Development* 17 (4): 2005.

URT 2022. Population and Housing Census: Population Distribution by Administrative Areas. Project Report. National Bureau of Statistics (NBS), Tanzania.