International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

Forest Landscapes Influence Black Coffee Twig Borer, *Xylosandrus compactus* Eichoff Infestation in Adjacent Robusta Coffee Gardens: Management Implications

Godfrey H. Kagezi[a*], Patrick Kucel[b], Judith Kobusinge[c], Lilian Nakibule[d], Geofrey Arinaitwe[e]

[a,b,c,d,e]*National Coffee Research Institute (NaCORI), National Agricultural Research Organisation (NARO), P.O. Box 185 Mukono, Uganda*

[a]*Email: gkagezi@gmail.com*

[b]*Email: patkucel@gmail.com*

[c]*Email: judithkobusinge24@yahoo.com*

[d]*Email: liliannakibuule@yahoo.com*

[e]*Email: aggarinaitwe@gmail.com*

Abstract

The black coffee twig borer, *Xylosandrus compactus* Eichhoff (Coleoptera: Curculionidae) is one of the major constraints facing the Robusta coffee industry in Uganda since its advent in 1993. Once in a new location, it spreads rapidly within and between coffee gardens. This is mainly driven by favorable climatic conditions, presence of alternate hosts, limited management by farmers and the fact that natural enemies present in the new eco-systems are yet to adapt to it. Its management is difficult due to its cryptic nature of spending almost its entire lifespan is spent inside the host galleries. *X. compactus* has >200 host plant species worldwide, whereas, >50 plant species have been proven to be hosts in Uganda including: - commercial and ornamental crops as well as shade and forest trees/shrubs. In addition, these trees provide shady conditions that promote infestation of this pest. A study was therefore conducted in central Uganda to elucidate the effects of forest landscapes on the distribution of *X. compactus* damage in the adjoining Robusta coffee gardens. New alternate host plants of *X. compactus* within the forests were also documented. This could inform further development of its management strategy Uganda.

----

* Corresponding author.

Results showed that the percentage of coffee suckers and primary branches infested by *X. compactus* increased significantly (p=0.0171 and p=0.0001 respectively) with increasing distance away from the forest edge towards the center of the forest. The percentage infestation however decreased significantly (p<.0001 and p=0.2367) for suckers and primary branches respectively with increasing distance from forest edge towards the center of the adjoining coffee plantation. These observations are explicable by the fact that the forest acts as a source of *X. compactus* infestation for the adjoining coffee plantation, commonly referred to as "pull-effect", the nearer the coffee trees to the forest the greater the initial infestation. Nine alternative host plant species, namely: - charcoal tree *Trema orientalis* Linn. Blume (Ulmaceae), African celtis, *Celtis mildbraedii* Engl. (Ulmaceae), bastard-wild-rubber, *Funtumia africana* Benth. Stapf (Apocynaceae), velvet-leaved combretum, *Combretum molle* R. Br. Ex. G. Don. Engl & Diels (Combretaceae) and five unidentified tree species were recorded in the forest. These tree/shrub species have been added to the existing inventory of *X. compuctus* alternate host plants in Uganda. This study clearly demonstrates the influence of natural forest landscapes on incidence and damage of *X. compactus* infestations in adjoining Robusta coffee gardens. The results suggest that farmers with coffee gardens neighboring forested landscapes should take into account managing the source of *X. compactus* infestation from natural forests as well as that on coffee and alternate hosts in their gardens. NARO-BCTB traps should therefore be deployed along the forest boundaries in order to intercept the *X. compactus* from the forests before they enter the coffee gardens. However, there is need to fully elucidate the interactions between the 'pull-effect' and landscape and aggregation factors that influence incidence and damage of *X. compactus* attacks so as to inform its management.

Keywords: Alternate-host-plants; black-coffee-twig-borer; damage; edge-effect; pull-effect; Robusta-coffee; Xylosandrus-compactus.

1. Introduction

The Black Coffee Twig Borer, *Xylosandrus compactus* (Eichhoff) (Insecta: Coleoptera: Curculionidae: Scolytinae) is currently one of the most destructive insect pests of coffee in Uganda [1, 2, 3, 4, 5, 6]. It is a small brown to black exotic ambrosia beetle [7] that infests more than 200 plant species worldwide [8, 9, 10, 11]. In Uganda, *X. compactus* attacks mostly Robusta coffee but has also been observed on more than 50 plant species, including: - commercial crops as well as ornamentals, shade and forest trees/shrubs [2, 6]. In coffee, the female beetle bores a characteristic pin-sized entry hole and excavates tunnels inside the berry-bearing coffee primary branches causing them to wilt and die within a few weeks [7, 8, 12]. The infested primary branches will not bear berries, resulting into loss of harvest and thus income for the smallholder farmers [1, 5] who produce about 98% of Uganda's coffee [13]. Recent studies by [4] showed that 9.6% of the primary branches of coffee in Uganda were infested by *X. compactus*. This could be translated into 9.6% loss of the current 4.53 million 60 kg bags of coffee being exported valued at US$ 42.9 million of the US$ 439 million raised from coffee exports [14]. Once in a new location, *X. compactus* spreads rapidly within and between coffee gardens [1, 2, 5]. Flight of adult females is the main means of movement and dispersal to new plants and new areas over short distances - dispersing at least 200 m, though, dispersal over several kilometers is probably possible, especially if wind-aided [15]. However, the main sources of *X. compactus* remain uncertain [16]. Habitats, especially wooded and forested areas, surrounding farmers coffee gardens could be important potential sources of *X. compactus*. In fact, recent studies of ambrosia beetles confirmed that source populations in ornamental nursery production in USA were originating from overwintering sites in forests adjacent to production fields [16, 17]. However, this hypothesis has not been tested experimentally for coffee, nor has the movement of *X. compactus* within the farmers' coffee gardens characterized in Uganda and elsewhere. Secondly, although, population density, colonization behavior and attack severity of several ambrosia beetles may be influenced by forest edges [18, 19, 20], these effects are poorly understood for most of these beetles including *X. compactus* [19, 21, 22]. We therefore conducted a study in coffee gardens neighboring forest to further improve the existing *X. compactus* management package by minimizing infestations of coffee gardens from adjoining forested landscapes. Specifically, the study sought to: - i) determine the distribution of X. *compactus* damage on wild coffee in a natural forest adjacent to a coffee plantation, ii) establish the pattern of *X. compactus* damage in the coffee garden adjoining the natural forest, iii) search for new alternative plant hosts of *X. compactus* in forested landscapes adjoining coffee gardens, iv) use the information generated to further strengthen the efficacy of existing *X. compactus* management package.

2. Materials and Methods

2.1 Study site

The study was conducted in Mabira forest and on farmers' coffee gardens adjacent to the natural forest in Mubango Village, Nsakya Parish, Najjembe Sub-county, Buikwe District (Figure 1). The district lies between 0° 18' 4.32" N and 33° 3' 6.624" E in central Uganda, 1000-1300 m above sea level [23]. The climate is tropical with two rainfall peaks from April to May and October to November ranging between 1,250-1,400 mm per annum. Annual mean temperature range, minimum: 16–17 ° C, maximum: 28–29 ° C [24]. The vegetation is medium altitude moist semi-deciduous forest. The soil types in the reserve and the surrounding areas can be summarized as ferrallitic sandy clay loams with dark clays in the valleys [25]. Crop farming is the main sources of livelihood to the community with Robusta coffee being the most important cash crop grown in the area [26].

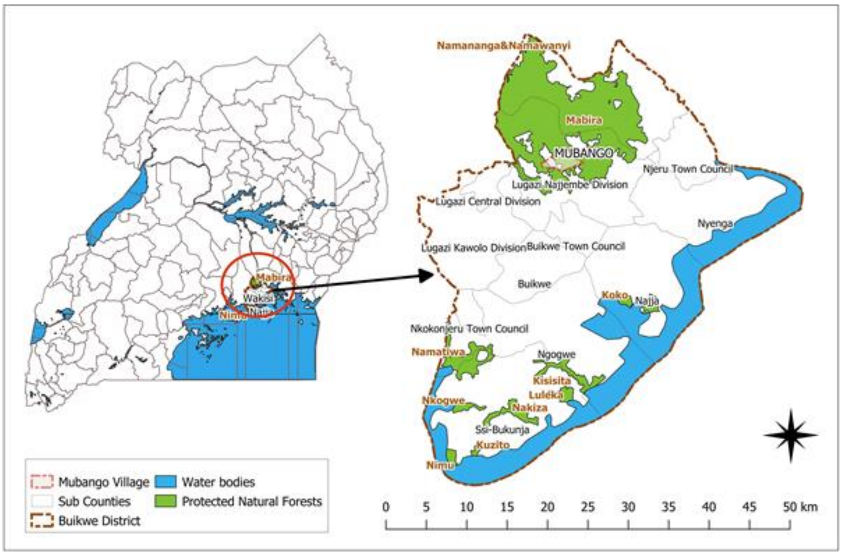

Figure 1: Location of the study area

2.2 Data collection

Three different points having wildly growing coffee in the forest and their adjacent coffee gardens were purposively selected for the study. A transect measuring 10 m in width was demarcated at the forest edge into the interior. All the coffee plants in the transect were sampled to the last plant in the forest. Similarly, an equal transect was demarcated from the forest edge into the adjacent coffee garden and all the coffee plants sampled. The distance of each sampled coffee plants from the forest edge was measured using a measuring tape (in meters). All the coffee stems on each of the sampled coffee plant were assessed for *Xylosandrus compactus* infestation by establishing the total number of suckers and primary branches and those with characteristic pin-sized entry holes [1, 4, 5]. In addition, other plant species in the forest were also examined for the characteristic entry holes in order to establish alternative host plant species of *X, compactus*. Samples of these tree species were taken to the National Coffee Research Institute (NaCORI) laboratory and identified where possible.

2.3 Statistical analysis

X. compactus infestation was calculated as percentage of the infested suckers and the primary branches to the total number of each parameter. We used simple regression analysis using Statistical Analysis System (SAS) software [27] to test for the relationship between the percentage of coffee suckers and primary branches infested by *X. compactus* to the distance from the forest edge.

3. Results and Discussion

Our study aimed at determining the effects of forest landscapes on the distribution of *X. compactus* damage in the adjoining Robusta coffee gardens so as to inform its management. Results for the distribution of *X. compactus* damage on wild Robusta coffee in the natural forest adjoining coffee gardens showed that the percentage of infested coffee suckers and primary branches increased significantly ($p<0.05$) with increasing distance from the boundary into the interior of the forest (Figure 2a and b). Our funding is in agreement with earlier studies on several insects including: - beetles [19, 20, 28, 29], leaf-miners [30], ants [31], butterflies [32], weevils, as reported by [20]. This could be in part due to the fact that as one moves into from the boundary or edge into the interior of forest, there are more conducive abiotic conditions that are provided by shade [33, 34]. Shade has been reported to have positive influence on the incidence and damage caused by *X. compactus* infestation on coffee [35, 36, 37, 38, 39, 40]. This is most likely because the high humidity provided by shade favors the growth of the ambrosia fungus, *Fusarium solani* (Mart.) Snyd. & Hans. (Hyphomycetes) that is associated with *X. compactus* and other beetles of the xyleborini tribe [12, 41]. This fungus provides food for the mother and her brood while in the coffee gallery [42]. On the other hand, forest boundaries or edges are characterized by reduced humidity, increased light, and greater temperature variability and wind disturbance [43, 44] that negatively affect reproduction and survival, and therefore, damage caused by several insect species [30, 32, 45] including *X. compaactus*.

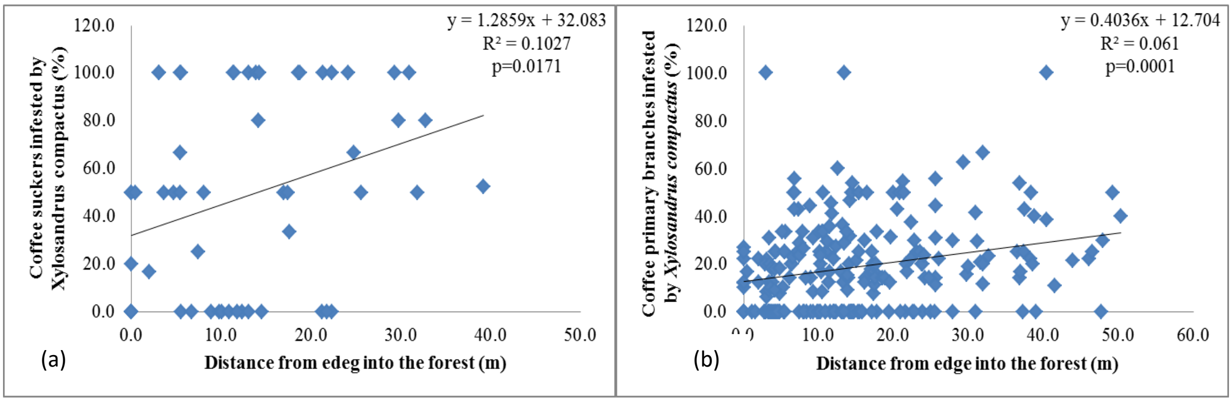

Figure 2: Relationship between the distance from the edge into the forest and the damage caused by *Xylosandrus compactus* on (a) coffee suckers, and, (b) primary branches

Contrary to the trend observed in the natural forest, the percentage of suckers and primary branches infested by *X. compactus* decreased with increasing distance from the forest boundary into the adjoining Robusta coffee garden. However, this decrease was significantly ($p<.0001$) for the suckers (Figure 3a) but not in case of the primary branches ($p=0.2367$; figure 3b). Our result supports prior studies by [16, 17, 46] that showed a decrease in captures of ambrosia beetles (majority being *X. compactus*) as the distance from forest edge to the nursery increased. Similarly, diversity and abundance of other beetle species were also reported to decrease from forest edge to sun-grown coffee garden [47] and pasture field [48]. This in part is due to the fact that trees are more diverse and abundant close to the forest margin, decreasing with increasing distance into the coffee garden [49, 50, 51]. This implies that even the shady conditions that favor development of *X. compactus* and its associated ambrosia fungus [12, 41] and therefore, *X. compactus* damage will decrease with increasing distance from forest margin into the coffee garden [35, 36, 37, 38, 39, 40].

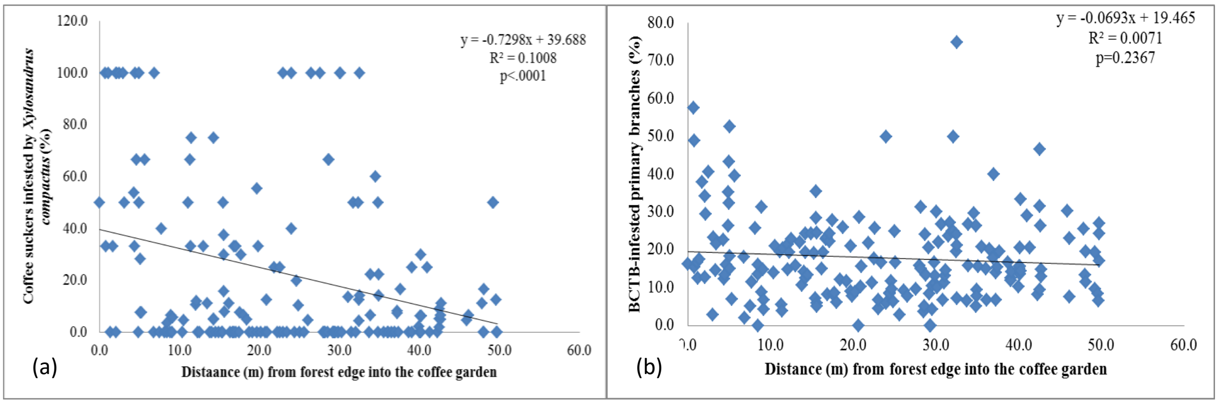

Figure 3: Relationship between the percentage of suckers (a) and primary branches (b) of coffee infested by *Xylosandrus compactus* and the distance from forest edge into the coffee garden

Furthermore, the search for alternative plant host in the forest yielded nine new tree/shrub species, namely: - Charcoal-tree (*Trema orientalis* Linn. Blume), African celtis (*Celtis mildbraedii* Engl.), Bastard-wild-rubber (*Funtumia africana* Benth.), Velvet-leaved combretum (*Combretum molle* R.Br ex G. Don) and five unidentified species. These plant species have been added to the existing list of alternative host plant species of *X. compactus* in Uganda. Of all these plant species, *X. compactus* has been report to infest only tree species in the genus Celtis [11, 53]. However, other related ambrosia beetles have also been reported to infest these plant species. For example, *X. morigerus* (Blandford) has been observed on *C. mildbraedii* and *T. orientalis* [54], *Xyleborus fornicatus* (Eichh.) and *Xylotrechus suscutellatus* (Chevrolat) on *T. orientalis* [55, 56]. Also, *Euwallacea whitfordiodendrus* (Schedl) has been reported on *C. molle*, *C. mildbraedii* and *T. orientalis* [57] while, *Ambrosiodmus guatemalensis* (Hopkins), *A. obliquus* (LeConte) and *Xyleborus sharpi* (Blandford) on *Trema* spp., and *Xyleborus perebeae* (Ferrari) on *Combretum* spp. [58]. This finding further illustrates that although the sources of *X. compactus* that colonize (attack) coffee are still uncertain [16], habitats such as wooded and forested areas that surround coffee gardens are potential sources of beetles that infest coffee [17, 46].

5. Limitations of the Study

The main limitation of this study was that we never quantified the damage caused by *X. compactus* on the alternative hosts as well as assessing the adult insect population emanating from the forested landscapes. This makes estimation of the contribution of forested landscapes to *X. compactus* infestation on Robusta coffee in gardens difficult.

6. Conclusion

Results emanating from our study clearly showed that the incidence and damage of *X. compactus* on wild Robusta coffee in the forest increased with increasing distance from forest. On the other hand, *X. compactus* incidence and damage were higher on Robusta coffee at forest boundary, decreasing significantly into the garden. In addition, nine new alternative plant hosts of *X. compactus* were also recorded in the forest landscapes and these have been added to the existing list of alternative hosts in Uganda. Our study therefore clearly demonstrated the influence of natural forest landscapes on incidence and damage of *X. compactus* infestations in adjoining Robusta coffee gardens.

7. Recommendations

Basing on our results therefore, farmers neighboring forested landscapes should always take into account managing the source of *X. compactus* infestation in natural forests in addition to the infestation on coffee and alternate hosts in their gardens. NARO-BCTB traps [59] should also be deployed along the forest boundaries in order to intercept adult flying *X. compactus* from these forested landscapes before they enter the coffee gardens [46]. However, there is need to fully understand local and landscape factors that influence the population dynamics and damage of *X. compactus* [60, 61] as well as this 'push-pull' strategy for managing it [62, 63].

Acknowledgement

This study was funded by the Government of Uganda (GoU) through the Uganda Coffee Development Authority (UCDA). The authors wish to acknowledge the contribution of Winfred Nanjego, Stephen Kigozi, Viola Kigonya and Ruth Nseranyi during data collection, Gerald Ddumba for providing maps and the farmers who participated in the study.

References

[1]. J.P. Egonyu, P. Kucel, A. Kangire, F. Sewaya and C. Nkugwa. ”Impact of the black twig borer on Robusta coffee in Mukono and Kayunga districts, central Uganda.” Journal of Animal and Plant Science vol., 3(1), pp. 163-169, Jan. 2009.

[2]. G.H. Kagezi, P. Kucel, D. Mukasa, P. van Asten, P.C. Musoli and A. Kangire. “Preliminary report on the status and host plant utilization by the Black Coffee Twig Borer, Xylosandrus compactus (Eichhoff) (Coleoptera: Curculionidae) in Uganda” in Proc. 24th ASIC. 2012, pp. 1323-1326.

[3]. G.H. Kagezi, P. Kucel, P.J. Egonyu, L. Nakibuule, J. Kobusinge, G. Ahumuza et al. “Impact and farmers’ coping mechanisms of the Black Coffee twig borer, Xylosandrus compactus (Eichhoff) (Coleoptera: Curculionidae) in Uganda,” Proc. ACSS, 2013, pp. 285-292.

[4]. G.H. Kagezi, P. Kucel, N. Olango, V. Tumuhaise, L. Nakibuule, J. Kobusinge et al. “Current distribution and impact of the Black Coffee Twig Borer (BCTB) and Coffee Wilt Disease (CWD) in Uganda,” study report, National Coffee Research Institute, 2016.

[5]. G.H. Kagezi, P. Kucel, L. Nakibuule, J. Kobusinge, G. Ahumuza and W.W. Wagoire “Current research status and strategic challenges on the black coffee twig borer, Xylosandrus compactus in Uganda,” presented at 2nd Scientific Conf. African Coffee, IACO, Yaounde, Cameroon, 2016.

[6]. J. Kobusinge, G.H. Kagezi, A. Kasoma, P. Kucel, L. Nakibuule, I. Perfecto et al. “Farmers’ knowledge of pests and diseases in the coffee-banana agroforestry systems of mid-eastern Uganda,” Journal of Agriculture and Environmental Sciences, vol., 7(2), pp. 109-119, Jan. 2018.

[7]. N.D. Ngoan, R.C. Wilkinson, D.E. Short, C.S. Moses and J.R. Mangold. “Biology of an introduced ambrosia beetle, Xylosandrus compactus, in Florida,” Annals of the Entomological Society of America, vol. 69, pp. 872–876, Sep. 1976.

[8]. A.H. Hara and J.W. Beardsley Jr. “The biology of the black twig borer, Xylosandrus compactus (Eichhoff), in Hawaii,” in Proc. Hawaiian Entomol. Soc., 1979, pp. 55–70.

[9]. P.B. Meshram, M. Husen and K.C. Joshi. “A new report of ambrosia beetle, Xylosandrus compactus Eichhoff. (Coleoptera: Scolytidae) as a pest of African mahogany, Khaya spp,” Indian Forester, vol. 119, pp. 75–77, Jan. 1993.

[10]. J. Intachat and L.G. Kirton. “Observations on insects associated with Acacia mangium in Peninsular Malaysia,” Journal of Tropical Forest Science, vol. 9(4), pp. 561-564, Jun. 1997.

[11]. K. Matsumoto. “Insect pests of Mahogany in Indonesia and Malaysia,” Tropical Forestry, vol. 55, pp. 29–36, 2002.

[12]. J.H. Chong, L. Reid and M. Williamson. “Distribution, host plants, and damage of the Black twig borer, Xylosandrus compactus (Eichhoff), in South Carolina,” Journal of Agricultural and Urban Entomology, vol. 26, pp. 199–208, Oct. 2009.

[13]. A.H. Hara. “Biology and rearing of the black twig borer, Xylosandrus compactus (Eichhoff) in Hawaii,” MSc. thesis. University of Hawaii, Honolulu, 1977.

[14]. TechnoServe. “A Business Case for Sustainable Coffee Production,” study report, 2013.

[15]. UCDA. "Uganda Coffee Development Authority (UCDA) Report 2019/20 Issue 3". https://www.ugandacoffee.go.ug/sites/default/files/reports/December%202019.pdf, Dec. 2019 [Apr. 02, 2020].

[16]. P.F. Entwistle. Pests of cocoa. London, UK: Longman, 1972, pp. 779.

[17]. M.F. Reding, C.M. Ranger, B.J. Sampson, C.T. Werle, J.B. Oliver and P.B. Schultz. "Movement of Xylosandrus germanus (Coleoptera: Curculionidae) in ornamental nurseries and surrounding habitats," Journal of Economic Entomology, 108, pp. 1947-1953, Jun. 2015.

[18]. C.T. Werle, J-H. Chong, B.J. Sampson, M.E. Reding and J.J. Adamczyk. "Seasonal and spatial dispersal patterns of select ambrosia beetles (Coleoptera: Curculionidae) from forest habitats into production nurseries," Florida Entomologist, vol. 98, pp. 884-891, Sep. 2015.

[19]. K. Maetô, K. Fukuyama and L.G. Kirton. "Edge effects on ambrosia beetle assemblages in lowland rain forest, bordering oil palm plantations, in Peninsular Malaysia," Journal of Tropical Forest Science, vol. 11, pp. 537-547, Jul. 1999.

[20]. M. Peltonen and K. Heliövaara. "Attack density and breeding success of bark beetles (Coleoptera, Scolytidae) at different distances from forest-clearcut edge," Agricultural and Forest Entomology, vol. 1, pp. 237-242, Sep. 1999.

[21]. B. Wermelinger, P.F. Flückiger, M.K. Obrist and P. Duelli. "Horizontal and vertical distribution of saproxylic beetles (Col., Buprestidae, Cerambycidae, Scolytinae) across sections of forest edges," Journal of Applied Entomology, vol. 131, pp. 104–114, Feb. 2007.

[22]. M. Kautz, R. Schopf and J. Ohser. "The "sun-effect": microclimatic alterations predispose forest edges to bark beetle infestations," European Journal of Forest Research, vol. 132, pp. 453-465, May 2013.

[23]. E. Akkuzu and H. Guzel. "Edge effects of Pinus nigra forests on abundance and body length of Ips sexdentatus," Šumarski list, vol. 9–10, pp. 447-453, Jan. 2015.

[24]. A. Nabatanzi, J.D. Kabasa and I. Nakalembe. "Wild edible plants consumed by pregnant women in Buikwe District, Uganda," International Journal of Technology Enhancements and Emerging Engineering Research, vol. 3 (11), pp. 18–27, Nov. 2015.

[25]. P. Tugume, E.K. Kakudidi, M. Buyinza, J. Namaalwa, M. Kamatenesi, P. Mucunguzi et al. "Ethnobotanical survey of medicinal plant species used by communities around Mabira Central Forest Reserve, Uganda," Journal of Ethnobiology and Ethnomedicine, vol. 12, pp. 1–28, Dec. 2016.

[26]. D. Akodi, E. Komutunga, C. Agaba, K.J. Oratungye and E. Ahumuza. "The effect of land use on soil organic carbon stocks in Lake Victoria crescent agro-ecological zone, Uganda,' Journal of Agricultural Science and Technology, vol. A 6, pp. 154-160, Mar. 2016.

[27]. MWE. Updating the ecological baseline and the socio-economic data for six central forest reserves (Mabira, Namukupa, Nandagi, Kalagala Falls, Namawanyi and Namananga) and updating the management plan for Mabira Central Forest, study report by Ministry of Water and Environment (MWE), 2017.

[28]. SAS Institute. SAS/STAT Software: Version 9.2, Cary, NC: SAS Institute Inc., 2008.

[29]. R.K. Didham, P.M. Hammond, J.H. Lawton, O. Eggleton and N.E. Stork. "Beetle species responses to tropical forest fragmentation". Ecological Monographs, vol. 68, pp. 295-323, Aug. 1998.

[30]. K.J. Dodds. "Effects of habitat type and trap placement on captures of bark (Coleoptera: Scolytidae)

and longhorned (Coleoptera: Cerambycidae) beetles in semiochemical-baited traps," Journal of Economic Entomology, vol. 104, pp. 879–888, Jun. 2011.

[31]. G. Valladares, A. Salvo and L. Cagnolo. "Habitat fragmentation effects on trophic processes of insect-plant food webs," Conservation Biology, vol. 20, pp. 212–217, Mar. 2006.

[32]. K.S. Carvalho and H.L. Vasconcelos. "Comunidade de formigas que nidificam em pequenos galhos da serrapilheira em floresta da Amazoˆnia Central, Brasil," Revista Brasileira de Entomologia, vol. 46(2), pp. 115–121, Jan. 2002.

[33]. K.S. Jr. Brown and R.W. Hutchings. "Disturbance, fragmentation, and the dynamics of diversity in Amazonian forest butterflies," in Tropical Forest Remnants: Ecology, Management, and Conservation of Fragmented Communities, W.E. Laurance and R.O. Bierregaard Eds, University of Chicago Press; Chicago, 1997, pp. 91-110.

[34]. K.A. Harper, S.E. MacDonald, P.J. Burton, J. Chen, K.D. Brosofske, S.C. Saunders et al. "Edge influence on forest structure and composition in fragmented landscapes," Conservation Biology, vol. 19, pp. 768-782, May 2005.

[35]. D. Faria, E. Mariano-Neto, A.M. Zanforlin, J.V. Ortiz, R. Montingeli, S. Rosso et al. "Forest structure in a mosaic of rainforest sites: the effect of fragmentation and recovery after clear cut," Forest Ecology and Management, vol. 257, pp. 2226-2234, May 2009.

[36]. A.M. Anuar. "Observation on damage by Xylosandrus compactus in coffee as affected by shade and variety," Mardi Re Bull, vol. 14, pp. 108–110, 1986.

[37]. P. Kucel, J.P. Egonyu, G. Kagezi and P.C. Musoli. Shade and varietal effects on diversity and prevalence of insect pests of Robusta coffee in central Uganda'" in Proc. CAFNET, pp. 10.

[38]. G.H. Kagezi, P. Kucel, J. Kobusingye, L. Nakibuule, R. Wekhaso, G. Ahumuza et al. "Influence of shade systems on spatial distribution and infestation of the Black Coffee Twig Borer on coffee in Uganda," Uganda Journal of Agricultural Sciences, vol. 14(1), pp. 1-12, Nov. 2013.

[39]. J. Dahlqvist. "What is the view of the Black Coffee Twig Borer (Xylosandrus compactus (Eichhoff) among farmers, advisers and experts, and is the infestation on Robusta coffee trees (Coffea canephora) higher or lower when grown close to a Ficus natalensis?," MSc. thesis, SLU, Sweden, 2016.

[40]. C. Hultman. "Black Coffee Twig Borer, Xylosandrus compactus (Eichhoff) on Robusta coffee in Uganda and knowledge levels about BCTB," MSc. thesis, SLU, Sweden, 2016.

[41]. H. Bukomeko, L. Jassogne, G.H. Kagezi, D. Mukasa, P. Vaast. "Influence of shaded systems on Xylosandrus compactus infestation in Robusta coffee along a rainfall gradient in Uganda," Agricultural and Forest Entomology, vol. 20(3), pp. 327-333, Nov. 2017.

[42]. R.A. Beaver. "Insect fungus relationships in the bark and ambrosia beetles," in Insect fungus interactions, N. Wilding, N.M. Collins, P.M. Hammond and J.F. Weber, Eds. Academic, New York, NY, 1986, pp. 121-143.

[43]. E.B. Greco and M.G. Wright. "Ecology, biology, and management of Xylosandrus compactus (Coleoptera: Curculionidae: Scolytinae) with emphasis on coffee in Hawaii," Journal of Integrated Pest Management, vol. 6 (1), pp. 8, Feb. 2015.

[44]. W.F. Laurance, T.E. Lovejoy, H.L. Vasconcelos, E.M. Bruna, R.K. Didham, P.C. Stouffer et al. "Ecosystem decay of Amazonian forest fragments: a 22-year investigation," Conservation Biology,

vol. 16(3), pp. 605–618, Jun. 2002.

[45]. M.D. Hunter. “Landscape structure, habitat fragmentation, and the ecology of insects,” Agricultural and Forest Entomology, vol. 4(3), pp. 159–166, Jul. 2002.

[46]. E.A. Arnold and N.M. Asquith NM. “Herbivory in a fragmented tropical forest: patterns from islands at Lago Gatún, Panama,” Biodiversity and Conservation, vol. 11(9), pp. 1663–1680, Sep. 2002.

[47]. C.T. Werle, B.J. Sampson and M.E. Reding. A role for intercept traps in the ambrosia beetle (Coleoptera: Curculionidae: Scolytinae) IPM strategy at ornamental nurseries,” Midsouth Entomologist, vol. 10, pp. 14-23, Oct. 2018.

[48]. S. Villada-Bedoya, C.A. Cultid-Medina, F. Escobar, R. Guevara and G. Zurita. “Edge effects on dung beetle assemblages in an Andean mosaic of forest and coffee plantations,” Biotropica, vol. 49(2), pp. 195-205, Mar. 2017.

[49]. J.O. Dantas, A.N. Ferreira, I.R.P. Oliveira, M.O. Alves, G.T. Ribeiro and T.G. de Araújo-Piovezan. “Edge effects on beetle assemblages in an Atlantic forest fragment and pasture in Sergipe, Brazil,” EntomoBrasilis, vol. 11(1), pp. 26-32, Feb. 2018.

[50]. I. Perfecto and J. Vandermeer. “Quality of agroecological matrix in a tropical montane landscape: ants in coffee plantations in southern Mexico,” Conservation Biology, 16(1), pp. 174–182, Feb. 2002.

[51]. TH. Ricketts. “Tropical forest fragments enhance pollinator activity in nearby coffee crops,” Conservation Biology, 18(5), pp. 1262–1271, Oct. 2004.

[52]. S. Gwali, H. Agaba, P. Balitta, D. Hafashimana, J. Nkandu, A. Kuria et al. “Tree species diversity and abundance in coffee farms adjacent to areas of different disturbance histories in Mabira forest system, central Uganda,” International Journal of Biodiversity Science, Ecosystem Services and Management, 11(4), pp. 309-317, Jun 2015.

[53]. L. Marinoni, G.F.G. Miranda and F.C. Thompson. “Abundância e riqueza de espécies de Syrphidae (Diptera) em áreas de borda e interior de floresta no Parque Estadual de Vila Velha, Ponta Grossa, Paraná, Brasil,” Revista Brasileira de Entomologia, vol. 48(4), pp. 554-559, Dec. 2004.

[54]. W.N. Dixon, R.E. Woodruff and J.L. Foltz. Black twig borer Xylosandrus compactus (Eichhoff) (Insecta: Coleoptera: Curculionidae: Scolytinae) Florida Cooperative Extension Service, IFAS University of Florida, EENY 311, 5 p, 2003.

[55]. S.A. Dole and A.I. Cognato. “Phylogenetic revision of Xylosandrus Reitter (Coleoptera: Curculionidae: Scolytinae: Xyleborina),” in Proc. Calif. Acad. Sci., 2010, pp. 451-545.

[56]. W. Danthanarayana. “The distribution and host range of the shot-hole borer (Xyleborus fornicatus Eichh.),” Tea Quarterly, vol. 39, pp. 61-69, Jul. 1968.

[57]. M. Dhanam, M. Ramachandran and PK. Bhat. “A note on Xylotrechus suscutellatus Chevrolat attacking Trema orientalis,” Journal of Coffee Research, vol. 22, pp. 129–130, 1992.

[58]. H. Fryer. “List of Trees Impacted by Polyphagous Shot Hole Borer (PHSB) in South Africa”. Internet: https://treesurvey.co.za/wp-content/uploads/2019/07/2019-07-11-TreeSurvey .co _.za- PSHB-List-of-Trees.pdf. Jul. 11, 2019 [Apr. 02, 2020].

[59]. T.H. Atkinson and A. Equihua-Martinez. “Biology of bark and ambrosia beetles (Coleoptera: Scolytidae and Platypodidae) of a tropical rain forest in southeastern Mexico with an annotated checklist of species,” Annals of the Entomological Society of America, vol. 79(3), pp. 414–423, May

1986.

[60]. P. Kucel, G.H. Kagezi, J. Kobusinge, L. Nakibuule, S. Kyamanywa and W.W. Wagoire. Trapping technology for black coffee twig borer (BCTB). Technical Advice, pp. 2.

[61]. Y. Carrie`, P.B. Goodell, C. Ellers-Kirk, G. Larocque, P. Dutilleul, SE. Naranjo et al. "Effects of local and landscape factors on population dynamics of a cotton pest," PLoS ONE, vol. 7(6), pp. 8, Jun. 2012.

[62]. P.H.W. Biedermann, J. Müller, J-C. Grégoire, A. Gruppe, J. Hagge, A. Hammerbacher et al. "Bark beetle population dynamics in the Anthropocene: challenges and solutions," Trends in Ecology and Evolution, vol. 34(10), pp. 914-924, Jun. 2019.

[63]. C.T. Werle, C.M. Ranger, P.B. Schultz, M.E. Reding, K.M. Addesso, J.B. Oliver et al. Integrating repellent and attractant semiochemicals into a push–pull strategy for ambrosia beetles (Coleoptera: Curculionidae)," Journal of Applied Entomology, vol. 143(4), pp. 333-343, Nov. 2018.

[64]. M.J. Rivera, X. Martini, D. Conover, A. Mafra-Neto, D. Carrillo and L.L. Stelinski. "Evaluation of semiochemical based push-pull strategy for population suppression of ambrosia beetle pathogen vectors in avocado," Scientific Reports, vol. 10(1), pp. 2670, Dec. 2020.