CITY OF CAPE TOWN
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POLYPHAGOUS SHOT HOLE BORER PROTOCOL

City of Cape Town

Invasive Species Unit

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Contents

ACRONYMS, DEFINITIONS AND TERMINOLOGY

FABI - Forestry and Agricultural Biotechnology Institute

Frass – Fine powdery refuse or fragile perforated wood produced by the activity of boring insects.

ISU – Invasive Species Unit

Mycangia – Special structures on the body an animal that are adapted for the transport of symbiotic fungi (usually in spore form).

PSHB – Polyphagous Shot Hole Borer

POLYPHAGOUS SHOT HOLE BORER

1. BACKGROUND

The Polyphagous Shot Hole Borer (PSHB), *Euwallacea whitfordiodendrus*, is an ambrosia beetle native to Southeast Asia. PSHB has a symbiotic relationship with three fungal species, including the pathogen *Fusarium euwallaceae*, which serves as a food source for the adults and their larvae. In susceptible hosts this leads to *Fusarium* Dieback, a disease-causing branch dieback and tree death. The beetles can establish in a wide range of alien and indigenous tree species in urban, agricultural and natural landscapes. Susceptible tree species can be reproductive or non-reproductive host trees and show different responses (see Appendix 2 for a list of known reproductive and non-reproductive host species):

- Reproductive host trees are those in which both the beetles and the fungus establish, and where the beetles successfully reproduce. In most cases the reproductive hosts will eventually be killed by the fungus.
- Non-reproductive host trees are attacked by the beetle and the fungus establishes, but the beetle does not successfully breed. The fungus may or may not cause disease and kill the tree.

The PSHB presents a significant threat to the agricultural and forestry sector as well as urban and natural forests across the country. While not yet quantified, the ecological, economic and social impacts are likely to be severe.

2. DESCRIPTION

Female beetles are black and 1.8–2.5 mm long. Male beetles are brown and smaller than females at 1.5 mm long. The female tunnels into the host tree forming galleries, where it lays its eggs. More females are produced than males. Mature siblings mate with each other so that females leaving to start their own galleries are already pregnant. Males do not fly but stay in the host tree.

The beetles have special structures in their mandibles called mycangia, in which they carry the spores of their fungal symbionts. PSHB carries three fungi: *Fusarium euwallaceae*, *Graphium euwallaceae* and *Paracremonium pembeum*. As adult female beetles burrow into trees to establish brood galleries, they introduce the fungal spores which colonise gallery walls, becoming a food source for developing larvae

and adult beetles. *Fusarium euwallaceae* invades tree vascular tissues, interrupting the transportation of water and nutrients and causing cambial necrosis. This can lead to branch dieback and tree death, otherwise known as Fusarium dieback.

3. DAMAGE

The visible response of the host trees to a beetle infestation varies among species. Staining, sugary exudate, gumming and frass (excrement and sawdust) may be noticeable before the tiny beetles are found. The beetles' entry and exit holes, which are about 0.85 mm in diameter, can be located beneath or near the symptoms. The abdomen of the female beetle can sometimes be seen protruding out of the hole, guarding the developing larvae. Advanced fungal infections will eventually lead to branch dieback. For a symptom and damage identification guide, see https://www.capetowninvasives.org.za/shot-hole-borer.

PSHB is not able to complete its life cycle on all the tree species it in which it establishes. Those that the beetle is able to breed on are referred to as 'reproductive hosts'. At least 80 trees species, 35 of them native, are known to be attacked in South Africa. To date, 20 tree species have been found to be susceptible reproductive hosts including maples (*Acer* spp.), liquidambar (*Liquidambar styraciflua*), plane trees (*Platanus* spp.), oaks (*Quercus* spp.), willows (indigenous and alien *Salix* spp.), indigenous coral trees (*Erythrina* spp.) and bushwillows (*Combretum* spp.) (see Appendix 2 and 3). PSHB also poses a threat to many economically important tree crops including pecan nut (*Carya illinoinensis*), avocado (*Persea americana*), and many native trees (see Appendix 2).

4. MANAGEMENT

Current uses of pesticides and fungicides have limited effect and have not proven effective at eradicating PSHB from infected trees, only in reducing the rate of recolonisation in lightly infected trees. The movement of infested wood is an important pathway for spread of the beetle. Appropriate disposal of infested trees (by chipping followed by incineration, solarisation or composting) is therefore essential for reducing the spread of this pest. Surveys to monitor the spread of the beetle and fungus in South Africa are in progress. The public can assist by looking out for symptoms (see identification guide: https://www.capetowninvasives.org.za/shot-hole-borer).

Importantly, burning biomass that has not been chipped (e.g. logs or branches) is not an effective disposal method. PSHB beetles will emerge and fly away (potentially carrying the *Fusarium* fungus with them) before the wood has reached lethal temperatures

4.1 Identifying and managing PSHB

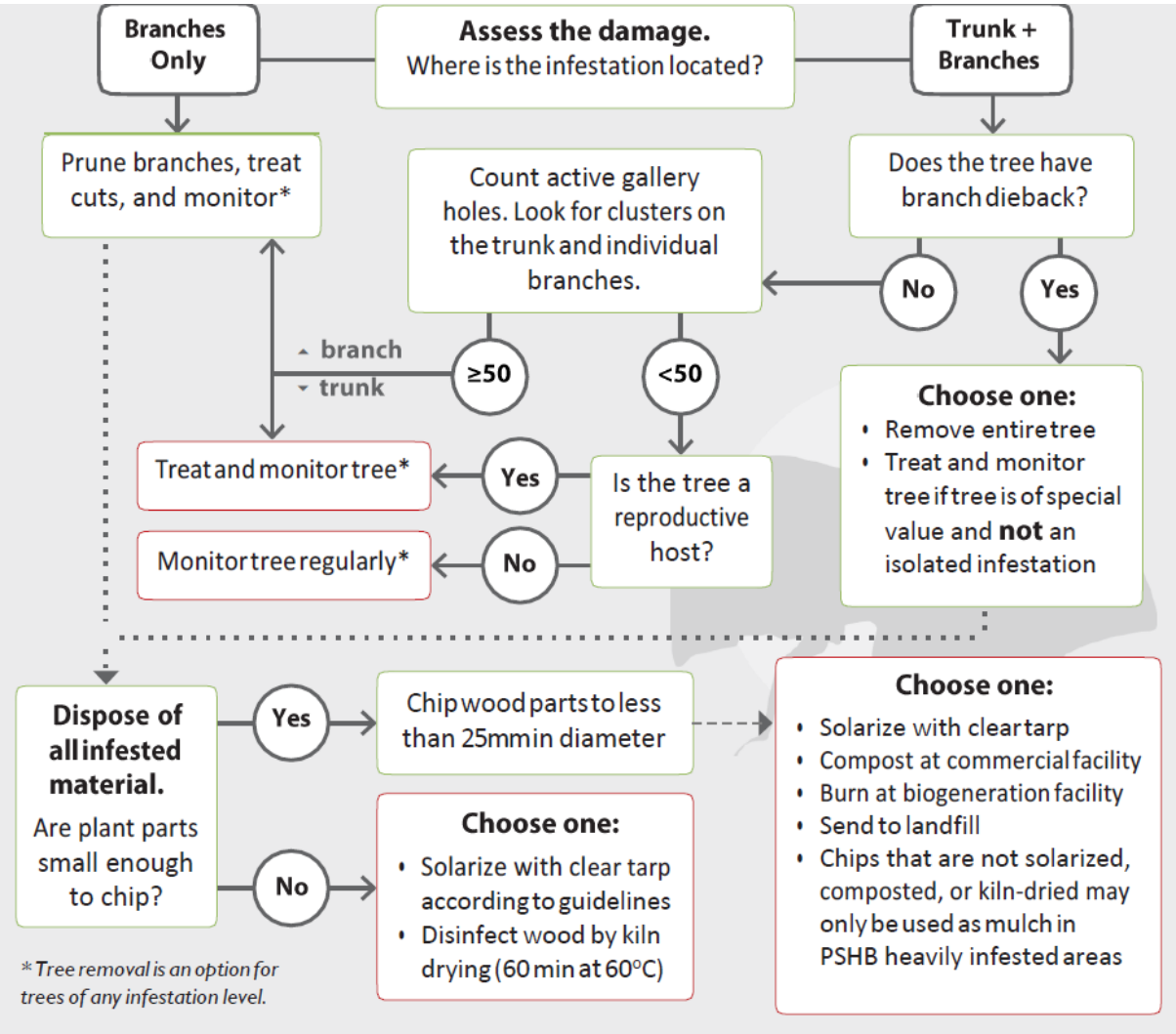

Figure 1: Adapted from Eskalen et al. (2017), University of California – Agriculture and Natural Resources.

The Invasive Species Unit (ISU) will assist in identifying and marking infected trees and give this information to the Contractor appointed to control PSHB. The Contractor will then deploy a team to this location(s). The ISU have included the PSHB as one of their Early Detection Rapid Response (EDRR) species, hence the public should not dispose of it themselves, but rather report any sightings to https://invasivescapetown.org.za/shot-hole-borer.

4.2 Method 1

4.2.1 Chip and Incinerate/Solarise

Wood material from PSHB-infested trunks and branches will still contain live beetles. If infested wood is not properly handled, beetles will emerge from the cut logs and attack new hosts. Do not use untreated, PSHB-infested logs or chips for firewood or mulch. Properly dispose of infested material. Beetles can emerge from infested material for up to four months after the branches or tree have been removed. If infested wood cannot be treated on-site, always cover wood chips and logs when

transporting them to other facilities for treatment. The wood should also be tightly covered if it needs to be kept on-site for a short period.

The two-phase process described below will help prevent the beetles from spreading to other locations (or re-infestation).

4.2.2 Phase One - Chipping

Inspect the tree for symptoms of PSHB. If beetles have established in branches but have not reached the branch collar or trunk (see Figure 1), cut the infected branches back, and move pruned material to a designated area for chipping or solarisation (described below). Do not cut into the branch collar. The aim is to save the infected tree by retaining the trunk and healthy branches while removing all infected parts. If the infection is evident all over the tree (including the trunk), the entire tree will need to be felled.

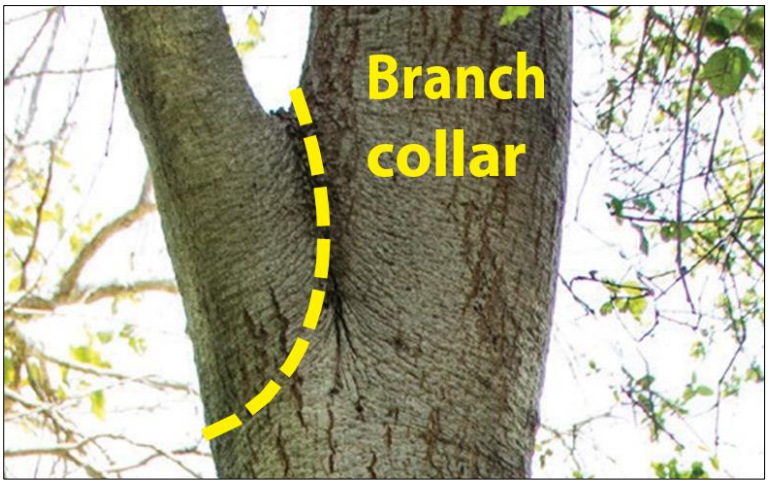

Figure 2: The point of attachment between a tree branch and the main stem is referred to as the 'branch collar'.

Chip infested wood immediately after tree removal or pruning. Running PSHB-infested material through a wood chipper is one of the most effective ways to kill most beetles living in cut logs.

- To destroy as many beetles as possible, chip wood to a diameter of 2.5 cm or less.
- Do not leave piles of contaminated wood uncovered - if wood cannot be chipped immediately, tightly wrap the logs in plastic to contain the beetles.
- During the process of chipping, the wood chips should be directed straight into the transport vehicle (lined with sturdy plastic sheeting) to avoid unnecessary handling of potentially infested material (Figure 2).
- Any material expelled outside of the transport vehicle or around/underneath the chipper during the chipping process should be swept up and discarded onto the existing pile of wood chips in the transport vehicle. Ensure all equipment used (e.g. brooms and/or spades) are thoroughly cleaned after use.
- Sawdust, twigs and leaves not suitable for chipping should be swept up and placed in tightly sealed plastic or bulk bags. Follow recommendations for solarisation or effective composting detailed in Method 2.

Figure 3: Chipping of infested material directly into the transport vehicle lined with thick plastic sheeting.

Alternatively, if work is to be carried out in an area for long periods, arrange for a large (e.g. >10cm^3) closed steel container to be positioned close to the site (obtaining permission from the relevant

authority). Dispose of all sawdust, twigs and leaves into the container for the duration of the work, ensuring that the container always remains closed and secured (e.g. with padlock). Once full or when the work has been completed, collect the container and dispose of the biomass at a secure facility for solarisation or composting (see Method 2).

- If wood cannot be chipped, tightly cover cut logs and follow directions for solarisation.
- If possible, tree stumps should be removed on the same day. If the stump is not removed the same day, a herbicide (e.g. Garlon) should be applied to the stump, then the stump should be tightly covered with plastic for solarisation for around six weeks (Figure 4). Once a registered insecticide and/or fungicide are available, the stump should be treated after cutting then covered with plastic for solarisation.

Figure 4: A herbicide (e.g. Garlon) should be applied to the cut stump, then the stump should be tightly covered with thick plastic for solarisation for around six weeks.

- Where possible (e.g. when the stump is in a garden and surrounded by soil or lawn), the stump can be completely covered with a combination of fertilizer (e.g Figure 4), topsoil and compost to facilitate the decomposition process and ensure any remaining beetles are eliminated.
- Expose tree roots are also susceptible to infestation and may harbour PSHB. Exposed roots should also be treated with a registered insecticide and/or fungicide (when available) and/or tightly covered for solarisation for at least 6 weeks.
- Tools used to fell, prune, or cut plants infected with PSHB should be disinfected afterwards to prevent the accidental spread of fungal pathogens carried by PSHB (see Box 1 for further details). Also ensure the chipper (parts which come into direct contact with infested material) is thoroughly disinfected after use.
- Pruning wounds or other injuries to a tree left intact can be treated with a registered insecticide and/or fungicide (when available) to prevent recolonisation by PSHB.
- After handling of infected material, perform a visual check on oneself and others to prevent possible beetle ‘hitch-hikers’ or fungal remnants.

4.2.3 Pruning Tips

- Poor pruning practices can facilitate the spread of plant disease. So far, researchers have only observed *Fusarium* Dieback spreading with the help of PSHB - but other species of *Fusarium* fungi have been known to travel on tools, equipment, and even through the soil.
- Avoid unnecessary pruning. Pruning depletes carbohydrate storage of the tree, slowing its growth. In addition, pruning wounds serve as entry points for PSHB and many other fungal pathogens.

Box 1. Cleaning of Equipment

Because propagules of many pathogens may persist on dead wood for several years, it is important to ensure that equipment is properly cleaned of plant debris before using tools and equipment on another tree or in another location. Residual debris may be a source of inoculum and sanitation practices will reduce further spread and potential introduction.

Any pruning, sampling, or other tools that come into contact with infected wood should be sterilised before being used on uninfected trees. This includes chainsaws and wood chipping equipment. If several infested and uninfested trees need to be maintained on a property, it is recommended that the trees are managed in batches: take care of all of the uninfested trees first, then move on to the infested trees, so that your tools will not need to be cleaned until the end of the day.

1. Prior to cutting/pruning, remove organic debris off equipment (hand and power tools used for cutting (e.g. loppers, chainsaws), then spray or wipe with an appropriate disinfectant (such as F10 disinfectant) or 70% ethanol. Bleach diluted to 25% may be used but may cause corrosion and thus pitting in the blades. Pitting can harbour microbes that are unaffected by quick sterilisation. Dry blades with a clean towel, and spray blades with sterilising solution in between trees.
2. Never use disinfections on pruning wounds, as they could be phytotoxic.
3. Remove any accumulated soil/mud or plant debris from heavy operating equipment with a hose (high pressure is best) or backpack sprayer prior to relocation of equipment. Equipment includes vehicle tires, shovels, stump grinders, trenchers, chipper trucks, mowing equipment, chippers, tractors, fertilisation and soil aeration equipment, cranes, etc. Spray with disinfectant (e.g. F10).
4. Prior to leaving a site, remove any accumulated soil/mud or plant debris from shoes and tyres and spray with disinfectant.

4.2.4 Phase Two – Incineration / Solarisation

Incineration

After chipping infested wood, incineration of infected biomass is recommended. Methods for effective transport and incineration:

- After chipping, the biomass should be transported to a designated biomass incineration facility (e.g. Sustainable Heating Pty (Ltd.)).

- Always cover wood chips and logs when transporting them to the facility. The wood should also be tightly covered if it needs to be kept on-site for a short period.
- Handling of infected material before incineration is complete should be restricted as much as possible to prevent possible transportation and further spread of PSHB.
- Use sturdy plastic (polyethylene) sheeting/tarp/bags that can withstand rain/wind, preferably at least 150 microns thick.
- Fully contain chips and logs (and beetles) by wrapping plastic sheets both underneath and over the material. Seal the material as much as possible to prevent any beetle from escaping.
- Should any plastic sheets tear, contents can be double-bagged. Again, ensure the contents are properly sealed to avoid escape of live beetles.
- Ensure the vehicles, all machinery (chipper), equipment (such as chainsaws, spades, brooms etc.) and clothes of those whom come into contact with the infested material are thoroughly cleaned after use/the disposal of the wood chips (See Box 1). The plastic sheeting should be thoroughly cleaned once all wood chips have been disposed of.

Solarisation

Should incineration not be feasible, solarisation of infected biomass (after chipping infested wood) is another recommended strategy. This method is suitable for handling both infested chips and logs. When done correctly, solar energy will heat plant material until both the beetle and fungi are killed.

Additional methods for effective solarisation:

- Biomass should be taken to a secure holding facility at a closed landfill.
- Always cover wood chips and logs when transporting them to other facilities for treatment. The wood should also be tightly covered if it needs to be kept on-site for a short period.
- Transport of infected material before solarisation is complete should be restricted as much as possible to prevent possible transportation and further spread of PSHB.
- Site selection for solarisation of infected biomass at the holding facility is important – ensure biomass pile is located away from buildings and trees as the shade will prevent sunlight from reaching the pile.
- If material is being moved before solarisation is complete, the material should be tightly covered or sealed to prevent further spread of PSHB.
- Ensure that each site is clearly demarcated, and signs are added to site (e.g. ‘Do Not Disturb or Remove Infected Material’ - see Appendix 1). Ensure these signs are weather proof and clearly visible.
- Use sturdy plastic (polyethylene) sheeting/tarp/bags that can withstand rain/wind, preferably at least 150 microns thick. Clear plastic is recommended as it lets more sunlight through and heats the content more efficiently.
- Fully contain chips and logs (and beetles) by wrapping plastic both underneath and over the material. Seal the material as much as possible to prevent any beetles from escaping.
- Keep log layers (where applicable) as thin as possible (maximum 2 logs deep) to ensure even heating throughout the pile.
- Should any plastic sheets tear, contents can be double-bagged. Again, ensure the contents are properly sealed to avoid escape of live beetles.

Solarisation is most effective during the peak of summer, when temperatures are higher and days are longer, but it may be used during other seasons if time and space can be committed.

- December - February**:** cover chips/logs with sturdy plastic for at least 6 weeks. Temperatures during these months should be regularly above 30°C.
- March - November**:** cover chips/logs with sturdy plastic for at least 6 months.

4.3 Method 2

4.3.1 Chip and Composting

Proper composting can effectively control the plant pathogen that causes *Fusarium* Dieback. Composted, chipped plant material may then be re-purposed as mulch or added back into soil to improve texture and water retention.

It is recommended that wood chips be composted at professional composting facilities which are tested for proper decomposition and pathogen control. These general composting guidelines will help assure the destruction of *Fusarium euwallaceae*:

- Woody material should be chipped to less than 2.5 cm in diameter.
- A mixture of equal volumes of green plant and dry plant material will normally achieve a proper carbon-to-nitrogen ratio of 30 to 1.
- Do not add soil, ashes from a stove or fireplace, dairy or meat products, or manure from meat-eating animals.
- A pile should be in bins at least 1 x 1 x 1 m to assure adequate heating.
- Monitor the internal temperature of the pile (pile should be around 70°C). If feasible (usually applicable for small volumes of chips), turn the pile every 1-2 days, and add nothing to it once the composting process has begun. Large piles should reach high enough temperatures without turning. If temperatures do not reach 70°C within 1-2 days, the pile is too wet or dry. If too dry, add water. If not enough nitrogen, add green material.
- Healthy compost has a pleasant odour, gives off heat as vapor when turned, has a white fungal growth on the decomposing material, gets smaller each day, and changes colour to dark brown. Compost is ready when no further heat is produced.

4.4 Alternative Options

4.4.1 Kiln-Drying

Unchipped, PSHB-infested wood can be decontaminated by the heat used in kiln-drying. To destroy the fungi that cause *Fusarium* Dieback, it is necessary to heat the material for at least 60 minutes at 60°C. Wood that has been disinfected can then be re-purposed. When transporting infested wood to another facility for treatment, always cover the material in transit.

4.4.2 Chemical Control

There is no proven solution to PSHB infestation and various approaches are needed to treat the beetle. Some treatments can harm the environment and your trees. Repeated use of some chemicals can

negatively affect trees, and some poisons should not be released directly into the ground or air – injection is the safest and most effective delivery mechanism.

PSHB are very difficult to control with pesticides. The best performing chemical treatments may be effective for trees that are more lightly infested and for tree species that are less favoured by the beetles. It may also be effective as either a preventative measure or a targeted treatment on high-value trees (frequent reapplication may be necessary). The beetles spend little time on the bark surface of the tree, which means they have minimal contact with spray-on insecticides or fungicides. As they do not ingest the tree's tissue, they also have limited interaction with systemic (injected) insecticides.

Currently there are no chemical products registered for treatment against PSHB in South Africa. Chemical formulations with specific active ingredients have been shown to be effective in US trials. For example, only the combination of emamectin benzoate (systemic insecticide), bifenthrin (contact or spray-on insecticide), and metconazole (the spray-on fungicide) was effective at reducing PSHB attacks at the six-month assessment (Jones et al. 2017). Local chemical companies need to register their own formulations for use against PSHB under Act 36.

4.4.3 Tree Injection

- Advantages: Active ingredients are delivered into the tree and are distributed by the tree via vascular flow. This has the least adverse impact on the ecosystem and surrounding environment. It is the most effective means to deliver treatment into the tree.
- Disadvantages: Specialised equipment is required.

Additional Considerations

- Treatment will need to be applied annually or every 6 months.
- Some treatments and chemicals are harmful to trees and, if applied too often, may damage or kill the tree, as well as the surrounding ecosystem.
- Insects develop tolerance and resistance to chemicals, and as such a structured programme for rotating treatments needs to be conducted over time.

5. DATA COLLECTION

The Contractor will be required to record the number and size (in meters) of sheets/tarps/bags used during disposal of infected biomass. The Contractor will also be required to record the estimated mass (in kilograms) of biomass removed. This information should be supplied to the Invasive Species Unit.

6. REPORTING

Report any sightings of PSHB to https://invasivescapetown.org.za/shot-hole-borer

7. IMPORTANT SOURCES

https://ucanr.edu/sites/ISHB/id-mgmt/

https://ucanr.edu/sites/ISHB/files/227287.pdf

https://www.fabinet.up.ac.za/index.php/pshb

8. Disclaimer

This protocol has been developed taking into consideration the management options suggested by peer reviewed scientific papers and lessons learned the City of Cape Town and elsewhere. Making use of this protocol must be at your own discretion. This protocol has been developed specifically for the City of Cape Town Municipality. The City of Cape Town will not take responsibility for any unintended consequences as a result of its use.

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APPENDIX 1. Example of signage to be used at demarcated solarisation sites.

INVASIVE SHOT HOLE BORER DISPOSAL SITE

WARNING

DO NOT DISTURB OR REMOVE INFECTED MATERIAL

For further information, contact the Invasive Species Unit
(021) 444 2357

APPENDIX 2. Tree species in South Africa known to be suitable reproductive hosts of polyphagous shot hole borer

Host trees in which both the beetles and the fungus establish, and where the beetle successfully reproduce. In most cases the reproductive hosts will eventually be killed by the fungus. Note FABI updates this list on a regular basis. Refer to the FABI website for the most updated list. https://www.fabinet.up.ac.za/index.php/pshb

Alien species	
Latin name	**Common name**
Acacia melanoxylon	Blackwood
Acacia mearnsii	Black wattle
Acer buergerianum	Trident (Chinese) maple
Acer negundo	Boxelder
Acer palmatum	Japanese maple
Brachychiton discolor	Pink flame tree
Gleditsia triacanthos	Honey locust
Liquidambar styraciflua	American sweetgum
Magnolia grandiflora	Southern magnolia
Pearsea americana	Avocado
Platanus x *acerifolia*	London Plane
Quercus palustris	Pin oak
Quercus robur	English Oak
Ricinus communis	Castor bean
Salix alba	White willow
Native SA species	
Combretum krausii	Forest bushwillow
Erythrina caffra	Coast coral tree
Podalyria calyptrata	Water blossom pea
Psoralea pinata	Fountain bush
Salix mucronata	Cape willow

Host trees that are attacked by the beetle and where the fungus establishes, but where the beetle does not successfully breed. The fungus might or might not cause disease and kill the trees.

Alien species	
Latin name	**Common name**
Bauhinia purpurea	Butterfly orchid tree
Betula pendula	Silver birch
Camellia japonica	Common camellia
Carya illinoinensis	Pecan nut
Ceiba pentandra	Kapok
Cinnamomum camphora	Camphor
Citrus limon	Lemon

Citrus sinensis	Orange
Eriobotrya japonicum	Loquat
Erythrina livingstoniana	Aloe coral tree
Eucalyptus camaldulensis	River red gum
Ficus carica	Common fig
Fraxinus excelsior	European ash
Jacaranda mimosifolia	Jacaranda
Melia azedarach	Syringa
Morus sp.	Mulberry
Platanus occidentalis	American plane
Platanus racemosa	Californian plane
Plumeria rubra	Frangipani
Populus nigra	Lombardy poplar
Prunus nigra	Black plum
Prunus persica	Peach
Psidium guajava	Guava
Schinus molle	Pepper tree
Taxodium distichum	Swamp cypress
Ulmus minor = procera	English elm
Ulmus parvifolia	Chinese elm
Viburnum sinensis	Viburnum
Vitis vinifera	Grapevine
Native SA species	
Bauhinia galpinii	Pride of De Kaap
Buddleja saligna	False olive
Calodendrum capense	Cape chestnut
Calpurnia aurea	Geelkeurboom
Combretum erythrophyllum	River bushwillow
Cordia caffra	Septee tree
Cussonia spicata	Cabbage tree/ Kiepersol
Diospyros dichrophylla	Star apple
Diospyros lycidioides	Monkey plum
Ekebergia capensis	Cape ash
Erythrina lysistemon	Common coral tree
Ficus natalensis	Natal fig
Grewia occidentalis	Cross berry
Gymnosporia buxifolia	Spike thorn
Halleria lucida	Tree fuschia
Harpephyllum caffrum	Wild plum
Melianthus major	Honey flower/ Kruidjie-roer-my-nie
Nuxia floribunda	Forest elder
Olea europea subsp. *africana*	Wild olive
Podocarpus falcatus	Outeniqua yellowwood
Podocarpus henkelii	Henkel's yellowwood

Protea mundii	Forest sugar bush
Rapanea melanophloeos	Cape beech
Schotia brachypetala	Weeping boerbean/ Huilboerboon
Senegalia galpinii	Monkey-thorn
Vachellia karoo	Sweet thorn
Vachellia sieberiana var. *woodii*	Paper bark thorn
Virgilia divaricata	Keurboom