TREE NOTES
CALIFORNIA DEPARTMENT OF FORESTRY AND FIRE PROTECTION

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Invasive Shot Hole Borers

By Kim Corella

Forest Pest Specialist, CALFIRE

Introduction/Summary

The Euwallacea fornicatus species complex consists of 3-5 species, two of which are found in Southern California. The two species in California, collectively known as the invasive shot hole borers (ISHB), are comprised of the polyphagous shot hole borer (PSHB), *Euwallacea fornicatus*, and Kuroshio shot hole borer (KSHB), *Euwallacea kuroshio* (Coleptera: Curculionidae: Scolytinae: Xyleborini) (Gomez et al., 2018; Smith et al., 2019). Ambrosia beetles in the *Euwallacea fornicatus* species complex are native to SE Asia and are considered pests of economic importance in many areas they have invaded. The PSHB cause damage to host plants and carry several fungal pathogens that cause disease within susceptible hosts in California, Israel, and South Africa and the closely related KSHB similarly affects hosts plants in California and Mexico. These ambrosia beetles carry three fungi that they use as their food source: *Fusarium* spp., *Graphium* spp., and *Paracremonium pembeum* (Carrillo et al., 2019). The main fungi used as a food source, *Fusarium*, are plant pathogens and cause the disease called Fusarium dieback (Eskalen et al., 2013). Trees that are susceptible to *Fusarium* experience branch dieback, canopy loss and tree mortality. These insects can infest and kill over 65 reproductive hosts of all age and size classes, many of which are riparian species (the full list of reproductive hosts can be found at www.ishb.org). A reproductive host are plant species that are capable of supporting beetle reproduction and growing the fungi that causes Fusarium dieback. PSHB was first detected in 2003 in a CDFA trap in Los Angeles County but wasn't linked to dieback until 2012 when it was isolated from a backyard avocado tree in Los Angeles County (Eskalen et al., 2013). The first detection of KSHB was in 2014, in San Diego County. Since then, ISHBs have been discovered in all the Southern California counties (San Luis Obispo, Santa Barbara, Ventura, Los Angeles, Orange, Riverside, San Bernardino and San Diego). The movement of infested firewood was most likely responsible for the large distances between infestations and will continue to be a mechanism for long-range dispersal.

Life Cycle and identification of the invasive shot hole borers

Xyleborini, the most species-rich tribe within subfamily Scolytinae, are considered one of the most injurious group of insects. This tribe includes many morphologically cryptic and economically damaging ambrosia beetles (Gomez, 2018). Two of the species in this tribe that are causing damage in California, PHSB and KSHB, are morphologically indistinguishable. Only DNA analysis of the beetle and fungal associates can reveal species identification. Female ISHB are 0.07 – 0.1 inches (1.8-2.5 mm) in length and range from brown to black in color. Males are 0.05 – 0.06 inches (1.5-1.67 mm) in length and are light brown to black in color and lack wings (see Figure 1). Long distance spread and gallery formation is strictly limited to females. Males are only able to disperse by walking (Umeda et al., 2016). Females create galleries that are only as wide as their bodies and bore into the tree to a depth of about 0.60 inches (15 mm) in the initial stages of colonization. Because ambrosia beetles do not feed on the wood, as they chew the wood they push the fine particles of wood, resembling sawdust, out of their galleries as they are created. Sawdust may be found on the outside of the bark or at the base of the tree. The female beetle carries fungal symbionts in specialized structures known as mycangia. The symbionts are deposited on the gallery walls as she chews through the wood in gallery construction. Each species of invasive shot hole borer carries unique fungal symbionts. *Fusarium euwallaceae* and *Graphium euwallaceae* are specific to PSHB, and *F. kuroshium* and *G. kuroshium* are specific to KSHB. Both species share symbioses with *Paracremonium pembeum* (Freeman et al., 2013; Lynch et al., 2015; Na et al., 2018; Carrillo et al., 2019). The two species of *Fusarium* are the causal agents of Fusarium dieback in the colonized susceptible hosts. Once fungal growth is sufficient to provide a food source, the female will lay eggs at the end of the gallery. The female adult will lay about 50 eggs in niches along the walls of the galleries. Most of the eggs will be fertilized eggs (female) and a few will be non-fertilized eggs (male). Larvae emerge after approximately 13-16 days, become pupae after 7-11 days and adults 2-3 days later (Cooperband et al., 2016), for a total development/maturation period of 22-30 days (see Figure 2). Development is temperature dependent with optimal development occurring at 80˚F (27˚C). As temperatures

Figure 1: Invasive shot hole borer female (top) and male (bottom) adults. Photo by Tom Coleman, USFS

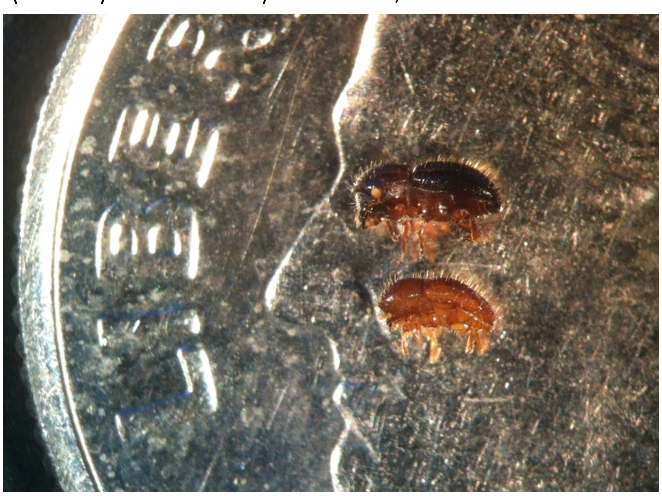

Figure 2: Invasive shot hole borer adults, teneral adults and larvae. Photo by John Kabashima, UCANR

increase from 64˚F (18˚C) to 90˚F (32˚C), the time it takes to complete their lifecycle decreases (Umeda et al., 2016).

While in the gallery, beetles will mate with their siblings and continue to feed on the fungi growing on the gallery walls (Umeda et al., 2016). Because of this feeding and sibling mating habits, female ISHB disperse already mated and carrying the *Fusarium* spores in their mycangia. The mated dispersing females may either fly from their natal host to search for a new suitable host tree or they may re-colonize the same host tree. The stimuli associated with the decision to disperse or re-colonize are poorly understood.

Symptoms and signs of infestation

Entrance and exit holes: The entrance holes are approximately 0.03 inches (0.85mm) in diameter and can be located beneath or near the visible response symptoms produced by the tree. ISHB entrance holes are most commonly seen on the trunk of the tree but ISHB can attack branches as small as 2cm in diameter (Mendel et al., 2012). The diameter of the holes is about the same size as a medium ball point pen tip, a helpful diagnostic tool for distinguishing ISHB holes from the entrance or exit holes of other beetle species (see Figure 3).

Figure 3: Invasive shot hole borer entrance hole. Photo by Kim Corella, CALFIRE

Staining symptoms: The presence of staining or discoloration of the bark associated with a ballpoint-pen tip sized entrance hole is a good indicator of ISHB infestation. Each host tree has a unique visible response to the damage caused by the insect-disease complex. Some hosts respond to the infestation by producing long streams of sap oozing down the trunk, while other hosts produce distinct staining around the entry holes. Sugary exudate, gumming and frass are other symptoms that may be noticeable even before ISHB entry holes are detected (see Figures 4a-4e). If the staining is caused by ISHB it will not be associated with cavities along the stem or human made mechanical wounds. When the outer bark is removed from the stained areas, the entrance hole for the ISHB gallery should still be visible and the gallery should extend down into the wood.

Figure 4: Different types of host responses to ISHB

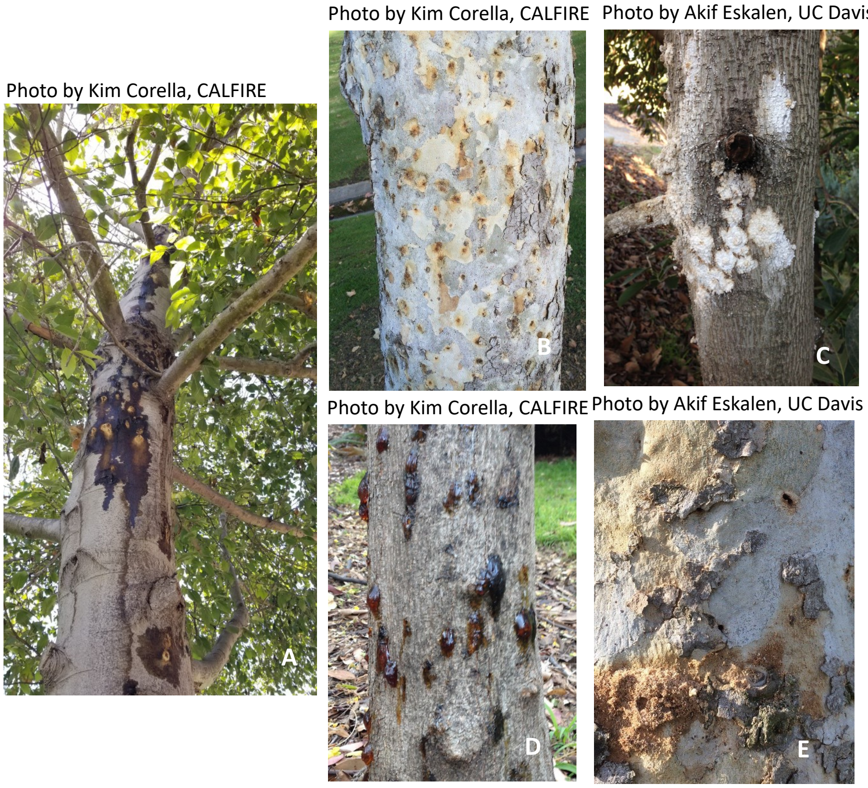

Photo by Kim Corella, CALFIRE (A); Photo by Kim Corella, CALFIRE (B); Photo by Akif Eskalen, UC Davis (C); Photo by Kim Corella, CALFIRE (D); Photo by Akif Eskalen, UC Davis (E)

Galleries: Unlike bark beetles, ambrosia beetles feed on the xylem, not the phloem or the cambial tissue of the main trunk. They instead bore into the wood of the tree, where the female will construct her galleries that are 0.85mm in diameter. However, ambrosia beetles will often completely colonize branch tissue. The galleries are clean and not packed with sawdust (also known as frass) and the walls are inoculated with the fungi carried in her mycangia, which colonize the gallery walls and serve as the food source for the developing larvae (see Figures 5a, 5b and 6). The female ISHB act as farmers for their symbiotic fungi and keep the galleries clean from any contaminants such as frass, bacteria or other fungi.

Crown thinning: *Fusarium euwallaceae* and *F. kuroshium* colonize the trees vascular system which blocks water and nutrient transport. The tree may exhibit symptoms of *Fusarium* dieback, wilting branches, discolored leaves and breaking of heavy branches (Umeda et al., 2016). These symptoms will typically be observed on the primary branches. However, ISHB also infests young, small branches (Mendel et al., 2012). Advanced infestations lead to branch dieback and crown thinning, which is usually seen after more than one year of infestation (see Figure 7).

Figure 5: Invasive shot hole borer galleries

Photo by Akif Eskalen, UC Davis

Photo by Tom Coleman, USDA Forest Service

Figure 6: Invasive shot hole borer and fungi growing in gallery walls. Photo by Akif Eskalen, UC Davis

Figure 7: Crown thinning and advanced branch dieback caused by *Fusarium* dieback. Photo by Akif Eskalen, UC Davis

Management

Monitoring by ground surveys is the most effective strategy for detecting ISHB infestation and severity, since these insects do not have a sex or aggregation pheromone to aid in detection. These insects do, however, respond to quecivorol, a semiochemical found in volatiles from boring frass of the oak ambrosia beetle and odors from *Fusarium euwallaceae*, which make it possible to trap beetles in a localized area (see Figures 8a & 8b). There are certain species of hosts that ISHB prefer such as box elder, willows and sycamore. These hosts should be the first surveyed in determining if an area is infested.

Figure 8: Two types of traps used for invasive shot hole borer.

Photos by Akif Eskalen, UC Davis

Figure 9: Chipped wood with a chip size of ≤ 1 inch. Photo by Kim Corella, CALFIRE

Mechanical treatment options:

<u>Chipping</u> – chipping ISHB-infested material is an effective strategy to eliminate live beetles. Infested logs and branches can be chipped in a commercial chipper to a size of ≤ 1 inches (2.5 cm) to kill 99.9% of live beetles or chipping to a size of ≤ 2 inches (5 cm) to kill 98% (Eatough Jones and Paine, 2015) (see Figure 9). Chipped material then should be composted, solarized on site or delivered to a landfill for disposal to effectively kill the fungi. These treatments can be used year-round. When composting infested chipped material, it is recommended that the chipped material be taken to a composting facility that has earned the US Composting Council's Seal of Testing Assurance (STA), https://www.compostingcouncil.org/page/participants.

<u>Solarization</u> – Solarization is a suitable method for handling either infested chips or logs. When done properly, solar energy will heat plant material until both the beetle and fungi are killed. This is most effective during the peak of the summer, when temperatures are higher and days are longer, but may be used during the rest of the year if time and space can be committed. To ensure solarization is done properly use clear polyethylene plastic sheeting that is UV resistant and at least 6-mil thick (Eatough-Jones and Paine, 2015). The edges of the sheeting must be buried in the soil or secured tightly and checked routinely for integrity. It is essential to check the integrity of the plastic sheeting periodically for any holes that may have formed to prevent any adults from escaping.

- July – August: cover chips/logs with 6-mil, UV resistant, clear polyethylene plastic sheeting for at <u>least 6 weeks</u>. Temperatures during these months should be regularly above 95˚F.

- July – August: cover chips/logs with 6-mil, UV resistant, clear polyethylene plastic sheeting for at least 6 weeks. Temperatures during these months should be regularly above 95°F.
- September – June: cover chips/logs with 6-mil, UV resistant, clear polyethylene plastic sheeting for at least 6 months.
- Infested logs stacked to only 2 logs deep maximum should be used to ensure even heating throughout the pile.
- Infested chips should be kept as thin as possible to ensure even heating throughout.

Pruning – Pruning of infested branches is another viable option. This technique can be used and is most effective for trees that only have infested branches. Be sure that the only part of the tree that is infested is that branch and follow proper pruning guidelines. Once the infested branch is removed it must be chipped and either properly disposed of or solarized. The pruning saw must also be surface sterilized to prevent the spread of the *Fusarium* pathogen to a healthy tree. Cleaning solutions containing at least 70% ethanol can be used to surface sterilize pruning saws (see Figures 10a & 10b).

Figure 10: Pruning infested branches with invasive shot hole borer and surface sterilizing pruning saws. Photo by Beatriz Nobua-Behrmann, UCCE

Cultural control - Avoid moving infested wood and chipped material out of infested areas unless the material is covered or contained during transport. This is the most effective method for reducing long distance spread of this insect. Firewood is easily moved and is one of the primary ways insects and diseases are transported. Limiting firewood movement to short distances and within the same ecosystem is the best management approach for limiting the spread of ISHB and other invasive pests. For more information on the impact of firewood movement and to reduce the spread of invasive insects and diseases visit, www.firewood.ca.gov.

Chemical treatments:

It may be possible to use direct control with insecticides to reduce the risk of infestation of individual high value trees. An insecticide plus fungicide combination should be used because control of the insect as well as the *Fusarium* pathogen is needed. Pesticides should only be applied to trees with low to moderate levels of infestation. For heavily infested trees it is advised that they be removed because they become "amplifier trees" contributing significantly to the local beetle population and are a potential hazard. Topical and systemic insecticides should only be applied after evidence of ISHB has been found in the immediate area.

Contact treatments - A topical insecticide applied by a certified pesticide applicator to the trunk and the larger branches of a high-value potential host tree is the best option for preventing further ISHB injury. Treating the entire crown is not necessary and would increase the impacts to non-target arthropods. Topical spray applications should occur in the spring before temperatures reach 68°F and before the fall flight to protect the trees before the beetles start to fly. Preventive synthetic pyrethroid contact sprays with insecticides, such as bifenthrin in combination with a fungicide, have been demonstrated to be effective at reducing the number of ISHB attacks and the densities of the galleries in both a lab and field setting. Bifenthrin is effective at establishing a barrier to beetles attempting to penetrate through the bark during colonization and leaving the galleries to disperse for low to moderately infested trees (Eatough Jones et al., 2017b; Mayorquin et al., 2018).,

For an alternative to contact pesticide treatments, the bacteria *Bacillus subtilis* has been shown to provide short term control (1 month) when sprayed onto the trunk of the tree up to 8 feet. Having a biopesticide option is an important option for areas where chemical sprays are undesirable (Eatough-Jones et al., 2017a).

Systemic treatment - Systemic insecticides and fungicides applied by a certified pesticide applicator as a trunk injection, trunk spray or soil drench may reduce the beetle population and slow the spread of the fungal pathogen in individual trees. In field studies, it has been shown that systemic insecticides and fungicides applied to trees with low to moderate infestation with ISHB can significantly reduce the number of beetle attacks. Field studies have shown that Bifenthrin applied as a trunk spray was effective at reducing the number of beetle attacks on PSHB infested castor bean, *Ricinus communis*, and California Sycamore trees (Eatough-Jones et al., 2017a; Eatough-Jones et al., 2017b). Though this is effective at reducing the number of beetles the *Fusarium* fungus is not controlled by this insecticide.

To control both the insect and the pathogen a combination of fungicides and insecticides have been studied. A combination of triazole fungicides, tebuconazole, metconazole (not registered for ornamental trees in California), or propiconazole, with an insecticide (emamectin benzoate, imidacloprid, or bifenthrin) were found to significantly reduce the number of beetle attacks on treated California Sycamore trees (Eatough-Jones et al., 2017a; Mayorquin et al., 2018; Grosman et al., 2019). Systemic treatments applied as trunk or soil (imidacloprid) --injections to trees should be applied in the spring and fall when the trees are actively taking up water and nutrients to allow for the translocation of the active ingredient into the vascular system. Care must be taken when injecting systemic insectides or fungicides as injection sites have been colonized by Botryosphaeria canker which can cause significant cankers in those areas which affect the health of the tree.

Suggested Management Summary:

- Careful monitoring of trees of interest, including surrounding trees, is always recommended.
- Pesticides should only be applied to tree with low to moderate levels of infestation.
- Applications should not be made to noninfested trees because ISHB typically colonize only a few trees in an area and do not disperse to other host trees until beetle populations have increased enough to cause branch dieback or tree death. Once trees are severely infested and suffering branch dieback or severe tree decline, pesticide applications will not “save” those trees.

- After pesticide application, treatment effectiveness needs to be assessed and trees need to be monitored regularly for ISHB activity.
- Heavily infested trees serve as amplifier trees of ISHB and contribute significantly to the local beetle population and those trees may also pose a physical hazard or risk of failure, therefore, they should be removed and infested wood sanitized appropriately.
- For up-to-date information regarding the management of ISHB please visit www.ishb.org.

Assistance

If you are unsure if you have found signs or symptoms of ISHB, please contact a pest control advisor, your local university cooperative extension office, local agricultural commissioner's office or local CAL FIRE or USFS pest specialists or foresters.

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Literature cited

Carrillo, J., Dodge, C., Stouthammer, R., and Eskalen, A. 2019. Fungal symbionts of the polyphagous and Kuroshio shot hole borers (Coleoptera: Scolytinae, *Euwallacea* spp.) in California can support both ambrosia beetle systems on artificial media. Symbiosis. https://doi.org/10.1007/s13199-019-00652-0

Cooperband, M.F., Stouthamer, R., Carrillo, D., Eskalen, A., Thibault, T., Cosse, A., Castrillo, L.A., Vandenberg, J.D., Rugman-Jones, P.F. 2016. Biology of two members of the Euwallacea fornicates species complex (Coleoptera: Curculionidae: Scolytinae), recently invasive in the U.S.A., reared on an ambrosia beetle artificial diet. Agricultural and Forest Entomology 18(3):223–237 DOI 10.1111/afe.12155

Eatough-Jones, M., Kabashima, J., Eskalen, A., Dimson, M., Mayorquin, J., Carrillo, J., Hanlon, C., and Paine, T. 2017a. Evaluations of insecticides and fungicides for reducing attack rates of a new invasive ambrosia beetle (*Euwallacea* Sp., Coleoptera: Curculionidae: Scolytinae) in infested landscape trees in California. Forest Entomology. 110:1611-1618.

Eatough-Jones, M. and Paine, T. D. 2017b. Potential pesticides for control of a recently introduced ambrosia beetle (*Euwallacea* sp.) in southern California. Journal of Pesticide Science. 91:237-246.

Eatough-Jones, M. and Paine, T. D. 2015. Effect of Chipping and Solarization on Emergence and Boring Activity of a Recently Introduced Ambrosia Beetle (*Euwallacea* sp., Coleoptera: Curculionidae: Scolytinae) in Southern California. Forest Entomology 108 (4): 1852-1859.

Eskalen, A., Stouthammer, R., Lynch, S.C., Rugman-Jones, P.F., Twizeyimana, M., Gonzalez, A., and Thibault, T. 2013. Host range of Fusarium dieback and its ambrosia beetle (Coleoptera: Scolytinae) vector in Southern California. Plant Dis. 97:978-951.

Eskalen, A., Mayorquin, J., Carrillo, J., Lynch, S., Kabashima, J., Paine, T., Stouthamer, R., Byrne, F., and Morse, J. 2016. Invasive Shot Hole Borers Threatening Trees in Southern California. Green Bulletin. 6(3):1-3.

Freeman S, Sharon M, Maymon M et al (2013) *Fusarium euwallaceae* sp. nov. a symbiotic fungus of *Euwallacea* sp., an invasive ambrosia beetle in Israel and California. Mycologia 105:1595–1606

Gomez, D.F., Skelton,.J., Steininger, M.S., Stouthamer, R. , Rugman-Jones, P., Sittichaya, W., Rabaglia, R.J., and Hulcr, J. 2018. Species Delineation Within the Euwallacea fornicatus (Coleoptera: Curculionidae) Complex Revealed by Morphometric and Phylogenetic Analyses. Insect Systematics and Diversity. 2:1-11.

Grosman, D.M., Eskalen, A. and Brownie. 2019. Evaluation of Emamectin Benzoate and Propiconazole for Management of a New Invasive Shot Hole (Euwallacea nr. Fornicatu, Colepotera: Curculionidae) and Symbiotic Fungi in California Sycamores. Journal of Economic Entomology. 112: 1267-1273.

Lynch S.C., Twizeyimana M., Mayorquin J.S., Wang, D.H., Na. F., Kayim, M., Kasson, M.T., Thu, P.Q., Rugman-Jones, P., Hulcr, J. Stouthamer, R., Eskalen, A. 2016. Identification, pathogenicity, and abundance of *Acremonium pembeum* sp. nov. and *Graphium euwallaceae* sp. nov.- two newly discovered mycangial associates of the polyphagous shot hole borer (*Euwallacea* sp.) in California. *Mycologia* 108:313-329.

Mayorquin, J.S., Carrillo, J.D., Twizeyimana, M., Peacock, B.B., Sugino, K.Y., Na, F., and Wang, D. 2018. Chemical Management of Invasive Shot Hole Borer and Fusarium Dieback in California Sycamore (Platanus racemose) in Southern California. Plant Disease 012:1307-1315.

Mendel Z, Protosav A, Sharon M et al (2012) An Asian ambrosia beetle *Euwallacea fornicatus* and its novel symbiotic fungus *Fusarium* sp. pose a serious threat to Israeli avocado industry. Phytoparasit Online publication. doi: 10.1007/s12600-012-0223-7

Na F, Carrillo JD, Mayorquin JS, Ndinga-Muniania C, Stajich JE, Stouthamer R, Huang YT, Lin YT, Chen CY, Eskalen A. 2018. Two novel fungal symbionts Fusarium kuroshium sp. nov. and Graphium kuroshium sp. nov. of Kuroshio shot hole borer (Euwallacea sp. nr. fornicatus) cause Fusarium dieback on woody host species in California. Plant Dis 102:1154–1164

Smith, S. M., Gomez, D. F., Beaver, R. A., Hulcr, J., & Cognato, A. I. (2019). Reassessment of the species in the Euwallacea Fornicatus (Coleoptera: Curculionidae: Scolytinae) complex after the rediscovery of the “lost” type specimen. *Insects*, *10*(9). https://doi.org/10.3390/insects10090261.

Umeda, C., Eskalen, A. and Paine, T.D. 2016 Polyphagous Shot Hole Borer and Fusarium Dieback in California. Chapter 26 in Insects and Diseases of Mediterranean Forest Systems. Springer International Publishing, Switzerland. DOI 10.1007/978-3-319-24744-1_26, Paine, T.D.