Treatment options for the invasive emerald ash borer

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Introduction of alien species to new areas often results in the alteration of their invasive ranges (Flower et al. 2013a, McCullough and Mercader 2012, Mercader et al. 2011). In particular, non-native, parasitic species both directly affect their host species and indirectly affect other native organisms (Flower et al. 2013a). The emerald ash borer, Agrilus planipennis, is one such alien species that both directly affects its host, ash trees, as well as indirectly affects other native species (Anulewicz et al. 2008, Flower et al. 2013a, Flower et al. 2013b). Ash trees in northern North America are currently being invaded by this Asian beetle, a native to China, Japan, and Korea (Anulewicz et al. 2008, Flower et al. 2013a, Flower et al. 2013b, Liu et al. 2003, Muirhead et al. 2006, Pureswaran and Poland 2009, Rebek et al. 2008, Siegert et al. 2010).

Treatments to slow the rate of spread of the emerald ash borer in North America are necessary because the North American environment is susceptible to the direct and indirect impacts of the beetles (Anulewicz et al. 2008, Flower et al. 2013a, Flower et al. 2013b, Liu et al. 2003, Pureswaran and Poland 2009, Rebek et al. 2008, Smitley et al. 2008).

Emerald ash borer beetles have directly affected native North American ash trees causing millions of their deaths in the United States (Anulewicz et al. 2008, Flower et al. 2013a, Flower et al. 2013b, McCullough and Mercader 2012, Puresaran and Poland 2009, Rebek et al. 2008). The female emerald ash borer lays her eggs under the bark of the ash tree and after the larvae hatch they chew into the trunk of the tree (Anulewicz et al. 2008, Flower et al. 2013b, Liu et al. 2003, McCullough and Mercader 2012, Mercader et al. 2011, Muirhead et al. 2006, Pureswaran and Poland 2009, Rebek et al. 2008). The larvae of the emerald ash borer negatively impact the health of ash trees by feeding on the phloem tissue, creating tunnels, or galleries, in the process (Anulewicz et al. 2008, Flower et al. 2013a, Flower et al 2013b, Liu et al. 2003, McCullough and Mercader 2012, Mercader et al. 2011, Muirhead et al. 2006, Pureswaran and Poland 2009, Rebek et al. 2008). These galleries interrupt the nutrient-transport system of the ash trees preventing them from being able to carry water to their leaves (Anulewicz et al. 2008, Flower et al. 2013a, Flower et al. 2013b, Liu et al. 2003, McCullough and Mercader 2012, Mercader et al. 2011, Muirhead et al. 2006, Pureswaran and Poland 2009, Rebek et al. 2008). This eventually leads to leaf loss which, in turn, leads to the death of the ash trees who are now unable to conduct photosynthesis (Anulewicz et al. 2008, Flower et al. 2013a, Flower et al. 2013b, Smitley et al. 2008).

Not only does the emerald ash borer affect its host species, American ash trees, they also have an indirect impact on other native organisms and the surrounding environment (Flower et al. 2013a). Emerald ash borer indirectly benefits the native non-ash trees in the northern United States, its invasive range, by causing the death of ash trees (Anulewicz et al. 2008, Flower et al. 2013a, Flower et al. 2013b). This decline in ash trees helps the other native trees in the area as they now have less competition for shared resources (Flower et al. 2013a).

Emerald ash borers do not lead to the death of non-ash trees (Anulewicz et al. 2008). This may be due to the specific dietary and developmental needs of the beetles that only ash trees can fulfill (Anulewicz et al. 2008). For two weeks before they lay eggs, the female beetles must eat the leaves from ash trees (Anulewicz et al. 2008, McCullough and Mercader 2011, Pureswaran and Poland 2009, Siegert et al. 2010). This may explain the beetles' preference for laying their eggs on ash trees over all other native North American trees (Anulewicz et al. 2008). The few larvae that do hatch on non-ash trees are unable to burrow into the trunks to feed and, therefore, do not survive (Anulewicz et al. 2008). The greater resistance of non-ash trees to emerald ash borer as compared to ash trees gives them a competitive advantage in places invaded by these beetles (Anulewicz et al. 2008).

With the decline in the number of ash trees as a result of the emerald ash borer invasion, the non-ash trees have greater access to resources that were previously being used by the ash trees (Flower et al. 2013a). Namely, non-ash trees have more access to nitrogen in the soil, as well as to light (Flower et al. 2013a). This enables them to have an increased growth rate compared to the growth rates of non-ash trees in areas that have been invaded by the emerald ash borer (Flower et al. 2013a). The growth rates of non-ash trees from the genera Ulmus and Acer increase by the greatest amount suggesting that they could become the new dominant species in emerald ash borer infested areas (Flower et al. 2013a).

Native non-ash trees also take in more carbon dioxide from the atmosphere in forests where ash trees have than in forests without ash tree decline (Flower et al. 2013a). Even with the increased uptake of carbon dioxide by non-ash trees, forests infested by emerald ash borer beetles have significantly lower total uptakes of carbon dioxide from the atmosphere than in forests without the beetle (Flower et al. 2013a).

Both the direct and indirect impacts of the emerald ash borer in its invasive range were made possible because of the increased susceptibility of North American forests (Liu et al. 2003, Pureswaran and Poland 2009, Rebek et al. 2008). Unlike the emerald ash borer's native range of Asia, its invasive range of North America has little to no defenses against the emerald ash borer as a result of never being exposed to these beetles before (Liu et al. 2003, Pureswaran and Poland 2009, Rebek et al. 2008). American ash trees are less resistant to the emerald ash borer than Asian ash trees due to differences in chemical signals and in hosted parasites of the emerald ash borer (Liu et al. 2003, Pureswaran and Poland 2009, Rebek et al. 2008).

When American ash trees are infested with emerald ash borer beetles, they have a much lower survival rate than their Asian counterparts (Liu et al. 2003, Rebek et al. 2008). For instance, the American green and white ash trees have a significantly lower survival rate than the Asian Manchurian ash tree when exposed to the beetle (Rebek et al. 2008). This decrease in survival rate is likely due to the finding that the American green and white ash trees have more exit holes in their trunks caused by the beetles' larvae (Rebek et al. 2008). More exit holes suggests that a greater amount of emerald ash borer larvae were present in the trees (Rebek et al. 2008).

Part of the reason for the greater amount of emerald ash borer larvae inside American ash trees can be explained by the differences in chemical signals (Pureswaran and Poland 2009). Wood boring insects such as the emerald ash borer are often attracted or repelled by chemical signals produced by the trees (Pureswaran and Poland 2009). In the case of emerald ash borers, they tend to be repelled by ash trees that give off greater numbers of chemical signals (Pureswaran and Poland 2009). In fact, the American green ash tree, the most preferred tree of emerald ash borer, gave off the least amount of volatile, or chemical, emissions while the Asian Manchurian ash tree gave off the greatest amount (Pureswaran and Poland 2009).

Like the differences in chemical signals, the variation in the amount of parasitism of emerald ash borer on Asian and American ash trees also suggests a reason for the higher susceptibility of American ash to infestation by the beetles (Liu et al. 2003, Pureswaran and Poland 2009). Nearly 50% of emerald ash borers on Asian ash trees are parasitized while emerald ash borers on American ash trees have less than a one percent parasitism rate (Liu et al. 2003). This could be because two specific parasitoids of emerald ash borer were only found on Asian ash trees: Spathius wasps and Tetrastichus wasps (Liu et al. 2003).

Due to the weaker defense mechanisms of American ash trees, the emerald ash borer has been able to, and is continuing to, spread throughout northern North America (Liu et al. 2003, McCullough and Mercader 2012, Mercader et al. 2011, Muirhead et al. 2006, Pureswaran and Poland 2009, Rebek et al. 2008, Siegert et al. 2010, Smitley et al. 2008). These beetles have the potential to spread through all of northern North America because ash trees are common to both urban and rural environments (McCullough and Mercader 2012, Siegert et al. 2010, Smitley et al. 2015). In order to slow the rate of spread of the emerald ash borer, treatment options should be implemented because they are effective, cost efficient, and different options are available for urban and rural areas (McCullough and Mercader 2012, Mercader et al. 2011, Siegert et al. 2010, Smitley et al. 2008, Smitley et al. 2015).

The most effective type of management option to reduce the population of emerald ash borers and limit their spread are insecticide treatments (McCullough and Mercader 2012, Mercader et al. 2011, Smitley et al. 2015). With the application of insecticides, the rate of ash tree decline was significantly slower than in areas where ash tree was left untreated (McCullough and Mercader 2012, Mercader et al. 2011, Smitley et al.

2015). Insecticides applied as basil soil drenches are taken up by the roots of the ash trees and transported to its leaves (Smitley et al. 2015). The adult emerald ash borers eat the toxic leaves and die (Smitley et al. 2015). When basil soil drenches were applied during the spring, even low doses of the insecticide enabled the treated ash trees to survive (Smitley et al. 2015). Injection of the insecticide into the xylem of the ash trees where it is transported to the leaves is another form of application for insecticides (McCullough and Mercader 2012, Mercader et al. 2011, Smitley et al. 2015). Injections of insecticides into ash trees exposed to the emerald ash borer prevent the deaths of 99% of the trees even when only 20% of the trees are treated (McCullough and Mercader 2012). The injection application method also significantly reduced the rate of spread of the emerald ash borer (McCullough and Mercader 2012, Mercader et al. 2011).

Because only a minimal amount of insecticide for each application option is necessary to protect the majority of ash trees in an area, insecticides are a cost efficient treatment option (McCullough and Mercader 2012, Mercader et al. 2011, Smitley et al. 2015). The total cost of the insecticides and the labor needed to apply the treatments is greatly cheaper than the cost of getting rid of the ash trees killed by the beetles (McCullough and Mercader 2012).

The use of insecticides to kill the emerald ash borer is the best treatment option for urban environments (McCullough and Mercader 2012, Mercader et al. 2011, Smitley et al. 2015). Insecticides are readily available in urban settings and the typical homeowner can afford them (Smitely et al. 2015).

Girdling is another viable option to reduce the population and spread of emerald ash borer beetles (McCullough and Mercader 2012, Mercader et al. 2011). By removing strips of bark from specific ash trees, these ash trees become more attractive to female emerald ash borers who lay their eggs on them (McCullough and Mercader 2012, Mercader et al. 2011). As a result, a greater proportion of the total amount of emerald ash borer larvae in an area are present on these trees (McCullough and Mercader 2012, Mercader et al. 2011). These select few ash trees are then destroyed, killing all of the larvae on them (McCullough and Mercader 2012, Mercader et al. 2011). In simulations, groupings of girdled trees spread through an infested area decreased the rate of spread and the rate of population growth of the emerald ash borer (McCullough and Mercader 2012, Mercader et al. 2011).

Girdled ash trees have the potential to become an economic resource making them cost efficient (McCullough and Mercader 2012, Mercader et al. 2011). Once these ash trees are destroyed, their wood can be harvested for fire wood as well as for lumber (McCullough and Mercader 2012, Mercader et al. 2011).

Girdling is the better treatment option for rural areas (McCullough and Mercader 2012, Mercader et al. 2011). Though insecticides are more effective at limiting the spread of emerald ash borer, they are not always an option in forests because of the risk they pose to local and endangered species (Mercader et al. 2011).

The emerald ash borer beetle's invasion of northern North America has not only resulted in the deaths of millions of native ash trees, it has also indirectly led to the alteration of the surrounding environment and to the increased growth rates of native non-ash trees (Anulewicz et al. 2008, Flower et al. 2013a, Flower et al. 2013b, McCullough and Mercader 2012, Puresaran and Poland 2009, Rebek et al. 2008). Since North American ash trees are less protected from emerald ash borer beetles than Asian ash trees, it is probable that these impacts will become increasingly more widespread (Liu et al. 2003, McCullough and Mercader 2012, Mercader et al. 2011, Muirhead et al. 2006, Pureswaran and Poland 2009, Rebek et al. 2008, Siegert et al. 2010, Smitley et al. 2008). In order to slow the expansion of this invasive beetle, the treatment options of insecticides and girdling should be implanted in areas with high densities of the emerald ash borer (McCullough and Mercader 2012, Mercader et al. 2011, Siegert et al. 2010, Smitley et al. 2008, Smitley et al. 2015). Furthermore, these solutions would likely be effective for other similar invasive wood boring insects.

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