N O T E

Injections of Emamectin Benzoate Protect Engelmann Spruce from Mortality Attributed to Spruce Beetle (Coleoptera: Curculionidae) for Two Years[1]

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In the western United States, protection of individual conifers from bark beetles typically involves liquid formulations of insecticides applied to the tree bole. Researchers attempting to find safer, more portable, and longer-lasting alternatives have evaluated injecting systemic insecticides directly into the tree. Early research indicated that several methods, active ingredients, and formulations were largely ineffective. For example, studies involving several bark beetle and host species found acephate (Shea et al. 1991, W. J. Appl. For. 6: 4–7; DeGomez et al. 2006, J. Econ. Entomol. 99: 393–400), azadirachtin (neem) (Duthie-Holt and Borden 1999, J. Entomol. Soc. Brit. Col. 96: 21–24), carbofuran and dimethoate (Shea et al. 1991), dinotefuran (DeGomez et al. 2006), fipronil (Fettig et al. 2010, J. Entomol. Sci. 45: 296–301; Grosman et al. 2010, W. J. Appl. For. 25: 181–185), and oxdydementon methyl (Haverty et al. 1996, USDA For. Serv. Res. Note PSW-RN-420) ineffective.

More recently, phloem-mobile active ingredients injected with pressurized systems have shown promise (reviewed by Fettig et al. 2013, in Insecticides—Development of Safer and More Effective Technologies, pp. 472–492.). For example, an experimental formulation of emamectin benzoate protected ponderosa pine, *Pinus ponderosa* Douglas ex Lawson, from mortality attributed to western pine beetle, *Dendroctonus brevicomis* LeConte, for three field seasons in California (Grosman et al. 2010). This and other research led to registration of a commercial formulation of emamectin benzoate for tree protection (TREE-äge®; Arborjet Inc.,

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Woburn, MA). Later, TREE-äge was demonstrated effective for protecting lodgepole pine, *Pinus contorta* Douglas ex Loudon, from mortality attributed to mountain pine beetle, *Dendroctonus ponderosae* Hopkins, but only when injected in the fall (September) before being challenged by beetles the following year (Fettig et al. 2014, Pest Manag. Sci. 70: 771–778). Similarly, Fettig et al. (2014, J. Entomol. Sci. 45: 296–301) showed injections of abamectin (Abacide™ 2Hp; Mauget Inc., Arcadia, CA) applied in fall (September) were effective for protecting *P. contorta* from mortality attributed to *D. ponderosae* the following year.

While injections can be applied at any time of year when trees are actively transpiring, sufficient time is needed for adequate distribution of the active ingredient to the target tissue (i.e., the phloem where most bark beetles feed) prior to colonization. This appears to be of significant importance in high-elevation (>2,438 m) forests in the western United States where cold temperatures retard transport within the tree. For example, research has shown that a root-zone threshold temperature of 8–12°C is required for normal physiological function in *P. contorta* and Engelmann spruce, *Picea engelmannii* Parry ex Engelmann (Running and Reid 1980, Plant Physiol. 65: 635–640; DeLucia 1986, Tree Physiol. 2: 143–154; Lopushinsky and Max 1990, New Forests 4: 107–124), and occurs for only a short period (~3.5 mo) each year in high-elevation forests of the Rocky Mountains (Fettig et al. 2014: fig. 4) where *Pi. engelmannii* is a dominant component.

Spruce beetle, *Dendroctonus rufipennis* Kirby, is the most significant mortality agent of mature spruce in the United States, and many forests in the Rocky Mountains are experiencing outbreaks. For example, in Utah outbreaks have resulted in mortality of >1 million *Pi. engelmannii* in recent years, spurring publication of a recent synthesis on *D. rufipennis* (Jenkins et al. 2014, Forests 5: 21–71) and research aimed at reducing negative impacts to forests. Grosman et al. (2010) evaluated the efficacy of an experimental formulation of emamectin benzoate for protection of *Pi. engelmannii* from mortality attributed to *D. rufipennis* in Utah. Despite injections being applied in August of the year prior to treatments being challenged by *D. rufipennis*, a lack of efficacy was observed. Here we describe an alternative timing of TREE-äge for protecting *Pi. engelmannii* from mortality attributed to *D. rufipennis*. This research is part of a larger, more comprehensive effort scheduled for completion in 2018.

This study was conducted on the Evanston Ranger District, Uinta-Wasatch-Cache National Forest, Utah (first tree: 40.85°N, 110.93°W; 2,825 m elevation; last tree: 40.85°N, 110.95°W; 2,898 m elevation), 2013–2016. Site selection was based on ground and aerial surveys indicating that infestations of *D. rufipennis* were evident. Thirty randomly selected trees were assigned to each of three treatments: (a) bole injections of TREE-äge (4.0% active ingredient [a.i.]; EPA Reg. No. 100+1309-74578) applied 18–21 June 2013 at 10 ml/2.54 cm diameter at breast height (dbh, 1.37 m in height), and (b, c) two separate untreated controls (Table 1). One control group was used to assess *D. rufipennis* population pressure during each field season (2014 and 2015) based on levels of tree mortality observed. TREE-äge was injected directly into the bole through plugs (#4 Arborplugs, Arborjet Inc.) inserted 7.6 cm apart (e.g., a 33-cm dbh tree required 14 plugs) at the root collar using the Tree IV™ microinfusion system (Arborjet Inc.). TREE-äge-treated trees and the first untreated control were baited with one commercially available tree bait (frontalin and α-pinene; Contech Inc., Delta, BC, Canada) stapled to the

Table 1. Bole injections of emamectin benzoate (TREE-äge®, Arborjet Inc., Woburn, MA) for protection of Engelmann spruce from spruce beetle, Uinta-Wasatch-Cache National Forest, Utah, 2013–2016.

Treatment	Dbh*	2014 Mortality/*n***	2015 Mortality/*n*†	Cumulative Mortality/*n*
Emamectin benzoate	36.3 ± 1.5	2/30	4/28	6/30
Untreated control 2014	39.4 ± 1.3	12/30	—	—
Untreated control 2015	38.1 ± 1.3	—	20/30	—

* Dbh = diameter at breast height (1.37 m in height), mean ± SEM.
** Tree mortality based on presence (dead) or absence (live) of crown fade on 16–17 September 2015.
† Tree mortality based on presence (dead) or absence (live) of crown fade on 8–10 August 2016.

bole of each experimental tree at ~2 m in height on the northern aspect 9 July–14 August 2014. All TREE-äge-treated trees that were alive in 2015, and the second group of untreated controls, were baited 10 June–17 September 2015. The manufacturer estimates the life expectancy of these baits is 100–150 d depending on weather conditions. There were no significant differences in tree dbh among treatments ($F = 1.3$; df = 2, 87; $P = 0.3$), which is known to influence susceptibility to colonization by *D. rufipennis* (Jenkins et al. 2014).

Tree mortality was based on the presence or absence of crown fade, an irreversible symptom of tree mortality, the year following baiting (2015 and 2016). The only criterion used to determine the effectiveness of TREE-äge was whether treated trees died as a result of colonization by *D. rufipennis*. Treatments were considered to have sufficient *D. rufipennis* pressure if ≥60% of the untreated, baited control trees died from colonization. TREE-äge was considered efficacious when fewer than seven trees died as a result of *D. rufipennis* colonization while ≥60% of the untreated, baited control trees died. These criteria were established based on a sample size of 22–35 trees/treatment and the test of the null hypothesis, H_0: S (survival ≥ 90%). These parameters provide a conservative binomial test ($\alpha = 0.05$) to reject H_0 when more than six trees die. The power of this test, that is the probability of having made the correct decision in rejecting Ho, is $P = 0.84$ (Hall et al. 1982, J. Econ. Entomol. 75: 504–508; Shea et al. 1984). This experimental design serves as a standard for such evaluations in the western United States, and provides a conservative test of efficacy (Fettig et al. 2013).

We observed no phytotoxic effects associated with injections of TREE-äge. Mean (± SEM) uptake time (i.e., the time required for TREE-äge to fully enter the tree) was 26.1 ± 2.5 min. In 2014, *D. rufipennis* pressure was insufficient to adequately challenge the treatment as only 40% of the untreated controls died (Table 1). During this time, 2 of 30 trees treated with TREE-äge died. *Dendroctonus rufipennis* pressure was sufficient to adequately challenge the treatment in 2015 as 66.7% of the untreated controls died (Table1). TREE-äge provided adequate levels of protection as only 6 of 30 trees were killed by *D. rufipennis* during the 2-yr period. Grosman et al. (2010) commented that injecting trees early the year prior to when efficacy is desired and/or increasing the number of injection points per tree could increase efficacy. Both appear critical for protection of *Pi. engelmannii*, as does placing the injection points as low as possible (root collar and exposed large roots) due to *D. rufipennis* adults colonizing these portions of the tree as well as the bole (Furniss and Carolin 1977, USDA For. Serv. Misc. Publ. 1339).

Several tactics are available to manage bark beetle infestations and to reduce associated levels of tree mortality. Direct control involves short-term tactics designed to address current infestations by manipulating beetle populations, and typically includes the use of insecticides, semiochemicals, sanitation harvests, trap trees, or a combination of these treatments. Indirect control is a preventative tactic designed to reduce the probability and severity of future infestations within treated areas by manipulating stand, forest, and/or landscape conditions by reducing the number of susceptible hosts through thinning, prescribed burning, and/or altering age classes and species composition (Fettig and Hilszczański 2015, in Bark Beetles: Biology and Ecology of Native and Invasive Species, pp. 555–584). Our results indicate narrowly spaced (7.6-cm) injections of TREE-äge are effective for protecting *Pi. engelmannii* when applied about 1 yr prior to treatments being challenged by *D. rufipennis*. Two years of efficacy can be expected (Table 1). Bole sprays of carbaryl are typically used for protecting high-value *Pi. engelmannii* from mortality attributed to *D. rufipennis* (e.g., in USDA Forest Service campgrounds) (A.S.M. pers. obs.), but require transporting sprayers and other large equipment into remote areas, which can be problematic. Additionally, many sites where bole sprays are frequently applied occur near water sources (e.g., streams and lakes), limiting applications due to restrictions concerning the use of no-spray buffers to protect nontarget aquatic organisms (Fettig et al. 2008, J. Environ. Qual. 37: 1170–1179), thus leaving some hosts untreated and susceptible to colonization by *D. rufipennis*. For these and other reasons, injections of TREE-äge may represent a desirable option for reducing levels of tree mortality attributed to *D. rufipennis*.

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This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides in the United States must be registered by appropriate State and/or Federal agencies before they can be recommended.