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The efficacy of fungal inoculation of live trees to create wood decay and wildlife-use trees in managed forests of western Washington, USA

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ABSTRACT

Decaying wood plays a vital role in maintaining biological diversity and ecological processes within forest ecosystems. One enhancement that may help to maintain wood-decay processes in managed forests involves the inoculation of healthy trees with fungus to create potential habitat trees to enable excavation for foraging and nesting by primary cavity nesters (i.e., woodpeckers); however, this approach has only received limited evaluation. We evaluated the inoculation of *Fomitopsis pinicola* into live trees in managed forests in western Washington in 1997 and 1998. In 2006, we revisited trees that were inoculated with live fungus or sterile controls, and inspected each tree for the presence of fungal growth and woodpecker activity. Of 650 trees inoculated with fungus ($n = 330$) or a sterile control ($n = 320$), 528 (81.2%) were alive and standing in 2006 ($n = 276$ with fungus, 83.6%; $n = 252$ control trees, 78.8%). Trees had been lost to harvest (11.1%), blowdown (3.8%), breakage (2.9%), and had died of undetermined causes (0.9%). A higher proportion of treatment trees displayed *F. pinicola* conks (0.200) and mycelia (0.073; inferred to be *F. pinicola*) than did control trees (0.004 conks [unknown species], 0.012 mycelia), although the difference for mycelia was marginally significant. We also found that western hemlock (*Tsuga heterophylla*) had a higher proportion of conks (0.313) and evidence of any fungal growth (conks or mycelia; 0.393) than Douglas-firs (*Pseudotsuga menziesii*; 0.064 and 0.112, respectively). Further, we observed evidence of significantly ($P = 0.010$) more woodpecker excavations and sapsucker (*Sphyrapicus* spp.) foraging holes associated with the fungal inoculations (6.2%) than at control trees (1.2%). Although use by woodpeckers was limited, we suggest that this finding is ecologically significant as we observed no woodpecker use, except for limited sapsucker foraging, when we inspected trees in 2002. The fungal inoculations completed 1997–1998, to some extent, were successful as *F. pinicola* was documented in at least 36.8% of the treated trees. In addition to *F. pinicola*, an ensemble of fungi and other microorganisms was established into the inoculation wounds of both control and treatment trees, suggesting that wounding of a healthy tree under the right circumstances may be sufficient to initiate this natural process in younger-aged forests as it occurs in old-growth forests.

1. Introduction

The maintenance of deadwood, including the presence of snags, and natural wood-decay processes is critical to functioning forest ecosystems worldwide. Dead and decaying wood play vital roles in maintaining biodiversity, including associated complex biological interactions fundamental to the support of a variety of ecological processes; soil development and porosity; water infiltration; nutrient and gas dynamics; natural resistance to a variety of pests; slope stability; control of sediment loss; site productivity; and long-term sustainable harvests (e.g., Brockerhoff et al., 2008; Chambers et al., 1997; Rose et al., 2001). Moreover, the amount of dead wood and associated decay dynamics in forest stands has been documented to decline with successive management actions (e.g., Bunnell et al., 2002a; Ohmann and Waddell, 2002; Franklin et al., 1997; Hanson et al., 1991; Kroll et al., 2012b; Rose et al., 2001). Thus, to maintain healthy functioning forests and sustainable harvests, it is integral to foster natural decay dynamics in intensively managed forests (Arnett et al., 2010; Brockerhoff et al., 2008; Bunnell et al., 2002b; Cline et al., 1980; Kroll et al., 2012a; Vuidot et al., 2011). Unfortunately, the effective management of these processes is limited by the lack of understanding of the dynamics and associated biological interactions of cavity formation and loss both in managed and natural forests (Bednarz et al., 2004; Jackson and Jackson, 2004; Kroll et al., 2012b; Remm et al., 2006).

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Several techniques have been developed to provide structural enhancements to managed forests to foster communities of primary and secondary cavity nesting birds, which are interdependent with a multitude of natural ecological processes that occur within forests (e.g., natural control of insect pests). These include topping of trees with chain saws, feller-bunchers, or explosives; girdling; injection of herbicides; pheromone applications to attract wood-boring beetles; and fungal inoculations (Arnett et al., 2010; Brandeis et al., 2002; Bull and Partridge, 1986; Huss et al., 2002; Rose et al., 2001). Of these techniques, fungal inoculation of live trees has received limited study and results have been confounded because of varied approaches used to inoculate trees (e.g., use of different species of fungi, differences in target tree species, use of single versus multiple inoculations of single trees, and varying heights of inoculation; Brandeis et al., 2002; Bull and Partridge, 1986; Filip et al., 2004, 2011; Huss et al., 2002). Also, monitoring of fungal inoculations has produced mixed results, and tree species and species of inocula seem to be important related to the efficacy of establishing wood decay (Brandeis et al., 2002; Bull and Partridge, 1986; Filip et al., 2004, 2011; Huss et al., 2002; Parks et al., 1996). One of the most encouraging reports to date was by Parks et al. (1996), who reported woodpecker nesting cavities in 14% of 60 live western larch (*Larix occidentalis*) within 5 years of inoculation in northeastern Oregon. Other studies showed limited success or reported that more time may be required before woodpecker or other wildlife use can be demonstrated (Bull and Partridge, 1986; Brandeis et al., 2002; Filip et al., 2004, 2011; Huss et al., 2002).

However, use of fungal inoculations to establish decay in live trees to potentially supplement the provision of suitable snags and wildlife trees has several potential advantages over topping trees below the live crown to create snags (e.g., Arnett et al., 2010; Bull and Partridge, 1986; Walter and Maguire, 2005). (1) Live, degraded trees with rot have been shown to be preferred by a number of cavity-dependent species of birds and other wildlife over snags (Remm et al., 2006; Rose et al., 2001). (2) Some cavity-dependent birds and deadwood-dependent organisms use habitat on relatively tall snags or dead wood near the tops of live trees; habitat higher than can be provided by topping trees below the lowest live whorl of branches (e.g., Bull and Holthausen, 1993; Kroll et al., 2012b; Lacki and Baker, 2007; Ormsbee and McComb, 1998). (3) By establishing fungal decay in live trees, such trees may provide relatively longer-term usable foraging and nesting substrates for birds and other organisms (Brandeis et al., 2002; Jackson and Jackson, 2004; Rose et al., 2001; Welsh and Capen, 1992). (4) Fungal inoculations may facilitate long-term recruitment of additional snags within harvest units without multiple entries to top trees at different times during the harvest rotation interval (Bunnell et al., 2002b). Green tree retention is currently the primary method employed to provide for the recruitment of future snags, but the efficacy of this approach in providing future snags is extremely variable as many retained green trees fall victim to blow down and the timing of tree death is unpredictable (Keeton and Franklin, 2004; Rosenvald and Lõhmus, 2008; Zenner, 2000). (5) Fungal inoculation may simulate more natural processes and accelerate wildlife-beneficial decay compared to creating simulated snags by tree topping (Huss et al., 2002; Jackson and Jackson, 2004). Therefore, further investigation of the various approaches and potential benefits of establishing wood decay and the delayed creation of snags through fungal inoculation of live trees should remain a priority for the potential enhancement of forest management techniques (Filip et al., 2011).

Our research implements and evaluates a proposed technique of introducing wood-decaying fungi (*Fomitopsis pinicola*) into selected live trees to encourage habitat use by woodpeckers (e.g., *Picoides* spp.) and secondary cavity users in northwestern coniferous forests (Huss et al., 2002). Specifically, we isolated and cultured fungi taken directly from woodpecker nesting trees and used it to impregnate wooden dowels for experimental fungal inoculations. In 1997 and 1998, we inoculated 650 trees with either *F. pinicola* (treatment, $n = 330$ trees) or sterile wooden dowels (control, $n = 320$).

Here, we report the results of revisiting all inoculation sites and specifically (1) summarize the condition of treatment and control trees; (2) quantify the presence of visible fungal growth in the form of conks or mycelia present in 2006, 8–9 years after treatment; (3) assess if there was any woodpecker use of inoculation trees as evidenced by nesting or foraging excavations; and (4) report our results from random sampling of two trees at each of 10 randomly selected sites to determine if *F. pinicola* and other fungal species were present.

2. Methods

2.1. Study area

Inoculation stands were identified by working with timberland managers of cooperating landowners in 1997 and 1998, which included Rayonier, Washington Department of Natural Resources, Weyerhaeuser, Port Blakely Tree Farms L.P., I.P. Pacific timberland, Inc., and Hancock Timber Resource Group. All inoculation clusters (each including 10 inoculated trees) are in western Washington in Clallam, Grays Habor, Jefferson, Lewis, and Pierce counties (Fig. 1). All study stands were dominated by western hemlock (*Tsuga heterophylla*), Douglas-fir, or both species were co-dominant. Sitka spruce (*Picea sitchensis*) was also present in many of the forest stands inoculated.

All study areas were comprised of state or private lands managed primarily for timber production (Fig. 1). Most inoculation clusters (67.8%; $n = 33$) were located in Riparian Management Zones (RMZ) to protect experimental trees against loss from harvest. Forest habitats surrounding experimental stands consisted of a mosaic of different even-aged forest stands ranging from recently clearcut to >100 year old. Habitats adjacent to the inoculation sites generally consisted of small forest stands (2–40 ha), often bordered by areas which had been clearcut within the past 5 year.

2.2. Experimental design

We developed an experimental design to test the effects of tree species (Douglas-fir or western hemlock), age/size classes of trees (approximately 50 years old, 30–45 cm dbh versus approximately 70 years old, 40–60 cm dbh), and the density of available snags (>7 or <7 snags ha^{-1}), and on the resulting use of inoculated trees by woodpeckers. Stand age and mean tree diameter data were derived from forest stand data provided by the landowner. If the site inspection of the candidate revealed that many trees were of ages or diameter sizes not consistent with forest stand data, we rejected the site for further consideration as an inoculation site. Density of snags was initially assessed by visual inspection and placed in one of two classes (i.e., large snags conspicuously present or large snags mostly absent). To confirm initial classifications, we counted all snags (>50 cm dbh) in a 0.202 ha circular plot centered on the candidate inoculation site. In most cases, inoculated and control clusters (each including 10 trees) were located in the same forest stand. In some cases, stands were either not large enough to accommodate two clusters of experimental trees or the structure varied within the stand. In these cases, we located the control cluster in a nearby stand. When experimental and control clusters were placed in separate stands, we made an effort to use stands