Deployment of Deer-Resistant Western Redcedar (*Thuja plicata*)

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ABSTRACT
Protecting planted western redcedar (*Thuja plicata*) seedlings from deer browse in the Pacific Northwest and British Columbia is estimated to cost up to CAN$ 25 million annually. Recent studies linking deer browse and needle monoterpenes has resulted in the initiation of a breeding program for deer-resistant western redcedar at Cowichan Lake Research Station on Vancouver Island. Selections that are not preferred by deer are currently going through non-preferred rapid breeding and testing cycles for enhanced needle monoterpene concentrations. However, planting stock with increased monoterpene concentrations through genetic manipulation selection and breeding alone may not ensure that seedlings will be adequately protected from browse if deployment strategies are not carefully considered. To provide more robust protection to allow seedlings to reach the free-growing stage, iInteractions must be evaluated of between genetic selection for enhanced monoterpene concentrations,ally enhanced plants with developmental stage (ontogeny), and nutritional quality, as well as appropriate deployment strategies that allow deer some level offorage choice, could ensure adequate protection from browse.

KEYWORDS
needle monoterpenes, ontogenetic effects, plant nutrients

Introduction

Deer and elk browsing on newly planted western redcedar (*Thuja plicata*) seedlings in the Pacific Northwest (PNW) can result in delayed regeneration and potential plantation failure. As a result, CAN$ 20 to 25 million are spent annually in British Columbia to bring a plantation to free-to-grow status using individual tree guards (van Nienjenhuis 2007). Licensees who avoid planting western redcedar incur additional indirect costs, including maladapted or inappropriate species selection, and reduced manufacturing opportunities.

The role of plant secondary metabolites (PSM) in plant defenses has long been recognized (Coley and Barone 1996; Huber and others 2004). Monoterpenes, a group of PSM, have been shown to reduce herbivore predation, including ungulate feeding (for example, Duncan and others 1994; Vourc'h and others 2002a). Plants contain both beneficial and deleterious phytochemicals that impact palatability and diet selection for ungulates (Kimball and Provenza 2003).

Levels of monoterpenes in conifer needles can be impacted by genetics and environmental factors, as well as their interactions (for example, Baradat and others 1972; Vourc'h and others 2002b). Monoterpene concentrations also vary seasonally and with age (for example, Schonwitz and others 1990; Powell and Raffa 1999).

Recent studies linking deer browse and needle monoterpenes in western redcedar (Vourc'h and others 2002b; Russell and Kimball nd) have driven the initiation of a deer-resistance western redcedar breeding program at Cowichan Lake Research Station, Mesachie Lake, British Columbia (CLRS). Deer "non-preferred" selections are currently going through rapid breeding and testing cycles for enhanced needle monoterpene concentrations. However, planting stock bred for higher monoterpene levels alone may not ensure that seedlings will be adequately protected from browse. Interactions between a plant's genetic background, developmental stage (ontogeny), nutritional quality, and silviculture, particularly appropriate deployment strategies that allow deer some level of choice, must all be considered to provide robust protection from browse. This paper outlines current knowledge, the ongoing breeding program at CLRS, and future research directions in western redcedar deer resistance.

Linking Deer Browse and Needle Monoterpene Concentrations in Western Redcedar

A subsample of individuals from a western redcedar population study with family structure at Holt Creek (HC) on southern Vancouver Island indicated that trees that were heavily browsed tended to have low monoterpene content (Vourc'h and others 2002b). A subsequent complete survey of all 2200 trial trees at HC confirmed this relationship (Russell nd). Both of these studies involved seedlings planted in an uncontrolled environment. To obtain a more precise measure of the relationship between deer browse and needle monoterpenes, a study was designed using multiple copies of clones planted in deer enclosures and in small openings in the forest with heavy deer browsing pressure. Cuttings were rooted from 60 trees at HC that varied in monoterpene concentrations and planted at the USDA National Wildlife Research Center, Olympia Field Station, Olympia, Washington (Figure 1) and 2 reforestation sites on southern Vancouver Island. Consistent results were obtained at all 3 sites, demonstrating that browse preference is a function of total needle monoterpene content (Figure 2; Russell and Kimball nd).

Some Factors Affecting Needle Monoterpene Concentrations in Western Redcedar

Genetics

In the HC trial mentioned earlier, a complete sample of needles from all test trees indicated substantial genetic variation in monoterpenes. Narrow-sense heritabilities for 6 of the major needle monoterpenes varied from 0.25 to 0.44, and coefficients of additive genetic variation varied from 19% to 27% (Russell nd). There were significant seed source effects, that is, northern British Columbia populations had greater needle monoterpene concentrations than southern British Columbia sources. Thus, a base population with substantial genetic variation in needle monoterpenes for the initiation of a breeding program is available.

Ontogenetic and Age Effects

In a fertilization study with planted western redcedar in western Oregon, total needle monoterpenes increased linearly from age 1 to 3 (Kimball 2007). Similarly, 1-year-old rooted cuttings originating from 7-year-old western redcedar trees had greater total needle monoterpene concentrations and significantly reduced browse damage than genetically comparable 1-year-old seedlings (Figure 3; Russell nd). Utilizing either 2-year-old seedlings, or rooted cuttings from older hedged donors, can increase needle monoterpene levels and potentially minimize deer browsing.

Figure 1. Western redcedar feeding choice trial with Columbian black-tailed deer at the USDA National Wildlife Center, Olympia Field Station.

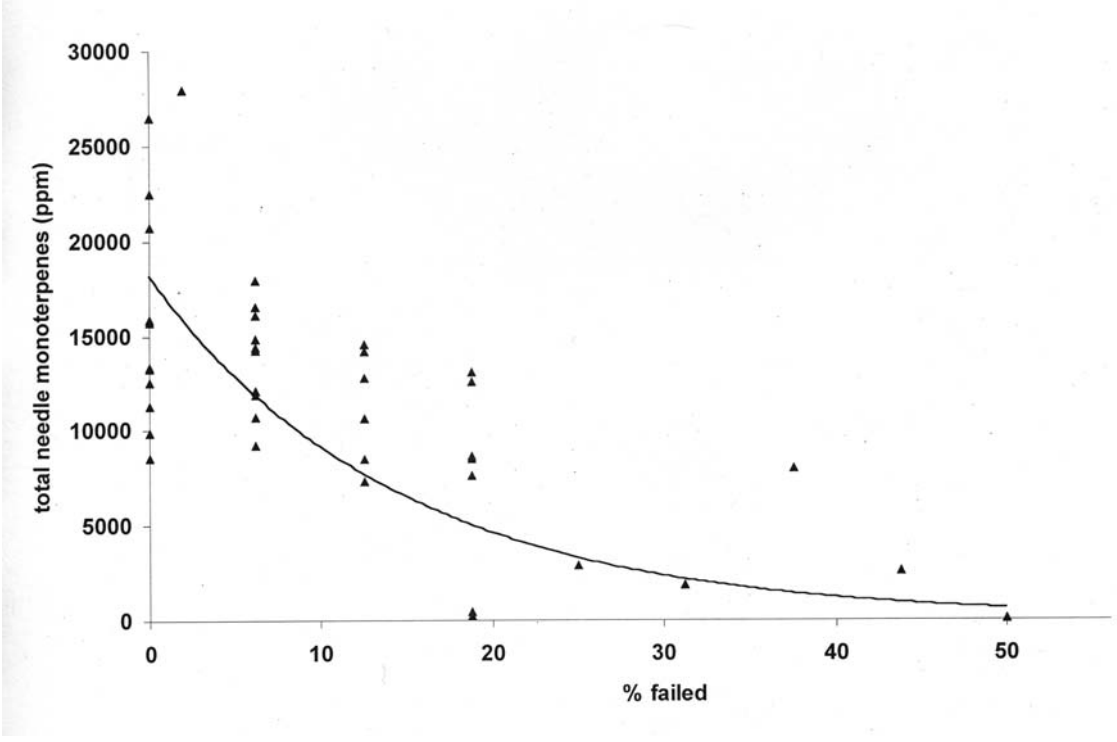

Figure 2. Relationship between total needle monoterpenes and mean failure by clone in western redcedar at the USDA National Wildlife Center, Olympia Field Station.

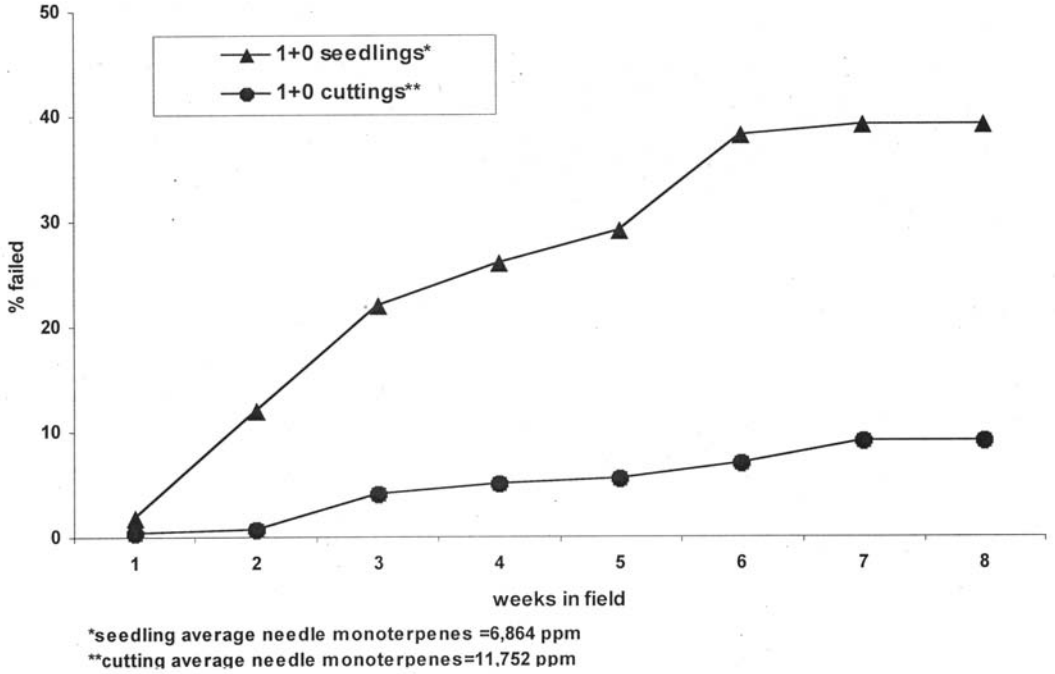

Figure 3. Relationship between deer browse and time since outplanting duration for western redcedar stocktypes.

Plant Nutrient Levels

Nutritional quality of seedlings at the time of planting can have a paradoxical effect. High nitrogen, for example, may make a seedling more palatable to deer, whereas it has been well documented for western redcedar that fertilization at planting stimulates early growth, and thus earlier free-to-grow status (Blevins and others 2006). A higher nitrogen level may also help seedlings recover following browse (see references in Jacobs 2005). Little research has explored the relationship between nutritional quality and monoterpene production. A current study is underway in the PNW examining the influence of mineral nutrition on susceptibility and recovery of planted western redcedar to animal browse (Jacobs 2005).

Breeding for Enhanced Needle Monoterpenes

A breeding program for enhanced needle monoterpene concentrations is currently underway at Cowichan Lake Research Station. Over 60 "not preferred" selections (minimal deer browse and enhanced needle monoterpenes) from a base population of approximately 2500 range-wide western redcedar trees have been selected for the breeding program. In addition, a number of "deer preferred" selections (high browse and low monoterpene concentrations) have also been included. Terpenes are expressed during a seedling's first year, and breeding can be done within 2 years (Figure 4; Russell and Ferguson forthcoming). Additional selections for deer resistance can be quickly incorporated into the program.

Figure 4. Breeding young western redcedar trees at Cowichan Lake Research Station.

Deployment of Deer-resistant Seedlots

Planting seedlings that are high in needle monoterpenes doesn't necessarily guarantee browse resistance. Plants contain beneficial and deleterious phytochemicals. If bitter, high monoterpene trees are the only available food source, deer will select based on the balance between energy input and cost of detoxification (Kimball and Provenza 2003). Results from a study deploying different mixtures of hybrid poplar clones in the Columbia Valley that were preferred and avoided by deer showed that a 2:1 mixture of "not preferred" to "preferred" trees was optimal to yield final free-to-grow stocking (Stanton 2004).

The next stage in developing deer-resistant western redcedar seedlots at CLRS is to outplant mixtures of trees with varying levels of needle monoterpenes in operational trials, including genetic selections, seedlings of varying age, and rooted cuttings. The ultimate goal is to develop custom-made seedlots with varying degrees of resistance tailored for specific sites.

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