Variable Retention Forestry Science Forum*

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Perspectives

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Variable Retention Forestry Science Forum: Overview and key messages

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Abstract

As a result of criticism of past forest management in coastal British Columbia, there was a shift away from the traditional clearcutting system to the retention system. In April 2004, FORREX, in partnership with the Canadian Forest Service, the British Columbia Ministry of Forests, the Forest Engineering and Research Institute of Canada (FERIC), Weyerhaeuser Canada, Madrone Consulting, and Malaspina University–College, hosted a science forum on Variable Retention Forestry. The forum provided an opportunity to discuss the latest findings, issues, and challenges of retention practices. This paper summarizes the important messages from the forum, including the following:

- The importance of developing and implementing adaptive management monitoring and evaluation frameworks.
- The use of variable retention (VR) as a tool that should be guided by goals and philosophies.
- Consideration of the costs of implementing VR.
- The importance of understanding disturbance patterns and their impact.
- The importance of an awareness of the possible effects on stand development of any insects and diseases.
- The importance of an awareness of local site and regional conditions when attempting to predict the outcome of windthrow damage.
- Consideration of public perception of forest management practices.

Outstanding issues and questions are also summarized, and a list of resources outlining the latest research findings in the area of variable retention is provided. It is important to invest in monitoring and understanding the biological implications of VR practices while addressing the social issues around forestry on a public land base—the original rationale for the retention system.

KEYWORDS: *forestry science forum, variable retention.*

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Introduction

In the early 1990s, coastal British Columbia was the focus of a global debate around forest management practices. The "retention system" became a jurisdictional response to the criticism of past forest management, creating a shift away from the traditional clearcutting system. Subsequently, the retention system has been applied, to a limited extent, outside of the coastal British Columbia environment. Now that 50–60% of the Coastal Forest Region is using the retention system, has the science documenting the effects of the shift from clearcutting provided information to assess the implications of this policy change? Have the many challenges and concerns been addressed?

In April 2004, FORREX, in partnership with the Canadian Forest Service, the British Columbia Ministry of Forests, the Forest Engineering and Research Institute of Canada (FERIC), Weyerhaeuser Canada, Madrone Consulting, and Malaspina University–College, hosted a science forum on Variable Retention Forestry. This forum provided an opportunity for forest researchers and practitioners to present and discuss their latest findings on variable retention forestry. Information presented at the forum was also designed to address the issues and unique challenges of applying variable retention (VR), with an emphasis on moving towards science-based management.

This paper summarizes the important messages presented during the plenary session of the forum and provides a reference list outlining the latest research findings in the area of VR.

Brief Summary of the Plenary Sessions of the Forum

"Variable retention" is currently used to describe the broad range of retention practices designed to create and (or) maintain structurally complex stands. By retaining structural elements, biological legacies can be perpetuated, habitat carrying capacity can be maintained, and connectivity can be conserved over the landscape. Designing a retention prescription requires a determination of what is retained, how much is retained, and the spatial pattern of retention. Our experience with retention is limited, however, and little is known about the effects such systems will have on subsequent stand growth and yield, future timber supply, and environmental values of interest.

To increase our knowledge and enhance discussion of the various risks and issues associated with VR, the Science Forum was broken into six distinct sections—two plenary and four poster sessions. During the plenary sessions, participants were introduced to the British Columbia coastal philosophy of retention and how it is currently applied. They were also introduced to how VR is viewed in other jurisdictions, such as Alberta and Europe. During the final plenary sessions, risks and pitfalls of VR were discussed in relation to science-based forest management. The poster sessions, specifically designed to enhance presenter and participant interactions, were broken into four themes:

Now that 50–60% of the Coastal Forest Region is using the retention system, has the science documenting the effects of the shift from clearcutting provided information to assess the implications of this policy change?

1. Regeneration – Information about the effects of the retention system on growth and yield, physiology, and genetics, and the modelling of long-term effects on site productivity.
2. Nutrient Cycling – Information about the effects of the retention system on soil physical and chemical properties, coarse woody debris and decomposition processes, and links between carbon and nutrient cycling.
3. Biodiversity – Information on linkages between forest management at all levels and the conservation of plant, animal, arthropod, and avian diversity, including forest health and indicators of changes in dynamics.
4. Forest Environment – Information on linkages between forest cover and microclimate, fire, water quality and quantity, and the influence of edges and gaps on important ecological processes and patterns.

In total, 39 abstracts were accepted for presentation during the poster session of the forum with equal representation within all theme areas. Extended abstracts from five of these posters are presented here. Information presented in many of the other posters is currently, or will soon be, available in various professional journals. Some of the citations for these publications are provided at the end of this summary section.

Throughout the plenary and poster sessions, some key messages related to the science of VR became apparent, including the following:

- Variable retention was introduced as a response to the social context surrounding the practice of forestry on a public land base. Because of the way VR was introduced, it is important that we develop and implement adaptive management monitoring and evaluation frameworks that use tangible indicators. We need to frame and answer questions that yield appropriate conclusions. Collaborating on these frameworks may improve the efficiencies and effectiveness of this system (Pedersen 2004).
- Variable retention is a tool—its use (aggregated or dispersed) can be guided by a number of goals and philosophies. For example, these philosophies include emulating natural disturbance, maintaining habitat structures based on the needs of certain species, and reducing the amplitude of impacts on wild stand changes caused by logging (Sougavinski and Doyon 2003). These philosophies will need to be clearly considered as the goals and objectives are set (Beese 2004; MacIsaac 2004).
- Variable retention is more expensive, but part of that increased cost may be attributed to the lower volume of timber per hectare removed using this system (or other partial cutting systems) relative to the traditional clearcut system. Variables, such as site and stand attributes, opening size, method of harvest and extraction, and road accessibility will also play a role in determining the additional costs for this system. Other issues, however, such as adjacency should be evaluated against the risks of these additional costs (Kardos 2004).
- With any form of disturbance, there can be species winners and losers. Our knowledge of how we affect the system in which these various species play a role is limited. It is important to look at the various disturbance patterns at work (wind, insect/disease, fire, etc.) and the impacts they have on stand dynamics. Typically, one size doesn't fit all, so it is important to practise the "variable" in Variable Retention (Beese 2004).
- When dealing with VR, it is important to be aware of the possible effects of insects and diseases, and how retention can subsequently affect stand development. Global climate change can potentially affect stand development and influence outbreaks of forest insects and diseases. Global trends indicate that the size of outbreaks is expanding and causing greater damage, accelerating the life cycles and population changes from one stable state to another with no transition period. Forests are resilient systems, but they are also chaotic—they can quickly jump to different states that we may not be prepared to deal with (Volney 2004).
- Although windthrow is expected with VR, we have tools to help in its prediction. Variable retention does not always result in all trees blowing down. When dealing with windthrow, it is important to be aware of local site and regional wind conditions, and to consider the following (among other questions):
  - Is the area very exposed or sheltered?
  - What is the mean annual wind speed?
  - What is the site index? The more fertile the site, the bigger are the trees that blow down.
  - What are the boundary characteristics? More exposure increases potential windthrow.
  - How many patch-edge segments are present? The probability of damage increases by 10% if a tree is on a patch edge (Mitchell 2004).
- Research on public perception of VR appears to indicate that some form of partial cutting is preferred over clearcutting (Sheppard 2004). It is important to remember that for the public, scenic beauty and acceptability are closely related. Some effort to regenerate forests also conveys a message of ecological concern in the eyes of the public.

Although a substantial amount of information was compiled, outstanding questions remain. As part of the last session of the forum, Bruce Larson, Professor of Forest Science at the University of British Columbia, provided some insight into what questions remain as we evaluate and try to implement our results to date. Some of his thoughts include the following:

- Variable retention is not a panacea—it is one of the tools to manage a forest. However, will it continue to provide the social licence to harvest timber in British Columbia? Is it the best way to meet the various objectives applied to the land base? What is the standard to which licensees will be expected to manage, and to what will that lead?
- As plans are developed for the various levels of retention, what future forests are being planned for?

Variable retention is not a panacea—it is one of the tools to manage a forest.

What is the regeneration mechanism that will be employed—a mix of planted and natural? What will be successfully regenerated and established? How fast will it grow? Are there issues of species shifts? What will be the structure and size of the trees, the types of crowns? What will be the fate of the leave trees?

- Risks associated with retention include windfirmness, insects, and disease. With the diversity of tree sizes and ages, is the window being widened for pathogens and insects that can affect the forest? If so, what are the potential impacts and future risks?
- In the regulatory world in which forestry is practised in British Columbia, there are always administrative issues that can affect economic viability. As the rules are adjusted, will they match up with the initiatives that have taken place? If not, success may not occur.
- Regarding biological and ecological research, knowledge of how trees respond is more advanced than knowledge of other components of the system. There needs to be an increased focus on the interactions within these other areas.
- Investment initiatives are lacking. Under the current forest policy structure, where the focus is on Allowable Annual Cut and is measured in cubic metres, it may be difficult to generate more investment incentives for different products.
- The current research initiatives in British Columbia are many and varied. These all need to be placed within an economic and investment setting, however. As well, more multi-objective thinking is required as the research is planned and carried forward.

In this paper, I have provided a brief overview of some of the important messages that were presented at the Variable Retention Forum, as well as a list of reference documents associated with the various presentations. A large amount of work has clearly been done and a substantial investment made, but have the crucial issues related to VR been addressed, or have the issues simply become more refined? As I pointed out at the beginning of this paper, VR was introduced to address social issues around the practice of forestry on a public land base. What are the biological implications of that social choice? We need to maintain investments in the monitoring processes and procedures that will help answer that question—our society's future may depend on the answers we generate.

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Extended Abstract

Green tree retention: A tool to maintain soil function after harvest

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Abstract

To achieve a long-term sustainable forestry, we need to ensure that we can maintain productivity with minimal environmental perturbation. Presently, there is much debate over suitable indicators that identify whether a particular management treatment is ecologically sustainable. The soil biological community plays a vital role in the cycling of nutrients; therefore, the protection of a healthy, functioning soil biotic community is essential for ecosystem function. Currently, only retention of coarse woody debris and limitation of soil scalping are recommended to protect soil organisms after harvest; however, a more suitable management treatment may involve the preservation of green tree retention patches on harvested sites. The aim of this project is to assess the potential of green tree retention as a management tool to maintain soil functioning and site productivity after harvesting. This project brings together a unique multidisciplinary group of researchers who apply a range of novel techniques to quantify changes in soil microbial and faunal diversity and function. The study is designed to run for at least 5 years so that significant new knowledge will be gained each year. This extended abstract outlines relevant background, methods, and planned deliverables related to this ongoing project.

KEYWORDS: *nutrient cycling, site productivity, soil biota, sustainable forest management.*

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Introduction

To achieve a long-term sustainable forestry, we need to ensure that we can maintain productivity with minimal environmental perturbation. Presently, there is much debate over suitable indicators that identify whether a particular management treatment is ecologically sustainable. The soil biological community plays a vital role in the cycling of nutrients; therefore, the protection of a healthy, functioning soil biotic community is essential for ecosystem function. Currently, only retention of coarse woody debris and limitation of soil scalping are recommended to protect soil organisms; however, a more suitable management treatment may involve the preservation of green tree retention patches on harvested sites. This would provide soil organisms with a living, continually replenishing source of energy from the tree roots and litter.

The aim of this project is to assess the potential of green tree retention (GTR) as a management tool to maintain soil functioning and site productivity after harvesting. This project brings together a unique multidisciplinary group of researchers who apply a range of novel techniques to quantify changes in soil microbial and faunal diversity and function in response to harvesting. Specifically, the project will identify the diversity and function of the largely unknown soil organisms, and the changes in these communities within several variable retention (VR) harvesting systems. This will help to resolve whether GTR is a suitable management option for maintaining a healthy soil, and to determine the most favourable size and density of retention patches for this purpose. The ultimate goal is to recommend the optimal design of VR systems for maintaining soil biodiversity and function.

We explore three main questions of interest:

1. Do patches of GTR maintain the structure and function of soil biota of the uncut forest?
2. Is a minimum retention patch size of GTR necessary to do this?
3. How far does the effect of a GTR patch extend into the harvested area, and does the "shadow" vary with GTR patch size?

Evidence clearly shows that clearcutting affects the biomass, diversity, and community structure of soil micro-organisms (Durall *et al.* 1999; Jones *et al.* 2003) and soil invertebrates (Addison *et al.* 2003a, 2003b). There is also evidence that partial cutting has less of an effect on soil organisms than clearcutting (Marshall 2000). What is not evident is which type of partial cutting best protects soil biodiversity and functioning.

The project is using the second replicate of the Silviculture Treatments for Ecosystem Management in the Sayward (STEMS; ***http://www.for.gov.bc.ca/hre/stems***) installation near Elk Bay, Vancouver Island. STEMS is a large, multidisciplinary field experiment that compares the ecological, biological, and socio-economic effects of seven silvicultural systems, including clearcut, uncut, group selection, patch cuts, dispersed retention, and aggregated retention. The site for the second replicate is the very dry Maritime Coastal Western Hemlock subzone (CWHxm2). The site series is 05 (Western redcedar – Sword fern), the soil moisture regime is slightly dry to fresh, and the soil nutrient regime is rich to very rich. The stand is 60 years old and has a site index of 35 m at 50 years.

The advantage of using the STEMS installation is that it allows us to examine the same soils pre- and post-harvest. We will sample four replicate aggregated retention patches of four sizes. In the first year (2004 – pre-harvest), we will sample:

- the centre of each retention patch;
- the edge of each retention patch; and
- 30 m from the edge of the retention patch.

We also sample four areas of what will become uncut control and clearcut to obtain a baseline comparison. In the second and subsequent years (2005 on – post-harvest), we will sample the patch centre and then along a transect going 30 m out from the patch edge into the clearcut. In year 3, we will compare treatments in the first STEMS replicate (5 years post-harvest), comparing the patches and associated openings with uncut forest and the dispersed retention treatment. This will determine whether the lighter influence-shadow cast by dispersed retention retains community structure and function across more of the opening than does aggregated retention.

Methods

Microbial community structure will be characterized by phenotypic and molecular methods and functions determined using biochemical analyses. DNA will be extracted from soil and the community profiled through PCR-DGGE analysis of ribosomal RNA genes (rDNA) (McCaig *et al.* 2001; Leckie *et al.* 2004a, 2004b). PCR primers specific for different phylogenetic groups will ensure fine resolution. Primers for catabolic genes characteristic of specific functional groups (e.g., NH_4 oxidizers and N_2 fixers) will be used to assess diversity of functional genes in different soils and treatments by T-RFLP (Marsh 1999). We will use primers designed to amplify the *nif*H subunit of nitrogenase, which has been widely used in functional ecology studies of nitrogen-fixing microbial communities (Widmer *et al.* 1999; Poly *et al.* 2001; Zehr *et al.* 2003). Ammonia-oxidizing bacterial communities will be targeted using primers for the *amo*A gene (Bruns *et al.* 1998; Norton *et al.* 2002).

The biomass and structure of the soil microbial community will be assessed by analyzing the ester-linked phospholipid fatty acid (PLFA) composition of the soil, since certain groups of micro-organisms have different "signature" fatty acids. PLFA will be extracted from soil, and then fractionated and quantified using the procedure described by Grayston *et al.* (2001b, 2004). Microbial activity and catabolic diversity will be assessed using basal- and substrate-induced respiration using various carbon sources (e.g., glucose, serine, malonic acid, cellulose, chitin) and a novel deep-well microplate approach. A rapid microplate enzyme assay system (Grayston *et al.* 2001a) will be used to measure and compare the key enzymes involved in carbon (cellulase, B glucosidase, phenol oxidase, and lignin peroxidase), nitrogen (chitobiosidase, N acetyl glucosaminidase, urease, and protease), and phosphorus (acid phosphatase) cycling in soil. To assess fungal community structure, abundance of mushrooms will be determined, mycorrhizal root tips sampled, and DNA will be extracted and analyzed by RFLP and sequencing.

Soil mesofauna (e.g., mites, collembola, and nematodes) will be extracted from the soil using standard wet and dry extraction techniques and identified to species or morphospecies (Addison *et al.* 2003a, 2003b). The methods for the extraction and processing to identify soil nematodes will follow those of Panesar *et al.* (2000; 2001). A digital library of images will be constructed to aid identification, allow remote species confirmations, and facilitate consultation with researchers worldwide. Functional roles of different species will be determined using published literature, analysis of gut contents, and mouth-part morphology. Coastal forests of Vancouver Island are unique in that they contain not only native earthworms, but a giant enchytraeid species, in addition to the keystone millipede *Harpaphe haydeniana*. The abundance and community structure of these elements of the soil macrofauna will be determined using Tullgren funnels and wet sieving.

Nutrient availability in the field will be determined close to each sampling point in the transect using ion-exchange membranes (PRS™-probes; Western Ag Innovations, Saskatoon, Sask.). To determine whether patterns of soil biodiversity are related to the "litter shadow" of remaining trees, litter fall will be measured by collecting litter four times per year in 0.08-m^2 trays placed at the transect sampling points.

Deliverables

The study is designed to run for at least 5 years so that significant new knowledge will be gained each year. In year 1, the project will identify the diversity of soil micro-organisms and fauna in forest soils, and produce molecular and taxonomic databases, culture collections, digital photographic records, and species keys. In year 2 and in subsequent years, the project will produce information on the initial effects of different retention treatments. This will allow us to make recommendations about the effectiveness of partial harvesting in maintaining soil diversity and function, and the most appropriate retention level and spatial arrangement. In year 3, we will be able to make use of the longer time that the first STEMS replicate has been in place, and make 5-year measurements on the control, clearcut, dispersed retention, and aggregate retention treatments. We will be able to use these results to test our initial predications and will adapt our recommendations on the basis of the new results. In year 4, we will use results and trends to identify important soil diversity indicators and soil functioning. We will be able to adapt our monitoring to emphasize these two factors. We will generate hypotheses regarding the link between these indicators and keystone groups to critical soil processes, which we will test using manipulative experiments.

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Extended Abstract

Does group retention harvesting protect amphibian habitat?

Elke Wind[1] and Glen Dunsworth[2]

Abstract

Increasing concern has been expressed over global amphibian declines in the past two decades, especially for many frog and toad species in the Pacific Northwest. Organism sensitivity to extreme climatic conditions created by harvesting, and the potential impact on their future recruitment in regenerating forests, is one of the reasons for a recent shift to a variable retention (VR) approach to forest management. Weyerhaeuser British Columbia Coastal Group has adopted this approach and is supporting its implementation with an adaptive management program. This amphibian pilot study was conducted from 2000 to 2003. Although high variability occurred within and among sites, we found that amphibians were more abundant in forests than in VR sites, especially terrestrial salamanders, and that small individuals of some species may be excluded from VR sites. We also found that all local aquatic-breeding amphibian species breed in wetlands in cutover areas, and that they experience rapid growth under open-canopy conditions, especially in early spring. The results, as described in this extended abstract, led us to conclude that aquatic-breeding amphibians may serve as indicators of the health of aquatic habitats within the terrestrial environment and of the effectiveness of VR approaches. We recommend addressing the following important issues regarding wetland buffers, amphibian conservation, and cost-effective harvesting: the number of wetlands that require buffers (e.g., all or priority areas); perimeter extent that requires buffers (e.g., all or partial buffers); and effective buffer width.

KEYWORDS: *amphibian habitat, aquatic ecosystems, indicator species, variable retention harvesting.*

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Introduction

Increasing concern has been expressed over global amphibian declines in the past two decades, especially for many frog and toad species in the Pacific Northwest (Doyle 1998; Wake 1998). The reason for the declines remains largely unknown, but factors put forth include non-native species (e.g., fish stocking), disease, pollution, and over-harvesting (or collection) of amphibians. In the majority of cases, habitat loss and a general increase in stress among populations have likely been contributing factors (Wake 1998).

Amphibian species of the Pacific Northwest have evolved in close association with forest habitats in which the dense canopy cover creates cool, moist climatic conditions that facilitate the transfer of moisture and gases through their semi-permeable skin (Zug 1993). Many studies have found reduced abundance of amphibians in clearcuts versus forests (see review by deMaynadier and Hunter 1995). The loss of canopy cover that results from clearcutting is unsuitable for amphibians because of the greater climatic extremes encountered, compared to forests, increase the risk of desiccation (i.e., the increased exposure to wind and sun dries them out).

Organism sensitivity to extreme climatic conditions created by harvesting, and the potential effect on their future recruitment in regenerating forests, is one of the reasons for a recent shift to a variable retention (VR) approach to forest management. Weyerhaeuser BC Coastal Group has adopted VR and is supporting its implementation with an adaptive management program. This program uses indicator species as one element in the assessment of ecological effectiveness. Amphibians are being evaluated through pilot studies as a candidate indicator species.

Methods

The amphibian pilot study was conducted from 2000 to 2003. During that time, the richness and abundance of amphibians was sampled in VR and forest sites, both terrestrially and aquatically, using pitfall traps with drift fences, visual surveys, and funnel traps. To compare growth and development rates, amphibian larvae were sampled at three wetlands with different amounts of canopy cover (unbuffered, patch pond, and in forest) in 2001.

Results and Discussion

Amphibians were more abundant in forests than in VR sites, especially terrestrial salamanders which were not captured in VR areas in Summer 2000. This is consistent with other studies in which salamanders appear to be more sensitive to forest harvesting than anurans (i.e., frogs and toads; deMaynadier and Hunter 1995). In addition, individuals of some species captured in VR sites tended to be larger than those caught in forest sites. Small amphibians are more susceptible to desiccation than larger ones (e.g., juveniles versus adults; Zug 1993), suggesting that cutover areas may be limiting to some individuals within the population even when tree patches have been retained.

High variability was observed in amphibian abundance among and within sites. This was likely due to the small sample sizes of the sites surveyed and animals captured, as well as the patchy distribution of amphibian populations which is associated with the location of wet areas. This variability led to high variance and low power, and it was determined that sampling amphibians terrestrially was not a cost-effective procedure for a long-term VR monitoring program.

We found that all aquatic-breeding amphibian species breed in wetlands in cutover areas, and that they experience rapid growth under open-canopy conditions. Based on general surveys throughout the season, and repeat sampling of larvae at three ponds with different amounts of canopy cover, larvae in cutover ponds were often larger than those in forest ponds, especially in early spring (Figure 1). This rapid growth under open-canopy conditions has been observed elsewhere (Halverson *et al.* 2003), and is likely advantageous for survival. For example, it may reduce predation pressure (e.g., through gap limitations, speed of escape, etc.), increase the likelihood of metamorphosing before temporary ponds have dried, or increase fitness by extending the period spent in terrestrial environments before overwintering.

Studies show that many aquatic-breeding amphibian species prefer ponds with mid-range canopy cover and hydroperiods (Skelly *et al.* 1999). We suspect that amphibians may be attracted to cutover ponds because of the reduced canopy cover and warm spring conditions, which may result in the creation of reproductive sinks. Although larvae in cutover ponds may have a competitive size advantage, they are exposed to greater risk of desiccation from premature pond drying. The cutover (unbuffered) pond sampled repeatedly in 2001, dried within 2 weeks of

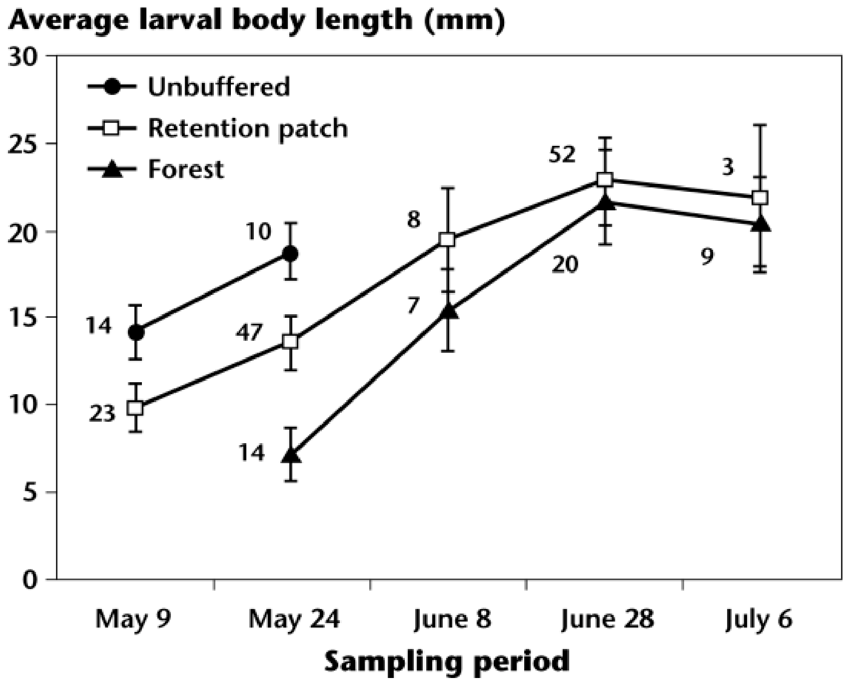

FIGURE 1. Average body length (mm) of Pacific chorus frog tadpoles at an unbuffered pond in a cutover area versus a pond within a group retention forest patch and one within continuous forest in 2001. Numbers beside points represent the sample size of tadpoles measured at each period. (Note: The unbuffered pond dried before June 8 and all larvae perished.)

the study start date and all larvae perished (Figure 2). Most larvae in this geographic area and elevation metamorphose in June or July.

Small wetlands (< 0.5 ha) do not require any protective measures under the *Forest and Range Practices Act* within British Columbia. Weyerhaeuser, however, uses these small wet areas as anchor points when deciding where to locate group retention patches within a block. This buffering may be beneficial to the wetland and to amphibian populations. The effect of buffering these small wetlands has not been studied. This provides a unique opportunity for research.

In 2004, we initiated an experiment to investigate the effects of buffering small wetland habitats. We collected pre-harvest data from 90 wetlands in three forest sites near the Nanaimo River on Vancouver Island, including

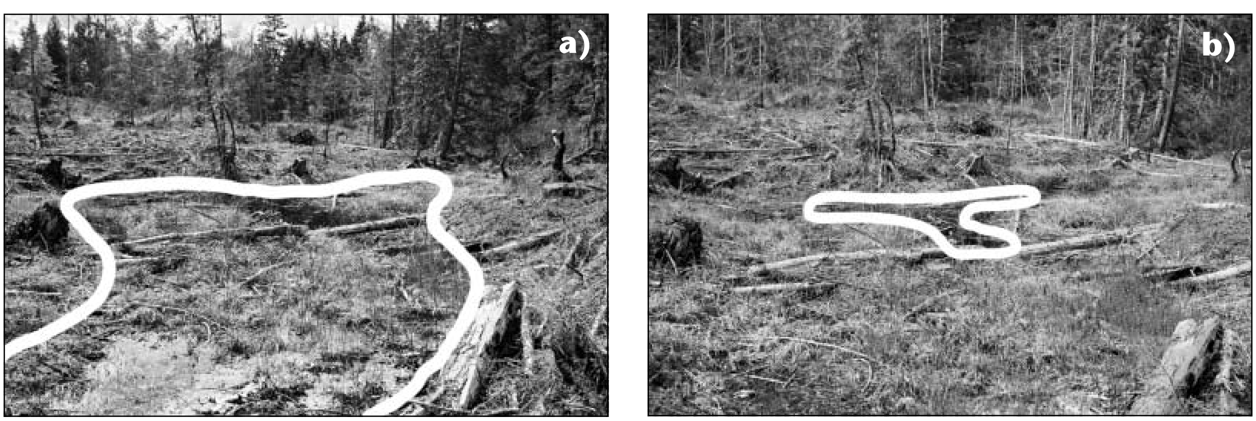

FIGURE 2. Unbuffered pond within a cutover area showing the drying rate over a 2-week period in Spring 2001: (a) May 9, 2001; (b) May 24, 2001. The white line delineates the waterline.

hydroperiod, species richness and reproductive success of amphibians, and percent cover of various wetland vegetation groups. These wetlands were divided into similar groupings and randomly allocated to one of three treatments:

- unbuffered
- narrow buffer (normally administered)
- wide buffer (twice the narrow)

Group retention harvesting is slated to begin in fall 2004, and post-harvest data will be collected in Spring and Summer 2005.

Conclusions

Amphibians are sensitive to forest harvesting. Variable retention systems may retain forest patch refugia that provide moist, moderate, climatic conditions that may aid amphibian recruitment in the harvested matrix. However, refugial effects are difficult to monitor because the location of amphibian populations is closely tied to that of wet areas, which results in a patchy distribution. Alternatively, amphibians are an excellent group to monitor in aquatic environments. Retention systems are often used to provide protection for small wetland habitats. In this way, aquatic-breeding amphibians may be used as indicators of the health of aquatic habitats within the terrestrial environment and of the effectiveness of variable retention approaches.

Important issues that need to be addressed regarding wetland buffers, amphibian conservation, and cost-effective harvesting include the number of wetlands that require buffers (e.g., all or priority areas), perimeter extent that requires buffers (e.g., all or partial buffers), and effective buffer width.

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Extended Abstract

Windthrow and conifer regeneration amongst a range of retention patterns within the Roberts Creek Study Forest

Brian D'Anjou[1]

Abstract

Social, legislative, and stewardship issues are driving forest managers to consider alternatives to clear-cutting for harvesting and managing forests in British Columbia. Trials established throughout British Columbia are evaluating implications of various silvicultural systems on a range of ecosystem attributes. The Roberts Creek Study Forest (RCSF), north of Vancouver, is one of these trials. The objectives of this trial are to: monitor and describe windthrow within harvested treatments and unlogged control areas; describe development of planted Douglas-fir and western redcedar, and the natural regeneration, within the harvested blocks; and describe management implications of alternative retention patterns. The results are summarized in two treatment categories: "regeneration harvests," which include treatments with specific reforestation targets and obligations (e.g., clearcut, variable, dispersed, and strip retention treatments); and "intermediate harvests" (e.g., extended rotation treatments), in which initial harvests are designed to enhance or hasten structural characteristics associated with old-growth-like habitats. Current conclusions are that logging operators successfully harvested with little damage to residual trees, that windthrow can be managed through crown manipulation, and that regeneration development (planted and natural) beneath dispersed trees differs from that in a clearcut.

KEYWORDS: *clearcut harvesting, dispersed retention, extended rotation, natural regeneration, silvicultural treatments, stand structure.*

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Introduction

Social, legislative, and stewardship issues are driving forest managers to consider alternatives to clearcutting for harvesting and managing forests in British Columbia. Trials established throughout the province are evaluating implications of various silvicultural systems on a range of ecosystem attributes. The Roberts Creek Study Forest (RCSF), north of Vancouver, is one of these trials. Located along the lower slopes of the southwest coast within mature, mixed-conifer forests, the RCSF consists of seven blocks harvested over a 7-year period (1993–2000), which demonstrate a range of tree retention patterns and harvest levels (Figure 1). Post-harvest monitoring to date has focussed on, but has not been limited to, stand structure (e.g., windthrow) and planted and natural regeneration development.

Current Study Objectives

The current study objectives are to:

- monitor and describe windthrow within harvested treatments and unlogged control areas;
- monitor and describe development of planted Douglas-fir and western redcedar, and the natural regeneration within the harvested blocks; and
- describe management implications of alternative retention patterns for meeting regeneration objectives and longer-term target stand objectives.

Study Site Description

Site and forest stand conditions within the majority of the RCSF include the following:

- Dry Maritime Coastal Western Hemlock biogeoclimatic subzone (CWHdm) between 350 to 590 m elevation
- southerly aspect and level to gentle slope (10%)
- Humo-Ferric Podzol soils with thin (5 cm) humus and an average 80 cm rooting depth

The mixed-species forest typically dominated by Douglas-fir (*Pseudotsuga menziesii* [Mirbel] Franco) by volume also contains western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*). Current forests initiated after fires in the mid-1860s. Stands are now in the stem exclusion phase (closed overstorey canopy) with sparse understorey vegetation and a low density of saplings and regeneration.

The overall goal of the RCSF trial was to create a range of tree retention patterns within which to monitor

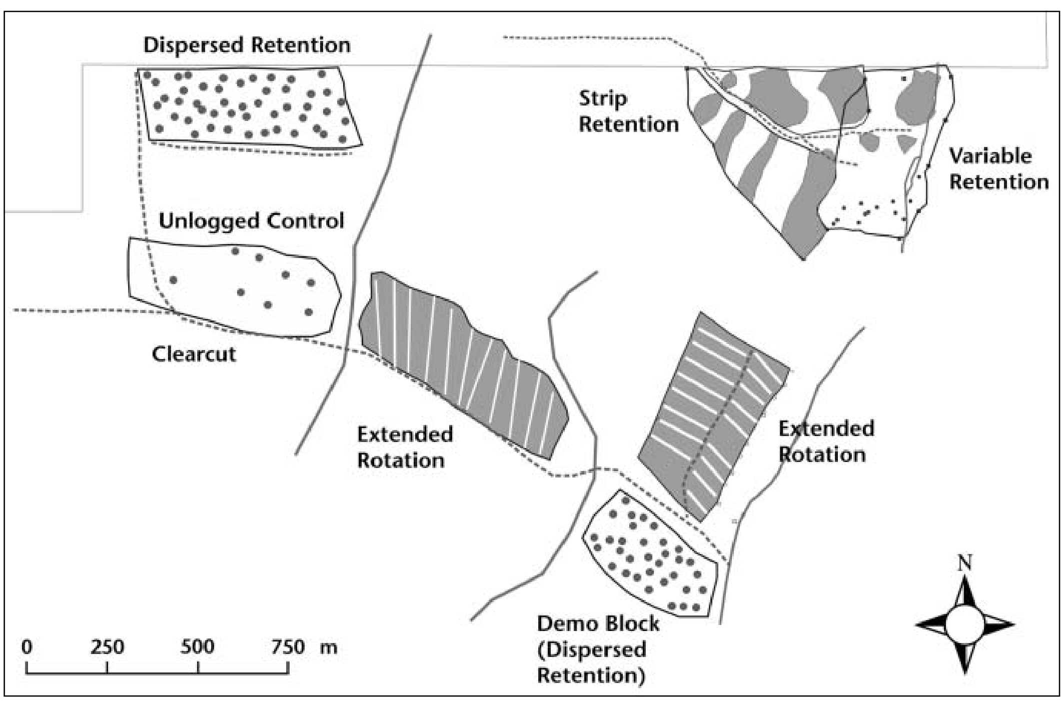

FIGURE 1. Layout of harvested blocks in Roberts Creek Study Forest (1993–2000).

attributes of interest. Silviculture prescriptions prepared for each treatment specified harvesting methods (restricted to manual falling and cable yarding), long-term target stand objectives, and regeneration obligations. An initial "Demo Block," designed in 1993 as a two-pass system retaining dominant, dispersed Douglas-fir and redcedar, provided operational experience and a demonstration of dispersed retention (DR). Hemlock was not retained because of concerns about excessive natural regeneration. West of the Demo Block were three blocks (Phase 1) harvested in 1996–1997 that consisted of a clearcut (CC) area retaining 1 stem per hectare, a two-pass DR area with final retention of Douglas-fir and western redcedar at 20–30 stems per hectare, and an extended rotation (ER) area with commercial thinning plus an unlogged control area located between the clearcut and the DR blocks. The ER prescription was designed to accelerate old-growth attributes through extending rotation age, to use thinnings to periodically reduce stand density, and to enhance understorey vegetation and regeneration development. Characteristics desired included a greater range of tree sizes including larger trees (> 100 cm DBH), well-developed intermediate canopies, and the presence of snags and downed logs. The initial entry of Phase 1 ER prescribed removal of 11% stand volume in narrow corridors (4–5 m) oriented roughly north–south. North of the Demo Block was Phase 2, harvested in 1999–2000. This phase consisted of a strip retention (SR) block with 50% of stand volume removed in strips ranging from 40 to 100 m in width, a variable retention (VR) block retaining both aggregated (in groups) and dispersed trees, and an ER block. The Phase 2 ER prescription was similar to that in Phase 1 except that the removal volume was higher (18% stand volume) and the orienting corridors were parallel to the dominant easterly winds. Each phase was harvested by a single operator.

Methods

Monitoring focussed on meeting long-term target stand structure objectives described for each harvested block. Windthrow was 100% sampled in Demo and Phase 1 blocks (including the unlogged control area) and was subsampled in Phase 2 blocks. Growth and condition of spring-planted Douglas-fir and redcedar seedlings were monitored in all harvested blocks. Monitoring of natural regeneration density used fixed-area, circular sampling plots. Seedfall was monitored in the Demo and Phase 1 blocks (unlogged control and DR) using seed traps. Seed traps were emptied yearly and counted by species.

Results

The results are summarized in two treatment categories:

1. "Regeneration harvests," which included treatments with specific reforestation targets and obligations (e.g., clearcut, variable, dispersed, and strip retention treatments); and
2. "Intermediate harvests" (e.g., extended rotation treatments), in which initial harvests were planned and designed to hasten the development of structural complexity typical of old-growth stands.

Regeneration harvests specify Douglas-fir as the primary species for regeneration and western redcedar and hemlock as secondary. Target densities were set at 900 stems per hectare.

Regeneration Harvests

Post-harvest retention objectives were met. Manual falling and cable yarding caused little damage to residual trees (e.g., 6.7% of trees scarred in the Demo Block). Falling and cable yarding caused little disturbance to soil substrate. Mineral soil was exposed on less than 3% of any harvested block. Mixed humus and mineral soil occurred on less than 5%.

Windthrow amongst aggregated and dispersed trees and windward block boundaries (e.g., the west clearcut boundary) followed fall and winter winds after harvest. Windthrow amongst dispersed trees in the Demo Block began in the fall after harvest. Five years after harvest, residual density declined from 57 to 39 stems per hectare, a 31% windthrow rate. For the Phase 1 DR treatment, in which 95 stems per hectare were retained, block-wide sampling estimated the windthrow rate at 22% after 5 years. (Note: Recent additional fixed-plot sampling suggests this estimate is low.) Retained strips at right angles to dominant wind direction in the SR treatment (Phase 2) were especially prone to windthrow during harvesting, and necessitated crown treatments (tree topping and branch pruning). Crown treatments were also applied to trees throughout the VR block including both dispersed and aggregated trees. Crown treatments appeared effective in preventing blowdown 3 years after treatment.

Natural regeneration development differed considerably between the DR (Demo and Phase 1 blocks) and the CC blocks. In the Demo DR block, despite no hemlock retention, hemlock dominated the natural regeneration composition because surrounding forests released hemlock seeds. The highest level of dispersion was in year 3 (266 000 seeds per hectare). Both

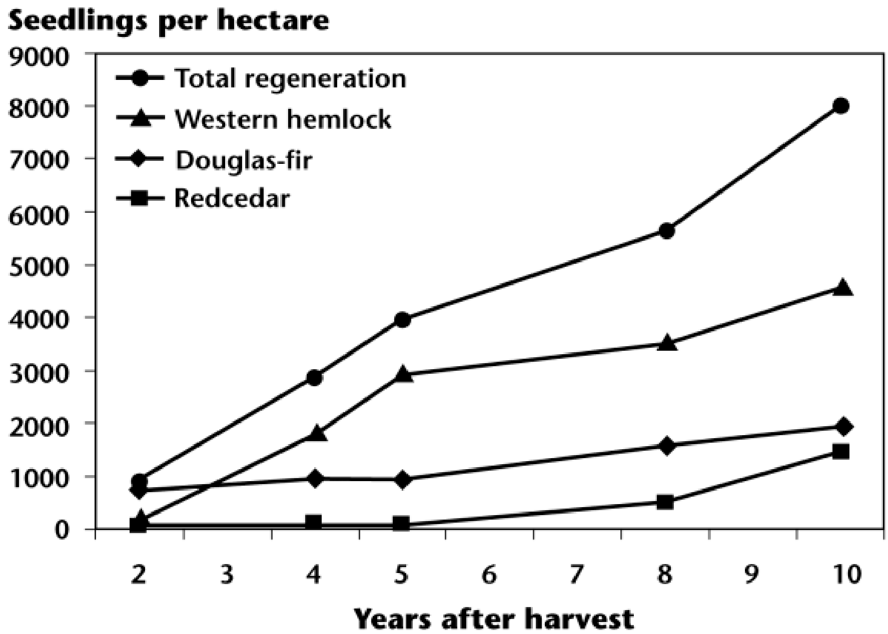

FIGURE 2. Natural regeneration density by species over 10 years in the demonstration dispersed retention (DR) block.

hemlock and total natural regeneration density increased in the 10 years after harvest (Figure 2). Douglas-fir seedfall was highest in year 2 (1.3 million seeds per hectare) with regeneration establishment most successful on mineral soil. Redcedar establishment was delayed and peaked in year 3 (1.75 million seeds per hectare). In the Phase 1 DR treatment, hemlock dominated natural regeneration as found in the Demo block. Total density was more than 100% greater than in the CC block (Figure 3). The low level of Douglas-fir regeneration in the Phase 1 DR treatment was attributed to poor Douglas-fir cone crops and low seedfall in the 3 years after harvest.

In the Phase 1 CC and DR blocks, planted Douglas-fir and redcedar survival (Figure 4) and growth (Figure 5) was greater in the CC block. Seventh-year height and stem caliper in the CC block was approximately double that in the DR block. Seventh-year total height of Douglas-fir (366 cm) and redcedar (370 cm) exceeded stated minimum free-growing height obligations. Planted Douglas-fir in both DR blocks developed stem galls attributed to Douglas-fir cone worm larvae (*Dioryctria* ssp.). After 8 years, over 25% of planted Douglas-fir in the Demo Block developed the stem galls, and over 50% of Douglas-fir seedlings in the Phase 1 DR block had galls by year 7. Low stem gall

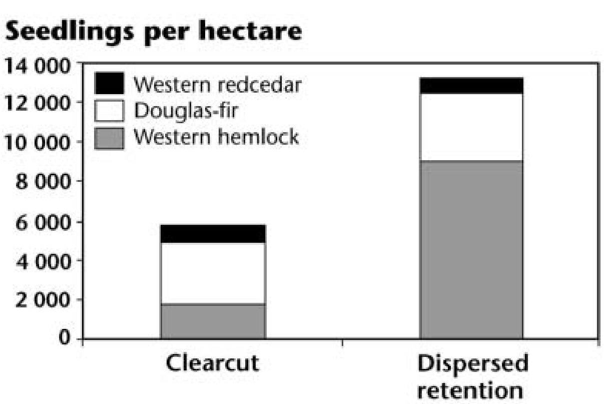

FIGURE 3. Seventh-year natural regeneration density by species in Phase 1 clearcut and dispersed retention blocks.

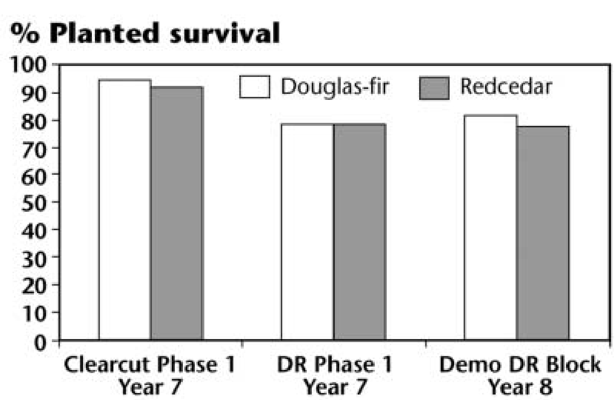

FIGURE 4. Survival of planted Douglas-fir and western redcedar by treatment and year of assessment.

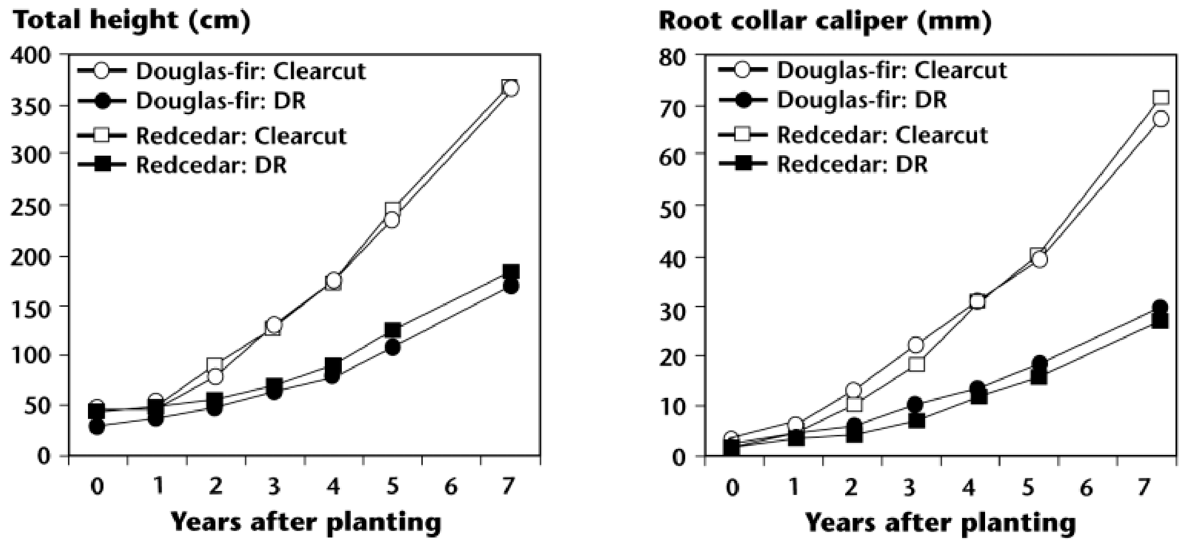

FIGURE 5. Height and root collar caliper of planted Douglas-fir and western redcedar (years 1–7 after planting).

incidence in the CC block (2%) implied the presence of dispersed trees for gall development. Galls similar to those on planted Douglas-fir have been found on upper branches of windthrown Douglas-fir.

Intermediate Harvests

Yarding corridors in the Phase 1 ER block increased windthrow rates slightly compared to the unlogged control (< 1 tree per hectare over a 5-year measurement period), but remained far below the rates in the regeneration harvests. Windthrow rates in the Phase 2 ER block, with yarding corridors approximately parallel to the direction of dominant winds, were twice that of the Phase 1 ER block with corridors at right angles to dominant winds.

In the ER treatments, western hemlock dominated natural regeneration development within the yarding corridors, with little regeneration establishing in the unlogged portions of the block. Survival of planted western redcedar in the Phase 1 ER treatment was highest in the corridors (over 90% after 7 years), although height growth remained slow, averaging 5 cm over the last 2 years. Declining redcedar survival in unlogged portions of the initial ER treatment (45%) suggested cedar establishment requires overstorey gap creation. Douglas-fir survival (60% in corridors and 4% in unlogged portions) lagged behind redcedar. The annual height growth of surviving Douglas-fir seedlings (2 cm/yr) reflected very low vigour. In the Phase 2 ER block, planted western redcedar and Douglas-fir survival exceeded 85% both within and outside the yarding corridors. These are higher than the rates in the Phase 1 ER block. This is perhaps a result of corridor width and orientation.

Some Conclusions to Date

Some conclusions that can be drawn from this trial include the following.

- Despite a lack of experience with partial cutting, logging operators, using a range of different cutting patterns, successfully harvested with little damage to residual trees.
- While dispersed and aggregated trees are subject to windthrow, it can be managed through crown manipulation. Selection of dispersed trees based on diameter, species, microsite, and alignment of timber edges to dominant winds can also be used for managing windthrow.
- Regeneration development (planted and natural) beneath dispersed trees differs from that in a clearcut. The differences include reduced seedling growth, increased natural regeneration density, and enhanced Douglas-fir stem gall development, all of which affect the ability to meet free-growing obligations.

Results of regeneration monitoring during the 2004 field season are currently being summarized and will be published and made available on the Internet as has past research within the RCSF (see *http://www.for.gov.bc.ca/rco/research/projects/RCSF/RCSF.htm*).

Acknowledgements

The Roberts Creek Study Forest began as an initiative under the provincial Silvicultural Systems Program started in the early 1990s to promote investigation of alternatives to clearcutting. This program funded the establishment of the project; subsequent funding came from the regional research program. Establishment of the Roberts Creek Study Forest would not have been possible without the constant support of the Sunshine Coast Forest District staff in the Sechelt and Powell River offices. Their contributions are sincerely appreciated.

Extended Abstract

Development of a biological control strategy to mitigate hemlock dwarf mistletoe in retention silviculture systems: *Colletotrichum gloeosporioides*–western hemlock dwarf mistletoe pathosystem

Sue Askew[1], Simon F. Shamoun[2], and Bart J. van der Kamp[3]

Abstract

Global concern about enhanced habitat diversity and sustainable forests expressed by wood product consumers has resulted in a change from clearcut to variable retention (VR) practices. The change to VR, however, opens stands and exposes western hemlock crowns to light, which can activate latent western hemlock dwarf mistletoe infections. An inundative biological control using the fungus *Colletotrichum gloeosporioides* may provide another method of control for western hemlock dwarf mistletoe, especially in variable retention areas and riparian and sensitive ecosystems. This study focussed on: determining a lead isolate through pathogenicity screening of PFC *C. gloeosporioides* for the field study; comparing the efficacy of *C. gloeosporioides* using a Stabileze and a sucrose and gelatin formulation; and determining the mode of infection of *C. gloeosporioides* on western hemlock dwarf mistletoe. Stabileze and sucrose-gelatin treatments formulated with *C. gloeosporioides* were shown to decrease the number of shoots and berries of dwarf mistletoe within a 3–4 month period, although it appeared that this biological control may not have the ability to kill dwarf mistletoe swellings. *Colletotrichum gloeosporioides* was re-isolated mainly from outer bark (44–71%) compared to living bark and wood (0–32%) for all the PFC 2415 formulation treatments. No re-isolation occurred in any of the dead wood samplings. Additional findings are summarized and discussed, and several research priorities are suggested. Further research in enhancing *C. gloeosporioides* efficacy and determining the mode of *C. gloeosporioides* infection on dwarf mistletoe is required.

KEYWORDS: *biological control, forest pests, variable retention.*

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Askew, S., S.F. Shamoun, and B.J. van der Kamp. 2006. Development of a biological control strategy to mitigate hemlock dwarf mistletoe in retention silviculture systems: *Colletotrichum gloeosporioides*–western hemlock dwarf mistletoe pathosystem. Extended Abstract presented at the Variable Retention Forestry Science Forum, April 21–22, 2004. *BC Journal of Ecosystems and Management* 7(1):23–29. URL: ***http://www.forrex.org/publications/jem/ISS34/vol7_no1_VRForum.pdf***

Introduction

Global concern about enhanced habitat diversity and sustainable forests expressed by wood product consumers of has resulted in a change from clearcut to variable retention (VR) practices (Mitchell and Beese 2002). The change to VR can result in an increase in the amount of western hemlock dwarf mistletoe (*Arceuthobium tsugense* [Rosendahl] G.N. Jones) infections in hemlock stands (*Tsuga heterophylla* [Raf.] Sarg.). Variable retention opens stands, exposing hemlock crowns to light that activates latent dwarf mistletoe infections. Latent dwarf mistletoe plants may produce seeds that can infect adjacent regenerating stands (Mathiasen 1996; Shamoun and DeWald 2002). Damage by dwarf mistletoe may result in a loss of tree growth and tree vigour, a reduction in wood quality, an elimination and reduction of healthy seeds and cones, and an increased susceptibility to diseases and tree death (Mathiasen 1996).

A biological control strategy may provide a method for controlling western hemlock dwarf mistletoe that involves no toxic chemicals and has relatively little impact on the environment. An inundative biological control using the fungus *Colletotrichum gloeosporioides* (Penz.) Penz. and Sacc. may provide an alternative method of control for western hemlock dwarf mistletoe, especially in VR areas and riparian and sensitive ecosystems (Parmeter *et al.* 1959; Charudattan 1989; Shamoun and DeWald 2002).

Colletotrichum gloeosporioides attacks the shoots and berries of dwarf mistletoe on western hemlock. A biological control strategy to control hemlock dwarf mistletoe can enhance natural disease events, which interferes with the dwarf mistletoe life cycle resulting in a reduction of seeds (Shamoun and DeWald 2002). To develop *C. gloeosporioides* as an inundative biological control agent, it is important to understand its biology, pathogenicity, mode of infection, and spread and persistence in the field, as well as the suitable formulations to be used. The ultimate goal of this research is to substantially reduce the ability of the treated dwarf mistletoe plants to produce seeds.

The research objectives of this study are:

- to determine a lead isolate through pathogenicity screening of PFC *C. gloeosporioides* for the field study;
- to compare the efficacy of *C. gloeosporioides* using a Stabileze and a sucrose and gelatin formulation; and
- to determine the mode of infection of *C. gloeosporioides* on western hemlock dwarf mistletoe.

Methods and Materials

Five isolates from three different locations in British Columbia were used for screening a potential *C. gloeosporioides* isolate for a field trial. The five isolates were grown on millet for 7 days to produce conidia for the screening trial. After 7 days, the conidia were harvested and adjusted to a concentration of 10^6 conidia per millilitre in 20 mL of sterilized distilled water using a haemocytometer. For each isolate, conidia suspended in the distilled water were sprayed onto six detached dwarf-mistletoe-infected hemlock shoots. Mycelial growth and conidia germination trials were also conducted on the five isolates. PFC 2415 was selected for a field trial at Spider Lake in the Nanaimo Forest District located on Vancouver Island as the lead isolate based on pathogenicity, vigorous growth, and speed of conidia germination. Mass conidia of PFC 2415 were produced on millet and formulated into a Stabileze formulation using the procedure described by Quimby *et al.* (1999) and a 2% sucrose and 0.5 % gelatin suspension described by Trujillo *et al.* (1994).

The field site consisted of western hemlock trees infected with dwarf mistletoe. The experimental design was completely random. A total of 237 clean *A. tsugense* swellings showing no evidence of fungal parasites were assigned to seven treatments. Before treatments were applied, the tagged cut shoot treatments and the controls were prepared by cutting off all the shoots at the base. The number of replicates for each treatment is listed in Table 1.

The goal of the Spider Lake trial was to determine the formulation efficacy, field performance, and mode of infection of *C. gloeosporioides*. Each tagged swelling was sprayed with a treatment until run-off. Treatments involved spraying Stabileze with the PFC 2415 on intact shoots (Stabileze treatment) and cut shoots (cut shoot Stabileze treatment). A Stabileze with no inoculum was sprayed on intact shoots (Stabileze control) and on cut shoots (cut shoot Stabileze control). Intact shoots were sprayed with the sucrose-gelatin suspension, with PFC 2415 (sucrose and gelatin treatment) and without inoculum (sucrose and gelatin control). Water spray was applied to intact shoots as a negative control (water control). For the Stabileze treatments and controls, 5 g of the granular formulation was mixed with 500 mL of distilled water and mixed for 30 minutes before field application. No preparation was required for sucrose and gelatin suspensions. The treatments used for the trial are listed in Table 1.

TABLE 1. Description of treatments used on the tagged Spider Lake dwarf mistletoe swellings, which included both shoots and berries

Treatment no.	Treatment description	Inoculum	No. replicates
1	Intact shoots treated with Stabileze formulation	PFC isolate 2415	35
2	Intact shoots treated with 2% sucrose and 0.5% gelatin suspension	PFC isolate 2415	35
3	Cut shoots treated with Stabileze formulation	PFC isolate 2415	35
4	Intact shoots treated with 2% sucrose and 0.5% gelatin suspension	No inoculum	35
5	Intact shoots treated with Stabileze formulation	No inoculum	35
6	Cut shoots treated with Stabileze formulation	No inoculum	36
7	Intact shoots treated with water spray	No inoculum	27

Treatments 1, 2, 4, 5, and 7 were used to determine the efficacy of *C. gloeosporioides* on the dwarf mistletoe shoots and berries. Treatments were applied on 29 August 2002 at the Spider Lake field site. Assessments were conducted on a biweekly basis for the first month followed by monthly assessments for 10 months. The number of replicates for berries and shoots is shown in Tables 2 and 3, respectively.

Destructive sampling included all the treatments to determine the mode of *C. gloeosporioides* infection including its ability to infect the endophytic system of hemlock dwarf mistletoe. A total of 83 swellings were collected and cultured for 10 months after the treatments were applied. Destructive sampling included dissecting the outer bark, living bark and wood, and dead wood from each sample, then surface sterilizing each wood tissue. Each tissue type was placed on potato dextrose agar plates for re-isolation of *C. gloeosporioides*. The number of destructive wood samples is listed in Table 4.

Results from the Spider Lake Trial

Analysis of Dwarf Mistletoe Berry Health

A two-way ranked ANOVA performed on the Spider Lake dwarf mistletoe berry data showed a significantly lower number of healthy berries for treatments formulated with *C. gloeosporioides* compared to control treatments ($p = 0.01$). The inoculum treatments reduced the number of healthy berries to 34–36% compared to their respective controls (72–76% healthy berries). No significant differences were detected between these two formulations (Figure 1).

TABLE 2. Number of hemlock dwarf mistletoe samples for each treatment for the berries analysis

Treatments	No. samples	No. berries per swelling
1	14	794
2	14	773
4	13	283
5	18	1120
7	4	370

TABLE 3. Total number of hemlock dwarf mistletoe sampled for each treatment for the shoot analysis

Treatment no.	No. healthy shoots on first assessment
1	513
2	556
4	480
5	499
7	348

TABLE 4. The number of dwarf mistletoe swellings used for each treatment for the destructive sampling

Treatment no.	No. sampled
1	9
2	7
3	22
4	7
5	7
6	18
7	13

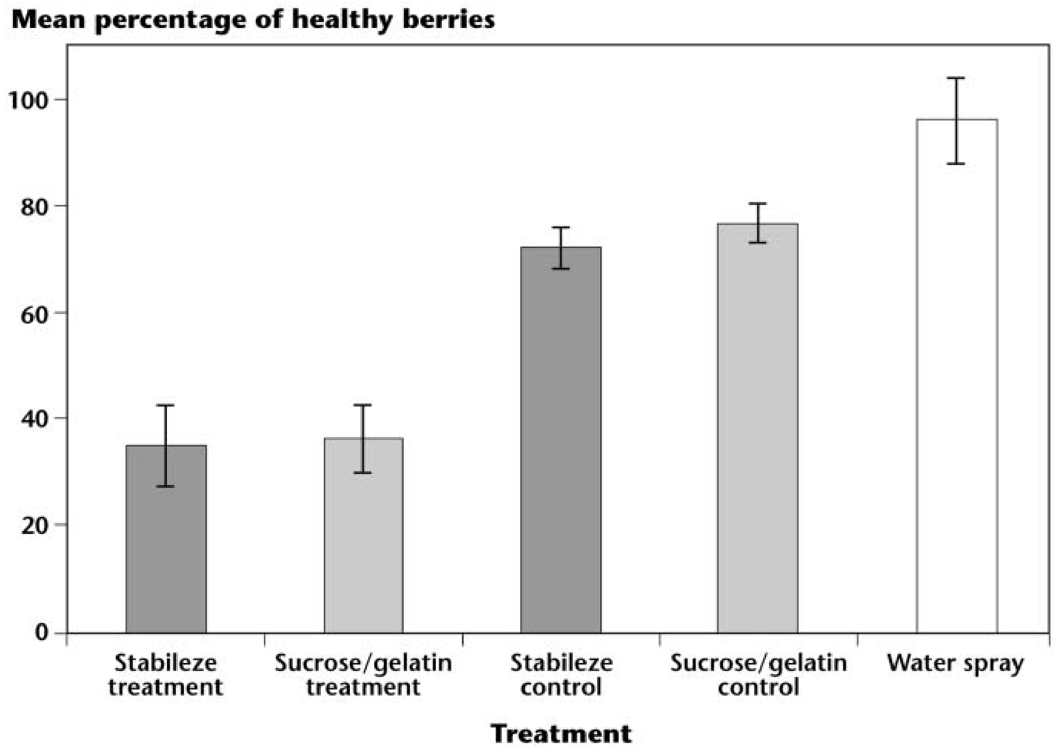

FIGURE 1. Percentage of healthy *Arceuthobium tsugense* berries 3 months after treatments were applied.

Analysis of Dwarf Mistletoe Shoot Health

Dwarf mistletoe shoot analysis was conducted by analyzing the number of healthy shoots per swelling for each treatment within an assessment period. A general decline was noted in the number of healthy hemlock dwarf mistletoe shoots in the control treatments and the *C. gloeosporioides* formulations throughout the 10-month assessment period.

A two-way ranked repeated ANOVA detected a significantly lower number of healthy hemlock dwarf mistletoe shoots in the treatments formulated with PFC 2415 for November and December ($p = 0.06$). The highest reduction in the number of hemlock dwarf mistletoe shoots was 27% for the Stabileze formulation in November (3 months after treatments were applied) and 25% for the sucrose-gelatin formulation in December (4 months after treatments were applied) compared to the control treatments. No significant differences were detected for dwarf mistletoe shoot health between these treatments using two-way repeated ANOVA for September, January, February, and May (Table 5).

Determining the Mode of Infection of *C. gloeosporioides* within Hemlock Dwarf Mistletoe Swellings

A chi-square test ($p = 0.01$) demonstrated that *C. gloeosporioides* was re-isolated mainly from outer bark (44–71%) compared to living bark and wood (0–32%) for all the PFC 2415 formulation treatments. No re-isolation was found in any of the dead wood samplings. The Stabileze cut shoot treatment re-isolated *C. gloeosporioides* 32% in living bark and 3% in dead wood tissue. The sucrose and gelatin treatments re-isolated *C. gloeosporioides* 14% in living bark. No *C. gloeosporioides* re-isolated in living bark for the Stabileze treatment. With the exception of the cut treatment, no *C. gloeosporioides* re-isolated from the dead wood.

For the water control, 8% *C. gloeosporioides* was recovered from the outer bark. The cut Stabileze control showed 6% recovery of *C. gloeosporioides* in the outer bark. No *C. gloeosporioides* was recovered from the living bark or dead wood for any of the controls. The re-isolation of *C. gloeosporioides* from the water control indicates that a low level of background inoculum of *C. gloeosporioides* was present on this site.

TABLE 5. Percentage of healthy hemlock dwarf mistletoe shoots for each treatment for each assessment date

Treatments	No. shoots	Sept	Nov	Dec	Jan	Feb	May
1	513	89.6a[a]	68.4a	54.3a	53.9a	48.3a	16.7a
2	556	80.1a	63.1a	37.9a	32.7a	23.1a	12.5a
4	480	92.0a	96.1b	69.1b	68.2a	51.8a	42.9a
5	499	82.6a	79.5b	63.3b	25.8a	27.6a	21.0a
7	348	100a	86.6b	67.9b	42.3a	26.7a	32.3a

[a] Mean percentage of healthy shoots followed by the different letters are significantly different from each other ($p < 0.05$).

Discussion

Biological control of hemlock dwarf mistletoe is very appealing from the standpoint of reduced costs and residue problems compared to the use of chemical herbicides such as Florel®. Other advantages of biological control include a reduction in the removal of infected hemlock trees, especially in riparian and ecologically sensitive areas (Shamoun and DeWald 2002).

Berry and Shoot Analysis

Under ideal environmental conditions, the application of large quantities of virulent endemic inoculum would favour the disease onset to the host. For this project, massive doses of isolate PFC 2415 inoculum were applied to the mistletoe to control outbreaks of *A. tsugense*. Since endemic pathogens are already adapted to the ecoclimate and host conditions in a given area, the provision of abundant inoculum improves the chances of the onset of the disease process (Charudattan 1989).

The Spider Lake trial results implied that PFC 2415 formulation treatments applied to berries can reduce the number of healthy berries by 36% after 3 months using Stabileze and 34% using sucrose-gelatin inoculum. No differences between the inoculum treatments were observed in this trial.

A significant decrease in the number of healthy shoots was noted in November and December, 3–4 months after inoculation with PFC 2415. For treatment 1 (Stabileze formulation), it took 3 months for the highest level of shoot disease to occur. For treatment 2 (sucrose and gelatin formulation), it took 4 months for a significant increase of disease symptoms to occur. No significant differences in the number of healthy shoots were noted between the inoculum treatments and the controls after 10 months. The number of shoots for all treatments generally declined as the trial progressed. This may be because the average life of individual aerial shoots is 2–3 years, although some shoots can produce at least three crops of flowers during a life span of 5 years (Smith 1977). Shading is another factor than can reduce the vigour of a swelling, especially if it is found on the lower third of the tree (Smith 1977; Smith 1985). Other factors that contribute to shoot loss are environmental conditions such as drought (as seen in 2002). Hawksworth and Wiens (1996) suggested that *Arceuthobium* spp. is not an xerophytic plant. Before and during our data collection, the weather was hot and dry. The hemlock dwarf mistletoe response to the dry conditions, or any other environmental stress, could have triggered shoots to drop off during the assessment period. Handling of the dwarf mistletoe shoots may have triggered shoot loss over the 10-month period.

Destructive Sampling

Numerous researchers have suggested that *Colletotrichum* species can infect the endophytic systems of dwarf mistletoe. Parmeter *et al.* (1959) observed that *C. gloeosporioides* invaded the endophytic system of *Arceuthobium campylopodum* f. *abietinum* on red fir. Methods of determining *C. gloeosporioides* invasion of the endophytic system to date have not been replicated (Ramsfield 2002).

Destructive sampling of the Spider Lake *A. tsugense* swellings was used to determine whether *C. gloeosporioides* invades the endophytic system by culturing the outer bark, living bark, and wood. The ability of *C. gloeosporioides* to infect the endophytic system of *A. tsugense* would be indicated by the re-isolation of *C. gloeosporioides* in the living bark and dead wood tissue. Death to the endophytic system would reduce the number of shoots and reproductive shoots, increasing the longevity effect of the biological control and reducing the number of applications of this biological control to maintain the reduction of *A. tsugense* (Shamoun and DeWald 2002). Investigating the role of *C. gloeosporioides* in the infection process of *A. tsugense* may give better insight into the *C. gloeosporioides* biology and infection cycle. Developing a genetic transformation system by introducing a reporter gene, Green Fluorescent Protein (GFP gene), into *C. gloeo-sporioides* will allow researchers a more accurate method of tracing the infection cycle within hemlock tissues.

Results from culturing western hemlock woody tissues infected with *A. tsugense* and inoculated with the treatments indicate that the fungus rarely invades the endophytic system. The higher re-isolation of *C. gloeosporioides* in the cut shoot treatments revealed that abscised dwarf mistletoe shoots may provide easier access for this fungus to enter *A. tsugense* living bark and dead wood (Muir 1977). The destructive tissue results indicate that more than one application of formulated *C. gloeosporioides* would be required to reduce dwarf mistletoe using PFC 2415 isolate formulated with Stabileze or sucrose and gelatin.

Conclusions

Colletotrichum gloeosporioides seemed to initiate disease in *A. tsugense* berries and shoots within the first 3–4 months after inoculation. Destructive sampling revealed that *C. gloeosporioides* does not attack the endophytic system unless shoots are abscised or cut near the base of the basal cup. The Stabileze with inoculum sprayed on cut shoots showed that *C. gloeosporioides* invaded the living wood of a hemlock branch infected with *A. tsugense*. Muir (1977) also suggested that aerial shoots killed by *C. gloeosporioides* may provide secondary entry points for other fungi to invade and kill the endophytic system of dwarf mistletoe.

Further research is required to determine the effect of field applications of *C. gloeosporioides* on *A. tsugense* berries and shoots, the spread of the disease, any other damages, and the reduction of *A. tsugense* intensification (Shamoun and DeWald 2002). Several research priorities need to be addressed, including:

- continued screening for the most efficacious *C. gloeosporioides* isolates;
- determining the mode of infection of *C. gloeosporioides* through histopathological investigations;
- fine-tuning the formulations and their shelf life;
- understanding host susceptibility;
- determining the efficacy of *C. gloeosporioides* conidia under control and field conditions; and
- using dwarf mistletoe models to predict the long-term effects of the biological control agent in reducing the spread of hemlock dwarf mistletoe.

The findings of this research may result in an economically successful method of controlling *A. tsugense* by using a virulent isolate of *C. gloeosporioides*.

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Extended Abstract

Development of a biological control strategy to mitigate hemlock dwarf mistletoe in silviculture systems: *Neonectria neomacrospora* hemlock dwarf mistletoe pathosystem

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Abstract

The current demand for non-clearcutting forestry practices is expected to result in substantially increased hemlock dwarf mistletoe infection because a much larger proportion of regenerating trees will be within the range of mistletoe seed dispersal from infected residual trees. Consequently, it has become necessary to develop alternative methods for its control. In this study, we investigated the effectiveness of *Neonectria neomacrospora* as an inundative biological control agent for hemlock dwarf mistletoe. Specifically, we determined whether wounding facilitates infection of mistletoe swellings by *N. neomacrospora* and measured the effect that successful infection had on dwarf mistletoe shoot production. Based on our results, the wounded, inoculated treatment had the greatest effect on *N. neomacrospora* infection. These findings do not concur with the inoculation study by Funk *et al.* (1973), perhaps because of the different time frames of the two studies. Although the extent of bark necrosis for the unwounded, inoculated treatment was not huge, the treatment had 39% more *N. neomacrospora* re-isolation success than its respective control. Although all dwarf mistletoe swellings lost shoots over the trial period, the confirmed group lost significantly more than the unconfirmed group ($p = 0.025$). In addition, more swellings from the confirmed group did not have shoots. Overall, infection of hemlock dwarf mistletoe by *N. neomacrospora* reduced the number of healthy shoots by 38%. This extended abstract presents a summary of the study results and its implications, and suggests some future research needs.

KEYWORDS: *biological control, forest pests, variable retention.*

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Introduction

Hemlock dwarf mistletoe (*Arceuthobium tsugense* [Rosendahl] G.N. Jones) occurs along the Pacific coast from Alaska to California. Primary hosts for *A. tsugense* are hemlock (*Tsuga heterophylla*) and shore pine (*Pinus contorta* var. *contorta*) (Hawksworth and Wiens 1972). Damage caused by *A. tsugense* consists of volume losses and reduced merchantability of wood by the production of large knots, development of abnormal grain, reduction in the strength of the wood, and occasionally dieback (Calvin and Wilson 1996).

The current demand for non-clearcutting forestry practices is expected to result in substantially increased mistletoe infection because a much larger proportion of regenerating trees will be within the range of mistletoe seed dispersal from infected residual trees. As a consequence of these changes in forest management, it has become necessary to develop alternative methods of control for *A. tsugense*. To date, chemical control of dwarf mistletoe has been limited to Ethephon (Florel®, active ingredient 2-chloroethyl phosphoric acid), which has shown contradictory results as a dwarf mistletoe shoot abscisor and has not been tested on *A. tsugense* (Gill 1956; Quick 1964; Scharpf 1972; Hawksworth and Johnson 1989). Although some evidence shows within-species resistance to infection by *A. tsugense,* research is still in its early stages (Shamoun and DeWald 2002). Biological control of several species of dwarf mistletoe has also been investigated, but none are as yet in use. A review of the many fungal parasites associated with dwarf mistletoes can be found in Hawksworth and Geils (1996).

The purpose of this study is to investigate the effectiveness of *Neonectria neomacrospora* (Booth and Samuels) Mantiri and Samuels (anamorph *Cylindrocarpon cylindroides*) as an inundative biological control agent for *A. tsugense*. This fungus inhabits the swollen endophytic region of the hemlock branch infected by *A. tsugense.* It is only weakly pathogenic to healthy host tree tissue. Infection of *A. tsugense* swellings by *N. neomacrospora* is often associated with resinosis, sunken cankers, dead aerial *A. tsugense* shoots, and in some cases, girdling and death of the infected branch (Funk *et al.* 1973). Other symptoms include significantly fewer and smaller *A. tsugense* shoots, shorter maximal distance between *A. tsugense* shoots, and a slower rate of swelling and elongation of the endophytic system (Smith and Funk 1980). The objectives of this trial were:

1. to determine whether wounding facilitates infection of *A. tsugense* swellings by *N. neomacrospora*; and
2. to measure the effect of successful infection on *A. tsugense* shoot production.

Methods

The field trial was established in a young hemlock stand heavily infested with *A. tsugense* near Parksville, Vancouver Island, British Columbia. The site was distributed across approximately 2 ha in the Coastal Western Hemlock biogeoclimatic zone (Meidinger and Pojar 1991). Hemlock was the primary tree present in the site and ranged in age from 5 to 40 years. Symptoms and signs of *N. neomacrospora* were present on the site.

Before commencing the field trial, the growth characteristics of six isolates of *N. neomacrospora* were measured. From this data, PFC 2559 was determined to be the most "vigorous" fungal isolate and was used in the field trial. Mass conidia were produced on sterile rice and formulated into Stabileze using the procedure described by Quimby *et al.* (1999). On the day of the treatment application, 5.0 g of the dried formulation was added to 500 mL of sterile distilled water. The solution was alternatively hand-shaken and stirred on a rotary shaker for 30 minutes, or until the formulation was mixed thoroughly. The final concentration of spores was approximately 54 000 conidia per millimetre. For each treatment, the Stabileze solution was hand-sprayed onto the *A. tsugense* infection until run-off.

A total of 90 *A. tsugense* infections of varying ages were selected, tagged, and assigned one of five treatments. Treatments were assigned randomly, regardless of the sex, size, or location of the *A. tsugense* infection in relation to other infections. Treatments involved spraying Stabileze onto unwounded (W–I+) or wounded (W+I+) *A. tsugense* infections, or spraying a control Stabileze (no spores) onto unwounded (W–I–) or wounded (W+I–) *A. tsugense* infections. Wounding of the *A. tsugense* infection involved cutting through the bark of the mistletoe swelling at several points using a sterile razor blade. The control treatment was used as a background control and was left untreated. There were 20 replicates of treatments W–I+, W+I+, W–I–, and W+I–, and 10 replicates of the control treatment. Inoculation occurred on 29 August 2002.

At 10 months, the experimental units were destructively sampled. The extent of bark necrosis and the occurrence of sporodochia were measured, and re-isolation of *N. neomacrospora* from the *A. tsugense* swellings was attempted. The extent of bark necrosis for each *A. tsugense* swelling was based on the circumference of bark necrosis at the widest point divided by the total circumference of the swelling at that point. Sporodochia were confirmed based on spore morphology. Re-isolation involved cutting 10 small sections from the bark and wood, then surface sterilizing them for 2 minutes in each of 10% bleach and 95% ethanol, followed by three washes of sterile distilled water. Preference was given to necrotic bark margins and wood beneath necrotic bark regions. The sterile sections were then plated onto potato dextrose agar and allowed to grow at room temperature. They were monitored weekly for 3 weeks.

Data were analyzed using SimgaStat 2.03 (Access Softek Inc. 1995). The extent of bark necrosis, the occurrence of sporodochia, and the successful re-isolation of *N. neomacrospora* for each treatment were used to address the first objective—to determine whether wounding facilitates infection of *A. tsugense* swellings by *N. neomacrospora*. The extent of bark necrosis was determined using analysis of variance. The occurrence of sporodochia and re-isolation of *N. neomacrospora* from the *A. tsugense* swellings were determined using chi-square analysis.

To address the second objective—to measure the effect of successful infection on *A. tsugense* shoot production—*A. tsugense* infections from all treatments were re-grouped based on whether or not infection of the mistletoe by *N. neomacrospora* had occurred. Confirmation that *N. neomacrospora* had infected the *A. tsugense* swellings was based on successful re-isolation of the fungus and (or) the occurrence of sporodochia. Chi-square analysis was used to determine whether any difference was evident in the number of healthy *A. tsugense* shoots at the end of the trial between the confirmed and unconfirmed groups.

Results

At 10 months, the proportion of *A. tsugense* swellings bearing sporodochia was significantly greater for the wounded, inoculated treatment (W+I+, 50%; $p = 0.014$) when compared to the unwounded, inoculated treatment (W–I+, 10%; $p = 0.014$). Significant differences in the extent of bark necrosis were observed for wounded ($p < 0.001$) and inoculated ($p < 0.001$) treatments. A statistically significant interaction was evident between wounding and application of inoculum ($p = 0.015$). No significant difference was evident between the proportion of swellings with successful re-isolation for the wounded, inoculated treatment (W+I+, 73%) and the unwounded, inoculated treatment (W–I+, 55%; Figure 1). The difference between the wounded, inoculated treatment (W+I+) and its respective control (W+I–) was nearly significant ($p = 0.056$). The difference between the unwounded, inoculated treatment (W–I+) and its respective control (W–I–) was significant ($p = 0.028$).

At 10 months, when grouped according to confirmed or unconfirmed infection by *N. neomacrospora*, the *A. tsugense* group with confirmed infection had 35.8% significantly fewer healthy shoots than the unconfirmed group ($p = 0.025$; Figure 2).

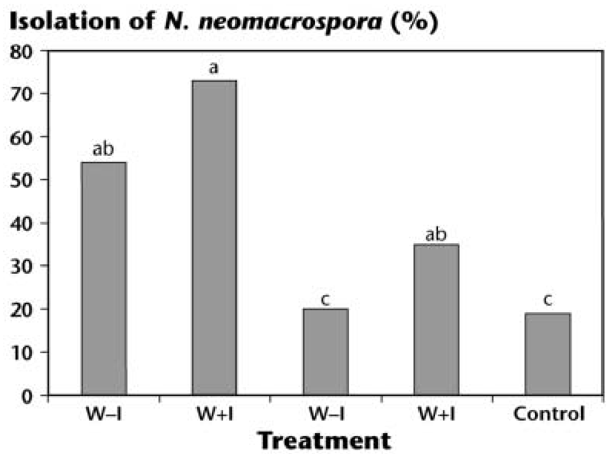

FIGURE 1. Percentage of *A. tsugense* from which *N. neomacrospora* was successfully re-isolated.

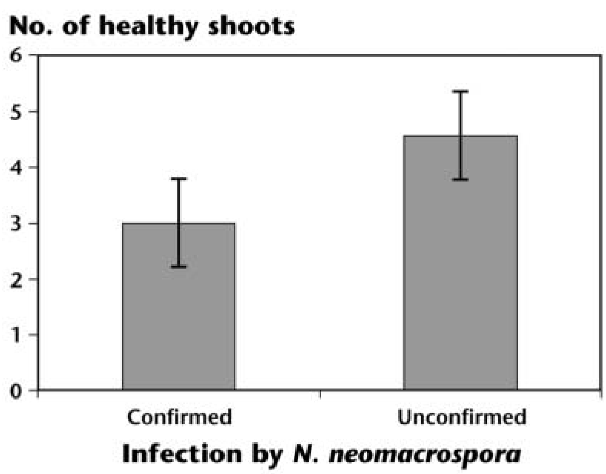

FIGURE 2. The mean number of healthy *A. tsugense* shoots observed for confirmed infection and unconfirmed infection groups. Bars measure standard error of the mean.

Discussion

Wound-related response to fungal attack is a complex process that involves necrosis (death) of host tissue at the site of pathogen attack. Successful pathogens are able to initiate infection and overcome host defence and compartmentalization. Although much potential exists to use necrotizing fungi as a biological control strategy, only a few studies have been conducted to do so.

Establishment of an inoculation procedure for *N. neomacrospora* is necessary before it can be further assessed as a biological control agent for hemlock dwarf mistletoe. Although some previous inoculation work has occurred with *N. neomacrospora* on dwarf mistletoe (Byler and Cobb 1972; Funk *et al*. 1973; Smith and Funk 1980), this is the first large field trial to use different wounding techniques.

Bark necrosis of an *A. tsugense* swelling is a symptom commonly associated with *N. neomacrospora* infection that often leads to cankering and girdling of the swelling (Funk *et al*. 1973; Smith and Funk 1980). It is advantageous to use bark necrosis to quantify *N. neomacrospora* infection because it is easy to measure and is consistently correlated with *N. neomacrospora* infection. Although some bark necrosis occurred in almost all the *A. tsugense* swellings regardless of treatment, a strong linear relationship was observed ($r^2 = 0.93$) between different classes of bark necrosis and the proportion of *A. tsugense* swellings from which *N. neomacrospora* was successfully re-isolated.

Based on our results, the wounded, inoculated treatment had the greatest effect on *N. neomacrospora* infection. These findings do not concur with an inoculation study done by Funk *et al*. (1973) where *N. neomacrospora* was successfully established after applying mycelial inoculum to undisturbed *A. tsugense* basal cups or young shoots. However, inoculated *A. tsugense* swellings in their trial were monitored for almost 2 years after treatment, and some *A. tsugense* swellings did not show signs of infection until as late as 21 months.

The disease development of *N. neomacrospora* is slow and can take a year or longer to establish symptoms (Funk and Baranyay 1973). The long-term effect of *N. neomacrospora* infection (i.e., 1 year or longer) was not measured in the large field trial because it was terminated at 10 months. Although the extent of bark necrosis for the unwounded, inoculated treatment was not huge, the treatment had 39% more *N. neomacrospora* re-isolation success than its respective control ($p = 0.028$; Figure 1). It is possible that development of symptoms and signs of disease (i.e., bark necrosis and sporodochia) in the unwounded, inoculated treatment is slower than the wounded, inoculated treatment. The effect of the unwounded, inoculated treatment on *A. tsugense* shoot health may therefore be larger in the long term when disease has had sufficient time to develop.

Measuring the number of healthy shoots is important because it estimates how much *N. neomacrospora* infection reduces *A. tsugense* reproduction. Since *N. neomacrospora* acts perennially, shoot reduction is expected to continue and negatively affect the ability of *A. tsugense* to produce inoculum in the year(s) following treatment. The effect of *N. neomacrospora* infection on the number of *A. tsugense* berries on female plants could not be measured directly because an insufficient number of healthy, female plants were available at the field site. In addition, since berries are produced annually, at least one complete year of data would be required before the effect of *N. neomacrospora* infection on the number of healthy berries could be determined. *Arceuthobium tsugense* shoots are produced throughout most of the year and remain attached to the *A. tsugense* infection. It is not known whether *A. tsugense* plants are pollen-limited. The effect of *N. neomacrospora* infection on the extent of bark necrosis and the occurrence of girdling were measured because these factors are expected to affect the number and health of *A. tsugense* shoots.

Although all *A. tsugense* swellings lost shoots over the trial period, the confirmed group lost significantly more than the unconfirmed group ($p = 0.025$; Figure 2). In addition, more *A. tsugense* swellings from the confirmed group did not have shoots. Overall, infection of *A. tsugense* by *N. neomacrospora* reduced the number of healthy shoots by 1.6 shoots, or 38%. These data were similar to those observed by Funk *et al*. (1973), who attributed a 30% reduction in the number of *A. tsugense* shoots to *N. neomacrospora* infection.

The confirmed group also had significantly more bark necrosis and girdling than the unconfirmed group. Although parts of the *A. tsugense* swelling were girdled, or had a large extent of bark necrosis, the swelling could still bear numerous healthy shoots in unaffected areas. As bark necrosis develops in infected *A. tsugense* swellings, the effect of *N. neomacrospora* on the number of healthy shoots is expected to increase.

At present, the unwounded, inoculated treatment is the only feasible treatment for use in the field to control *A. tsugense*. The necessity of wounding before inoculating is impractical for large-scale control. Wounding vectors, frost damage, and emerging

A. tsugense buds and basal cups may provide some natural wound entry points for *N. neomacrospora* infection (Byler *et al*. 1972). Insect galleries and larvae were observed in some of the destructively sampled *A. tsugense* swellings, but the identity of the insects was not determined. Further research is required into manipulation of wound vectors to increase *N. neomacrospora* infection.

The unwounded, inoculated treatment reduced the number of healthy *A. tsugense* shoots by about 14%. The true impact of the unwounded, inoculated treatment on the number of *A. tsugense* shoots at 9 months may have been greater because of the large loss of shoots across all treatments during the trial. The long-term effects of *N. neomacrospora* infection on *A. tsugense* shoot and swelling vigour is expected to be larger than that observed in the large field trial.

Closing Remarks

Neonectria neomacrospora is a unique biological control agent for *A. tsugense* because of its host specificity and its infection mechanism. This fungus attacks the swellings of *A. tsugense* and has the potential to exert a long-term negative impact on seed production. In some cases, *N. neomacrospora* may girdle and kill the *A. tsugense* swelling (Funk *et al*. 1973).

Unless an effective wounding mechanism is discovered, applying *N. neomacrospora* inoculum to unwounded *A. tsugense* swellings is the only economically feasible approach to control *A. tsugense*. Although the initial effect of the unwounded, inoculated treatment on *N. neomacrospora* infection appeared minor, it cannot be dismissed as a potential biological control method. It is possible that disease development (i.e., bark necrosis and sporodochia) is slower for the unwounded, inoculated treatment, and that the long-term effect on *A. tsugense* vigour will be greater than that observed in the large field trial.

Results from the trial also suggest that, once established, *N. neomacrospora* can significantly reduce *A. tsugense* shoot numbers by 38% in 9 months. Based on the extent of bark necrosis and girdling of the *A. tsugense* swellings observed during destructive sampling, the effect of *N. neomacrospora* infection on shoot vigour was lower than anticipated. Again, the extent of bark necrosis and girdling of the *A. tsugense* swellings are expected to have a greater, long-term effect on shoot production and the *A. tsugense* life cycle.

In the future, it would be interesting to measure the long-term effect of *N. neomacrospora* infections on *A. tsugense*, as well as on other dwarf mistletoe species. The rate of bark necrosis spread in the swellings is of particular interest, as it can determine whether *A. tsugense* is able to outgrow *N. neomacrospora* infections. It would also be worthwhile to determine whether *N. neomacrospora* isolates from different locations vary in levels of virulence, and to confirm whether this fungus is able to infect other hosts such as *Abies* spp. Combining *N. neomacrospora* with other *A. tsugense* pathogens such as *Colletotrichum gloeosporioides* is also worth investigating. The study of natural *A. tsugense* wound vectors, which may allow for increased infection of *N. neomacrospora* in the field, is also of interest. Finally, the use of molecular markers in the early detection of *N. neomacrospora* infection is an important contribution in the study of host–pathogen interactions.

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Test Your Knowledge . . .

How well can you recall some of the main messages in the preceding perspectives paper and extended abstracts? Test your knowledge by answering the following questions.

Variable Retention Forestry Science Forum: Overview and key messages, by Kathie Swift

1. Why was the retention system introduced?
2. What should guide your application of the retention system?
3. Name at least one knowledge gap that still exists related to this area of practice?

***Green tree retention: A tool to maintain soil function after harvest, by Susan Grayston* et al.**

4. Green tree retention may conserve the soil biotic community and its important nutrient cycling processes after harvest because living trees supply carbon from their roots and litter for growth of soil organisms.
   A) True
   B) False

Does group retention harvesting protect amphibian habitat? by Elke Wind and Glen Dunsworth

5. Aquatic-breeding amphibians were selected as a suitable group to investigate variable retention harvesting because:
   A) They respond negatively to extreme climatic conditions found in clearcuts
   B) They may be attracted to ponds in cutover areas due to the warmer waters
   C) Variable retention often results in retention patches being left around small ponds not normally buffered
   D) All of the above

Windthrow and conifer regeneration amongst a range of retention patterns within the Roberts Creek Study Forest, by Brian D'Anjou

6. Trees retained in a dispersed pattern are subject to windthrow. To limit the amount of windthrow, what factors should be considered when selecting a tree for retention?
   A) Tree diameter
   B) Microsite
   C) Direction of dominant winds
   D) All of the above

Development of a biological control strategy to mitigate hemlock dwarf mistletoe in retention silviculture systems: Colletotrichum gloeosporioides–western hemlock dwarf mistletoe pathosystem, by Sue Askew, Simon F. Shamoun, and Bart J. van der Kamp

7. The biological control agent *Colletotrichum gloeosporioides* is most effective in reducing hemlock dwarf mistletoe:
   A) Berries
   B) Shoots
   C) Swellings
   D) Flowers

Development of a biological control strategy to mitigate hemlock dwarf mistletoe in silviculture systems:* Neonectria neomacrospora *hemlock dwarf mistletoe pathosystem, by Lea M. Rietman, Simon F. Shamoun, and Bart J. van der Kamp

8. The biological control agent *Neonectria neomacrospora* is most effective in reducing hemlock dwarf mistletoe:
   A) Shoots
   B) Berries
   C) Swellings
   D) Flowers

ANSWERS

1. To address social issues around the practice of forestry on a public land base.

2. Your goals and objectives for the land base.

3. Effects of insects and diseases, impact on growth and yield, interactions on stand growth and development with the addition of dispersed or aggregated retention, etc.

4. A 5. D 6. D 7. A 8. A