MONITORING WESTERN HEMLOCK DWARF MISTLETOE \((\textit{Arceuthobium tsugense}\) subsp. \(tsugense\)) IN COASTAL BRITISH COLUMBIA (2009-10):
YEAR-END REPORT FOR
Project No. 6886003 Sunshine Coast TSA and Project 6884002 Arrowsmith TSA.

by

\textbf{John A. Muir} PhD RPF (Ret)
Owner and Forest Pathologist
John Muir Consulting
2881 Heath Drive
Victoria British Columbia Canada  V9A 2J6
tel.: 250 477 1805
johnmuir@consultant.com

March 31, 2010

For:

\textbf{Warren Warttig}, RPBio, Senior Planning Biologist,
International Forest Products Ltd
Forestry & Land Use Division
1250-A Ironwood Street
Campbell River, British Columbia V9W 6H5
tel: 250 286 5168  warren.warttig@interfor.com
### Table of Contents

Abstract......................................................................................................................................................................3  
Introduction ...............................................................................................................................................................4  
Introduction ...............................................................................................................................................................5  
Background and Introduction ....................................................................................................................................6  
  Biology and effects of hemlock dwarf mistletoe: ..................................................................................................7  
  Effects of forest practices on hemlock dwarf mistletoe infestations: .................................................................7  
  Monitoring hemlock dwarf mistletoe infestations: ..............................................................................................9  
  Monitoring hemlock mistletoe seed dispersal: ......................................................................................................9  
Objectives ................................................................................................................................................................10  
Methods ...................................................................................................................................................................10  
Results .....................................................................................................................................................................11  
Discussion................................................................................................................................................................15  
Acknowledgements .................................................................................................................................................16  
References ...............................................................................................................................................................17  
Appendix 1. HDM Seed Dispersal results and analyses ..........................................................................................20  
  Development of methods and monitoring data ....................................................................................................25  
  Establishment of monitoring plots .......................................................................................................................27  
  Re-measurement of HDM monitoring plots ........................................................................................................28  
  Monitoring hemlock mistletoe seed dispersal ......................................................................................................28  
  Aerial surveys of infested trees............................................................................................................................30  
  Publications and reports.......................................................................................................................................31

### Abstract

Forest Investment Account, Innovative Project 6886003 Sunshine Coast TSA and Project 6884002 Arrowsmith TSA, were undertaken in coastal British Columbia young, western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) forests to monitor the seed dispersal of hemlock dwarf mistletoe (*Arceuthobium tsugense* (Rosendahl) G.N. Jones subspecies *tsugense*). The goal of the monitoring projects is to provide baseline data that facilitate sustainable management of retention-harvested, mistletoe-infested coastal forests. Seed traps were established at 5m, 10m, 15m and 20m distance from three residual, mistletoe-infested trees: two near the previously established monitoring plot at Wilson Creek near Sechelt in the Sunshine Coast TSA, and one tree (Tree II) previously sampled at block UC5C, near Ucluelet, in the Arrowsmith TSA. Numbers of mistletoe seeds caught were 35 and 122 at the two trees at Wilson Creek, and 7 at block UC5C. Most mistletoe seeds were caught on the traps set at 5m from the source trees. At Wilson Creek, the numbers of seeds decreased logarithmically with increasing distance from the source trees. No seeds were caught on the traps set at 20m from the source trees at Wilson Creek and none on the traps at 15 and 20m at UC5C. A summary of previous results from the mistletoe monitoring projects from January 2005 to March 31, 2009 is appended.
- This page intentionally left blank -
Introduction

These projects\(^1\) were undertaken to monitor the infection of young western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) in coastal British Columbia (BC) retention-harvested forests by western hemlock dwarf mistletoe (*Arceuthobium tsugense* (Rosendahl) G.N. Jones subspecies *tsugense*, HDM). There were several reasons or considerations for initiating these recent projects, including:

1. HDM is a common, damaging parasite of western hemlock in coastal British Columbia forests (Hennon et al. 2001, Muir and Hennon 2007);
2. Spread of HDM from residual infested trees and infection of regenerating trees can be substantial within a few years (Bloomberg and Smith 1982; Smith 1966, 1973, 1977);
3. Retention harvesting that leaves numerous HDM-infested trees could result in substantial infestation of residual trees and regenerating forests;
4. Actual data on rates of spread of HDM and its infection of young hemlock in coastal BC are limited to a multi-year study of one residual tree (Smith 1966, 1973, 1977; Smith et al. 1993), and a detailed survey of HDM infestation of several stands of regenerating trees on southern Vancouver Island (Bloomberg and Smith 1982);
5. Spread of HDM appears slower than expected in some areas, particularly in mid- and north-coast BC, based on observations of low incidences of HDM, and several reports reviewed by Muir and Hennon (2007) that indicated very slow rates of HDM infestation in higher elevation (650m or greater) forests in BC and in low elevation/high latitude forests in southeastern Alaska;
6. Information on HDM biology and effects in young trees and recommended practices to reduce or prevent infestations have been based mostly from studies in 4, above, of regenerating trees in clear-cut forest areas;
7. Current monitoring programs for certification of sustainable forest management practices lack sufficient detail for determining occurrences, severity and effects of HDM infestations; and
8. Free-growing assessments of western hemlock regeneration in coastal forests includes a criterion that regeneration trees situated within 10m distance of a residual mistletoe-infested hemlock are not acceptable as future crop trees. This criterion is based on limited data on spread and impacts of HDM as mentioned above, and does not take into account any locations or features of residual trees that appear to be associated with more or less extensive spread and impacts of the parasite.

Therefore, the goal of the monitoring has been to develop methods and to determine data on the spread and infection of young western hemlock trees by HDM that will facilitate sustainable management of retention-harvested, HDM-infested coastal forests.

The 2009-10 FIA projects were to monitor HDM seed dispersal near the monitoring plots at: 1) Wilson Creek, near Sechelt, in the Sunshine Coast Timber Supply Area, coastal western hemlock dry maritime (CWHdm) biogeoclimatic subzone; and 2) in the Ucluelet-Tofino area of the Arrowsmith TSA, coastal western hemlock hypermaritime (CWHvh) biogeoclimatic subzone. This year-end (March 31, 2010)

---

\(^1\) In March 2010, FIA project MC 6851 008 was undertaken to survey hemlock dwarf mistletoe infestations in the Mid-Coast TSA for potential monitoring plots and seed trap establishment. Results are reported separately.

Background and Introduction
Western hemlock is an “opportunity” species in over 3.5 million hectares in coastal British Columbia, where it is a major to dominant component of tree species (T. Niemann, personal communication, British Columbia Ministry of Forests and Range, July 24, 2003). In many mid- and northern-coastal timber supply areas, western hemlock constitutes up to 80 percent of the total tree volume available for harvest (Forest Practices Board 2008). One of the major challenges to ensure long-term sustainability of coastal forest resources is to manage infestations of HDM, particularly in retention-harvested areas (Beese et al. 2003, Coast Region Implementation Team 2006, Forest Practices Board 2008, Muir and Hennon 2007).

In coastal forests, HDM occurs frequently and often is damaging (Muir and Hennon 2007, Hennon et al. 2001). Data on incidence and impact of HDM in British Columbia are scarce or lacking for most areas. Hildebrand (1995) compiled inventory data that included occurrence and severity of HDM infestation in Washington and Oregon. Muir et al. (2004b) extrapolated their results to 2.7 million hectares of coastal British Columbia, timber-producing, western hemlock forests and estimated that reduction in growth of mature trees due to HDM infestations could total 1 million cubic meters per year. However, impacts of HDM in immature and managed forests in British Columbia have yet to be determined, nor have the ecological benefits of HDM infestations been quantified.

Data on spread and effects of HDM are scarce, limited to a few southern geographic areas and usually are quite variable. Consequently, since 1995 in several FIA projects we have been monitoring HDM infection of young trees in retention-harvested areas on the west coast and northern Vancouver Island, and on the mainland in the Sunshine Coast TSA. The methods that we developed and data acquired for several recent monitoring projects were described in FIA project reports (Muir 2005, 2006, 2007, 2008, 2009, available on-line at the Ministry of Forests and Range Research Branch library website). Monitoring HDM seed dispersal should give an early indication of where HDM infestation could become severe or less so in future.

Distance of HDM seed dispersal from infested trees is a critical component in determining whether young trees adjacent to infested trees should be considered “free growing” for regeneration assessments. Currently, it is assumed that young western hemlock trees within 10m of an infested tree will become severely infested and unacceptable as future crop trees. However, as mentioned above, data on dispersal of HDM seeds are limited to results from a multi-year study of only one tree on southern Vancouver Island and in other areas dispersal distances are unknown and could be quite different.

Results of this monitoring project are needed to provide more extensive baseline data on infestations of HDM in coastal forests and to facilitate long-term sustainable management. Data on HDM effects on tree growth and
timber quality appear essential for determining timber supply projections and silviculture strategies. However, such data for HDM-infested western hemlock forests, particularly for second-growth trees and retention-harvested forests are very limited and have not been applied to timber projections. Further, monitoring methods developed here should facilitate development of more extensive monitoring methods to determine forest-level effects of HDM. Finally, monitoring results should provide valuable data for developing and applying an HDM component for tree-based growth models (Muir 2003) such as the Tree and Stand Simulator (Goudie and DiLucca 2004) and/or forest-level ecosystem models for evaluating impacts on tree growth in HDM-infested coastal forests.

Biology and effects of hemlock dwarf mistletoe:
HDM spreads within tree crowns and between trees by small seeds that are explosively discharged in October to distances of 10 to 15 meters. HDM seeds hit needles on branches or stems, lodge at the base of needles, germinate in spring and penetrate into the tree bark and sapwood. If infection is successful, a swelling develops within two to five years. Usually, in two or more years, a proliferation of branches called a witches broom develops on the swelling. Over periods of several decades, swellings and witches brooms grow in size and multiply in tree crowns. When 50 percent or more of branches on a tree become infested, annual tree growth is reduced by 15 to 40 percent (Thomson et al. 1985).

HDM swellings and witches’ brooms reduce wood quality, strength and commercial value of old growth trees (Wellwood 1956). Infested trees can have large HDM brooms and swellings weighing 50 to 100 kg or more. These infections often result in substantial associated compression wood, wood decay and breakage of branches and boles, resulting in substantial waste and breakage during felling and harvesting. Often, severely HDM-infested trees are a safety concern for forest workers, recreational users and building owners.

Infestations of HDM might have some positive ecological effects particularly in older, second-growth western hemlock forests. HDM infestations with infested, stunted and dead residual old-growth and second-growth trees can create stand openings and other tree features and/or local forest canopy or ecological conditions that could enhance habitat for wildlife species (Shaw et al. 2004). Although beneficial effects have been reported for other dwarf mistletoes and tree species, they have yet to be determined for HDM infestations (Muir and Hennon 2007). The extent of HDM infestations that should be retained or created per stand, and practices to establish or sustain infestations have to be determined.

Effects of forest practices on hemlock dwarf mistletoe infestations:
Muir and Hennon (2007) synthesized available information on HDM related to forest management, particularly for retention harvesting and uneven-aged management of infested forests, and identified knowledge gaps. They concluded that a wide variation and lack of data on HDM, particularly its spread and impacts in second-growth forests, resulted in considerable uncertainty.

---

2 With FIA funding and substantial effort and ongoing encouragement and support by W. Warttig, a shortened version of the review was prepared for British Columbia (Muir et al. 2007).
and at times controversy about its potential impacts in retention-harvested forests.

Until recently, HDM was considered to be a problem only in old-growth hemlock forests. Traditional clear-cut harvesting and silvicultural practices such as cutting residual infested trees and extensive planting of Douglas-fir, a species very rarely infected by HDM, drastically reduced the incidence of HDM in young, managed forests. Harvested sites were often broadcast burned and small residual trees were usually felled. Consequently, HDM appeared to be scarce and of little importance in coastal second-growth forests.

However, in recent years in British Columbia coastal forests, retention harvesting practices have been widely implemented to retain attributes of old-growth forests and maintain biodiversity (Beese et al. 2003). As a consequence of harvesting small blocks and retaining many live trees in reserved blocks and/or scattered or dispersed trees in harvested areas, HDM-infested trees often have been deliberately or inadvertently retained (Edwards 2002, Forest Practices Board 2008). These residual infested trees are situated in positions which many mistletoe researchers believed, or have observed are optimal for extensive infection of nearby regenerating young trees (Buckland and Marples 1952, Muir and Hennon 2007, Trummer et al. 1998). Retention of infested trees therefore could enhance HDM spread and result in more severe future growth impacts and other detrimental effects (Hennon et al. 2001, Muir and Hennon 2007).

In mature or old growth forests, small understory trees are exposed to HDM seed for several decades and often become infested. After a disturbance such as logging or wind storms, some of these infested residual trees can grow rapidly, can become sources of large numbers of HDM seeds (Smith 1966, 1973, 1977) and can become severely infested dominant or co-dominant trees in the new stand (Thomson et al. 1985). In southeastern Alaska, the spread of HDM from infested residuals to young trees is slow, possibly because there HDM is almost at the northern latitudinal and upper altitude limits of its geographical range (Muir and Hennon 2007). However, in southeastern Alaska in older second-growth forests severity of HDM infestation is directly proportional to the sizes and numbers of residual infected trees that survive a windstorm disturbance (Trummer et al. 1998).

HDM in coastal British Columbia retention-harvested forests was recognized as an important forest health issue by the coastal region implementation team consisting of industry and government-employed forestry professionals (Coast Region Implementation Team 2006). Recently, an audit by the Forest Practices Board (2008) in several selectively harvested, high-retention coastal forests indicated that HDM was common and regarded as an important issue for future productivity.

Unfortunately there are few data on occurrence, spread and impacts of HDM infestations in many areas that are either clear-cut or retention-harvested and managed as uneven- or even-aged forests. Data on infection of young hemlock in coastal British Columbia are limited to a multi-year study of one residual tree by Smith (1966, 1973, 1977) and Smith et al. (1993), and a detailed survey of several stands of regenerating trees on southern Vancouver Island (Bloomberg and Smith 1982). Conditions that affect tree growth and HDM impacts appear highly variable in coastal forests, depending on ecological
zones, harvest practices, long-term forest management, geographic location and other possible factors. Further data are needed on incidence, spread and potential future impacts of HDM to determine and substantiate the best approach for forest management on an individual stand basis and for management of landscapes or large forest areas.

Monitoring hemlock dwarf mistletoe infestations:
Recent initiatives to ensure sustainable forestry and resource management practices require monitoring of the health of forests including the health of regenerating young trees in harvested areas. Most current monitoring procedures include measurements of criteria and indicators of forest health (Canadian Council of Forest Ministers 2006, sections 2.4, 2.5, 5.3.4), but almost solely for epidemics of bark beetles and defoliating insects. Most criteria and indicators are inadequate to characterize incidence, severity and long-term impacts of many other chronic or recurrent infestations of forest insects and pathogens, particularly HDM (Muir et al. 2004a). Therefore, procedures needed to be developed for monitoring HDM in young retention forests (Muir 2005, 2006, 2007).

From our initial work on the FIA monitoring projects and our review of the literature (Muir and Hennon 2007), we concluded that the most economical approach to monitor effects of HDM was to select representative, infested residual trees and determine spread and infection of adjacent young trees. We recognized that this approach does not give an unbiased sample of HDM occurrences and infection of young trees. However, monitoring HDM spread from several residual infested trees in a wide range of stand, geographical and ecological conditions should give useful, basic data on HDM spread and infection.

Monitoring hemlock mistletoe seed dispersal:
Another approach to monitor hemlock mistletoe spread and infection was to determine dispersal of mistletoe seeds from residual infected trees.

Results of Smith (1966, 1973, 1977) suggested that the number of HDM seed dispersed from infested trees could indicate their relative infectivity or importance as sources of mistletoe infection before infection of young trees was evident. Data on dwarf mistletoe seed dispersal could be used with models of dwarf mistletoe spread, e.g., Robinson et al. (2002), Robinson and Geils (2006), to estimate HDM spread and future impacts.

Distance of mistletoe seed dispersal from infested trees is a critical component in determining whether young trees adjacent to infested trees should be considered “free growing” for regeneration assessments. Currently, it is assumed that young trees within 10m of any infested tree will become severely infested and will be unacceptable as future crop trees. However, as mentioned above, data on dispersal of hemlock mistletoe seeds from residual trees and subsequent infection of nearby young trees are limited to one tree on southern Vancouver Island and dispersal distances are unknown or suspected to be much less in other areas. Also, knowledge of features or characteristics of residual infested trees that indicate greater or less mistletoe seed dispersal would greatly facilitate management of the parasite. Monitoring of mistletoe seed dispersal could give an early indication of where HDM infestation will become more or less severe in the future.
Objectives
Based on the previous results of the monitoring projects and information outlined above, the following work objectives were proposed for the 2009-10 HDM-monitoring projects:

1. Determine HDM seed dispersal from selected trees in the Sunshine Coast and Arrowsmith Timber Supply Area.
2. Prepare a year-end report for both TSAs summarizing the work done, results and comparisons of data to previous results.

Methods
In 2009 for the projects in the Sunshine Coast and Arrowsmith TSAs, we established eight seed traps at two infested trees near the monitoring plot established in 2008 at Wilson Creek south of Sechelt (Figure 1) and eight seed traps at the infested Tree II monitoring plot at block UC5C, near Ucluelet Figure 2).

With one exception we selected single, relatively isolated residual infected trees, i.e., approximately 50m from any other residual infested tree, to facilitate comparisons with Smith (1966, 1973, 1977) results. Judging by the amount (or scarcity) of infection of young trees in some stands in our monitoring projects, we suspected that HDM seed dispersal could vary considerably from tree to tree, but there were no criteria available for selecting particular residual trees for monitoring. Selection of the mistletoe-infested trees for seed dispersal was based mainly on the accessibility of trees for installing seed traps and demonstration of results, and the previous establishment of monitoring plots at or near the same trees. We inspected young hemlock trees near the traps to ensure that HDM seeds were dispersed from the older residual trees and not from any of the regenerated young trees.

![Figure 1](image1.png)

**Figure 1.** Location of seed traps for hemlock dwarf mistletoe at Tree A and B near monitoring plot at Wilson Creek southeast of Sechelt, BC.

![Figure 2](image2.png)

**Figure 2.** Location of seed traps for hemlock dwarf mistletoe at tree II monitoring plot, block UC5C, Trestle Main, Ucluelet.
Only a few trees were selected because of the late start of the project and the imminent peak period of HDM seed dispersal in early to mid October. Our previous results of monitoring seed dispersal at UC5C and results of previous studies by Smith of seed dispersal from one infested tree on southern Vancouver Island indicated that most mistletoe seed dispersal occurs in a southerly direction and most HDM seeds land within 5 to 10m distance from an infested tree. For this study, we established 0.7m² cloth-covered, cedar frame traps at 5, 10, 15 and 20m from the base of the selected tree in a southerly direction. Each direction was selected to avoid or minimize vegetation and regenerating trees that could interfere with seeds dispersed from the source tree. Seed traps are constructed of 3 x 5cm cedar lumber made into 60 x 120cm frames which are covered with cotton muslin fabric. Traps are attached to 3 x 5cm stakes driven into the ground or attached to solid stumps or logs. Traps are placed with the 120cm-sides of the trap oriented towards the base of the source tree, and the farthest end of each trap is situated approximately at 5, 10, 15 or 20m distance from the tree.

We recorded the coordinates for each tree using a hand-held GPS and checked the extent of HDM seed dispersal in during late September to late October by inspecting berries and shoots on pistillate infections. On October 31 at Wilson Creek and November 4 at block UC5C, mistletoe seeds on the traps were counted. At Wilson Creek traps were removed and supporting stakes were left in position for possible monitoring of dispersal in 2010. At UC5C traps with attached HDM seeds were left in place.

Results
At Wilson Creek, two trees were selected and traps installed on September 26, 2009. Tree A was situated southeast of the previously established HDM monitoring plot at the edge or margin of a block of residual trees (Figures 3 to 6). There were three to six other HDM-infested trees approximately 5 to 10m to the north of Tree A in the residual stand. Because of the tree canopies
adjacent to tree A, it was not possible to get sufficient satellite signals to record GPS coordinates at the base of the source tree. Instead, we recorded coordinates at a junction of the forestry road approximately 200m west of the tree that were N 49 degrees, 27.561 minutes; W 123 deg., 41.413 min. Although the flagged tree is visible to the northeast from the junction, the easiest route from the junction to the tree is to walk or drive approximately 150m north of the junction along the road and then walk approximately 150m east along the margin of the residual stand to the tree. The two lines of seed traps at tree A were run at compass bearings of 240 and 290 degrees.

Tree B at Wilson Creek was a single infested tree situated approximately 200m north of the junction and 150m west of the road (Figures 7 and 8) at coordinates N 49 deg 27.630 min, W 123 deg 41.365 min.

Figure 5. Hemlock dwarf mistletoe seed traps along line 2 looking toward base of tree A (flagged with tape) at Wilson Creek, near Sechelt.

Figure 6. Upper crown of Tree A, Wilson Creek, showing hemlock dwarf mistletoe infestation.

Figure 7. Hemlock dwarf mistletoe seed traps at tree B, Wilson Creek, near Sechelt, looking east at trap 1, line 1, toward base of tree B.
Tree II at block UC5C was the centre tree for a monitoring plot established in 2005 near Ucluelet (Figures 9 and 10).

Lines of traps were run at 50 and 200 deg compass directions from the base of the source tree. When traps were inspected on October 31, a large forked stem from a western white pine situated approximately 30m from tree B had fallen and crushed the trap at the 20m distance on line one (50 deg). No HDM seeds were found on the trap cloth.

As expected, HDM seed dispersal occurred mostly in October. Inspection of HDM infested trees at several locations near Courtenay BC in mid-September indicated that most berries were green and difficult to detach from the stems. On October 28 at a site on Denman Island, with several severely infested trees, most berries had been discharged except for those on a few infections that were located near the stems of trees and that appeared shaded by tree foliage. On the monitoring plot at Wilson Creek, which had numerous infections on young trees (Muir 2009), we were unable to find any infections with berries on October
31. However at the time of installation of traps at tree B at Wilson Creek, we observed one HDM seed on the trap at 5m, line 1, just as the trap was being attached to the stakes. Apparently, some HDM seeds were dispersed before traps were installed.

Total numbers of HDM seeds caught in the seed traps were: seven at tree II near Ucluelet; 35 at Tree A; and 122 at Tree B near Sechelt. Numbers of HDM seeds per trap are shown in Table 1.

As found by Smith (1966, 1973, 1977) and results of other workers with other dwarf mistletoe and tree species, the number of HDM seeds caught decrease exponentially with distance from the source tree. Tests of the goodness of fit for linear correlations

\[ Y = a - bX \]

where

\[ Y = \log_{10} (\text{numbers of seeds} + 2) \]

and

\[ X = \text{mean distance of trap from the source tree} \]

indicated very significant \( r^2 = 0.8 \) to 0.9 relationships for numbers of HDM seeds and distances from the source tree (Appendix 1). Data for Tree II near Ucluelet were not analyzed because of the low numbers of HDM seeds caught. There appeared to be a significant difference between Tree A and Tree B due to the difference in numbers of seeds caught but we did not test this possibility.

In contrast to results of Smith (1973, Figure 4) who found approximately 170 HDM seeds per m\(^2\) at 5m distance from the source tree, we found that numbers of HDM seeds per m\(^2\) caught at 5m were much less: approximately 3 at Tree II near Ucluelet; 21 at Tree A; and 54 at Tree B, near Sechelt.

### Table 1. Numbers of hemlock dwarf mistletoe seeds caught in October 2009 on seed traps at tree II near Ucluelet, and tree A and B near Sechelt, BC.

<table>
<thead>
<tr>
<th>Location</th>
<th>Tree</th>
<th>Line</th>
<th>Mean distance (m) of trap from source tree</th>
<th>No. mistletoe seeds on 0.72m(^2) trap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ucluelet, block UC5C</td>
<td>II</td>
<td>1</td>
<td>4.4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9.4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14.4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>19.4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>4.4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9.4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14.4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>19.4</td>
<td>0</td>
</tr>
<tr>
<td>Sechelt, Wilson Creek</td>
<td>A</td>
<td>1</td>
<td>4.4</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9.4</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14.4</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>19.4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>4.4</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9.4</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14.4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>19.4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>1</td>
<td>4.4</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9.4</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14.4</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>19.4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>4.4</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9.4</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14.4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>19.4</td>
<td>0</td>
</tr>
</tbody>
</table>
**Discussion**

Other than by examining HDM shoot growth on infections and counting numbers of berries, or by sampling amounts of seeds dispersed, there are few means of determining or predicting which infested residual trees will produce more seed and thus more severe infestations of nearby young trees. Direct observation of HDM seed production in tall residual trees is difficult because most HDM shoot production occurs in the upper crown (Shaw and Weiss 2000). Devices such as scaffolds or mobile cranes are needed to determine HDM seed production in the mid- to upper crowns of residual trees, but this approach has not been possible with the limited funding for our projects. Currently, monitoring HDM seed dispersal using seed traps as in these projects appears to be the most feasible approach.

All of the HDM seeds were caught on traps within 10 to 15m of the infested source trees. However, these data, results of previous studies, e.g., Smith (1973), and particularly, the significant linear relationships that were found when our dispersal data were transformed to logarithmic values, suggest that HDM seed dispersal is not limited to a specific distance. The logarithmic relationships and the differences in numbers of HDM seeds caught between the three source trees illustrate that the maximum distance to which HDM seeds are dispersed is related to the number of HDM seeds produced on a source tree. With fewer HDM seeds produced on a source tree, seed dispersal distances are less, as was found at Tree II near Ucluelet.

The relationship between numbers of HDM seeds dispersed from source trees and rates of infection of nearby young hemlock trees needs to be established. Smith (1977) found that almost all of approximately 60 hemlock seedlings planted adjacent to the source tree were infested within approximately 10 years. At tree II near Ucluelet where low numbers of HDM seeds have been dispersed in recent years, only three young trees have been infested at approximately 10 years after the block was logged.

Results of these monitoring projects revealed that fewer HDM seeds were dispersed from three residual infested trees near Sechelt and Ucluelet than previously reported by Smith (1966, 1973, 1977) for one infested tree west of Lake Cowichan. Our results suggested that there were large differences in numbers of HDM seeds dispersed between areas and trees.

Several factors have been determined or postulated to affect HDM seed production, dispersal and infestation of young trees, including, for example:

a) number of residual infested trees per hectare, tree height and severity of HDM infection rating (DMR) of infested residual trees (Trummer et al. 1998);

b) growth or vigour of infested residual trees that affects HDM shoot growth and seed production (Bickford et al. 2005);

c) light conditions in forest canopies (Shaw and Weiss 2000);

d) differences in numbers of HDM seeds dispersed north, south, east and west from infested trees (Smith 1966, 1973, 1977);

e) more extensive spread from single dispersed or scattered residual trees as compared to spread from margins of reserve blocks of residual trees (Muir 1970); and

f) a combination of factors such as seed removal by rainfall and snow (Wicker 1967), damage to fruit by early frosts (Baranyay and Smith 1974), and slow development of HDM infections due to...
cooler temperatures associated with higher latitudes, higher elevations and cooler/wetter climatic subzones (Muir and Hennon 2007).

Although the number of trees monitored was small, the lower numbers of HDM seeds and large differences in numbers of HDM seeds dispersed per tree that we found, particularly in contrast to the results of Smith (1973), suggest that numbers of HDM seeds dispersed could be associated with differences in tree vigour, microsite or microclimate, and regional differences such as biogeoclimatic zone or subzone.

So far, our results have not met our expectation that HDM seed dispersal is greater from trees that appear more severely infested, based on the occurrence of large witches’ brooms. In 2005 and in 2006 at Ucluelet, 0 and 0.5 seeds per m² were trapped at 5 m from the bole of Tree I, and 4 and 8.6 per m², from Tree II. We expected that more dwarf mistletoe seeds would be dispersed from Tree I, which appeared more severely infested, with several large witches’ brooms throughout the crown.

HDM seed production appears to be affected by tree vigour. Tree I had a dead top with several dead witches’ brooms that could indicate poor or declining tree health or vigour. Bickford et al. (2005) determined that shoot production and spread of southwestern dwarf mistletoe on ponderosa pine was correlated with tree vigour and a similar relationship might exist for HDM on western hemlock. A similar study of effects of tree vigour on HDM seed dispersal appears warranted.

Regional differences in climate could have a significant effect on HDM seed dispersal. HDM shoot growth, seed production and seed dispersal appears more abundant and extensive in the warmer/drier CWHdm subzone than in the cooler/wetter CWHvh, vm and xm subzones (Muir 2009).

The relatively small differences in temperatures between the subzones suggests that climatic change, particularly temperature warming, could result in much faster and more extensive future spread of HDM in more northerly mid- to north-coastal regions. However, the possibility of more rapid spread of HDM due to climatic change is admittedly speculative.

The characteristics and/or attributes of infested western hemlock trees that are associated with dispersal of large or few numbers of HDM seeds have yet to be determined, and we believe that this is an important issue. More HDM-infested trees should be monitored to determine the importance of factors affecting HDM seed production and/or dispersal in different areas or ecosystems and to determine if there are substantial year-to-year variations in numbers of HDM seed dispersed. Further observations and data from HDM monitoring plots and likely other experimental studies are required to substantiate the effects of the various factors. Based on our results, further work to monitor seed dispersal and infection from various residual infected trees could provide very useful information to predict HDM spread, infection and growth effects on young trees in retention-harvested areas.

Acknowledgements
Several individuals substantially assisted the project work. These included:
• Vivian Muir, for technical services, support and on-going advice; and
• Warren Warttig, for continuing support.
References


Coast Region Implementation Team. 2006. Silviculture system and partial cut harvesting issues in the Coast Forest Region. Silviculture systems issues working group. Discussion paper. 40 p.


Smith, R.B.; Wass, E.F.; Meagher, M.D. 1993. Evidence of resistance to hemlock dwarf mistletoe (Arceuthobium tsugense) in


Appendix 1. HDM Seed Dispersal results and analyses
Results 2009

Wilson Creek  October 2009

**Hemlock dwarf mistletoe seed dispersal at Wilson Creek, 2009**

Tree A, approx. 21 seeds/m² at 5m distance; Tree B, 55 seeds/m²; Dick Smith (1973), 170 seeds/m²

**Tree A line 1**

<table>
<thead>
<tr>
<th>Distance trap from tree</th>
<th># HDM seeds caught</th>
<th># HDM seeds plus 2</th>
<th>log10 # seeds plus 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.4</td>
<td>16</td>
<td>18</td>
<td>1.255273</td>
</tr>
<tr>
<td>9.4</td>
<td>2</td>
<td>4</td>
<td>0.60206</td>
</tr>
<tr>
<td>14.4</td>
<td>2</td>
<td>4</td>
<td>0.60206</td>
</tr>
<tr>
<td>19.4</td>
<td>0</td>
<td>2</td>
<td>0.30103</td>
</tr>
</tbody>
</table>

correlation coefficient 0.91699
Tree A line 2

<table>
<thead>
<tr>
<th>Distance trap from tree</th>
<th># HDM seeds caught</th>
<th># HDM seeds plus 2</th>
<th>log10 seeds plus 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.4</td>
<td>13</td>
<td>15</td>
<td>1.176091</td>
</tr>
<tr>
<td>9.4</td>
<td>2</td>
<td>4</td>
<td>0.60206</td>
</tr>
<tr>
<td>14.4</td>
<td>0</td>
<td>2</td>
<td>0.30103</td>
</tr>
<tr>
<td>19.4</td>
<td>0</td>
<td>2</td>
<td>0.30103</td>
</tr>
</tbody>
</table>

Correl coeff 0.915

Tree B line 1

<table>
<thead>
<tr>
<th>Distance trap from tree</th>
<th># HDM seeds caught</th>
<th># HDM seeds plus 2</th>
<th>log10 seeds plus 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.4</td>
<td>38</td>
<td>40</td>
<td>1.60206</td>
</tr>
<tr>
<td>9.4</td>
<td>18</td>
<td>20</td>
<td>1.30103</td>
</tr>
<tr>
<td>14.4</td>
<td>6</td>
<td>8</td>
<td>0.90309</td>
</tr>
<tr>
<td>19.4</td>
<td>0</td>
<td>2</td>
<td>0.30103</td>
</tr>
</tbody>
</table>

correlation coefficient 0.988
Tree B line 2

<table>
<thead>
<tr>
<th>Distance trap from tree</th>
<th># HDM seeds caught</th>
<th># HDM seeds plus 2</th>
<th>log10 seeds plus 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.4</td>
<td>40</td>
<td>42</td>
<td>1.623249</td>
</tr>
<tr>
<td>9.4</td>
<td>17</td>
<td>19</td>
<td>1.278754</td>
</tr>
<tr>
<td>14.4</td>
<td>3</td>
<td>5</td>
<td>0.69897</td>
</tr>
<tr>
<td>19.4</td>
<td>0</td>
<td>2</td>
<td>0.30103</td>
</tr>
</tbody>
</table>

Correl coeff 0.99532

![Graph showing correlation between distance trap from tree and seed counts with correlation coefficient 0.99532]
<table>
<thead>
<tr>
<th>distance</th>
<th>log10 No. Seeds plus 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree A</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td>14.4</td>
</tr>
<tr>
<td></td>
<td>19.4</td>
</tr>
<tr>
<td></td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td>14.4</td>
</tr>
<tr>
<td></td>
<td>19.4</td>
</tr>
</tbody>
</table>

**Tree A HDM seeds Wilson Creek**

![Graph showing line equation and R² value](image)

<table>
<thead>
<tr>
<th>Tree B</th>
<th>4.4</th>
<th>1.6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9.4</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>14.4</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>19.4</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>4.4</td>
<td>1.62</td>
</tr>
<tr>
<td></td>
<td>9.4</td>
<td>1.28</td>
</tr>
<tr>
<td></td>
<td>14.4</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>19.4</td>
<td>0.3</td>
</tr>
</tbody>
</table>

**Tree B Wilson Creek 2009**

![Graph showing line equation and R² value](image)
UC5C Trestle Main Tree II

<table>
<thead>
<tr>
<th>Line 1 (closest to road)</th>
<th># HDM seeds on trap</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 (closest to source tree)</td>
<td>1</td>
</tr>
<tr>
<td>1.2</td>
<td>1</td>
</tr>
<tr>
<td>1.3</td>
<td>0</td>
</tr>
<tr>
<td>1.4</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Line 2</th>
<th># HDM seeds on trap</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>4</td>
</tr>
<tr>
<td>2.2</td>
<td>1</td>
</tr>
<tr>
<td>2.3</td>
<td>0</td>
</tr>
<tr>
<td>2.4</td>
<td>0</td>
</tr>
</tbody>
</table>

Development of methods and monitoring data
In 2004-05 with funding from the Forest Investment Account, we reviewed and developed monitoring procedures for hemlock dwarf mistletoe (HDM). Forest-level programs to certify and monitor sustainability of forestry practices and forest ecosystem productivity do not include monitoring data on the incidence, severity and effects of HDM (Muir et al. 2004a). Initially, we investigated possibilities of using existing data sources such as permanent tree growth and inventory sample plots. Due to several deficiencies in establishing and measuring these types of plots, and with limited funding available for the monitoring project, we concluded that developing or using an inventory scale program was not feasible for monitoring HDM.

Based on our work on this project, our reviews of the literature and previous experience, we decided that the most effective approach to monitoring effects of hemlock dwarf mistletoe was to determine spread and infection from selected infested residual trees. HDM infection of nearby young trees within a period of 10 to 20 years after logging or disturbance appears to be a critical and highly variable process in determining the severity of HDM infestation of young trees and, eventually, effects on tree growth. Monitoring residual infested trees in a wide range of stand and ecological conditions would provide basic data on hemlock dwarf mistletoe spread and infection.

One limitation of monitoring HDM spread from selected residual infected trees is that it does not give an unbiased estimate of the incidence, spread and potential impact of hemlock dwarf mistletoe in a large forest area. Further work was needed to determine and monitor hemlock dwarf mistletoe incidence and impacts in conjunction with forest level inventory or sampling programs. For example, Interfor Ltd. is calibrating a forest or landscape level ecosystem management model (LLEMS) being developed by Dr. J.P. Kimmins and associates at University of British Columbia. To supplement this work, a monitoring procedure is needed to evaluate HDM.

For our studies, we decided to establish 11.28-m radius plots around the base of residual mistletoe-infected trees in young regenerating forests. To minimize costs, these plots were situated in readily accessible areas to serve as convenient demonstration sites and to facilitate re-measurements. On each plot we recorded the number of mistletoe-infected and non-infected trees and mapped the approximate location of each infected tree. The plot location was determined using a hand-held GPS unit. All residual infected trees on the plots were noted as possible sources of mistletoe seeds for infection of young trees.

Several biological features of spread and infection of young trees were considered when we developed procedures for monitoring HDM. HDM seeds are dispersed to a maximum distance of 15m from a HDM-infested tree (Smith 1966, 1973, 1977) but most seeds land below the outer extent of the tree crown, and most within 10m of the outer extent of the crown. Beyond 15m, the number of mistletoe seeds landing on young trees is very low. Based on previous work by Mathiasen and Daugherty (2005) and for ease of calculations, we decided to establish an 11.28-m radius plot (400 m²) around the base of each selected residual HDM-infested tree.
Generally, we established monitoring plots only where there were 20 or more young hemlock trees of approximately 1m height or taller (trees shorter than 1-2 m height or younger than 10 years of age seldom exhibit HDM infection). Reasons for infrequent or little obvious infection of young or small trees include: a) a low probability of small trees being hit by HDM seeds (Wicker 1967); and b) a usual period of 2 to 5 years required for new infections to develop from seeds. Young trees 5-6m height and taller were judged to be too tall to permit accurate observation of new infection from ground level. To minimize costs, we selected monitoring plots only in readily accessible areas to serve as convenient demonstration sites and to facilitate re-measurements.

On each plot we recorded the number of HDM-infested and non-HDM-infested trees, and tagged each infested tree. Plot locations were determined using a hand-held GPS unit. All residual infested trees on the plots were noted as possible sources for infection of young trees.

In summary, the procedure developed for monitoring HDM included:

1. Inspect retention-harvested areas in a number of different ecosystem variants. Select suitable study sites with approximately 80-100-year-old western hemlock that were logged 5 to 10 years previously.
2. Select residual infected trees that have definitive evidence of HDM infection, e.g., characteristic spindle-shaped swellings and HDM aerial shoots. (Note that some logging injuries can cause adventitious branching on residual trees that can resemble HDM witches’ brooms).
3. Select HDM-infested residual trees that are at least 50-100m apart, and reference or record the locations with, e.g., a hand-held GPS unit.
4. Establish an 11.28-m radius plot around the base of each selected HDM-infested residual tree. To facilitate tallying and sketch-mapping, flag hemlock trees at the circumference with yellow flagging tape.
5. Record the number and approximate height of all uninsected hemlock trees 1.3m height and taller in the quadrants.
6. Tag each HDM-infested hemlock tree with a label attached at approximately 1.3 m height or lower showing plot number and tree number. (Use embossed tags or a “China marker” crayon to label tags to ensure that numbers do not fade.) Record tree and HDM data for each quadrant. Note if the tree appears to be advanced regeneration (established before the area was logged) or natural regeneration.
7. For the infested residual tree at plot center and all other residual trees 9.0cm dbh (at 1.3m above point of germination) or larger, record approximate height, dbh, and 6-class dwarf mistletoe rating for each one-third of the live crown, starting with the lower third. Note any decay or condition features, such as dead tops.
8. For each infested (tagged) hemlock tree, record the radius or distance from plot centre, height, and for trees 1.3m height or more, approximate dbh.
9. For HDM-infested trees, record the height of each stem infection. For branch infections, record the height of the infested branch and the distance along the branch from the stem to the swollen area. For each swelling, note the number of HDM shoots 2cm length or more, and, if present, number of berries.
10. For documentation, photograph the general aspect of the plot. Where feasible, photograph individual infected trees and HDM infections.
11. Re-measure plots at intervals of two to three years to detect and record new incidence and severity of infection. Record dates of observations.
Establishment of monitoring plots

In 2004-05 and 2005-06, two and 18 plots were established near Ucluelet in the CWHvh1 subzone; in 2006-07, 13 plots, near Port Alice and Port McNeill in the CWHvm1 and CWHxm2 subzones, and one plot near Courtenay in the transition between the CWHxm1 and xm2 subzones; and in 2007-08, one plot each at Sechelt, West Redonda Island, and Ramsay Arm in the CWHdm subzone. Plot data are summarized in Table 1a and 1b.

Table 1a. Tree and mistletoe data from stem-mapped plots established around single dwarf mistletoe-infested residual western hemlock trees.

<table>
<thead>
<tr>
<th>Location and plot type</th>
<th>Plot area (m²)</th>
<th>No. plots</th>
<th>No. trees</th>
<th>No. hemlock dwarf mistletoe-infested trees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>regen</td>
</tr>
<tr>
<td>UC5C Ucluelet</td>
<td>400</td>
<td>1 (tree 1)</td>
<td>93</td>
<td>0</td>
</tr>
<tr>
<td>UC5C Ucluelet</td>
<td>400</td>
<td>1 (tree 2)</td>
<td>48</td>
<td>3</td>
</tr>
<tr>
<td>Nimpkish R.</td>
<td>400</td>
<td>1</td>
<td>113</td>
<td>0</td>
</tr>
<tr>
<td>Waukwass Cr.</td>
<td>400</td>
<td>1</td>
<td>430</td>
<td>1</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>4</strong></td>
<td><strong>684</strong></td>
<td><strong>4</strong></td>
<td><strong>3</strong></td>
</tr>
</tbody>
</table>

Table 1b. Tree and mistletoe data from hemlock dwarf mistletoe monitoring plots established around single dwarf mistletoe-infested residual western hemlock trees where only mistletoe-infested trees were mapped.

<table>
<thead>
<tr>
<th>Location and plot type</th>
<th>Plot area (m²)</th>
<th>No. plots</th>
<th>Total no. trees inspected</th>
<th>No. hemlock dwarf mistletoe-infested trees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>regen</td>
</tr>
<tr>
<td>Ucluelet, UC5C</td>
<td>400</td>
<td>9</td>
<td>439</td>
<td>4</td>
</tr>
<tr>
<td>Dispersed tree</td>
<td>200</td>
<td>9</td>
<td>208</td>
<td>1</td>
</tr>
<tr>
<td>Margin tree</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port McNeill, Waukwass Creek</td>
<td>400</td>
<td>2</td>
<td>442</td>
<td>2</td>
</tr>
<tr>
<td>Dispersed tree</td>
<td>200</td>
<td>9</td>
<td>926</td>
<td>0</td>
</tr>
<tr>
<td>Margin tree</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Courtenay-Margin tree</td>
<td>200</td>
<td>1</td>
<td>74</td>
<td>19</td>
</tr>
<tr>
<td>Sechelt, Wilson Creek</td>
<td>200</td>
<td>1</td>
<td>106</td>
<td>11</td>
</tr>
<tr>
<td>Margin tree</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>West Redonda Island, Redonda Bay</td>
<td>200</td>
<td>1</td>
<td>108</td>
<td>1</td>
</tr>
<tr>
<td>Margin tree</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ramsay Arm</td>
<td>200</td>
<td>1</td>
<td>76</td>
<td>7</td>
</tr>
<tr>
<td>Margin tree</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>33</strong></td>
<td><strong>2379</strong></td>
<td><strong>45</strong></td>
<td><strong>12</strong></td>
</tr>
</tbody>
</table>
Re-measurement of HDM monitoring plots
Previously established monitoring plots should be re-inspected periodically to determine and document any further infection of young trees. New infections take approximately two to five or more years to produce a swelling with aerial shoots, so we proposed to re-measure plots at intervals of approximately three to five years.

At Ucluelet in 2005-06 out of a total of 646 trees inspected on plots 1 to 18, and at tree I and II, there were five infested young trees. In 2008, there were a total of 11 infested young trees. At tree II, one infested young tree was found in 2005 at plot establishment, three additional infested trees were recorded in 2007 but in 2008, no newly infested trees were found. There were no infested young trees found in the plot at tree I from 2005 to 2008.

Most of the HDM infections on the young trees appeared quite vigorous with several long shoots and occasional berries as compared with the usually “sterile”-appearing infections on the larger residual trees. An exception was relatively prolific shoot growth and numerous berries on infested residuals in plot 11. One infested young tree with a stem infection in 2006 did not have any visible signs of infection in 2008.

Most of the residual infested trees selected as plot center trees in 2005 and 2006 had survived to 2008. The exception was tree I that was windthrown in 2006, probably in one of the two severe windstorms in December 2006. In 2008, the foliage of tree I appeared mostly green and only slightly chlorotic. Possibly, some mistletoe infections on tree I will survive and become sources of infestation of nearby young trees. We observed that several windthrown trees that had HDM infections with shoots in 2006, e.g. plot 11, were still bearing shoots and berries in 2008. Apparently, some windthrown, HDM-infested trees can survive for several years after they have fallen and continue to be sources of infestation of young trees.

Monitoring hemlock mistletoe seed dispersal
Another approach that we proposed to monitor hemlock mistletoe spread and infection was to determine dispersal of mistletoe seeds from residual infected trees. Results of Smith (1966, 1973, 1977) suggested that measurements of the number of dwarf mistletoe seed dispersed from mistletoe-infected trees could be used to indicate the relative infectivity or importance of certain residual infected trees as sources of mistletoe infection before infection of young trees was evident. Data on dwarf mistletoe seed dispersal could be used with models of dwarf mistletoe spread, e.g., Robinson et al. (2002), Robinson and Geils (2006), to estimate spread and future impacts.

We selected residual infected trees that were similar to the infected hemlock tree studied by Smith to facilitate comparisons with his results. Judging by the amount (or scarcity) of infection of young trees in some stands in our studies, we suspected that seed dispersal could vary considerably from tree to tree, but there were no criteria available for selecting particular residual trees for monitoring. Selection of the mistletoe-infected trees for seed dispersal was based on the accessibility of the trees for installing seed traps and the proximity to previously established HDM monitoring plots.

Inspection of young trees on the monitoring plots indicated only one small infection on one tree, so we concluded that the seeds dispersed would be from the older residual trees and not from infections on any of the regenerated trees.
Smith’s data indicated that the seed traps should be placed at a distance of approximately 5 m from the base of each tree to sample the largest number of mistletoe seeds per square metre. Traps were placed around each tree at the cardinal and intermediate compass points to sample possible differences in amounts of mistletoe seed dispersed with aspect. Smith found that more seeds were dispersed to the south of his tree.

Trap sizes were selected arbitrarily, based first on the availability in 2005 of plastic traps 38 x 54-cm. In 2006, we decided to make cedar-frame traps (61 x 122-cm). In 2005 the proportion of the area at 4 to 5 m from each tree that was sampled was 1.5 percent and in 2006 and 2007, 1.8 percent. Traps were covered with cotton cloth, which retained the sticky mistletoe seeds, until the traps were collected in late October. We inspected the traps in mid- to late-September to observe seed dispersal and to repair or reposition any disturbed traps. Two of the plastic traps were damaged apparently by bears but in subsequent years there was very little disturbance of the cedar frame traps.

In 2005 and 2006, we established traps to sample HDM seed dispersal adjacent to trees I and II monitoring plots at block UC5C, near Ucluelet. The two western hemlock trees were selected in 2005 and 2006. Seed traps were established in the same position around each tree and monitored from early September to late October. The methods of selection and documentation for these two monitoring plots were outlined in the 2004-05 year-end project report (Muir 2005).

In 2007, eight seed traps to collect dwarf mistletoe seeds were established around Tree II at UC5C as described in previous reports. Tree I had been windthrown and was not sampled. Unfortunately, funds were not available to continue this monitoring in 2008.

The results of monitoring hemlock dwarf mistletoe seed dispersal at Ucluelet, although limited, indicated that there were substantial differences in the amounts of hemlock dwarf mistletoe seed dispersed from residual trees. In 2005 and in 2006, 0 and 0.5 seeds per m$^2$ were trapped at 5 m from the bole of Tree I, and 4 and 8.6 per m$^2$, from Tree II. In 2007, nine mistletoe seeds were caught in the eight traps at Tree II and one seed in the four extra traps placed near Tree II. Three seeds were caught in the traps placed at a second residual infested tree near Tree II.

These results were contrary to our expectation that more dwarf mistletoe seeds would be dispersed from Tree I, which appeared more severely infested, with several large witches’ brooms throughout the crown. However, Tree I had a dead top with several dead witches’ brooms that could indicate poor or declining tree health or vigour. Bickford et al. (2005) determined that shoot production and spread of southwestern dwarf mistletoe on ponderosa pine was correlated with tree vigour and a similar relationship probably exists for hemlock dwarf mistletoe on western hemlock.

These results indicated that very low numbers of dwarf mistletoe seeds were dispersed from the infested trees near Ucluelet compared to tree studied by Smith (1966, 1973, 1977) near Lake Cowichan. Apparently, dwarf mistletoe seed production on and dispersal from residual infested trees could limit infection of young trees in retention-harvest forests in some areas. Factors affecting dwarf mistletoe seed
production and/or dispersal in different areas or ecosystems have yet to be determined. Further monitoring of seed dispersal is needed to increase geographic and ecosystem replication of the number of infected-residual trees sampled and determine if there is a substantial year-to-year variation in numbers of mistletoe seed dispersed.

The characteristics and/or attributes of infested western hemlock trees that are associated with dispersal of large or few numbers of hemlock-dwarf-mistletoe seeds have yet to be determined, and we believe that this is an important issue. Our results suggested that further work to monitor seed dispersal and infection from various residual infected trees could provide very useful information to predict hemlock dwarf mistletoe spread, infection and growth effects in retention-harvested areas.

Aerial surveys of infested trees
To facilitate selection of HDM infested residual trees in cut-over stands of trees and eventually to facilitate forest-level sampling, we investigated the feasibility of using low-level aerial surveys for detecting HDM infestations. Low-level flights with fixed-wing aircraft or helicopters have been used for aerial surveys of several other dwarf mistletoe species (Muir and Moody 2002).

Several known areas of infestation of older second-growth, mature old-growth and recently logged stands were previously identified by roadside surveys west of Kennedy Lake, near Tofino, in the northern portion of TFL 54. These and nearby forest areas were flown to determine if it were possible to detect HDM infestations. HDM infestations were documented by video and single-frame photography.

Our observations indicated that it was feasible to detect HDM infested trees, particularly in old-growth and retention-harvested forests. Interestingly, Tree II at UC5C, which was the centre tree for one of our monitoring plots and which was rated from ground level as severely infested, had indistinct signs of infestation when viewed from the helicopter. A second 2.6-hour helicopter flight from Campbell River indicated infested trees in several retention-harvested and clearcut blocks on West Thurlow, Gilford and Turnour Islands near Port McNeill. The infested trees were documented by GPS points that were overlaid onto Interfor's geo-referenced satellite imagery. Infested trees were not verified by ground inspections. Several different tree crown conditions indicating HDM infestation were recorded. In 2008, we used a low-level helicopter flight to survey several recently harvested areas north of Powell River in the Sunshine Coast TSA. Potential sites for monitoring HDM infestation were recorded and later inspected using boat transport. These very promising initial results suggested that aerial surveys for HDM were feasible, particularly for selecting sites for monitoring HDM infestations in retention-harvested forests.

Although an aerial survey appears feasible to detect HDM infestations, our experience suggests that further work is needed, including: a) determine the accuracy of aerial HDM surveys; b) determine how aerial survey data and/or images will be stored and accessed; and c) develop a system for more efficient and coordinated flight navigation, data recording and photography of infested trees.

A potential application of low-level aerial surveys for HDM is a forest-level monitoring program for HDM infestations. However, several challenges are apparent.
One is to determine how areas of HDM infestation will be defined and delimited. Another is to determine what kind of stratified randomized sampling method should be used to establish monitoring plots for HDM. Ideally, monitoring plots should utilize recent inventory sampling and/or silviculture surveys, with, if necessary, extra plot data collected to characterize HDM incidence and severity per tree. The feasibility of undertaking aerial surveys for HDM over an extensive forest area will depend on several factors including access, availability of equipment to map and record mistletoe occurrences, transportation costs, and availability of funding. If low-level aerial surveys are practicable, other more costly methods of determining mistletoe occurrence, such as re-sampling inventory or silviculture sample plots, could be reduced or possibly avoided.

Publications and reports
With FIA funding in 2006, we were able to prepare an extensive literature review and synthesis of information on ecology and management of hemlock dwarf mistletoe (Muir and Hennon 2007), and based on that report, an abbreviated review that emphasizes ecology and management in British Columbia (Muir et al. 2007).

An invited report summarizing our monitoring project activities was submitted to and published in Canadian Silviculture (Muir and Warttig 2008). Similar information was provided to R. Winters, RPF, for a presentation at the Coastal Silviculture Committee annual meeting, February 2008. A summary was prepared for the “2008 Summary of Forest Health Conditions in British Columbia”.

Results of the monitoring project work have been reported in several FIA year-end reports (Muir 2005, 2006, 2007, 2008, 2009) that are available on the Ministry of Forests and Range library website.