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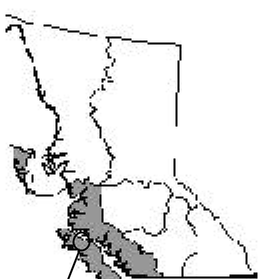
**BRITISH COLUMBIA**




# Impacts of hoe-forwarding on site productivity: nine-year results from the Woss study

by Mary-Jane Douglas[1] and Paul J. Courtin

## 1.0 INTRODUCTION

The development of site disturbance guidelines by the Vancouver Forest Region in the late 1980s and early 1990s resulted from concern over the impacts of ground-based harvesting systems, in particular rubber-tired skidders, on forest soils and site productivity. Use of these systems can cause compaction and rutting of soils (Millar and Sirois 1986, Corns 1988), depending on soil texture, thickness of forest floor, and water content of the soil at time of harvest. These effects can result in increased soil density, leading to reduced seedling survival and growth as a result of decreased soil aeration, rooting volume, and soil water permeability, and increased resistance to root growth (Heilman 1981; Minore et. al 1969). Studies have shown these effects may last for decades (Hatchell et al. 1970, Butt 1987, Miller et al. 1996).

In the late 1980s, hoe-forwarding (or "hoe-chucking") was introduced to coastal British Columbia on gently sloping terrain as a means of reducing logging costs while avoiding some of the site impacts associated with other ground-based harvesting systems. The hoe-forwarder was developed through modification of a hydraulic log loader by: increasing the height of the carriage to allow for stump clearance; increasing track width for increased flotation; increasing fuel capacity; and lengthening the boom to increase machine reach.

The hoe-forwarder lifts logs clear of the ground, and swings them toward the road for loading. An ideal pattern is to make only one pass as the hoe-forwarder travels across the logged area. However, multi-pass trails may occur where machine maintenance and site access are required. Impacts to the soil were expected to be less than those with skidders, even with additional passes, and particularly with the use of protective puncheon (logs and debris placed under the tracks of the machine) to reduce ground pressure and soil disturbance.

The main objective of this study was to determine the short- and long-term impacts of hoe-forwarding on survival, growth, and performance of seedlings planted in soils subjected to varying levels of machine disturbance. This report focuses on results from a study near Vernon Lake, south of Woss on north-central Vancouver Island. A more complete report of these results is available in Douglas (2002). Results from a previous study at Stranby River, near Holberg on northern Vancouver Island, were reported in the Vancouver Forest Region Research Extension Note 009 (Douglas and Courtin 2001).

## 2.0 STUDY AREA

The elevation of the study area is 370 m and lies within the CWHmm1 biogeoclimatic variant. The site is representative of the 03: HwCw – salal site

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series, with minor proportions of 01: HwBa – pipecleaner moss (Green and Klinka 1994). The site was selected because of its relatively uniform mineral soils on gently to moderately sloping terrain. The soils are sandy loam to loamy sand Orthic Humo-Ferric Podzols, developed from ice-contact, morainal parent materials that are moderately well drained. Coarse fragment content is approximately 55%, ranging from gravel to large boulders. Thickness of the forest floor at the time of logging averaged 29 cm. Under the Forest Practices Code, this site would have had a moderate to low hazard rating for soil compaction and puddling (BC Ministry of Forests 1999).

The original stand consisted of 40% Douglas-fir (*Pseudotsuga menziesii*), 38% western hemlock (*Tsuga heterophylla*), 19% western redcedar (*Thuja plicata*), and 3% amabilis fir (*Abies amabilis*). The understory vegetation consisted of a moderately developed shrub layer including salal (*Gaultheria shallon*), dull Oregon grape (*Mahonia nervosa*), red huckleberry (*Vaccinium parvifolium),* and Alaskan blueberry (*V. alaskaense*); a poorly developed herb layer with sporadic vanilla leaf (*Achlys triphylla*), and a well developed moss layer (*Hylocomium splendens, Eurhynchium oreganum, Rhytidiadelphus loreus*, and *Rhytidiopsis robusta*).

## 3.0 EXPERIMENTAL LAYOUT AND SAMPLING

The study area was logged by hoe-forwarding between December 1991 and mid-February 1992, at a time when water content of the soil was high. The hoe-forwarding machine used was a Komatsu PC400-5 log loader, weighing approximately 120,000 lb, with a nominal ground pressure of 11.2 psi. In contrast to the Holberg study, puncheon was rarely used on this site. The medium to coarse-textured soils on this drier-than-mesic site are often considered relatively "robust" in terms of ground-based logging impacts. It was originally planned that the site would be logged with one-pass hoe-forwarding during the summer, with the use of puncheon prescribed only "where necessary". However, because of operational constraints, this site was logged in winter under rather unfavourable, very moist to wet soil conditions.

The original intention was to establish a study parallel to that at the Holberg site, whereby undisturbed areas between hoe-forwarded trails would be re-trafficked under controlled conditions, using a specified number of passes. However, the extent of site disturbance during the logging operation precluded this approach. Consequently, fifteen 20-metre strips were established across the study area, along tracks made by the hoe-forwarding machine. It appeared that these tracks had resulted from two to four passes with the hoe-forwarding machine, although this could not be determined with certainty. Fifteen control lines were also established in untrafficked areas.

Soil properties were assessed soon after logging. These included soil texture, thickness of the forest floor, and soil water content. Bulk density of the mineral soil was not determined for this site.

Soil disturbance levels were assessed following treatment, along the easterly track of each 20 m trafficked strip using point samples at 2 m intervals. This methodology was similar to Curran and Thompson (1991), but predates that currently used for ground disturbance surveys under the Forest Practices Code (BC Ministry of Forests 2001). Disturbances tallied included: depth of compression into the forest floor, decayed wood, or mineral soil, i.e., ruts; and depth of deposits of either organic material, mineral soil, or mixes of organic and mineral materials. Incidences of gouging of the mineral soil within the ruts was tallied separately. The puncheon impressions/deposits found on the Holberg site were almost non-existent on the Woss site. Various combinations of these disturbance types were also noted. Depth of disturbance was tallied using the following classes: shallow = < 5 cm; deep = 5 - 25 cm; and very deep = > 25 cm.

Ten Douglas-fir seedlings were to be planted in one of the tracks, in between the tracks, and on one of the flanks of each of the trafficked strips. A single row of 10 trees was to be planted on the control treatment, for a target of 600 seedlings across the research area. During planting in the spring of 1993, a mixture of both Douglas-fir and western redcedar seedlings were planted along the experimental lines. The number of each species varied for each treatment. In total, 568 Douglas-fir seedlings and 90 western redcedar were planted. Mortality has since reduced the number of Douglas-fir to 555, and western redcedar to 67.

Seedling height, root collar diameter, and survival were assessed at the end of the first, third, fifth and ninth growing seasons. Tree vigour was also assessed using five condition classes:

1. excellent – seedling has good form and healthy green colour;
2. good – seedling may be slightly chlorotic but generally looks healthy, or seedling is green and healthy, but has double or multiple leaders;
3. fair – seedling is quite chlorotic, small in size, may have double/multiple leaders and generally fair to poor health;
4. poor – seedling is stunted, losing needles, chlorotic, may have multiple leaders, possibly moribund;
5. dead – seedling has died between two measurement periods.

Each treatment line was photographed at each measurement period. Growth data for western redcedar seedlings planted along the trafficked strips has also been collected; however, only results for the Douglas-fir trees are reported here.

**Foliar Analysis:**

Foliar analysis of the seedlings was carried out at the end of the fifth growing season to determine the foliar content of N, P, K, Ca, Mg, Al, S, Cu, Zn, Fe, Mn, B and $SO_4$-S. Differences in foliar levels were compared between the treatments to determine apparent treatment impacts on nutrient uptake. In addition, the foliar levels were compared with critical levels suggested by Ballard and Carter (1986), and more recently by Carter (1992).

## 4.0 RESULTS AND DISCUSSION

### 4.1 SOIL WATER CONTENT

Gravimetric soil water content on the moderately well drained portions of the area averaged 75%, and ranged from 52% to 123%. On localized wetter, imperfectly drained areas, soil water content ranged from 148% to 175%. These higher water contents can render the soil vulnerable to damage, including track slippage of the machinery, and puddling of saturated soil.

**Figure 1.** Compression of the organic matter by the hoe-forwarder. (Photo courtesy of Alex Inselberg)

**Figure 2.** Compression of the mineral soil by the hoe-forwarder. (Photo courtesy of Alex Inselberg)


**Figure 3.** Treatment line H-4 soon after logging (1992). Note track impression. (Photo courtesy of Alex Inselberg)

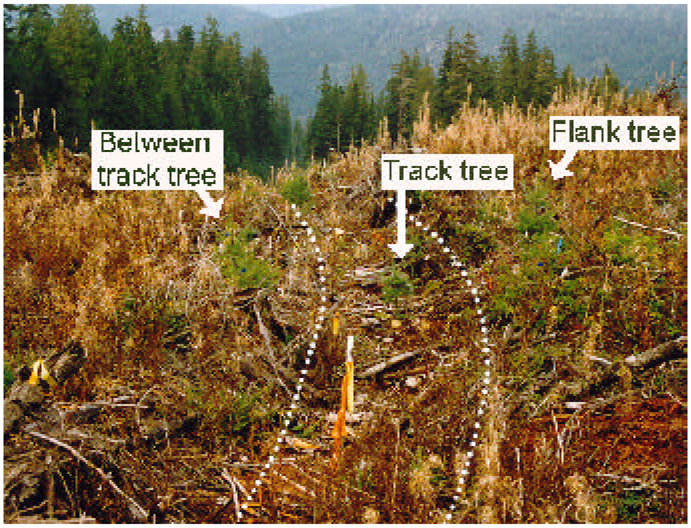


**Figure 4.** Treatment line H-4 after 3 years (1995). Note trees planted between the track (left), on the track (centre), and on flank (right).

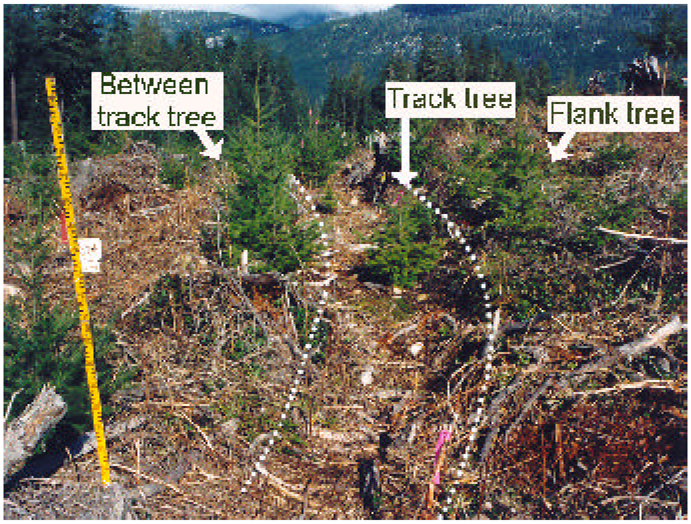


**Figure 5.** Treatment line H-4 after 5 years (1997). Note trees planted between the track (left), on the track (centre), and on flank (right).

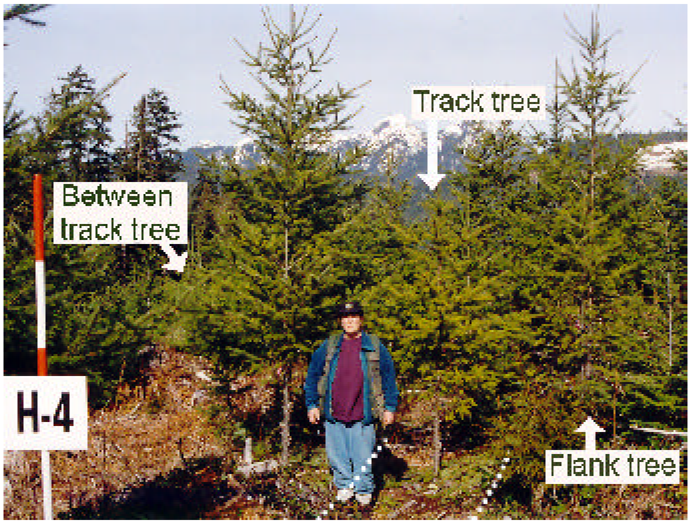


**Figure 6.** Treatment line H-4 after 9 years (2001). Note trees planted between the track (left), on the track (centre), and on flank (right).

**Table 1.** Disturbance levels on the tracked strips.

| DISTURBANCE CLASSES (% of track length) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| UN[1] | DWI(c) | OI(c) | MI(c) | OI(p) | MI(p) | OD | MD | MOD | MG |
| 6 | | 6 s | 6 s | 0 | 0 | 1 s | | 1 s | |
| | 12 d | 25 d | 23 d | | | 7 d | 1 d | 5 d | 5 d |
| | 1 vd | | 1 vd | | | | | | 1 vd |

[1]Disturbance Class Abbreviations:

First letter(s): UN - undisturbed, intact forest floor; DW - decayed wood; O – organic matter; M - mineral soil; MO - mixed mineral soil and organic matter.

Second (third) letter: I – impression; D – deposit; G - gouge.

Lower case, in brackets: (c) - compression by machine tracks; (p) - impression or deposit caused by puncheon.

Disturbance class depths: s - shallow = < 5 cm; d - deep = 5-25 cm; vd - very deep = >25 cm.

## 4.2 TRACK DISTURBANCE SURVEYS

Several disturbance classes were observed on the trafficked strips following logging by the hoe-forwarding machine (Table 1). The most common disturbance type (74%) was impression into the soil, as a result of compression by the machine tracks, i.e., ruts. Forty-four percent of these occurrences were found in the forest floor or decayed wood (Figure 1); 30% were impressions into the mineral soil (Figure 2). Although incidence of mineral soil gouging along the ruts accounted for only an additional 6% of the tracks, up to 40% of one particular track was gouged by the hoe-forwarder. This track was situated on an incline, and wet soil conditions reduced soil strength, increasing the displacement and puddling of the underlying mineral soil.

Puddling of mineral soil, like compaction, results in reduced soil permeability and aeration, but soil density increases are lower than for compaction. Adverse impacts on tree growth can be expected where puddling and gouging occur. Incidences of deposits (either organic or mixed organic and mineral soil deposits) were few on this site (15%). Deposits and impressions created by puncheon as found on the Holberg site were non-existent on the Woss site.

## 4.3 SEEDLING SURVIVAL

Seedling survival after five years was greatest on the control and flank treatments (95%). Lowest survival was found on the tracks (91%). After nine years, an additional 2% mortality occurred on both the track and the flank treatments. The main causes of mortality after five years included root disease (*Armillaria ostoyae*) and damage by Roosevelt elk (*Cervus canadensis roosevelti*). However, by nine years, incidence of root disease was insignificant, and damage by elk was limited to only a few trees.

## 4.4 HEIGHT AND DIAMETER INCREMENTS

Figures 3 to 6 show an example of the growth of Douglas-fir across a trafficked strip over the past nine years. Douglas-fir trees growing on the tracks had the poorest height growth after both five and nine years (Figures 5, 6, 7; Table 2). No significant differences in height growth were found between the other treatments after five years, but those trees growing between the tracks, and on the undisturbed controls, had the best height growth after nine years.

**Table 2.** Height increments of Douglas-fir showing significant differences.

| Height increment (cm) | "p" value for model | Treatment[1] | | | |
|---|---|---|---|---|---|
| Three Year | 0.000 | *a* Between track | *a* Control | *a* Flank | *b* Track |
| Five Year | 0.000 | *a* Control | *a* Between track | *a* Flank | *b* Track |
| Nine Year | 0.011 | *a* Between track | *a* Control | *ab* Flank | *b* Track |

[1]Treatments with the same letter are not significantly different.

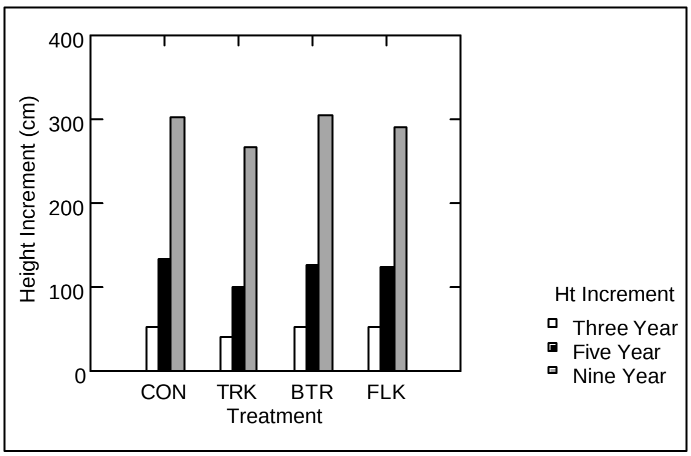


**Figure 7.** Nine year height increment of Douglas-fir.

In the first five years, trees growing on the controls had the poorest diameter growth; the best diameter growth was found in those trees growing between the tracks (Figure 8; Table 3). By year nine, diameter growth was best in those trees growing between the tracks. Poorest diameter growth was found in the track trees. Diameter growth increased considerably in those trees growing on the undisturbed controls after nine years. Competing vegetation in the control plots likely resulted in increased height growth at the expense of diameter increment during the first five years. However, once the trees overtopped the competing vegetation, diameter increment increased considerably.

### 4.5 SEEDLING VIGOUR

Trees with good form and vigour were more commonly found in the control and flank treatments after both five and nine years (29 to 53%). Those with slight chlorosis (condition class 2) were more abundant on the track and between-track treatments (61 to 80%). A greater incidence of "fair" (class 3) trees was found in trees growing between the tracks and on the flanks, particularly after nine years. However, a general chlorosis was observed after nine years in most of the trees on this site, including those growing on the controls.

### 4.6 FIVE YEAR FOLIAR NUTRIENT LEVELS

Foliar levels of S were significantly higher after five years in those trees growing on the trafficked areas (Table 4). The reason for this apparent increase in S availability is unclear, since one would expect reduced S uptake where organic matter was removed or the soil was compacted. After nine years, some of the trees showed a patterned chlorosis, whereby the younger foliage appeared chlorotic while the previous year's foliage remained green. It is possible these trees are now deficient in S (Tisdale et al. 1985; Walker and Gessel 1991).

Although no significant differences in foliar N were found between treatments after five years, critical values (Ballard and Carter 1986, Carter 1992) suggest that trees growing on the tracks were moderately to severely deficient in N. Those trees growing on the control, between the tracks, and on the flanks were suggested to have a slight to moderate N deficiency. A general chlorosis was observed in many of the Douglas-fir trees after five years, supporting the suggestion of a possible N deficiency. By nine years, many of the trees appeared to be even more chlorotic, including those growing on the controls. Site factors, other than treatment, are likely contributing to this overall effect on tree vigour and performance.

Comparison of five-year foliar Mg levels to critical values suggested a moderate to severe deficiency, regardless of treatment. The occurrence of patterned chlorosis on the foliage where the mid-vein of the needle remained green, was observed on several trees. This is characteristic of low foliar Mg levels. The relatively coarse texture of the soils on this site, together with a low soil organic matter content, low base saturation, and low cation exchange capacity have likely contributed to a possible Mg deficiency on this site (Ballard and Carter 1986, Leaf 1968, Pritchett 1979).

Treatment effects on foliar micronutrient levels were also indicated after five years. Foliar levels of Cu, Mn, and B all showed significant though inconsistent differences between treatments (Table 4). However, critical values suggested no deficiency of Cu or Mn, regardless of treatment. A possible deficiency was suggested for B, regardless of treatment. Occurrence of leader dieback, which is characteristic of B deficiency, was observed on several trees. Foliar levels of Al were significantly higher on the trafficked areas. Elevated levels of this element can interfere with the uptake of other essential nutrients, such as Mg.

**Table 3.** Diameter increments of Douglas-fir showing significant differences.

| Diameter increment (cm) | "p" value for model | Treatment[1] | | | |
|---|---|---|---|---|---|
| Three Year | 0.003 | a<br>Between track | ab<br>Track | b<br>Flank | b<br>Control |
| Five Year | 0.014 | a<br>Between track | ab<br>Track | b<br>Flank | b<br>Control |
| Nine Year | 0.043 | a<br>Between track | ab<br>Control | ab<br>Flank | b<br>Track |

[1]Treatments with the same letter are not significantly different.

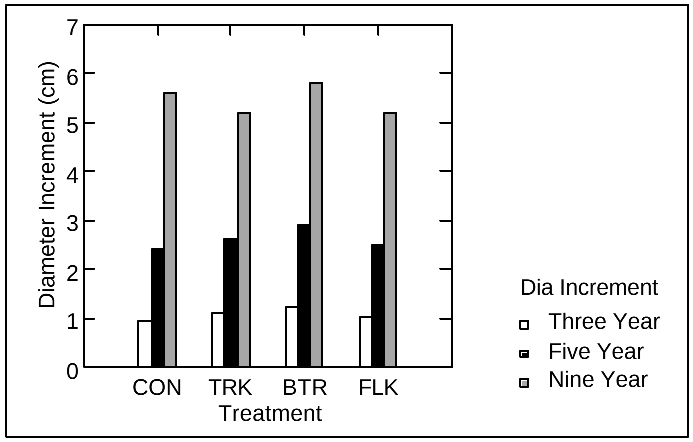


**Figure 8.** Nine year diameter increment of Douglas-fir.

**Table 4.** Levels of foliar nutrients at five years showing significant contrasts.

| Treatment | S | $SO_4$-S | B | Cu | Mn | Al |
|---|---|---|---|---|---|---|
| | percent | ppm | | | | |
| | dry matter basis (Mean)[1] | | | | | |
| **Control** | 0.119 | 121 | 8.74 | 4.43 | 707 | 240 |
| **Track** | **0.130*** | **203*** | 7.83 | 4.08 | **563*** | **317*** |
| **Between Track** | **0.132*** | **202*** | **7.35*** | 4.39 | **590*** | **328*** |
| **Flank** | **0.130*** | **192*** | 7.80 | **5.19*** | **534*** | **318*** |

[1] indicates significant difference to the control at alpha=0.05

## 5.0 CONCLUSIONS

The impacts of trafficking this site under relatively wet soil conditions have become increasingly apparent up to the nine year assessment. Douglas-fir trees growing on the tracks had reduced height and diameter growth; the best growth was found in those trees growing between the tracks. However, vigour of the between-track trees indicated a greater proportion of lower vigour class 2 and 3 trees for this treatment. Trees with the best vigour were found on the control and flank treatments.

Foliar analysis at five years, along with observations of chlorosis and signs of other nutrient deficiencies across the study site after nine years, indicates that tree nutrition is generally a limiting factor at this study site. This is very likely due to the relatively coarse texture, high coarse fragment content, and low organic matter content of the mineral soils, which have a low cation exchange capacity and low base saturation. Deficiencies of N, Mg, and B are indicated at the site regardless of treatment effects. Whether and to what extent the treatment has changed the severity of deficiencies is unclear based on the limited analysis available. However, with inherent site characteristics that have the potential to be limiting, it is important that site nutrient capital be preserved and maintained as much as possible.

Although these soils were anticipated to be "fairly robust," i.e., having a moderate to low hazard rating for soil compaction and puddling, it now appears that these medium to coarse-textured soils were prone to soil compaction and puddling under wetter soil conditions. Therefore, these soils require some protection from the impacts of trafficking, particularly if they are to be logged under wet, winter conditions.

As in the Holberg study, soil disturbance results for this site were obtained only for the tracked areas of the treatment, since the intent was to determine the effects of specific disturbances. This approach does not compare to the current procedure under the Forest Practices Code, whereby a survey is conducted on an area or cutblock basis. Results of a survey by Thompson (1997) showed that eight hoe-forwarding sites that were surveyed using Forest Practices Code procedures were all compliant and within the allowed 5 percent detrimental disturbance limit.

## 6.0 MANAGEMENT IMPLICATIONS

Sites with moderate to low compaction and puddling hazard, i.e., mesic and drier sites with sandy loam to loamy sand soil, should be considered for seasonal or weather operating restrictions. Hoe-forwarding without puncheon during wet soil conditions will likely result in detrimental disturbance, leading to reduced growth and performance of Douglas-fir or other species. The extent of such detrimental effects can be controlled with the use of protective puncheon or mats, and by the pattern used during logging. In addition, spot remediation of disturbed areas with the machine concurrent with logging will also reduce the level of detrimental disturbance.

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