Research Report

BC Journal of Ecosystems and Management

Coarse woody debris: Inventory, decay modelling, and management implications in three biogeoclimatic zones

Nancy Densmore[1], John Parminter[2], and Victoria Stevens[3]

Abstract

To assess recent management practices, post-harvest levels of coarse woody debris (CWD) were measured in the Southern Interior and Northern Interior forest regions of British Columbia. A simple input and decay model was used to estimate the volumes of CWD that might be present at the end of managed forest rotations.

In four ecosystems (Sub-Boreal Spruce [SBS] mk1 variant, Interior Douglas-fir [IDF] dm2 variant, Interior Cedar–Hemlock [ICH] dw variant, and ICHvk2/wk3 variants) that were sampled a few years after harvest, between 58 and 80% of the CWD volume came from pieces less than 6 m in length. Modelling of CWD decay and net new CWD input from the developing stand indicated that by rotation end (after 90 years), CWD volumes would have decreased to about 15% (SBSmk1) and 1% (IDFdm2) of the CWD volumes found in mature unmanaged stands.

In the ecosystems studied, this research suggests that specific management guidance for deadwood will be required to maintain CWD (outside of reserves) in managed stands. Various techniques could be employed to manage the CWD resource. The purpose of this paper is not to present such techniques; however, the sampling and modelling methodology outlined here will help to formulate management approaches by allowing an assessment of CWD presence throughout a managed forest rotation.

KEYWORDS: *course woody debris, decay, modelling, ecology, Northern Interior and Southern Interior forest regions.*

Contact Information

1 Biodiversity Specialist, Forest Practices Branch, British Columbia Ministry of Forests, PO Box 9513 Stn Prov Govt, Victoria, BC V8W 9C2. E-mail: Nancy.Densmore@gems2.gov.bc.ca

2 Research Ecologist, Research Branch, B.C. Ministry of Forests, PO Box 9519 Stn Prov Govt, Victoria, BC V8W 9C2. E-mail: John.Parminter@gems7.gov.bc.ca

3 Protected Area Ecologist, Parks and Protected Areas, B.C. Ministry of Water, Land and Air Protection, PO Box 9398 Stn Prov Govt, Victoria, BC V8W 9M9. E-mail: Tory.Stevens@gems1.gov.bc.ca

Densmore, N., J. Parminter, and V. Stevens. 2004. Coarse woody debris: Inventory, decay modelling, and management implications in three biogeoclimatic zones. *BC Journal of Ecosystems and Management* 5(2):14–29.
URL: ***www.forrex.org/jem/2004/vol5/no2/art3.pdf***

Introduction

For operational purposes in British Columbia, coarse woody debris (CWD) is defined as dead woody material greater than 10 cm in diameter in all stages of decay, and consists of above-ground logs, bucking waste, exposed roots, and large fallen branches (British Columbia Ministry of Forests 2000a).

Coarse woody debris is an important, and sometimes essential, habitat element for species ranging from bacteria and insects to fungi, plants, and animals. It provides organic matter to the soil which can enhance its moisture carrying capacity (Harvey *et al.* 1981). Moisture is an essential habitat component for many organisms and plays an important role in decomposition, nitrogen fixation (Harmon *et al.* 1986), and nutrient transfer from soil to trees and shrubs via ectomycorrhizal root tips (Harvey *et al.* 1983). In some dry ecosystems, woody material is the most important organic matter added to forest soils during a rotation (Harvey *et al.* 1981).

In British Columbia, CWD is important for a number of species listed at risk (B.C. Ministry of Water, Land and Air Protection 1999), such as northern goshawk, tailed frog, fisher, and grizzly bear. Many other species, such as the pileated woodpecker and a host of other plants and animals, either depend on, or are associated with, CWD (Lofroth 1998). Downed logs also help to stabilize steep slopes and stream channels, provide a significant source of moisture during dry periods, and act as a refuge for many species that might not otherwise survive droughts. In addition, many types of mycorrhizal fungi are closely linked with CWD (Stevens 1997).

Fridman and Walheim (2000) stated that 39% of the 1487 red-listed (extinct, endangered, rare, vulnerable, or care-demanding) forest species in Sweden require deadwood for their survival. Of that number, 26% of the species require CWD and 21% require standing dead trees. Rydin *et al.* (1997) found that a high proportion of Swedish wood-inhabiting macrofungi species is red-listed. This was interpreted as the result of a large decrease in decaying wood in Swedish forests. Of a total of 3196 Swedish macrofungi, 520 (16%) are considered threatened. Over one-half (59.2%) of these threatened macrofungi use dead fallen trees as their main habitat.

Even within a given ecosystem variant, natural levels of CWD vary dramatically both temporally and spatially. After a stand-initiating disturbance (e.g., wildfire or windthrow), significant volumes of CWD, including large sound logs, are added to the ecosystem. This initial CWD decays over time. Small pieces of CWD may last only a few years, while large pieces (in diameter and length) can last several hundred years, depending generally on the type of wood and the ecosystem. Large pieces of CWD provide the greatest habitat value (Lofroth 1998). Additions of CWD occur when competition mortality, or other gap-creating dynamics, begin in the new stand. Remnants of the original stand also contribute to CWD inputs.

Coarse woody debris is an important, and sometimes essential, habitat element for species ranging from bacteria and insects to fungi, plants, and animals.

In a managed ecosystem, harvesting provides a periodic input of CWD. These volume inputs are significantly less than those resulting from natural disturbances, where the entire volume of the stand becomes CWD over a period of years. Reserve patches and reserve trees serve as remnants of the original stand and provide CWD, though not in the same quantity as a natural stand. Resource management objectives may direct that a specific volume of standing and down deadwood be left dispersed on cutblocks after harvesting.

Both diameter and length are important measures of CWD. For example, Barclay *et al.* (2000) found a relationship between log volume, log length, and an invertebrate population in their study of the microenvironment of decaying logs in Australia. Increasing log volume was significantly correlated with an increased population of the invertebrate, but not with its presence or absence. Increasing log length was significantly correlated with an increased likelihood of presence of the invertebrate. This was possibly due to a better ability of the invertebrate to find long logs versus short logs during dispersal.

In Scandinavia, where many rotations of managed stands have occurred, deadwood (both standing and downed) in the reserved natural conifer forests is present in the range of 50–120 m^3/ha. Scandinavian managed forests typically have less than 10% of the natural level of deadwood (Stenlid and Gustafsson 2001), and for northern Europe the amount ranges from 2 to 30% of natural levels (Fridman and Walheim 2000).

The amount of CWD required on site to maintain a healthy ecosystem is not known, although the European literature cited above indicates that problems occur when deadwood on managed stands ranges from

2 to 30% of natural levels. A general tenet of maintaining biodiversity in British Columbia forests is that "the more managed forests resemble the forests that were established from natural disturbances, the greater the probability that all native species and ecological processes will be maintained" (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995). The *Biodiversity Guidebook* suggests that a general level of 50% of natural levels should remain after harvesting. To mimic most natural ecosystem dynamics, it is assumed desirable to ensure that:

- sufficient large pieces are present at harvest and will remain for the long term, and
- a staggered input of CWD will occur throughout the life of the stand as dead trees fall.

Coarse woody debris has been a component of the British Columbia Forest Practices Code since 1995. British Columbia is currently in transition from the Forest Practices Code to the more results-based *Forest and Range Practices Act*. Within the Forest and Range Practices legislation, maintenance of minimum levels of course woody debris is a practice requirement. A key directive concerning CWD management under the Forest Practices Code stated that utilization standards took precedence over requirements for coarse woody debris (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995). Timber utilization standards define the requirements for cutting and removing timber from an area, in terms of tree species, stump height and diameter, log top diameter, log length, and log quality. Management direction for CWD was given in May 2000 with the provincial "Short-term Strategy for Coarse Woody Debris Management in British Columbia's Forests" (B.C. Ministry of Forests 2000a). This strategy recognizes that timber below mandatory utilization standards can be left as CWD; however, depending on market conditions, some wood that is below utilization standards may still have economic value. The strategy, therefore, emphasizes the appropriate management of uneconomic wood left on site after harvesting and aims to maximize the ecological value of CWD, while considering:

- utilization standards,
- avoidable waste benchmarks, and
- logging costs.

The terms of reference for the provincial Coarse Woody Debris Committee directed it to undertake an extensive pilot study of post-harvest CWD as part of its mandate to develop workable CWD management recommendations and evaluation techniques.

Under the Forest Practices Code's legislative framework, general objectives for CWD are contained within a licensee's Forest Development Plan (FDP). This plan contains information about proposed roads and cutblocks and how non-timber forest resources will be protected. The Silviculture Prescription (a stand-level plan required before harvesting a cutblock) would contain any specific CWD objectives necessary to accommodate an FDP objective.

Study Purpose

The terms of reference for the provincial Coarse Woody Debris Committee[1] directed it to undertake an extensive pilot study of post-harvest CWD as part of its mandate to develop workable CWD management recommendations and evaluation techniques. This study was implemented during the field seasons of 2000 and 2001. Cutblocks chosen for sampling were harvested between 1995 and 2001.

No provincially set mandatory CWD target levels existed during that time period and, therefore, CWD management statements in silviculture prescriptions were very general. For example, in the data set for the Sub-Boreal Spruce (SBS) mk1 variant, 39% of the silviculture prescriptions contained a CWD management objective. Some of these include:

- "Currently, utilization standards will take precedence of requirements for CWD. However efforts will be made to maintain residue and waste well distributed across the stand. Large piles will be burned when moist to attempt to retain some unburned residue. Non-merchantable material will be left on site."

[1] B.C. Ministry of Forests' Coarse Woody Debris Committee: Nancy Densmore, John Parminter, Victoria Stevens, Gerry Davis, Andre Arsenault, Don Heppner, Andy MacKinnon, Paul Sanborn, Bill Chapman, Mike Curran, Don Mullet, Doug Steventon, John Wai, and Shawn Hedges.

- "Actions to maintain CWD will be undertaken during site preparation."
- "Where possible, non-merchantable CWD will remain within the area to be reforested for biodiversity."
- "Non-utilized wood residue remaining on site following harvesting and site preparation activities (if any) will provide for some CWD. Additional future CWD will result from retained deciduous and wildlife trees."

The 2001 field surveys included an assessment of CWD left in piles to determine the potential for increasing the amount of CWD dispersed over cutblocks by decreasing the amounts brought in and piled at roadsides and on landings.

The objectives of the study were to:

- examine the amount and type of CWD left behind after the original stands were logged without regard to CWD targets;
- predict the amount of CWD volume present in the new stands after a 90-year rotation period; and
- compare this amount with that occurring in mature or old unmanaged stands.

Methodology

Surveys

Choice of Ecosystem and Cutblock Location

Provincial CWD committee members from the two forest regions where the sampling occurred chose ecosystems in the Sub-Boreal Spruce (SBS), Interior Cedar–Hemlock (ICH), and Interior Douglas-fir (IDF) biogeoclimatic zones for sampling (see Table 1). Based on professional experience, it was suspected that attaining sufficient quantities and qualities of post-harvest CWD would be especially problematic in these ecosystems.

For each biogeoclimatic subzone variant, a list of potential cutblocks was derived from the B.C. Ministry of Forests' Integrated Silviculture Information System (ISIS).[2] This list included all clearcut or clearcut-with-reserve sites harvested after 1995, and constituted the complete population of cutblocks that could be sampled. A subset of this list was created for sampling. A significant criterion for choosing sample cutblocks was accessibility by road. Beyond that, cutblocks were chosen randomly. The total number of cutblocks sampled (163) was dictated by available funding.

TABLE 1. Subzones and variants sampled for post-harvest coarse woody debris[a]

Region	Sampled in 2000	Sampled in 2001
Northern Interior	SBSmk1	ICHvk2 and ICHwk3[b]
Southern Interior	IDFdm2	ICHdw

[a] Ecosystems are delineated according to the Biogeoclimatic Ecosystem Classification System (***www.for.gov.bc.ca/hre/becweb/***). IDF = Interior Douglas-fir biogeoclimatic zone; ICH = Interior Cedar–Hemlock zone; and SBS = Sub-Boreal Spruce zone. The subzone designations refer to very wet cool (vk), wet cool (wk), moist cool (mk), dry mild (dm), and dry warm (dw). The numbers following the subzones refer to variants.

[b] In the Northern Interior sampling of 2001, 17 cutblocks were in the ICHvk2 and 6 cutblocks were in the ICHwk3. These wet subzones were lumped together for the purposes of this analysis.

Line Transect Surveys

The line transect method (Van Wagner 1982) was used to assess the types and amounts of dispersed CWD. Two plots were established by randomly choosing points from a 100-m grid overlain on the cutblock. Each plot consisted of three 50-m spokes emanating from a common point with an equal angle between the spokes.

Measurements were taken on all pieces of deadwood on the line transects that were greater than 7.5 cm in diameter at the intersection point. This procedure was derived from the Vegetation Resources Inventory coarse woody debris methodology (B.C. Ministry of Sustainable Resource Management 2002).

Data collected for each piece of CWD included:

- tree species
- length class (the 2000 field season used length classes of: LC1 < 6 m, LC2 6–12 m, LC3 12–18 m, LC4 18–24 m, LC5 > 24 m; the 2001 field season split[3] LC1 and therefore had the following classes: LC1 < 3 m, LC2 3–6 m, LC3 6–12 m, LC4 12–18 m, LC5 18–24 m, LC6 > 24 m)
- diameter at transect crossing
- tilt angle (away from the horizontal)
- decay class

[2] For a description of ISIS and a user guide, go to the B.C. Ministry of Forests' Information Management Group Web site at: ***www.for.gov.bc.ca/his/isis/***

[3] This split was done to further differentiate the size class that had the highest volume in the 2000 data set.

Landing Piles and Spot Accumulations

The 2001 survey of the ICH ecosystems in the Southern Interior and Northern Interior forest regions included a separate assessment of CWD piled at roadsides, on landings, and in spot accumulations within the cutblocks. The residue and waste survey methodology was used for assessing piles (B.C. Ministry of Forests 2002). Landing piles and spot, or strip, accumulations were measured to determine the amount of CWD that could potentially have been dispersed in logged settings. The partial sampling of accumulations was allowed for; therefore, single piles may have been only partially measured, and (or) measurements may have only been completed on a random subsample of the total number of accumulations. Partial sampling was necessary for safety reasons, or to allow completion of sampling during a reasonable time frame.

All (or a partial sample of) CWD pieces greater than 10 cm in diameter and less than 3.0 m long in the piles and accumulations were tallied, and the following parameters recorded:

- tree species
- decay class
- large- and small-end diameters
- length of portion of CWD piece greater than 10 cm in diameter (estimated or measured)

The total volume of CWD in piles and spot accumulations was calculated, with some prorating to account for partial sampling. The nature of sampling complex CWD accumulations, coupled with safety considerations for survey crews, resulted in poorer accuracy for these volume calculations. In addition, many of the landing piles had been burned before they could be sampled. Although uncertainty surround these data, they were still useful in determining the relative amounts of CWD left in piles and accumulations.

Comparison to Pre-harvest Levels of Coarse Woody Debris

Pre-harvest CWD data were not available for the sampled cutblocks. For comparison purposes, however, alternate sources of pre-harvest data were used for the SBSmk1 and IDFdm2 subzones. These included data for mature natural SBSmk1 stands obtained from the Northern Interior Vegetation Management Association (NIVMA) and CWD data for mature natural IDFdm stands obtained from a B.C. Ministry of Forests Research Branch database (Liang 1997). Both of these data sets were representative of stands that could be chosen for harvesting. The intention was to compare a projected CWD volume potential at 90 years after harvesting to that found just before harvesting of an unmanaged stand.

The NIVMA routinely collects pre- and post-harvest information using their TRENDS Protocol (Northern Interior Vegetation Management Association 2002). Line transect surveys are used to collect information on CWD, including data on piece diameter, length, height above ground, and decay class. The NIVMA cutblocks are all mature or old unmanaged stands chosen for harvesting. Although ages were not available for every block, the range was 93–183 years. Leading species included hybrid spruce, lodgepole pine, subalpine fir, and trembling aspen. The moisture description for these sites ranged from subxeric to subhydric, though the majority were mesic.

The data collated by Qiwei Liang came from a wide variety of sources, but were summarized in a consistent fashion and shows the number of pieces per hectare and the volume per hectare by sampling point diameter class and piece decay class (Liang 1997). Although the transect layouts and lengths varied among the different surveyors, the line transect methodology produces comparable volumes per hectare by correcting for such differences.

Modelling

Decay Rates

The length of time that various-sized CWD pieces remain on a site was estimated using the following exponential model for volume change due to decay:

$$V_t = V_0 e^{-kt},$$

where: V_t is the piece volume at time t; V_0 is the piece volume at time 0; e is the exponential constant (approximately 2.718282); and k is a decay rate constant that varies by species (Harmon *et al.* 1986; Mackensen and Bauhus 1999).

Log volume (assuming a cylinder) was calculated using the following formula:

$$V = \pi\, r^2 \times \text{length}$$

The midpoint of each length class was used for piece length.

Default decay rate constants were chosen for each species in the B.C. Ministry of Forests' TIPSY (the Table Interpolation Program for Stand Yields) stand-level model. These constants are independent of piece size or decay class (see Table 2).

TABLE 2. Decay rate constants

Species	Decay rate constant, *k*
Interior and Coastal Douglas-fir	0.02
Sitka and white spruce	0.02
Interior and Coastal western hemlock	0.03
Lodgepole pine	0.04
Western redcedar	0.01

Although TIPSY[4] primarily models the growth and yield of live trees and is used to predict future harvest volumes for managed stands, it also provides output on tree mortality, dead trees, and CWD. Mortality tables describe the trees that die between age steps from non-competitive juvenile mortality and suppression. To generate standing dead tree statistics, data from the mortality tables is used in a logistic model that determines the falldown rate of snags. This provides a stand table of standing dead trees expected at each age step by DBH class.

To determine the amount of CWD, several different tables can be generated that show the periodic recruitment of CWD from the fallen dead trees or the cumulative recruitment of CWD less decay (based on a simple exponential decay model) and breakage. The report can include all CWD that accumulated since time zero, or just the standing deadwood that became CWD during a specified period.

The TIPSY model assumes that no CWD is present on the forest floor at stand establishment and that CWD is derived only from tree boles, not from large branches. Another assumption is that dead trees fall as a single piece, which has the net effect of delaying CWD input (recruitment) and lengthening the period required for decay. However, because standing dead trees and CWD may fragment in many different ways and the resulting effects on deadwood distribution and persistence, it is difficult to correct for these factors.

The decay rates used in TIPSY either came from the literature or were interpolated from existing data where none existed for the species in question. For further information regarding the determination of decay rates see, for example, Alban and Pastor (1993), Edmonds *et al.* (1986), Erickson *et al.* (1985), Graham and Cromack (1982), or Sollins *et al.* (1987).

The decay rate constants were used to model the decay of representative plot samples of CWD. To estimate the input of CWD as the regenerating stands developed and grew, TIPSY runs of representative managed stands for the chosen ecosystems were completed using the model's CWD function.

The decay of different-sized Douglas-fir logs is shown in Table 3. A 30 cm × 9 m log begins at time zero with a volume of 0.64 m^3. After 90 years, this volume will decrease to 0.1 m^3. By comparison, one can assume that a 10 cm × 3 m piece of CWD (volume 0.02 m^3 at time zero) would be virtually gone before 90 years, or approximately one rotation.

Stone *et al.* (1998) demonstrated the effect of decay class, piece diameter, and piece length on the decay constant (*k*). Larger pieces decay more slowly; thus, as diameter and (or) length increases, *k* decreases. As the decay rate of a CWD piece increases, so does the decay constant, *k*. However, the effect of piece size on the decay constant was not accounted for in this exercise.

To account for the coincident changes in CWD piece size and decay class, and their combined effects on the decay constant, a complex modelling approach would be required; however, this could not be carried out because the specific decay constants for the different combinations of piece size and decay class are still unknown. Therefore, the actual difference in longevity between small and large pieces is more pronounced than the model shows. In reality, the smaller pieces (e.g., 10 cm × 3 m logs) would disappear more quickly than shown in Table 3, and the larger pieces (e.g., 50 cm × 9 m logs) would actually last longer than shown. The use of decay constants averaged for the range of piece sizes accounts for these effects.

Stone *et al.* (1998) compared CWD in research plots measured in 1929–1930 with the same plots remeasured in 1995–1996. After 65 years, 38 of the original 186 logs remained distinguishable as CWD (logs > 10 cm and > 1 m). In particular, this study found that most of the CWD that was originally less than 20 cm in diameter at the large end was assimilated into soil after 65 years.

[4] Information on TIPSY can be found at the B.C. Ministry of Forests, Research Branch Web site: ***www.for.gov.bc.ca/hre/gymodels/tipsy/software.htm***

TABLE 3. Decay table for different sizes of Douglas-fir logs showing piece volumes in cubic metres, all with a decay constant, $k = 0.02$

Years since harvest	10 cm × 3 m	10 cm × 9 m	10 cm × 12 m	30 cm × 3 m	30 cm × 9 m	30 cm × 12 m	50 cm × 3 m	50 cm × 9 m	50 cm × 12 m
0	0.024	0.071	0.094	0.212	0.636	0.848	0.589	1.767	2.356
10	0.019	0.058	0.077	0.174	0.521	0.694	0.482	1.447	1.929
20	0.016	0.047	0.063	0.142	0.426	0.569	0.395	1.185	1.579
30	0.013	0.039	0.052	0.116	0.349	0.466	0.323	0.970	1.293
40	0.011	0.069	0.042	0.095	0.286	0.381	0.265	0.794	1.059
50	0.009	0.026	0.035	0.078	0.234	0.312	0.217	0.650	0.867
60	0.007	0.021	0.028	0.064	0.192	0.255	0.177	0.532	0.710
70	0.006	0.017	0.023	0.052	0.157	0.209	0.145	0.436	0.581
80	0.005	0.014	0.019	0.043	0.128	0.171	0.119	0.357	0.476
90	0.004	0.012	0.016	0.035	0.105	0.140	0.097	0.292	0.389

Decay and Input in Representative Plots

In general, four factors determine the amount of CWD available on a managed site:

1. initial volume of CWD present in the post-harvest cutblock;
2. input of CWD as the new stand grows and experiences mortality;
3. depletion of the initial and new CWD through various decay processes; and
4. input of CWD from within reserves such as Wildlife Tree Patches and from reserved trees.

A simple modelling exercise illustrates the first three factors. Using the TIPSY program, CWD input derived from a regenerating stand was determined. Three plots were chosen from the Northern Interior SBSmk1 post-harvest CWD data set and the Southern Interior IDFdm2 data set. The plots chosen had post-harvest volumes per hectare close to the minimums, averages, and maximums of all cutblocks sampled in the particular ecosystems. The following steps were taken.

- The volume of each piece of CWD on the representative plots was calculated.
- The number of pieces per hectare represented by each piece in the plot was calculated after Van Wagner (1982): $[(p)/(2 \times L \times \text{length})] \times 10\,000$, where L = sample line length.
- Each piece was decayed using the appropriate default decay coefficient (Table 2). Remaining piece volumes were calculated every 10 years for 160 years into the future.
- Volume per hectare was calculated by multiplying the volume of each piece in the plot by the number of pieces per hectare that it represented and then summing the total.

In many cases, a tree species could not be assigned to the sampled CWD piece and so a default decay coefficient of 0.02, equivalent to Douglas-fir or white spruce, was used for these unknowns.

To determine CWD input from the newly harvested stands, runs of the TIPSY model were performed by choosing species and planting density (target stocking standard) for the zonal site (01 site series) of the subzone variant from the *Establishment to Free Growing Guidebook* for the appropriate region (B.C. Ministry of Forests 2000b). Site index was taken from *Site Index Estimates by Site Series for Coniferous Tree Species in British Columbia* (Forest Renewal BC and B.C. Ministry of Forests 1997).

Results

Surveys

Post-harvest Data Tables

Volume data by piece diameter class at the sampling intersect is summarized in Table 4. These data show a consistent pattern in post-harvest CWD for the SBSmk1, IDFdm2, and ICHdw. In each of these three subzones, 38–47% of the total post-harvest CWD volume occurred in

TABLE 4. Total CWD volume and CWD volume by diameter class (all decay classes)

						Average volume (m^3/ha) by diameter class				
Subzone	Region	No. of blocks	Min. vol. (m^3/ha)	Avg. vol. (m^3/ha) (SD)	Max. vol. (m^3/ha)	7.5–20 cm (%)	20–40 cm (%)	40–60 cm (%)	60–80 cm (%)	> 80 cm (%)
SBSmk1	Northern Interior	60	22.84	145.04 (80.71)	390.41	68.61 (47.3)	66.14 (45.6)	5.55 (3.8)	0.69 (0.8)	4.06 (2.8)
IDFdm2	Southern Interior	54	3.96	37.97 (29.95)	155.43	17.51 (46.1)	14.51 (38.2)	4.84 (12.7)	1.12 (2.9)	0 (0)
ICHdw	Southern Interior	26	16.07	81.67 (49.42)	243.39	31.12 (38.1)	34.83 (42.6)	12.02 (14.7)	3.67 (4.5)	0 (0)
ICHvk2 and wk3	Northern Interior	23	87.66	232.73 (92.25)	486.32	45.81 (19.7)	97.10 (41.7)	39.50 (17.0)	13.19 (5.7)	37.12 (15.9)

the smallest diameter class, 7.5–20 cm (i.e., large amounts of small pieces of CWD). The Northern Interior ICHvk2 differed in that a lower volume (19.7%) occurred in the smallest diameter class and a higher volume in the greater than 80 cm diameter class (15.9%).

A summary of the large pieces that could be expected to survive a full rotation, and still considered to be a sizeable piece of CWD, is included in Table 5 (large piece volume > 30 cm diameter and 12 m length). These data show a consistent pattern of distribution of CWD volume by length class for all four subzones. Of the total CWD volume, 58–80% is in pieces less than 6 m long. The amount of volume in large pieces (> 30 cm diameter and > 12 m long) ranges from 3.9 to 8.5% of the total CWD volume.

A summary of volume by decay class is shown in Table 6. The decay classes range from decay class 1, which is sound wood, to decay class 5, which is highly decayed and being incorporated into the organic soil. The more decayed pieces (decay classes 4 and 5) often do not survive harvesting activities because they are crushed by machine traffic. The distribution of CWD into decay classes varies significantly between the biogeoclimatic zones. The SBS cutblocks have very little volume in decay class 1, but significant amounts in the remaining four decay classes. The IDF cutblocks have more CWD in decay class 1 and a fairly even distribution of volume throughout the remaining decay classes. The ICH cutblocks have the majority of CWD in decay classes 2 and 3.

Table 6 also shows the number of pieces of CWD by length class. The data indicate that the vast majority of pieces are shorter than 6 m. Although the Northern Interior ICHvk2 had a significant amount of volume in the largest diameter class (Table 5), the pieces were generally short.

TABLE 5. Coarse woody debris volume by length class and volume of large pieces (all decay classes)

		Average volume (m^3/ha) by length class						
Subzone	Region	< 3 m (%)	< 6 m (%)	6–12 m (%)	12–18 m (%)	18–24 m (%)	> 24 m (%)	Large piece volume (%)[a]
SBSmk1	Northern Interior	[b]	115.82 (79.8)	16.25 (11.2)	8.42 (5.8)	4.32 (3.0)	0.23 (0.1)	5.70 (3.9)
IDFdm2	Southern Interior	[b]	26.53 (69.9)	7.56 (19.9)	3.42 (9.0)	0.35 (0.9)	0.11 (0.3)	1.89 (5.0)
ICHdw	Southern Interior	21.91 (26.8)	25.47 (31.2)	22.31 (27.3)	10.33 (12.6)	1.51 (1.8)	0.12 (0.1)	6.94 (8.5)
ICHvk2 and wk3	Northern Interior	103.10 (44.3)	60.16 (25.8)	47.15 (20.3)	17.65 (7.6)	4.37 (1.9)	0.30 (0.1)	17.67 (7.6)

[a] Greater than 30 cm and 12 m.
[b] The smallest length class for data collected in year 2000 was less than 6 m.

TABLE 6. Coarse woody debris volume by decay class and number of CWD pieces by length class

		Average volume (m^3/ha) by decay class					Number of pieces by length class (m)					
Subzone	Region	1	2	3	4	5	< 3	< 6	6–12	12–18	18–24	> 24
SBSmk1	Notherrn Interior	1.78	19.79	42.04	36.52	44.92	[a]	1644	53	13	4	0
IDFdm2	Southern Interior	14.62	5.18	5.63	4.74	7.80	[a]	375	30	5	0	0
ICHdw	Southern Interior	8.5	29.6	19.1	12.5	11.9	653	176	62	13	1	0
ICHvk2 and wk3	Northern Interior	17.85	84.60	88.81	33.11	8.36	1945	202	65	11	2	0

[a] The smallest length class for data collected in year 2000 was less than 6 m.

TABLE 7. Pre-harvest CWD volume

Subzone or variant	Cutblocks sampled	Minimum volume (m^3/ha)	Average volume (m^3/ha)	Maximum volume (m^3/ha)
SBSmk1	21	41.6	176.1	532.0
IDFdm	17	13.3	108.5	427.5

Comparison to Pre-harvest Levels of Coarse Woody Debris

SBSmk – Pre-harvest CWD information was obtained for 21 SBSmk1 cutblocks. Average CWD volume was 176 m^3/ha (Table 7). The actual plot data ranged from 41 to 532 m^3/ha. Sixty percent of the average volume came from pieces greater than 12 m long (length classes 3 and 4). By comparison, the sampled post-harvest stands had only 9% of the average volume coming from pieces longer than 12 m. Probably less significant, the average CWD volume was somewhat lower on post-harvest sites (145 m^3/ha) and the range of volumes was smaller.

IDFdm – Pre-harvest CWD information was obtained for 17 IDFdm cutblocks. Average CWD volume was 108.5 m^3/ha (ranging from 13.3 to 427.5 m^3/ha). The average post-harvest CWD volume was much lower at 36.45 m^3/ha. Some of the drier IDFdm2 sites have been affected by several decades of fire exclusion, leading to a build-up of more CWD than would have existed historically. The influence of fire exclusion has been less pronounced on the wetter IDFdm2 sites. Only 11 of the 17 cutblocks had the data broken down by size class and, therefore, this comparison is not presented.

Pile and Spot Accumulations

Surveyors for the 2001 sampling also collected information on the amount of CWD found in landing piles or spot accumulations on the cutblocks. Table 8 shows averages only for cutblocks in which it was possible to

TABLE 8. Summary of total CWD volume (cubic metres) found in landing piles and spot accumulations

Region/		Total cutblock volume (m^3)			Average volume (m^3) in length classes (m)					
subzone	No. blocks	Min.	Average (SD)	Max.	< 3	3–6	6–12	12–18	18–24	> 24
Southern ICHdw	21	0.24	7.03 (7.95)	27.05	0.23	4.24	1.70	0.55	0.32	0.00
Northern ICHvk2/wk3	15	11.93	312.98 (431.29)	1465.33	18.55	54.39	175.10	59.00	5.93	0.00

measure a portion of the piles or spot accumulations. This was 81% of the sampled ICHdw cutblocks and 65% of the ICHvk2/wk3 cutblocks. In many of the cutblocks, landing piles were already burned, making measurement impossible or meaningless. Table 8 also presents data on the total volumes (not on a per hectare basis) of CWD that could potentially be made available as dispersed CWD, if it had not been concentrated in landing piles or spot accumulations.

Sampled ICHdw cutblocks in the Southern Interior Forest Region averaged 9.1 ha in size. In addition to the average of 81.7 m^3/ha dispersed across the cutblocks (Table 4), this works out to a potential 0.8 m^3/ha of CWD (7.03 m^3 divided by 9.1 ha) contained in piles and spot accumulations.

Sampled ICHvk1 and wk3 cutblocks in the Northern Interior Forest Region averaged 67.7 ha in size. In addition to the average 232.7 m^3/ha dispersed across the cutblocks (Table 4), this works out to a potential 4.6 m^3/ha of CWD (312.98 m^3 divided by 67.7 ha) contained in piles and spot accumulations. These data indicate that, at least for the ICHdw subzone, there is likely little opportunity for increasing the dispersed volumes of CWD by decreasing the amount being placed in landing piles or spot accumulations. A slightly greater amount of CWD occurs in landing piles and spot accumulations in the Northern Interior samples, where dispersed volumes could potentially be increased by about 3%.

Modelling

Decay and Input in Representative SBSmk Plots

The data in Table 9 show the decay of three plots of post-harvest CWD volumes (minimum, average, maximum) and the cumulative CWD input from the new SBSmk1 stand. At a harvest age of 90 years, the CWD input from the new stand totalled only 4.33 m^3/ha. A 90-year-old managed stand in the SBSmk1 does not contribute significant volumes of CWD. After 90 years, the minimum CWD volume plot has 2.97 m^3/ha remaining, the average CWD volume plot has 22.34 m^3/ha remaining, and the maximum volume plot has 53.43 m^3/ha remaining.

Total CWD volumes can be estimated by adding the remaining CWD from the original plots to the net CWD

TABLE 9. Modelling of CWD input from regenerating stand and decay in the SBSmk1

Year since harvest	Net CWD input from new stand (m^3/ha)	Decay of CWD on min. vol. plot (m^3/ha)	Decay of CWD on avg. vol. plot(m^3/ha)	Decay of CWD on max. vol. plot (m^3/ha)
0	0	23.25	143.92	379.77
10	0.01	17.93	115.40	300.88
20	0.16	13.99	93.15	239.61
30	0.42	11.03	75.54	191.66
40	0.52	8.76	61.44	153.89
50	0.55	7.00	50.09	123.97
60	0.7	5.62	40.89	100.13
70	1.22	4.53	33.41	81.07
80	2.27	3.66	27.32	65.76
90	4.33	2.97	22.34	53.43
100	7.47	2.41	18.28	43.47
110	11.95	1.96	14.96	35.41
120	18.32	1.59	12.25	28.87
130	25.21	1.30	10.03	23.55
140	31.35	1.06	8.21	19.23
150	[a]	0.87	6.72	15.70
160	[a]	0.71	5.50	12.83

[a] TIPSY data exceeded.

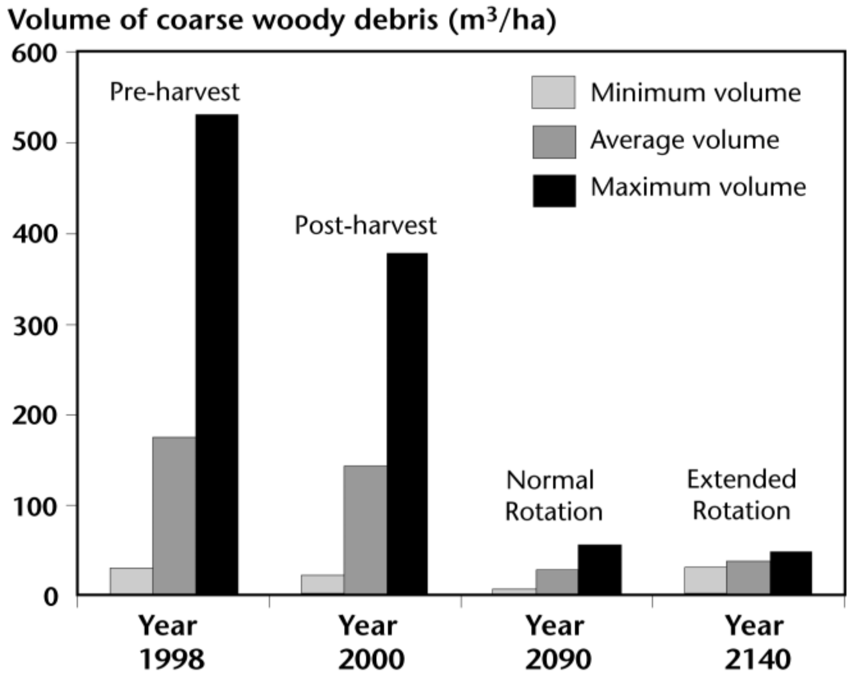

FIGURE 1. Modelling of coarse woody debris through time for the SBSmk1: pre-harvest, harvest, normal rotation end, extended rotation end.

input from the new stand. Therefore, total CWD volumes on these representative plots would be 7.3 m^3/ha (minimum), 26.67 m^3/ha (average), and 57.76 m^3/ha (maximum) around the time of the next harvest. This range of volumes is substantially below the average of the pre-harvest SBSmk1 CWD data (range 41–532 m^3/ha; average 176 m^3/ha). Without specific management for CWD values, subsequent rotations of managed stands will have much lower CWD volumes remaining on site.

Figure 1 illustrates the amount of CWD in the SBSmk1 at three times in the stand history (2000, 2090, 2140), exclusive of any CWD volume found in reserves. The 1998 bars represent the 21 SBSmk1 pre-harvest cutblocks. The 2000 bars represent data collected in the SBSmk1 on newly harvested stands. The 2090 and 2140 bars represent projected volumes (90 and 140 years into the future), resulting from decaying the CWD present in 2000 and inputting net CWD from the new stand. The 2140 bars represent the potential CWD present if a longer rotation is used.

The information in Table 9 and Figure 1 show that current management practices will not meet the level of CWD present in the SBSmk1 pre-harvest stands. This is attributed to the high proportion of small pieces of post-harvest CWD (as measured in 2000), which will decay rapidly. In addition, the new managed SBSmk1 forest does not contribute significant amounts of CWD during normal rotation lengths.

A sensitivity analysis was done to assess the effect of site index on the CWD volume in a managed stand as projected by TIPSY. The 1997 Site Index/Biogeoclimatic Ecosystem Classification estimates use 3-m classes and present estimates for the middle of each class (Shirley Mah, B.C. Ministry of Forests, pers. comm., 2003). Runs of the TIPSY model were therefore performed at a 19.5 and 22.5 m site index, as well as a mid-point of 21 m. Using a site index of 19.5 m versus 21 m resulted in 1.9 m^3/ha of CWD at a stand age of 90 years, compared to 4.3 m^3/ha at a site index of 21 m. The higher site index of 22.5 m resulted in 9.4 m^3/ha of CWD at age 90. This higher level of CWD input from the managed stand combined with the level of CWD on the maximum CWD plot would give a potential level of CWD at age 90 of 62.8 m^3/ha—a level that is 5% and 1% closer, respectively, to the average and maximum unmanaged pre-harvest values compared to using the mid-class site index of 21 m.

Increasing planting density to 400 stems per hectare above the target standard also results in increased predicted CWD. This increase would likely result in increased competition mortality. The TIPSY model predicts a CWD level of 11.4 m^3/ ha with a site index of 21 m and planting density of 1600 stems per hectare. This amount of CWD from the managed stand at age 90 means a total level of CWD that is 10% and 3%, respectively, of the average and maximum levels found in the data from the pre-harvest unmanaged stands.

Decay and Input in Representative IDFdm2 Plots

Table 10 data show the decay of three plots of post-harvest CWD volumes (minimum, average, maximum) and the cumulative net CWD input from the new IDFdm2 stand. At 90 years, the CWD input from the new stand totalled only 0.61 m^3/ha. A 90-year-old managed stand in the IDFdm2 does not contribute significant volumes of CWD. After 90 years, the minimum CWD volume plot has 0.74 m^3/ha remaining, the average CWD volume plot has 0.86 m^3/ha remaining, and the maximum volume plot has 16.99 m^3/ha remaining.

Therefore, based on the sum of CWD remaining plus net inputs, total CWD volumes would be 1.35 m^3/ ha (minimum), 1.47 m^3/ha (average), and 17.60 m^3/ha (maximum) around the time of the next harvest. This range of volumes is substantially below the average of pre-harvest CWD (range: 13–427 m^3/ha; average: 108 m^3/ha). Without specific management for CWD values, subsequent rotations of managed stands will have dramatically lower averages of CWD volumes remaining on the site.

Figure 2 illustrates the amount of CWD in the IDFdm2 at three times in the stand history (2000, 2090, 2160), exclusive of CWD volumes present in reserves. The 1998 bars represent pre-harvest data on 17 IDFdm cutblocks. The 2000 bars represent the data collected in the IDFdm2 on newly harvested stands. The 2090 and 2160 bars represent projected volumes (90 and 160 years into the future) resulting from decaying the CWD present in 2000, and net CWD input from the new stand. The 2160 bars represent the potential CWD present if a longer rotation is used.

The information in Table 10 and Figure 2 show that with current management practices, it is not possible to meet the level of CWD present in the IDFdm2 pre-harvest stands. As with the SBSmk1, this is attributed to the high proportion of small pieces of post-harvest CWD (as measured in 2000), which decay rapidly. In addition,

TABLE 10. Coarse woody debris input and decay on IDFdm2

Year since harvest	Net CWD input from new stand (m^3/ha)	Decay of CWD on min. vol. plot (m^3/ha)	Decay of CWD on avg. vol. plot(m^3/ha)	Decay of CWD on max. vol. plot (m^3/ha)
0	0	4.46	37.74	125.67
10	0	3.65	24.40	98.82
20	0.01	2.99	15.87	78.18
30	0.05	2.45	10.37	62.19
40	0.15	2.01	6.80	49.69
50	0.32	1.64	4.48	39.86
60	0.50	1.34	2.96	32.09
70	0.62	1.10	1.96	25.90
80	0.66	0.90	1.30	20.96
90	0.61	0.74	0.86	16.99
100	0.54	0.57	0.60	13.80
110	0.49	0.38	0.49	11.23
120	0.45	0.26	0.40	9.14
130	0.43	0.17	0.33	7.45
140	0.42	0.11	0.27	6.08
150	0.43	0.08	0.22	4.96
160	0.45	0.05	0.18	4.05

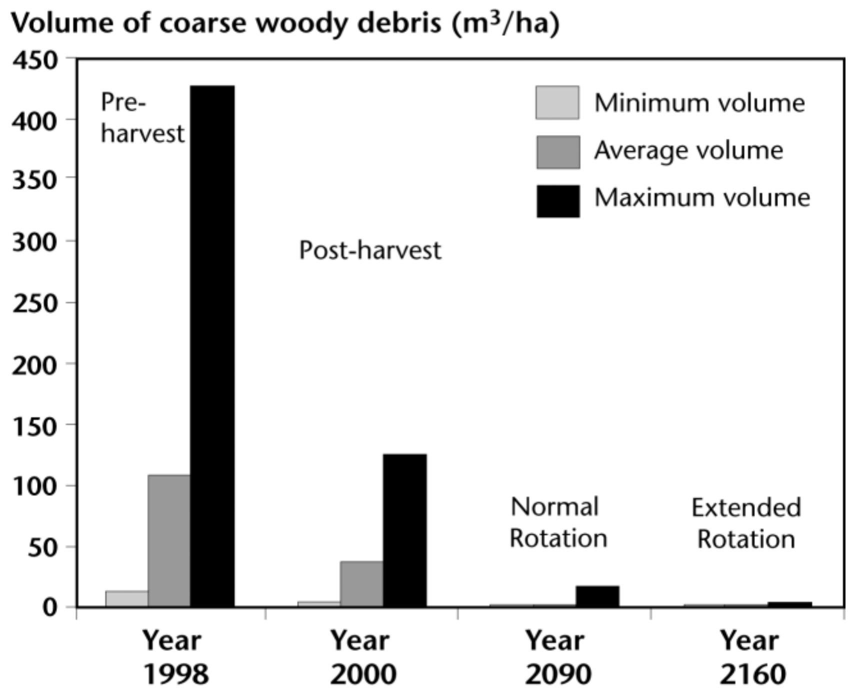

FIGURE 2. Modelling of coarse woody debris through time for the IDFdm2: pre-harvest, harvest, normal rotation end, extended rotation end.

the new managed IDFdm2 forest does not contribute significant amounts of CWD to the stand during normal rotation lengths.

A sensitivity analysis on site index, similar to that explained above for the SBSmk1, was done on the IDFdm2 data. For the IDFdm2, the 3-m class suggested a potential site index ranging from 13.5 to 16.5 m. Changing site index within this range did not change the amount of CWD predicted for age 90 by TIPSY. Increasing planting density by 400 stems per hectare over the target stocking standard only slightly increased the level of CWD predicted for age 90 on a site index 15 m stand from 0.6 to 0.7 m^3/ha.

Discussion

The average volume of CWD in SBSmk1 post-harvest plots in the Northern Interior Forest Region was comparable to the average volume found in the pre-harvest unmanaged stands in this variant. However, the volumes would not be comparable by the end of a rotation. By 90 years after harvest, the post-harvest CWD in an average stand would have decayed from 144 m^3/ha to about 22 m^3/ha. The net input from the newly growing stand would be approximately 4 m^3/ha by age 90. Therefore, at the time of the next rotation, the average managed stand would have approximately 26 m^3/ha of CWD—about 15% of the CWD found in the natural stands.

The average post-harvest CWD volume found in ICHdm2 plots in the Southern Interior Forest Region was less than half that in pre-harvest natural stands. Modelling for decay and net input of CWD in ICHdm2 stands showed that by 90 years after harvest, CWD volumes are only about 1.5 m^3/ha. This is roughly 1.5% of the CWD found in the natural stands.

This simple input and decay model does not consider the contribution of CWD from reserve areas, such as wildlife tree patches and variable retention blocks. A British Columbia government evaluation of 128 cutblocks showed that, on average, 9.4% of a cutblock area is left as wildlife tree retention and riparian reserves (B.C. Ministry of Forests and B.C. Ministry of Water, Land and Air Protection 2003). This current paper, therefore, would represent CWD on the approximately 90% of a cutblock where no long-term retention exists. To provide for CWD functions including soil surface stability, travel-ways across the forest floor for small mammals, and refugia through dry periods, we believe it is important to manage for CWD outside of reserves.

The decay constants used were approximate, since they considered only tree species and not the various additional combinations of species and decay class, piece diameter or piece length. The decay constants are, however, applied to pieces of known length and diameter class.

The results illustrate that without specific management of the deadwood resource, the amount of CWD found outside reserves in managed stands 90 years after harvesting will likely be a small fraction of what is found in natural stands. Coarse woody debris of small diameter and (or) length decays more quickly than larger material of the same species in the same initial decay class.

Using the default decay rate constant, without considering the effects of log size or decay class, likely underestimates the decay rate. The SBSmk1 ecosystem showed 56% of CWD volume in decay classes 4 and 5. Stone *et al.* (1998) showed a much higher decay rate for such rotten pieces of wood. The IDFdm2 had more wood (52% of the total) in decay classes 1 and 2 and would likely have slower decay rates. The CWD volume in both ecosystems came predominantly from pieces less than 6 m long, with the highest percentage of volume in the smallest diameter class. These relatively small pieces would likely decay faster than indicated by the default decay constant.

Landing piles and spot accumulations were sampled during the 2001 surveys to determine whether they contained significant amounts of CWD that potentially could have been left dispersed on the cutblock. The sampling was crude and included some partially burned piles. However, the results indicate that large amounts of functional CWD are not being left in piles or spot accumulations in the sampled subzones.

It is not known conclusively what effect low volumes of post-harvest CWD will have on provincial ecosystems. Results from northern Europe indicate that decreasing the volume of deadwood to 2–30% of that present in natural stands is correlated with increasing numbers of deadwood-dependent species being classified as threatened. The model described here indicates that, under current practice, the volume of CWD will fall well under 30% in the two ecosystems modelled.

Various techniques are available to manage the CWD resource. Using the quantities and qualities of deadwood present in natural stands is suggested as a starting point when determining how much CWD should be retained in managed stands (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995). The actual amount retained depends on numerous site-specific and landscape-level factors.

. . . without specific management of the deadwood resource, the amount of CWD found outside reserves in managed stands 90 years after harvesting will likely be a small fraction of what is found in natural stands.

Forest managers who wish to develop CWD targets should assess the effect of increasing CWD levels on factors such as planting spots and fuel loading. A comparison of CWD in harvested and unharvested sites determined that retaining clumped groupings of structural elements, such as CWD, stubs, and live trees undamaged, is a practical method. These groupings are visible to equipment operators during harvest and, therefore, are relatively easily avoided (Morice and Lakes IFPA 2003). Using a minimum intertree spacing with such groupings of stand structure elements would allow for maintenance of stocking (B.C. Ministry of Forests 2000b).

While fine, dead, woody fuels are the most easily ignited and are responsible for fire spread, CWD can burn with high intensity for extended periods, challenging fire suppression operations and serving as a source of new fires (Pyne *et al.* 1996). Thus the characteristics, quantity, and arrangement of CWD are of potential concern to fire managers, especially during periods of high and extreme fire danger when fuel moisture levels are low.

Experience elsewhere indicates that adequate amounts of CWD are required throughout a managed rotation to provide for important ecological processes. The sampling and modelling techniques used here contribute towards the formulation of stand-level CWD management approaches by providing an indication of the quantity, piece size, and distribution of CWD that remains on harvested sites and its expected longevity. This technique can be used to assess whether a chosen level of CWD retention for a stand is effective in maintaining a CWD presence over a rotation.

Acknowledgements

Thanks to Paul Sanborn and Pamela Dykstra for choosing the ecosystems for sampling of post-harvest CWD. Thanks also to: Harry Quesnel for the 2001 field work in Southern Interior, Art Myers for the 2000 Southern Interior field work, Dean Strachan for the 2001 Northern Interior field work, and Andre Stauble for the 2000 Northern Interior field work. Lisa Guss cheerfully worked her way through much of the data entry and helped with the data compilation. Hana Hermanek helped summarize the 2000 data set. Mike Fenger, Craig DeLong, John Harkema, and Peter Ott provided insightful comments on earlier drafts of this paper.

References

Alban, D.H. and J. Pastor. 1993. Decomposition of aspen, spruce, and pine boles on two sites in Minnesota. Canadian Journal of Forest Research 23(9):1744–1749.

Barclay, S., J. Ash, and D. Rowell. 2000. Environmental factors influencing the presence and abundance of a log-dwelling invertebrate, *Euperipatoides rowelli* (Onychophora: Peripatopsidae). Journal of Zoology 250:425–436.

British Columbia Ministry of Forests. 2000a. Provincial coarse woody debris short-term strategy. Victoria, B.C. URL: ***www.for.gov.bc.ca/hre/deadwood/DTgui3.htm***

________. 2000b. Establishment to free growing guidebook. Forest Practices Code of British Columbia, Victoria, B.C. URL: ***www.for.gov.bc.ca/tasb/legsregs/fpc/FPCGUIDE/Guidetoc.htm***

________. 2002. Logging residue and waste procedures manual. Victoria B.C. URL: ***www.for.gov.bc.ca/hva/manuals/rwprocedures/***

B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks. 1995. Biodiversity guidebook. Forest Practices Code of British Columbia, Victoria, B.C. URL: ***www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/biodiv/biotoc.htm***

B.C. Ministry of Forests and B.C. Ministry of Water, Land and Air Protection. 2003. Evaluation of wildlife tree retention for cutblocks harvested between 1996 and 2001 under the Forest Practices Code. Victoria, B.C. URL: ***www.for.gov.bc.ca/hfp/Pubswildlifetrees.htm***

B.C. Ministry of Sustainable Resource Management. 2002. Vegetation resources inventory: Ground sampling procedures. Victoria, B.C. URL: ***http://srmwww.gov.bc.ca/risc/pubs/teveg/index.htm***

B.C. Ministry of Water, Land and Air Protection. 1999. Managing identified wildlife: Procedures and measures. Volume 1. Victoria, B.C. URL: ***www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/other/wild/index.htm***

Edmonds, R.L., D.J. Vogt, D.H. Sandberg, and C.H. Driver. 1986. Decomposition of Douglas-fir and red alder wood in clear-cuttings. Canadian Journal of Forest Research 16(4):822–831.

Erickson, H.E., R.L. Edmonds, and C.E. Peterson. 1985. Decomposition of logging residues in Douglas-fir, western hemlock, Pacific silver fir, and ponderosa pine ecosystems. Canadian Journal of Forest Research 15(5):914–921.

Forest Renewal BC and B.C. Ministry of Forests. 1997. Site index estimates by site series for coniferous tree species in British Columbia. Victoria, B.C.

Fridman, J. and M. Walheim. 2000. Amount, structure, and dynamics of dead wood on managed forestland in Sweden. Forest Ecology and Management 131(2000):23–36. URL: ***www.elsevier.com/locate/foreco***

Graham, R.L. and K. Cromack, Jr. 1982. Mass, nutrient content and decay rate of dead boles in rain forests of Olympic National Park. Canadian Journal of Forest Research 12(3):511–521.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack, Jr., and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15:133–302.

Harvey, A.E., M.F. Jurgensen, and M.J. Larsen. 1983. Effects of soil organic matter on regeneration in northern Rocky Mountain forests. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. Portland, Oreg. GTR-PNW-163. pp. 239–242.

Harvey, A.E., M.J. Larsen, and M.R. Jurgensen. 1981. Forest management implications of improved residue utilization: Biological implications in forest ecosystems. *In* Harvesting and utilization opportunities for forest residues in the northern Rocky Mountains. U.S. Department of Agriculture Forest Service Intermountain Forest and Range Experiment Station, Ogden, Utah. GTR-INT-110. pp. 259–269.

Liang, Q. 1997. A summary report on baseline data of coarse woody debris in British Columbia. Maple Leaf Science Services, Victoria, B.C. Appendices, electronic files.

Lofroth, E. 1998. The dead wood cycle. *In* Conservation biology principles for forested landscapes. J. Voller and S. Harrison (editors). University of British Columbia Press, Vancouver, B.C. pp. 185–214. URL: ***www.for.gov.bc.ca/hre/deadwood/DTrol.htm***

Mackensen, J. and J. Bauhus. 1999. The decay of coarse woody debris. Australian Greenhouse Office, Canberra, Australia. National Carbon Accounting System Technical Report No. 6. URL: ***www.greenhouse.gov.au/ncas/reports/tech06.html***

Morice and Lakes Innovative Forest Practices Agreement. 2003. A comparison of CWD in harvested and unharvested sites. Summary No. 32. URL: ***www.moricelakes-ifpa.com/publications/index.html***

Northern Interior Vegetation Management Association. 2002. TRENDS field manual. Treatment regime evaluation: Numerical decision support. Prince George, B.C. Unpublished report. URL: ***www.nivma.bc.ca***

Pyne, S.J., P.L. Andrews, and R.D. Laven. 1996. Introduction to wildland fire. Second edition. John Wiley and Sons, New York, N.Y.

Rydin, H., M. Diekmann, and T. Hallingback. 1997. Biological characteristics, habitat associations, and distribution of macrofungi in Sweden. Conservation Biology 11(3):628–640. URL: ***http://conbio.net/SCB/Publications/ConsBio/***

Sollins, P., S.P. Cline, T. Verhoeven, D. Sachs, and G. Spycher. 1987. Patterns of log decay in old-growth Douglas-fir forests. Canadian Journal of Forest Research 17(12):1585–1595.

Stenlid, J. and M. Gustafsson. 2001. Are rare wood decay fungi threatened by inability to spread? *In* Ecology of woody debris in boreal forests. B.G. Jonsson and N. Kruys (editors). Ecological Bulletin 49:85–91. URL: ***www.oikos.ekol.lu.se/eb49.abstracts/eb49.12.htm***

Stevens, V. 1997. The ecological role of coarse woody debris: An overview of the ecological importance of CWD in British Columbia forests. Research Branch, B.C. Ministry of Forests, Victoria, B.C. Working Paper No. 30. URL: ***www.for.gov.bc.ca/hfd/pubs/Docs/Wp/Wp30.htm***

Stone, J.N., A. MacKinnon, J.V. Parminter, and K.P. Lertzman. 1998. Coarse woody debris decomposition documented over 65 years on southern Vancouver Island. Canadian Journal of Forest Research 28(5):788–793. URL: ***http://pubs.nrc-cnrc.gc.ca/cgi-bin/rp/rp2_abst_e?cjfr_x98-047_28_ns_nf_cjfr5-98***

Van Wagner, C.E. 1982. Practical aspects of the line intersect method. Petawawa National Forestry Institute Canadian Forestry Service, Chalk River, Ont. Information Report PI-X-12. URL: ***www.for.gov.bc.ca/hre/deadwood/DTmes7.htm***