Coarse Woody Debris decomposition - principles, rates and models

Coarse Woody Debris

- forms part of the dead wood cycle,
- is primarily created by tree death, and
- persists for some time

Natural disturbances (including insects and diseases) can add much CWD and forest harvesting activities can remove much CWD.

The comprehensive study of CWD decay requires a long time period and so our knowledge is limited.

As new stands develop

- competition mortality,
- small-scale disturbances, and
- other forms of tree death

add CWD to the ecosystem.

At any particular time, the total amount of CWD can be

- increasing,
- constant,
- or decreasing

depending on the

- timing,
- amount,
- and nature of CWD inputs

cmpared to

- the rates of decay of existing CWD
Figure 5 (from Stevens 1997) showing the cycle of CWD volume in NDT 3 ecosystems.

CWD exists in many combinations of

- tree species,
- piece diameter,
- piece length,
- decay class (1 → 5), and
- form

CWD piece decay is a function of these conditions as well as:

- cause of death
  - was tree windthrown while alive?
  - wind and diseases lead to more dead down
    - wind can produce CWD as dead tops and branches
- insects can lead to more standing dead
- wildfire can lead to both, depending on duff consumption
- insects or decay in standing live/dead tree before it fell?
- lightning can shatter a tree bole
- if fire-killed, is the bole charred?  
  - can inhibit excavation by invertebrates and vertebrates  
  - may or may not affect fungal activity

- amount of physical and biotic activity within the down piece
  - microbial and fungal activity  
    - larger CWD may have more fungi present, also varies with tree species
  - smaller CWD may have only bark beetles, larger diameter pieces may have wood borers
  - degree of physical and/or biological fragmentation

- local environment and regional climate
  - slope, aspect, elevation, exposure to sunlight
  - moisture and temperature regimes within and between pieces  
    - affect microbial and insect activity
  - piece orientation  
    - with or across slope?
  - is CWD suspended or in contact with the ground?  
    - ground contact maintains more moisture and allows entry of organisms  
    - can double the decomposition rate  
    - even faster if buried (up to 6 times faster than on ground)
  - is CWD frozen, very dry or very wet for part of the year?  
    - limits biological activity  
    - very dry especially influences smaller sized pieces

- natural disturbances
  - will surface fires consume some or all of the CWD?
Figure from Maser et al. (1979) illustrating how standing dead trees can enter different CWD decay classes after falling, depending on their existing condition.

CWD decay is due to five processes

- respiration
  - microbes transform bound carbon into CO₂
  - fungi break down components
    - white rot fungi break down cellulose and lignin
    - brown rot fungi break down only cellulose

- biological transformation
  - microbes and invertebrates metabolise organic matter

- leaching
  - water percolates through CWD and dissolves soluble materials

- fragmentation, collapse and settling
  - physical due to breakage during or after falling to the ground or impact from new CWD arrivals, shrinkage/swelling and freeze/thaw cycles forming cracks, machinery traffic
- biological due to microbes, fungi, bark beetles, wood borers, other invertebrates, vertebrates (birds, mammals), invading plant roots
  - weathering
    - disintegration by atmospheric elements

The CWD decay class distribution in any stand depends on

- cause of tree death
- decay resistance of the tree species
- rates of decay
- residence time in each decay class
- piece size (diameter, length)
  - some fungi work in from the piece ends at ~1 m/decade, so if the piece is < 2 m in length it will be gone, regardless of piece diameter
- CWD inputs
Figure 1 from Brown et al. (1998) showing the relationship between time since death and CWD decay class for lodgepole pine and Engelmann spruce on different aspects. Class 1 is very fresh so CWD class 2 is what is usually called class 1, class 3 is what is usually called class 2, etc.

Residence times for coastal species in two studies were

<table>
<thead>
<tr>
<th>Decay class</th>
<th>Douglas-fir</th>
<th>Western redcedar</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 – 10 yr</td>
<td>3 – 4 yr</td>
</tr>
<tr>
<td>2</td>
<td>5 – 20</td>
<td>17 – 67</td>
</tr>
<tr>
<td>3</td>
<td>15 – 80</td>
<td>52 – 293</td>
</tr>
<tr>
<td>4</td>
<td>60 – 150</td>
<td>550 – 1200</td>
</tr>
<tr>
<td>5</td>
<td>100 – 300</td>
<td></td>
</tr>
</tbody>
</table>
CWD decay rates are usually expressed as a single negative exponential model.

The decay rate constant, k, is derived from a variety of techniques that examine changes in volume, wood density or mass.

The model assumes the decay rate is constant and that CWD is homogeneous and not transformed into components with different decay rates.

In fact, the decay rate varies over the life of the piece and depends on:

- climate
- tree species (chemical makeup)
- size (diameter and length: small western redcedar decays 20 X faster than larger; amabilis fir rates don’t change very much with size)
- specific part of the piece (sapwood or heartwood)
- existing condition (decay class)
- position (suspended, on ground, buried)
- which major decay process(es) is/are underway
  - respiration and leaching
  - fragmentation
- site conditions (temperature and moisture regimes; O₂, CO₂ levels)

Realistically, a separate decay constant is required for these factors and then double- or multiple-exponential models or other models to account for the most important and significant processes.

But for ease of application usually one parameter at a time is examined by species:

- diameter class
- length class
General order of species decay rates, slowest to fastest

<table>
<thead>
<tr>
<th>Species</th>
<th>Decay Rate (k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western redcedar</td>
<td>.009</td>
</tr>
<tr>
<td>Douglas-fir</td>
<td>.004 → .037</td>
</tr>
<tr>
<td>Sitka spruce</td>
<td>.01</td>
</tr>
<tr>
<td>Western hemlock</td>
<td>.016 → .036</td>
</tr>
<tr>
<td>Mountain hemlock</td>
<td>.015</td>
</tr>
<tr>
<td>Red alder</td>
<td>.035 → .52</td>
</tr>
<tr>
<td>Interior spruce</td>
<td>.01 → .03</td>
</tr>
<tr>
<td>Lodgepole pine</td>
<td>.01 → .05</td>
</tr>
<tr>
<td>Birch</td>
<td>.05</td>
</tr>
<tr>
<td>Trembling aspen</td>
<td>.05 → .07</td>
</tr>
<tr>
<td>Ponderosa pine</td>
<td>.012 → .035</td>
</tr>
</tbody>
</table>

A variety of methods are used to determine the rates of CWD decay:

- **Dendrochronology**
  - Determine the time since death of CWD and then relate that to piece decay class, species, size, and other parameters
  - If windthrown live, then time since death = time as CWD
  - Can cross-date outer growth rings of CWD, date scars on adjacent live trees, date seedlings on nurse logs
  - Carbon 14 dating has been used for western redcedar

- **Chronosequences**
  - Characterize changes in CWD quality (wood density or piece decay class) or quantity (volume) by sampling comparable sites with different and known times since disturbance (= creation of CWD)
Figure 1 from Harmon et al. (1987) illustrating changes in bole density with time since falling. The density of boles on the ground for more than 24 years was adjusted to reflect volume losses.

Figure 1 from Harmon et al. (1987) illustrating changes in bole density with time.
Figure 1 from Means et al. (1985) showing the relationship between wood density and CWD residence time.

- **time series with repeat measurements**
  - usually monitor changes in mass and wood density in the short-term, changes in volume and piece decay class in the long-term
  - monitoring wood density loss changes neglects fragmentation and biological transformation processes and so $k$ is underestimated

- **time series monitoring over a few decades**
  - monitoring mass loss in wood samples placed in different environments
  - sampling for changes in wood density of CWD

$$D_t = D_0 e^{-kt}$$

where $D_0 =$ initial density

$D_t =$ density at time $t$

$k =$ the decay constant
- time series monitoring over many decades
  - monitoring changes in CWD placed in different environments for 200 years (six old-growth sites in PNW)
  - repeat measures of CWD dimensions enables calculation of volume at different times and accounts for
    - decomposition of bark, sapwood, heartwood
    - losses due to fragmentation

\[ V_t = V_0 e^{-kt} \]

where \( V_0 \) = initial volume

\( V_t \) = volume left at time \( t \)

\( k \) = the decay constant

CWD was mapped and measured in the five Schenstrom plots at the Cowichan Lake Research Station in 1929 - 1930, 1945 - 1947 and 1995 - 1996.

The volume lost by each piece of CWD during those time periods can be calculated and thus, the decay constant as well.

The following images show the physical location of CWD present in three of the plots at each measurement period.
Results for Douglas-fir (from Stone et al. 1998) showing the shift in decay classes and the derived decay constants:

<table>
<thead>
<tr>
<th>Large end diameter class</th>
<th>1929 - 1930</th>
<th>1995 - 1996</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class</td>
<td>I</td>
<td>II</td>
</tr>
<tr>
<td>&lt; 21 cm</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td>21 ± 40</td>
<td>6</td>
<td>27</td>
</tr>
<tr>
<td>41 ± 80</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>&gt; 80</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Large end diameter class</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 21 cm</td>
<td>0.067</td>
</tr>
<tr>
<td>21 ± 40</td>
<td>0.056</td>
</tr>
<tr>
<td>41 ± 80</td>
<td>0.021</td>
</tr>
<tr>
<td>&gt; 80</td>
<td>0.012</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Length</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 3 m</td>
<td>0.033</td>
</tr>
<tr>
<td>3.1 – 6.0</td>
<td>0.038</td>
</tr>
<tr>
<td>6.1 – 9.0</td>
<td>0.017</td>
</tr>
<tr>
<td>&gt; 9.0</td>
<td>0.019</td>
</tr>
</tbody>
</table>

Even without exact knowledge of species- and site-specific CWD decay rate constants, CWD piece decay can be modelled and used to indicate the expected lifetime of an individual CWD piece.

You need to use the most appropriate k value for your situation, keeping in mind the methodologies and contexts of studies providing the decay rate constants.
Coupled with information about expected CWD inputs, the future behaviour of the CWD component of the dead wood cycle in natural and managed stands can be estimated.

This graph shows the decay of actual CWD encountered on a 150 m transect line, decayed piece by piece and then summed versus the expected input of dead wood predicted by a TIPSY program run. While the two scales are not comparable, this demonstrates the general principles of CWD outputs through decay and inputs through mortality and disturbance.

**Literature cited**

[http://www.nrc.ca/cgi-bin/cisti/journals/clipart?cjfr_x98-059_28_ns_nf_cjfr6-98](http://www.nrc.ca/cgi-bin/cisti/journals/clipart?cjfr_x98-059_28_ns_nf_cjfr6-98)


Presented to:

Northern Interior Vegetation Management Association (NIVMA) and Northern Silviculture Committee (NSC) Winter Workshop: Optimizing wildlife trees and coarse woody debris retention at the stand and landscape level. January 22 - 24, 2002. Prince George, B.C.

John Parminter
Research Ecologist
Ministry of Forests
Victoria, B.C.