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Decay progression and classification in two old-growth forests in Atlantic Canada

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Abstract

This paper investigates the relationship between visually apparent stage of decay of coarse woody debris (CWD) and time since death of decaying balsam fir (*Abies balsamea* L.) and black spruce (*Picea mariana* [P. Mill]) in old-growth forests in western Newfoundland and in the Cape Breton Highlands (CBH) of Nova Scotia. These sites are two of the least disturbed old-growth forest locations remaining in Atlantic Canada. In Newfoundland, a total of 42 detrital samples were collected from downed logs and standing snags, of which 36 had their mortality dates determined. In the CBH, 50 detrital samples were collected, of which death dates for 44 samples were obtained. For both sites, samples represented all visually discernable classes of decay. In Newfoundland, these visual decay classes were separated by approximately 17 years for a minimum decay time of 85 years. In CBH, a faster rate of decomposition was apparent, with 12-year classes and a minimum decay time of logs of 60 years. Evidence points toward a climate-driven decay regime in both locations, with the longer time frame evident in Newfoundland thought to result from lower temperatures and fewer snow-free days than in CBH.

Keywords: Coarse woody debris; Dendrochronology; Decay classification; Decay progression; Old-growth forests; Newfoundland; Cape Breton Highlands

1. Introduction

Eastern Canadian old-growth forests have not been well described in terms of their ecological characteristics or community associations (Thompson et al., 2003). In particular, very little research has investigated the dynamic processes of coarse woody debris decay in forests of Atlantic Canada (McCarthy, 2001; Stewart et al., 2003; Thompson et al., 2003). Coarse woody debris (CWD) is a critical component of forest ecosystems and is primarily generated by small-scale disturbances (Daniels et al., 1997; Gray and Spies, 1997; McCarthy, 2001; Kneeshaw and Gauthier, 2003). It plays an important role in nutrient cycling and is a key component of plant and animal habitat in old-growth forests (Storaunet and Rolstad, 2002; Mosseler et al., 2003; Yatskov et al., 2003).

Decay studies usually classify CWD using a categorical index based on a visual assessment of decomposition of CWD structures (Newberry et al., 2004; Woldendorp et al., 2004). Although there is no unifying system or index to use in different ecosystems, the one thing that most systems share in common is that they have no objective time frame linked to their decay classes.

The relationship between visually apparent stage of decay (hereafter simply "decay class") and length of time the woody debris remains in each stage has rarely been studied. Studies such as those by Daniels et al. (1997) and Kellner et al. (2000) have begun trying to unravel the relationships between time since death and decay class in Pacific Canada, but this type of investigation has never been attempted in Atlantic Canada.

In part because centuries of logging have dramatically reduced the amount of original forest, few studies have investigated CWD or other aspects of Atlantic Canadian old-growth forests. In western Newfoundland's wet boreal forest, studies have acknowledged a larger amount of fallen wood with increasing forest age (Thompson and Curran, 1995; Sturtevant et al., 1996), but they do not elaborate on other aspects of CWD, especially the progression through decay classes over time. Similarly, there has been relatively little research on the old-growth forests of Cape Breton Highlands in northeastern Nova Scotia. An extensive old-growth study by Stewart et al. (2003) investigated forest stand attributes in Nova Scotia, but covered only the general characteristics of CWD.

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The parameter of time since death is not commonly built into decay class models because accurately aging decaying wood is a difficult process. If an assessment of the relationship between time since death and decay class can be made, then chronosequences based on decay classes can also be developed (Daniels et al., 1997). These chronosequences can then contribute to better long-term management strategies for forests (Daniels et al., 1997; Kellner et al., 2000).

This paper establishes a relationship between visual stage of decay of CWD and time since death in old-growth forests in western Newfoundland and in the Cape Breton Highlands. Specific objectives were to establish a common decay class system to be used at each site, and then to establish rates of progression through these classes for balsam fir (*Abies balsamea* L.) and black spruce (*Picea mariana* [P. Mill]) at two of the few remaining old-growth stands in Atlantic Canada.

2. Study sites and species

In July 2004 and August 2005 we studied standing snags (hereafter ''snags'') and downed logs (''logs'') of balsam fir and black spruce in two old-growth forest stands in Atlantic Canada (Fig. 1). One representative site from each region was selected and intensively sampled to ensure adequate within-site replication. Each study plot measured 50 m × 50 m (0.25 ha), within which all CWD was mapped and measured. Care was taken to stay away from forest edges when selecting the plot locations.

Our western Newfoundland study site (50°12.6′N, 50°17.0′W) was located in a multistoried, multi-aged stand of old-growth forest as typified by McCarthy (2001). The site was co-dominated by balsam fir and black spruce, as is typical for Newfoundland's primarily wet boreal forest ecosystem. Balsam fir is a late-successional species that is fire-susceptible,

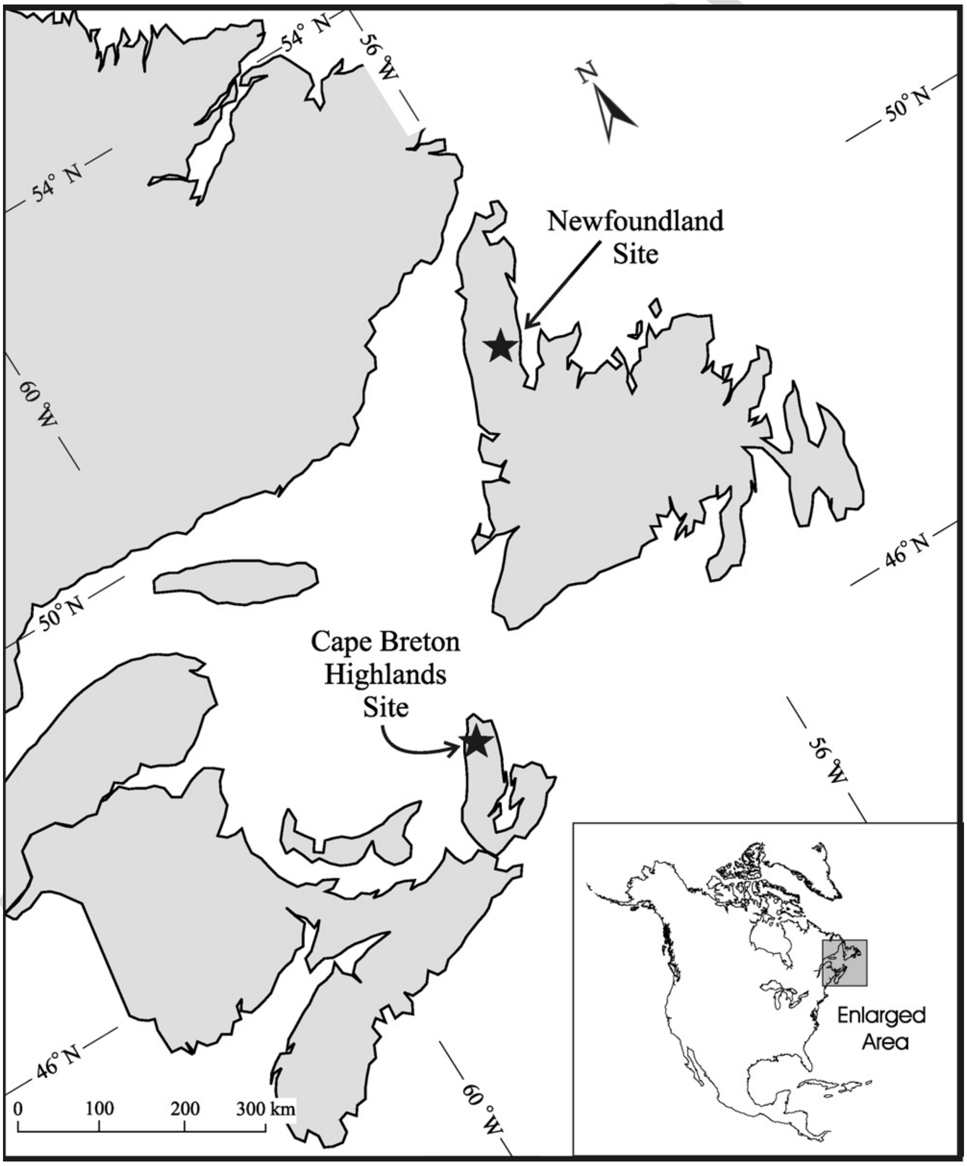

Fig. 1. The location of the two study plots in Atlantic Canada.

therefore, it is able to thrive in Newfoundland's wet climate (Thompson et al., 2003). Wet boreal forests receive much of their moisture from precipitation and fog, characteristics common to the region's maritime climate (Thompson et al., 2003). Climatic normals (1971–2000) from nearby Deer Lake indicate that average daily temperature is 3.3 °C, while yearly precipitation averages 0.72 m in the form of rain, and 4.25 m as snow (Environment Canada, 2006).

Our Cape Breton Highlands National Park (CBH) study site (46°47.8′N, 60°51.7′W), in northern Cape Breton Island, Nova Scotia, was situated in the Fishing Cove area of the park on the highland plateau. The site was a multistoried, multi-aged section of old-growth forest, with tree species characteristic of both boreal and Acadian forest found within a relatively small area. The plot was placed within a continuous zone of boreal forest, dominated by black spruce, with a lesser component of balsam fir and white birch (*Betula papyrifera* Marsh.).

Cape Breton Highlands National Park boasts a series of unique forest types in the Cape Breton landscape, including Acadian, boreal, and taiga ecosystems (Bridgeland, 1996). Surrounded on three sides by the ocean, CBH has a maritime climate (Mosseler et al., 2003), and the dramatic topography of the park strongly influences the species composition and structure of the forest (Bridgeland, 1996). Mean annual temperature at Ingonish Beach is 6.2 °C, and the region receives on average 1.32 m of rain and 3.75 m of snow yearly (Environment Canada, 2006).

The old-growth forest stands in the highland plateaus of the park were formerly dominated by late-successional balsam fir, but CBH has experienced a series of natural disturbances that have returned much of the forest to early-successional stages. These disturbances have impeded the growth of or outright killed the dominant species, resulting in a patchwork distribution of forest cover (Bridgeland, 1996). The principal cause of the mixture of forest ages is several infestations of spruce budworm (*Choristoneura fumiferana* [Clem.]) that targeted late-successional stands beginning in the late 1970s and eliminated the majority of the balsam fir in the park (Bridgeland, 1996). Cape Breton plateau forests are currently experiencing a regeneration growth phase with balsam fir slowly re-establishing.

Both sites were littered with large amounts of coarse woody debris. Many of the downed boles were serving as nurse logs for seedlings, and there were numerous indications that the CWD was providing habitat for resident wildlife.

3. Methods

3.1. Decay classification

Decay class is a qualitative, categorical index based on visual assessment of decomposition in coarse woody debris (Newberry et al., 2004). The CWD at each study site was classified using a system adapted from Daniels et al. (1997). The five classes are based on a series of features of the dead wood, including bark condition, branch system, presence of needles and twigs, and bole fragmentation (Daniels et al., 1997).

Logs were classified on the following I–V scale. In classes I, II, and III, it is possible to visually determine the species of the log, while in classes IV and V, it is not.

- Class I: Boles and branches with sound structural integrity; bark intact; branch system present, complete with twigs and needles; no moss or other vegetation present on bole.
- Class II: Boles and branches with sound structural integrity; bark mostly intact; branches lack needles; minimal moss/vegetation.
- Class III: Boles maintain structural integrity; bark detached; no branch system present; minimal moss/vegetation.
- Class IV: Boles oval in shape; wood soft and covered with moss/vegetation.
- Class V: Boles often hidden as lumps on forest floor; very soft wood, covered in thick moss vegetation.

Snags were also classified using a five-decay-class system similar to that described by Daniels et al. (1997). In classes I, II, and III snags, it is possible to visually determine the species of the snag, while in classes IV and V, it is not.

- Class I: Declining live trees in which all components appear intact; twigs present, bark in good condition; many needles remain on tree.
- Class II: Further decline of snags evidenced by browning needles.
- Class III: Branches and twigs present, but all needles gone.
- Class IV: Some branches detached; no twigs or needles; detached or absent bark.
- Class V: Bole often hollow or crescent shaped; no branches remain; only fragmented bark.

3.2. Live chronologies

Increment cores from live black spruce and balsam fir trees were collected on both the Newfoundland and CBH study sites to create four master chronologies (two species at two sites). A minimum of 40 cores (2 cores per tree) of each species at each site was collected. Master chronologies were created using core samples from trees inside and surrounding the two representative plots. Increment cores were glued into slotted mounting boards and sanded to a progressively finer grit. The finished samples were polished with 600-grit paper. Cores were then scanned and measured with WinDendro (Guay et al., 1992). Tree core samples were first visually crossdated, and then statistically crossdated using the program COFECHA to check for signal homogeneity (Holmes, 1983).

3.3. Coarse woody debris analysis

All CWD inside each quarter-hectare plot was first mapped and measured. Samples of CWD were selected in a two-step process, so as to obtain a minimum of one log and one snag in each decay class at each site. Since visual classes IV and V present more difficulties with obtaining viable log and snag samples, a first pass through each 10 m × 10 m subplot

Table 1
The type, number and size of coarse woody debris (CWD) samples found within the two sample plots in the study (DBH, diameter at breast height)

Location	Type	Number of samples per class					CWD/0.25 ha	Mean DBH (cm)	Mean height (cm)	Mean length (cm)
		I	II	III	IV	V				
NFLD	Log	32	21	12	16	10	91	57.3	n/a	591
	Snag	17	5	7	26	12	67	52.3	473	n/a
	Total	49	26	19	42	22	158	54.8		
CBH	Log	5	19	42	57	14	137	16.9	n/a	481
	Snag	1	8	9	44	48	110	15.3	252	n/a
	Total	6	27	51	103	62	247	16.1		

determined where the most viable samples from the entire 50 m × 50 m could be acquired, while trying to maintain as wide a spatial distribution as possible. Once viable class IV and V samples were tagged for collection, a second pass through each 10 m × 10 m subplot was made, systematically selecting CWD samples in each of the subplots until each of the 25 subplots contributed two tagged samples for collection. Transverse discs from the tagged CWD were cut at approximate breast height, then each sample was wrapped and labeled, and transported back to the Mount Allison Dendrochronology Laboratory. As was suspected when tagging representative samples in both Newfoundland and CBH, it was difficult to process logs and snag samples in classes IV and V due to the nature of the soft, decaying wood. Most classes of wrapped samples held together well through transportation and sample preparation, but class IV and V samples would probably have degraded rapidly once they were removed from their plastic wrapping in the laboratory. For this reason, many class IV and V samples had to be prepared in the laboratory by impregnating the discs with common canning wax to hold the sample together and retain the ring structures of the deteriorating wood. Most class IV and V samples that were unidentifiable in the field were determined to species by microscopic analysis.

The prepared disc samples were sanded to a smooth surface in order to discern the ring structure more clearly, and then polished with 600-grit paper. The rings on each sample were then measured using a Velmex stage system or a WinDendro image analyzing system (WINDENDRO, 2004). Three paths were measured on each disc surface to maximize the entire growth record of the log or snag.

The resulting floating chronologies were pattern-matched into the living master chronologies of their corresponding species and study site. This procedure was conducted by visual and statistical means using the program COFECHA (Holmes et al., 1986). If bark was present on the sample, the year of death could be calculated accurately because no outer rings were lost. If no bark was present, the three paths read on each surface sometimes yielded different years of death due to perimeter loss of wood on parts of the samples. When this occurred, the most recent year was chosen as the approximate year of death for the sample. For samples of unknown species that could not be detected by microscopic analysis, floating chronologies were pattern-matched into both master chronologies from their site. These samples were then identified to species when they correlated more strongly to a particular master chronology.

4. Results

4.1. Attributes of CWD

At the Newfoundland study site, a total of 158 CWD structures were mapped in the quarter-hectare plot (Table 1). On the CBH site, a total of 247 CWD structures were mapped in the plot (Table 1). In Newfoundland, the average diameter of the CWD structures was 54.8 cm, while in CBH, the average diameter of CWD was 16.1 cm. The average height of snags and length of logs was much higher in Newfoundland (height = 4.73 m; length = 5.91 m) than in CBH (height = 2.52 m; length = 4.81 m) (Table 1). The Newfoundland site contained more logs and snags classified as class I CWD, compared to the CBH site, where most samples were classified as class IV CWD.

4.2. Live chronologies

The Newfoundland site generally had older living trees than CBH (Table 2). In Newfoundland, the balsam fir were younger than the black spruce, with the oldest balsam fir tree 165 years old (Fig. 2). Most black spruce trees aged over 150 years, and the oldest was 182 years. The Newfoundland balsam fir master chronology, based on 50-year segments of 34 tree cores, had a mean series correlation coefficient of 0.422 in COFECHA (Table 2). The Newfoundland black spruce master chronology

Table 2
The number of cores and number of live trees incorporated into the master chronology for each site

Location	Species	Number of cores	Number of trees	Mean series correlation[a]	Length (years AD)
NFLD	Balsam fir	34	23	0.422	1818–2004
	Black spruce	28	21	0.409	1840–2004
CBH	Balsam fir	42	26	0.444	1928–2005
	Black spruce	36	21	0.429	1895–2005

The mean correlation coefficient produced from program COFECHA for each series is also reported as well as the length of the constructed chronologies.
[a] *Note*: All series above 0.3281 are significant above the 99% confidence interval.

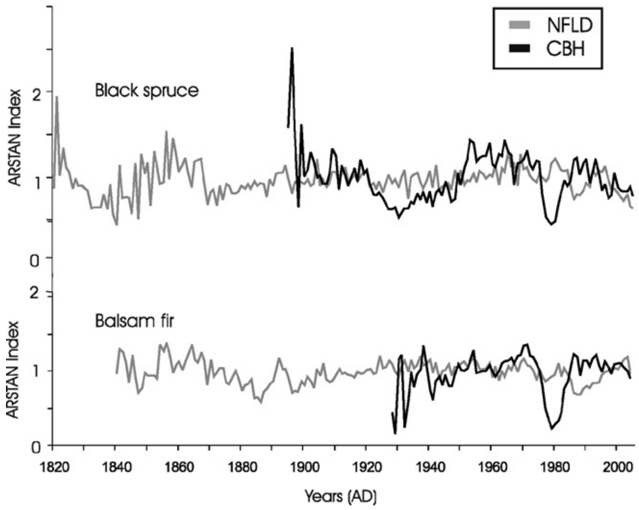

Fig. 2. The black spruce and balsam fir master chronologies for each site. Each master chronology presented was standardized in program ARSTAN with a single detrending pass of a 60-year spline curve. The ARSTAN standard chronologies are presented.

was constructed with 28 tree cores and had a mean series correlation coefficient of 0.409 in COFECHA (Table 2). Both series were significant at the 99% confidence interval ($r > 0.3281$ for 50-year segments).

At the CBH site, more balsam fir were sampled to try to lengthen the chronology, as the trees were younger. The oldest balsam fir found in CBH was 77 years old (Table 2). The oldest black spruce found in CBH was 109 years old (Fig. 2). The CBH balsam fir master chronology had a mean series correlation of 0.444, which was created with 42 cores from living trees (Table 2). The CBH black spruce master chronology had a mean series correlation coefficient of 0.429, and was constructed with data from 36 tree cores (Table 2). Both series were significant at the 99% confidence interval ($r > 0.3281$ for 50-year segments).

4.3. Age of coarse woody debris

In the Newfoundland quarter-hectare plot, a total of 42 samples were processed as 4 subplots did not have a CWD sample, and other samples selected did not remain intact during processing. Of this total, 23 logs and 13 snags were successfully dated for a total of 36 samples (Table 3; Fig. 3). Years of death for logs were spread across a wide timeline, from as recent as 2002 for a class I sample, to as early as 1920 for a class V sample (Fig. 3). The oldest dated snag in Newfoundland died in 1946 and was a class IV snag, while the youngest snag died in 1981 and was class II (Fig. 3).

In CBH, 50 detrital samples were collected, of which 25 logs and 19 snags were successfully dated for a total of 44 samples (Table 4; Fig. 4). The oldest log died in 1925 and was a class IV log, while the remaining logs were spread from 1925 to the year of sampling (2005; Fig. 4). The oldest dated snag sample in Cape Breton was class V and died in 1938. The remaining samples, from classes I to IV, died across all intervening decades, nearly up to the year of sampling (Fig. 4).

Table 3
The species and type of CWD at the Newfoundland site

Species	Log/snag	Decay class	Year of death	Life span	Average time since death of class (S.D.)
Black spruce	Log	I	2002	1889–2002	12.3 (14.0)
Balsam fir	Log	I	2001	1953–2001	
Black spruce	Log	I	2001	1891–2001	
Black spruce	Log	I	2000	1858–2000	
Balsam fir	Log	I	1999	1916–1999	
Balsam fir	Log	I	1999	1857–1999	
Balsam fir	Log	I	1994	1970–1994	
Balsam fir	Log	I	1986	1966–1986	
Balsam fir	Log	I	1975	1906–1975	
Balsam fir	Log	I	1960	1917–1960	
Balsam fir	Log	II	1996	1956–1996	17.3 (8.1)
Balsam fir	Log	II	1983	1867–1983	
Black spruce	Snag	II	1981	1904–1981	
Balsam fir	Snag	III	1977	1830–1977	42.3 (10.2)
Balsam fir	Log	III	1973	1907–1973	
Balsam fir	Snag	III	1970	1885–1970	
Balsam fir	Log	III	1969	1890–1969	
Balsam fir	Snag	III	1968	1850–1968	
Black spruce	Snag	III	1967	1912–1967	
Black spruce	Snag	III	1966	1872–1966	
Black spruce	Log	III	1961	1896–1961	
Balsam fir	Log	III	1960	1909–1960	
Balsam fir	Snag	III	1960	1859–1960	
Black spruce	Snag	III	1952	1794–1952	
Black spruce	Snag	III	1949	1790–1949	
Balsam fir	Snag	III	1948	1822–1948	
Black spruce	Log	III	1943	1807–1943	
Black spruce	Log	IV	1960	1867–1960	59.3 (9.4)
Balsam fir	Snag	IV	1951	1883–1951	
Black spruce	Log	IV	1948	1894–1948	
Balsam fir	Snag	IV	1947	1880–1947	
Balsam fir	Snag	IV	1946	1857–1946	
Black spruce	Log	IV	1941	1889–1941	
Balsam fir	Log	IV	1933	1857–1933	
Black spruce	Log	IV	1931	1893–1931	
Black spruce	Log	V	1920	1884–1920	84 (–)
Average change in time since death from class to class					16.8

Year of death, life span and visual decay class of each CWD sample are also listed, along with the average time since death for each class and its standard deviation (S.D.). The samples are ranked first by decay class, and then by year of death.

5. Discussion

5.1. Decay classification

The decay class model adapted from Daniels et al. (1997) worked well in both Newfoundland and CBH. Unlike the study by Daniels et al. (1997), radiocarbon dating is not required to approximate the age of CWD in old-growth forests of eastern Canada because the forests are generally so much younger, and decay is more rapid. Climate, wood chemical properties, and tree age and size are factors that make wood decay on Canada's west coast a much slower process. The smaller trees (even in the absence of logging) and more rapid decay rates in Atlantic Canada lend themselves well to this type of dendroecological analysis to establish death dates and rates of progression through decay classes.

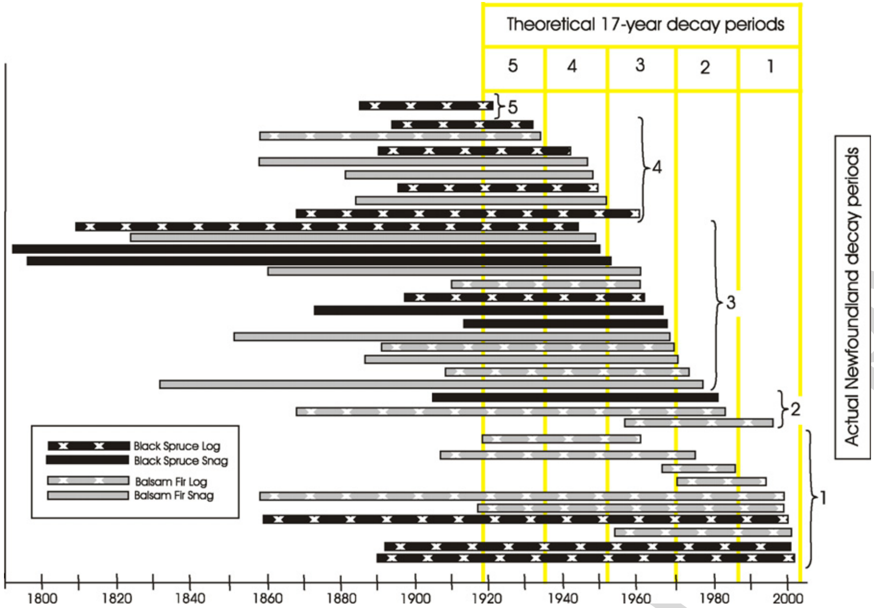

Fig. 3. The timeline for each piece of coarse woody debris dated in Newfoundland, indicating when each tree was alive and with both theoretical and actual decay class intervals indicated.

The sample area covered in this study and plot replication at each site was limited owing to the painstaking effort required to process decaying samples. However, a strength of this study was the number of CWD samples collected and aged at both the Newfoundland and CBH study sites. Other similar studies that have aged CWD through dendroecological methods (e.g., Daniels et al., 1997; Kellner et al., 2000) collected 17 and 18 samples in total, respectively. In this study, with a total dated sample size of 80, a more robust picture of decay progression can be developed and generalized at the plots. Future such studies should continue to sample all visual decay classes and both snags and logs, for these and other species, and with

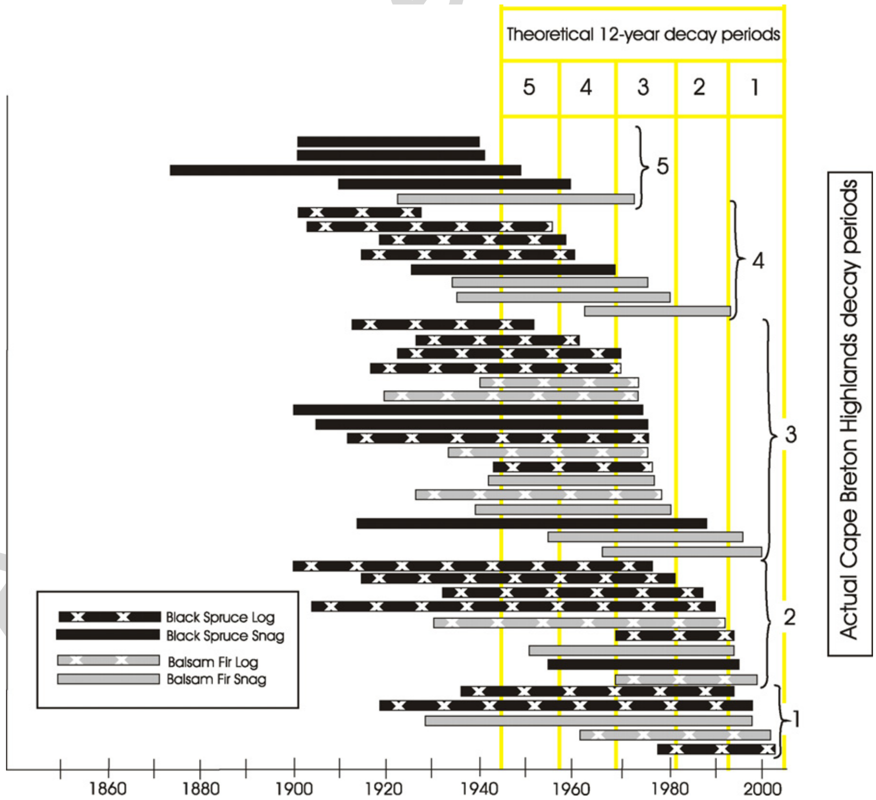

Fig. 4. The timeline for each piece of coarse woody debris dated in Cape Breton Highlands, indicating when each tree was alive and with both theoretical and actual decay class intervals indicated.

Table 4
The species and type of CWD at the Cape Breton Highland site

Species	Log/snag	Decay class	Year of death	Life span	Average time since death of class (S.D.)
Black spruce	Log	I	2003	1977–2003	6 (3.6)
Balsam fir	Log	I	2002	1960–2002	
Balsam fir	Snag	I	1998	1926–1998	
Black spruce	Log	I	1998	1916–1998	
Black spruce	Log	I	1994	1934–1994	
Balsam fir	Log	II	1999	1968–1999	15.2 (7.3)
Black spruce	Snag	II	1995	1953–1995	
Balsam fir	Snag	II	1994	1949–1994	
Black spruce	Log	II	1994	1968–1994	
Balsam fir	Log	II	1992	1928–1992	
Black spruce	Log	II	1990	1901–1990	
Black spruce	Log	II	1987	1929–1987	
Black spruce	Log	II	1981	1912–1981	
Black spruce	Log	II	1976	1897–1976	
Balsam fir	Snag	III	2000	1965–2000	29.2 (11.7)
Balsam fir	Snag	III	1996	1953–1996	
Black spruce	Snag	III	1988	1911–1988	
Balsam fir	Snag	III	1980	1937–1980	
Balsam fir	Log	III	1978	1924–1978	
Balsam fir	Snag	III	1976	1940–1976	
Black spruce	Log	III	1976	1941–1976	
Balsam fir	Log	III	1975	1931–1975	
Black spruce	Log	III	1975	1909–1975	
Black spruce	Snag	III	1975	1902–1975	
Black spruce	Snag	III	1974	1897–1974	
Balsam fir	Log	III	1973	1917–1973	
Balsam fir	Log	III	1973	1938–1973	
Black spruce	Log	III	1969	1914–1969	
Black spruce	Log	III	1969	1920–1969	
Black spruce	Log	III	1960	1924–1960	
Black spruce	Log	III	1950	1910–1950	
Balsam fir	Snag	IV	1993	1961–1993	41.1 (20.4)
Balsam fir	Snag	IV	1980	1933–1980	
Balsam fir	Snag	IV	1975	1932–1975	
Black spruce	Snag	IV	1968	1923–1968	
Black spruce	Log	IV	1959	1912–1959	
Black spruce	Log	IV	1957	1916–1957	
Black spruce	Log	IV	1954	1900–1954	
Black spruce	Log	IV	1925	1898–1925	
Balsam fir	Snag	V	1972	1908–1972	56 (15.8)
Black spruce	Snag	V	1958	1907–1958	
Black spruce	Snag	V	1947	1870–1947	
Black spruce	Snag	V	1939	1898–1939	
Black spruce	Snag	V	1938	1898–1938	
Average change in time since death from class to class					12.4

Year of death, life span and visual decay class of each CWD sample are also listed, along with the average time since death for each class and its standard deviation (S.D.). The samples are ranked first by decay class, and then by year of death.

greater replication over a broader area, so that latitudinal gradients in temporal patterns of decay can begin to be developed.

5.2. Live chronologies

The master chronologies of both species from Newfoundland extend farther back in time than their respective CBH chronologies. The CBH chronologies did not reach past 1900, while the Newfoundland chronologies reached back as far as 1820 (Fig. 2). No other annual-resolution chronologies from either the Newfoundland or CBH region exist, so the two sets of chronologies could only be compared to each other.

Visually there is a general similarity in the radial-growth trend for a given species between the two sites (Fig. 2). For each species, however, there are years when the two series are very closely related and years when they completely decouple for a poor synchronicity. Historical records indicate that when the two chronologies do decouple, the reductions in radial growth at the reduced location can be attributed to known spruce budworm infestations (Bridgeland, 1996), to which both species are susceptible. Similar decoupling in years prior to historical budworm records probably signifies the same type of disturbance events. Although budworm infestation is the most probable reason, without further investigation the possibility of localized climatic or other environmental irregularities cannot be discounted.

5.3. Coarse woody debris

At least in part because of the strong periodic (probably infestation-induced) reductions in growth reflected in the master chronologies, the majority of the floating chronologies were successfully pattern-matched and had mortality dates assigned. Crossdating provided the precise date of death for 80 of the 92 samples collected from the sites. Of the 12 samples for which we were not able to assign a precise death date to the wood, most were class IV and V samples whose ring patterns had degenerated too far for a confident analysis.

Holding detrital samples together by the waxing process in most cases successfully retained the ring pattern to obtain the longest floating chronology possible from the sample. When the procedure was complete, the longer floating segments allowed more overlap between the detrital samples and the master chronologies and delivered a more robust statistical pattern match. In samples where the floating segments measured were too short, the floating segments tended to match into a number of places in the cyclical master chronology sequences, and made death date assignment more difficult, or impossible.

In our study, no discernable difference could be found between the visually apparent rate of decay of balsam fir and black spruce at either site. On average, decay classes of CWD on the Newfoundland site changed at 16.8-year intervals (Fig. 3; Table 3). The standard deviation is large for each class (as would be expected given the small number of samples per class), but similar. Clearly any imposition of classes on a continuous process will produce a measure of artificiality, and a field-identified class III log in Newfoundland varies, in our samples, from 27 to 61 years since death. Still, an estimate of interval length is clearly important for practical purposes.

Snags from the Newfoundland site produced a less clear decay class–kill date relationship than the logs. Obtaining snag samples in Newfoundland from each of the visual decay classes was a difficult task because the majority of the first few classes of dead wood were in the form of fallen logs and not snags. The snag samples that were found were considerably decayed, which resulted in incomplete ring measurement paths.

CWD structures progressed into new decay classes at 12.4-year intervals (Table 4), with the standard deviation of each class being similar except for class IV where extremes at the tails of the distribution increase the value. As was the case at the Newfoundland site, this relationship was evident for both species studied, pointing toward a decay regime driven more by an external factor such as climate than by species-specific properties.

When the samples at each location are sorted by year of death, a continuous timeline of death dates appears, but when the samples are sorted by decay class and then year of death, the death dates cluster at roughly 12- and 17-year intervals. The larger sample size in this project allows us to see that the samples in most decay classes probably approximate a normal distribution about a mean for each class. For example, of the class III logs at CBH, the 17 samples have a few representatives that died more recently than the 24–36-year time interval predicted, and a few samples that died earlier than the predicted interval. This was probably caused by either samples losing excess perimeter wood for later than predicted samples (two samples), or samples that looked more heavily decayed visually for earlier than predicted samples (three samples), or from the difficulty in categorically defining a class to a visually borderline sample. But the majority of the dated class III discs at CBH fell into the predicted range (12 samples).

We believe that an even greater sample depth would have supported with more confidence the decay class intervals our results revealed in both Newfoundland and CBH. To prove this, future studies would need to include a minimum of 30 CWD samples in each decay class to establish a normal distribution about the mean. In particular, sufficient samples are needed for classes 4 and 5, for which selection of samples tends to be biased towards viable wood with discernable rings, leading to an underestimate of the interval length for those classes. With a greater sample depth, the decay class intervals would be more evident as the vast majority of visually classified samples would fit more clearly into distinguishable time periods, with the few outliers that are present in each normally distributed visual class being less evident.

These results indicate that CWD is decaying more rapidly in CBH than in Newfoundland, presumably due to the latitudinal difference between the two study sites. Temperature has been found to be a key factor for determining decay rate of CWD, whereby an increase in temperature results in an increase in rate of decomposition (Chen, 1999; Hicks, 2000). In upper-elevation regions with a persistent snowpack, decay progression has also been shown to be slow considerably (Kellner et al., 2000). The Newfoundland site is not high in elevation, but because its annual temperature is approximately 3 °C cooler than the CBH site, the length of time that the downed CWD is free of snow cover is significantly shorter. Although both study sites are maritime in respect to climate, the added weeks of snow-free time and higher temperatures at the CBH site probably accelerate the decay at that site significantly by increasing fungal activity, with decay accelerated by the approximately 5 years per decay class seen in our study. Therefore, a log that takes a minimum of 85 years to decompose in Newfoundland would take a minimum of 60 years to decompose in Cape Breton. In turn, nutrient and habitat development cycles would run at a faster rate in Cape Breton forests than in the more northern Newfoundland location.

5.4. Management implications

The survival of many organisms depends on CWD as habitat (Kellner et al., 2000; Ferguson and Archibald, 2001; Thompson et al., 2003; Mazurek and Zielinski, 2004), and nutrient retention and nutrient cycling are also key processes that rely on CWD production within a forest (Spears et al., 2003; Yatskov et al., 2003). It is therefore critical to consider the long-term timelines of CWD when sustainable forest management practices are reviewed. Even limited knowledge of the length of time required to allow CWD to die and decompose provides a better management tool for old-growth forest environments in Atlantic Canada. Putting a time frame on the progression of decay of CWD provides a sense of how long each stage of decay provides a source of nutrients back into the forest, as well as how long each stage provides habitat for plants and animals. It is crucial for forest managers to consider the full length of time involved in the decay of CWD in a forest, when planning for the health of the complete ecosystem.

If a tree naturally grows and dies in a 200-year period in a Newfoundland wet boreal forest, and decay class studies indicate that it will take more than another 85 years for it to fully decompose on the forest floor once it dies, then management plans should encompass the longer 285-year window, not the shorter 200-year window over the tree's natural life. Management plans often aim to maintain CWD abundance on the forest landscape for long periods of time, but by adding a time component to the often used visual decay class models, they should be able to concretely incorporate this length of time into their management plans for each individual class of CWD. This information should be particularly important for those forest managers who are trying to preserve rare or endangered plants or animals whose welfare depends on a critical component of CWD. While the distribution of CWD is important for these organisms, it may be the stage of decay of CWD that determines its use (Bowman et al., 2000). Examples include the endangered Newfoundland pine marten (*Martes americana atrata*) in western Newfoundland, which depend on class IV and V logs for foraging and nesting (Kyle and Strobeck, 2003), or potentially endangered saproxylic vertebrates in the CBH which might depend on class III logs as their hosts (Majka and Pollock, 2006). Both endangered species can be better managed if forest overseers are able to make relatively accurate estimations of how long different classes of CWD have served as part of that particular forest, and in turn can also determine how long they will continue to serve as important habitat.

6. Conclusion

There has been little research investigating the dynamics of the scant remaining old-growth forest in eastern Canada. The relationship between visually apparent stage of decay and the length of time that CWD has been in such a condition has rarely been studied in any region, and has never been studied in Atlantic Canada. Our results from plots in two regions with two boreal forest species revealed that logs and snags in old-growth forests in western Newfoundland take approximately 17 years to move from one decay class to the next until, after at least 85 years, they are no longer recognizable boles. CWD in the more southern Cape Breton Highlands forests take on average 12 years to move from one decay class to the next, for a decaying period of at least 60 years. Because balsam fir and black spruce CWD did not differ appreciably in decay progression within sites, external factors such as climate, which affects the length of the snow-free period, appear to drive the rate of decay more than properties specific to the two tree species studied. It is likely such external factors are more significant than internal properties in driving decay for spruce and fir forests circumboreally.

Knowing the approximate time since death of CWD in a given forest allows forest managers to better assess the status of flora and fauna that depend on CWD at a particular stage of decay. By shedding light on rates of decomposition, this research also contributes to a better understanding of CWD as a little-studied but critically important component of nutrient cycling in forest ecosystems. Such understanding is particularly important for Atlantic Canada, where so little old-growth forest remains.

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