Forest Succession and Woody Debris - an Analysis of Volume, Species, and Decomposition within a Northern Hardwood Forest Chronosequence

Thesis Research Proposal
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Introduction

The composition of forested environments is dynamic due to the nature of forest succession (Allison et al. 2003). Changes in vegetative diversity as a result of forest succession are well documented (Allison et al. 2003; Hilmers et al. 2018; McGee et al. 2007, Neuendorff et al. 2007), though a comprehensive understanding of how these factors influence woody debris accumulation is lacking (Arthur et al. 1992; Gore and Patterson 1985; Vanderwel et al. 2008).

Woody debris, or downed dead wood, composed of both coarse and fine woody debris (CWD ≥ 3.0cm diameter and FWD <3.0cm), is an important asset to forest ecosystems. CWD provides habitat for saproxylic insects and small mammals, promoting ecological diversity (Grove 2002; Hilmers et al. 2018; Sullivan et al. 2012; Ucitel et al. 2003). CWD also has a higher capacity to retain moisture than forest soil (Harmon et al. 1986). Fungal communities are more diverse in old-growth forests, due largely to the variability in substrates created by coarse and fine woody debris (Runnel and Lõhmus 2017). Yellow birch (*Betula alleghaniensis*), eastern hemlock (*Tsuga canadensis*) and red spruce (*Picea rubens*) seedlings have been noted to occur more frequently on downed logs as opposed to the forest floor, highlighting the importance of heterogeneous substrates created by downed wood for species diversity (McGee 2001; McGee and Birmingham 1997). CWD specifically assists in nutrient retention in streams, and riparian ecosystems benefit from nutrient efflux as woody debris decomposes (Jamieson et al. 2018; Aumen et al. 1989). Woody debris is integral in fire ecology as it determines fuel loads and severity of fires (Peterson et al. 2015; Shang et al. 2004). Furthermore, physical and chemical properties of soil are altered by decomposing woody debris and the subsequent additions of organic matter, which improve water retention and promote microbial activity (Piaszcyk et al. 2019; Stutz et al. 2017; Stutz and Lang 2017). Accumulation of woody debris is influenced by anthropogenic activity as well as natural processes and disturbances.

Timber harvests significantly influence the characteristics of woody debris within a given stand, even after immediate additions of woody debris from slash or residual tree damage. Future forest composition and subsequent woody debris input from fallen trees is shaped even by single-tree selection harvesting (Runkle 1991). The canopy of trees may further expand given adequate resources, but are often harvested prior, and as a result the windthrow of these trees creates smaller gaps in the forest canopy than found in old growth forests (Runkle 1991). Smaller canopy gaps limit the light which is able to penetrate to the forest floor, preventing shade-intolerant species from persisting at the site, limiting overstory species diversity

(Neuendorff et al. 2007). As trees succumb to mortality, the effect of harvesting on overstory species diversity is reflected in the downed wood within a stand.

Woody debris is consistently produced during the stem exclusion phase of succession resulting in individual tree mortality, existing on a relatively small spatial scale in comparison to woody debris produced from natural disturbances (Perry et al. 2018). Natural disturbances, including invasion from pests or disease as well as extreme precipitation/flooding, may inflict large scale tree mortality. The 1938 hurricane caused extensive tree mortality within New Hampshire providing inputs of DDW, and further resulted in a more uniform basal area distribution in live trees compared to pre-hurricane conditions, implicating future woody debris inputs (D'Amato et al. 2017). The heterogeneous distribution of woody debris within a forest is in part a result of the dynamic relationship between natural disturbances and tree mortality (Kraft et al. 2002). Quantifying how northern hardwood forests accumulate woody debris will allow for more robust understandings of forest carbon and nutrient cycles, as well as future implications.

Within the northeastern United States, mean and maximum precipitation is expected to increase until the end of the 21st century with projected temperature increases (Wuebbles et al. 2014). Woody debris within northern hardwood forests may therefore be implicated by mortality attributed to intense rainfall and flooding, as well as ice storms (Kraft et al. 2002). Invasion from pests and disease, also result in an increase of CWD and FWD in the area directly affected (Perry et al. 2018, Berbeco et al. 2012). Beech bark disease (BBD) and emerald ash borer (EAB), for example, have increased mortality and lead to larger volumes of CWD of American beech (*Fagus grandifolia*) and ash (*Fraxinus spp.*) in northeastern forests (Dillon 2019; Perry et al. 2018). Infestation and potential mortality from invasive pests and diseases may also increase in wake of climate change. Trees with higher N contents, particularly in environments which have historically been thought of as N limited such as in temperate ecosystems, are more susceptible to infestations from BBD (Latty et al. 2003). N deposition, and a changing atmospheric chemistry may therefore result in increased infestations and potentially increased mortality, contributing to differences in woody debris distributions. Understanding downed wood accumulation in northern hardwood forests will assist in making informed management and research decisions in wake of climate change and infliction from pests or disease.

Woody debris accumulation and decomposition also has direct implications on forest nutrient cycling. A depletion of base cation concentrations in temperate forest soils has resulted from anthropogenic activity, namely timber harvesting, leaching from acid rain, and nitrogen (N) deposition (McGee et al. 2007; Federer et al. 1989; Federer 1984). Though Biotic factors such as overstory species composition, subsequent downed dead wood additions, and microbial activity have been shown to have more significant influences on forest nutrient cycles than anthropogenic activity alone (Rastetter et al. 2013; Hamberg et al. 2003). Furthermore, forest floor nutrient concentrations are not static, past research within this chronosequence found base cations increasing in the forest floor of young stands (<30yrs old) and decreasing in middle-aged stands (>30yrs old) (Yanai et al. 1999). Changes to base cation concentrations within forest soil may be attributed to stand development, and differences in nutrient concentrations of woody debris produced from varying species.

Decomposition of woody debris makes nutrients available within the soil matrix, a crucial step in maintaining the productivity of forests (Briggs and Horton 2011). Some fungi and microorganisms that decompose organic matter require the substrate created by woody debris in order to persist, and woody debris is among the most vital habitats for the proliferation of macrofungi (Brazee et al. 2014; Copot and Tănase 2019). FWD volume in temperate ecosystems is more closely correlated with ascomycetes and basidiomycetes fungi than CWD (Nordén et al. 2004). Nutrient composition and stage of decay largely determine the suitability of the substrate for various microorganisms, features that vary based on anatomical properties of the wood produced by different species (Blanco et al. 2018; Palviainen and Finér 2015; Palviainen et al. 2010; Spears et al. 2003; Arthur et al. 1992). Forest succession and stand age have direct implications on the contribution of certain species (and subsequent nutrients) to the overall pool of woody debris within a stand as previous overstory trees succumb to mortality. Leachate derived from shade intolerant angiosperms for instance, consists of a higher base cation concentration than that of gymnosperms (Lasota et al. 2018).

Nutrient concentration and resistance to decomposition varies among species, though more comprehensive harvests, such as clear-cuts, increase the decay rate of woody debris regardless of species (Hagan and Grove 1999; Jurgensen et al. 2016). Clear-cut harvests raise forest floor temperatures via increased light penetration, resulting in larger mass loss from decomposition where sufficient moisture and N for microbial processes are present (Jurgensen et al. 2016, van der Wal et al. 2007). Environmental conditions created by clear-cuts are conducive to pioneer and shade-intolerant species, including many that succumb to mortality as a result of increased competition (Hilmers et al. 2018). Biomass from CWD contributes significantly to the total terrestrial efflux of CO_2 from forests (Fissore et al. 2016). With recent improvements on estimating decomposition rates for specific species of CWD, the extent to which global CO_2 emissions exceed forest C stores can be better understood (Harmon et al. 2020). Increased average air and soil temperatures due to climate change results in more rapid decomposition, especially of FWD (Berbeco et al. 2012). FWD represents a relatively small (~2%) but stable component of the global C cycle, presenting implications for the C storage of forests as CO_2 is released at greater rates due to more rapid decomposition (Berbeco et al. 2012). Understanding how succession will influence woody debris accumulation will therefore help to more accurately describe carbon (C) stocks within forested ecosystems, and the effects of management strategies on CO_2 efflux.

This study will assess the volume, species, and state of decomposition of woody debris across a northern hardwood forest chronosequence. Analysis of woody debris will determine the degree to which the aforementioned variables are influenced by forest succession and overstory stand structure. This research also aims to provide a more robust understanding of the progression of woody debris accumulation in northern hardwood forests following clear-cut, including the time-frame to achieve old-growth forest status.

Study Relevance

Distinguishing how forest succession influences woody debris accumulation allows for more informed management and research decisions. Following large scale disturbances or harvests, shade-intolerant species such as paper birch (*Betula papyrifera*), yellow birch (*Betula alleghaniensis*), and pin cherry (*Prunus pensylvanica*) establish in the open canopy (Allison et al. 2003; Hilmers et al. 2018). The pool of woody debris within young northern hardwood forests is composed of residual debris left behind from harvests, replaced with small diameter stems as a regrowing forest self-thins (Gore and Patterson 1985). As competition for light and nutrients increases (~20 years since either establishment or harvest), small diameter (<15cm) stems of shade-intolerant species can be found in downed dead wood (Gore and Patterson 1985; Vanderwel et al. 2008). Particularly distinct during stem-exclusion is the abundance of pin cherry woody debris. Pin cherry seeds lie dormant in the soil seed bank awaiting enough light penetration to allow the species to successfully recruit, and succumbs to self-thinning as light and nutrient availability becomes more scarce, resulting in near elimination of the species from live forest overstory ~30yrs following clear-cut (Tierney and Fahey 1998; Hughes and Fahey 1994).

Overstory dominance shifts from shade-intolerant species to mid-tolerant species such as sugar maple (*Acer saccharum*) and American beech (*Fagus grandifolia*) ~30-50+ yrs following establishment; an important change, reflected in a more diverse array of species within the woody debris pool (Allison et al. 2003; Vanderwel et al. 2008).

Old-growth forest structure is described as a stable state where carbon (C) and nutrients stored in wood on the forest floor are supplemented by additions from individual tree mortality, at a rate that balances the translocation of C and nutrients from wood decomposition (Vanderwel et al. 2008). Mature trees that have succumbed to infection and decay produce woody debris in higher states of decomposition (decay class ≥3) than debris left behind from harvests, windthrow, or self thinning (Vanderwel et al. 2008). Woody debris of diameter greater or equal to that of the largest overstory trees and of high states of decomposition are indicative of old-growth ecosystems (Vanderwel et al. 2008; Gore and Patterson 1985). Inputs and outputs of woody debris may be stabilized in northern hardwood ecosystems when mass of woody debris is 30-40 t/ha, or significant contributions of diameter classes 20-40cm and 40-60cm are found (Gore and Patterson 1985; Hura and Crow 2004). Larger volumes of woody debris found within old growth forests when compared to developing northern hardwood forests, result from the mortality of large mature trees (basal area >60m^2/ha, downed biomass 105-119m^3/ha) (Fisk et al. 2002, McGee et al. 2007). Based on the literature, old-growth status may be attained as early as 100yr following clear-cutting, though past data obtained in the 13 stands included in this study did not find old-growth characteristics among CWD in any of the stands (oldest ~129 yrs old) (Gore and Patterson 1985, Acker 2006 *unpublished*).

Objectives

The primary objective of this study is to distinguish characteristics of woody debris corresponding to successional stages in northern hardwood stands. Specifically, this research aims to determine if left unmanaged for 145 years following establishment, northern hardwoods will develop stand structure of downed wood indicative of an old growth forest. Past research within this chronosequence did not find CWD as large as the diameter of the largest living trees (woody debris ≤ 40cm diameter, largest living trees >60cm diameter), and the most woody debris biomass found was 80.9m^3/ha in a ~129 year old stand (Acker 2006 *unpublished*). Defining characteristics of old-growth northern hardwood forests include CWD larger than 40cm diameter, or biomass of downed wood ~82-125m^3/ha (Hura and Crow 2004; Gore and Patterson 1985). Integration of coarse and fine woody debris data from this study as well as data gathered in 2004 and 2006 (Acker 2006 *unpublished*; Vadeboncoeur 2006 *unpublished*) will provide an analysis of forest downed wood volumes present in northern hardwood stands of varying ages, as well as nutrient concentrations and influences from stand succession.

Hypotheses

I hypothesize based on previous data obtained in 2004 (Acker 2006 *unpublished*) that three distinct coarse woody debris pools will be apparent at stands of varying age. If CWD is distinct in stands of varying ages in terms of species contribution, total volume, and stage of decomposition, then in stands <35 years, residual CWD will be present from the previous overstory. The residual CWD pool will be characterized by heavily decayed (decay class 3, 4 or 5) debris, and species left during the harvest which may have been economically undesirable (Vanderwel et al. 2008). In stands ~35-55 years old, early-successional CWD will become apparent as a result of self-thinning during the stem exclusion phase of succession (Allison et al. 2003). Early-successional CWD will be characterized by small diameter, moderately shade tolerant and pioneer species such as pin-cherry (*Prunus pensylvanica*), paper birch (*Betula papyrifera*), and yellow birch (*Betula alleghaniensis*). CWD within stands >55 years old (mid-successional) will be the most diverse in terms of both species, volume, and state of decomposition (Gore and Patterson 1985).

I also hypothesize based on data obtained in 2006 (Vadeboncoeur 2006 *unpublished*) that fine woody debris volumes in stands <40 years old will be significantly greater in total volume than FWD in stands >40 years old. If stands <40 years old differ significantly from stands >40 years old in terms of total FWD volume, then I expect to find a linear relationship with FWD and stand age from establishment to 40 yrs as young stands accumulate FWD.

(See expected results)

Research Approach and Methods

Site Description

The stands to be surveyed for this research include 13 stands in the White Mountains of New Hampshire, harvested between ~1875 and 1990 (Table X). The regional climate is cool-temperate humid continental, with a mean temperature range of -9℃ in January to 19℃ in July (Dillon 2019). Average annual precipitation is ~130cm, ~30% of which falls as snow (Taylor et al. 1999). All of the stands occur within the White Mountain National Forest (WMNF), 5 stands are within Bartlett Experimental Forest (BEF), 1 stand is within Hubbard Brook Experimental Forest (HBEF), and the remaining 7 stands are in the adjacent WMNF. The 13 stands occur on a chronosequence within the northern hardwoods forest complex, on moderately to well drained Orthods deriving from granitic glacial till and a mor-type forest floor (Federer 1984).

Overstory forest composition varies as a function of stand age, with American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), and red maple (*A. rubrum*) dominating basal areas of mid-age (35-65 years) and old stands (>65 years). Young stands (<35 years) are made distinct by the increased presence of early successional and shade mid-tolerant species such as pin cherry, as well as paper and yellow birch (*Betula papyrifera* and *B. alleghaniensis*) (Federer 1984; Taylor et al. 1999; Acker 2006 *unpublished*).

Stand Survey and BBD (Summer 2021)

Forest composition will be quantified based on a stand survey, conducted from north to south on 50m transects. Following previous vegetation surveys within the study site, 5 50m transects will be placed within each stand. For all trees sampled, species and dbh should be recorded, as well as status (live or dead). For american beech trees, a quantitative assessment of the state of infection from beech bark disease (BBD) will be noted. To quantify BBD, presence of wax secretion from beech scale (*Cryptococcus fagisuga*) will be noted on a scale of 0 (no infestation) to 5 (large portions of bark completely white). Evidence of *neonectria* fungi will be classified on a scale of 0 (absent) to 4 (very heavy with large areas of fruiting bodies and large portions of the trunk covered in sunken legions). Furthermore, american beech tree condition will be noted as part of the BBD inventory, on a scale of 1 (good, < 10% dead crown branches) to 4 (dead, no live foliage).

All trees ≥10cm dbh will be measured within 5m of the transect. All trees 2-10cm dbh will be measured in five 5mx5m subplots on alternating sides of the transect (starting on the right at 0m, 11.25m between subplots). All seedlings and shrubs <2cm dbh but >50cm height will be counted in five 2mx2m nested subplots. All seedlings and shrubs <50cm height will be counted in five 1mx1m nested subplots. For stands which do not facilitate a 50m transect, subplots will still be placed on alternating sides, starting on the right at 0m. 30m transects (with six subplots, 0m in between) will be used in stands H1 and CC2. Two 25m transects (one 3 subplots, 5m in between, and 2 subplots, 20m in between respectively), will be used in stands M5, T20, and T30. (Acker 2006 *unpublished*)

Coarse Woody Debris Sampling (Summer 2020)

Results from this research will be compared with past findings within the same stands, indicating distinct characteristics of coarse woody debris corresponding to successional stages of northern hardwood forest ecosystems in the White Mountain National Forest, New Hampshire, USA (Acker 2006 *unpublished*). CWD will be surveyed using the line intersect sampling method (LIS) used by the U.S Forest Service for Forest Inventory Analysis (FIA) (Van Wagner 1968; Woodall and Monleon 2008; U.S Forest Service 2020). Within each stand, three permanent clusters were established in 2004, each composed of three 25m transects diverging from a randomly placed center point. The three transects which make up a cluster, diverge from the center point at three randomly selected azimuths, with 120° between them (20, 140, 260, or 120, 240, 360, for example) (Acker 2006 *unpublished*). Within two of the sites (CC2 and T20) an alternative sampling design to the standard cluster was used due to limitations in site size (CC2), and obstruction of a skid rd. (T20). For CC2 transects were arranged in a box with each edge a 25m transect, and two 25m transects diagonally within the box (Figure X). Transects within T20 were arranged similarly to CC2, with the addition of another transect due to size not being a limiting factor in T20 (Figure X). Utilizing maps and field notes from past sampling, as well as cluster locations and azimuths, sampling transects will be relocated, and CWD resampled (see appendix).

When conducting surveys for CWD, navigation will occur from the center point outward to the end of each transect. CWD will be included in sampling if it is of sufficient size at point of intersection with the transect, and at least partially above the soil surface. CWD must also be leaning at an angle <45° from the ground (Forest Service 2005; Woodall and Monleon 2008). CWD is further delineated into size classes of woody debris not including leaf litter or bark, which is ≥3.0cm but <7.6cm, and ≥7.6cm diameter at intersection with the transect. CWD must be at least 1m long to be counted (Forest Service 2005). For the initial 5m of each transect, no measurements will be taken to avoid oversampling. On the subsequent 5m of each transect, CWD ≥3.0cm but <7.6cm and ≥7.6cm will be recorded. On the final 15m of each transect, only CWD ≥7.6cm will be recorded (Figure X).

For all woody debris included in measurements, species will be identified when possible as well as decay class (1 - least decayed, 5 - most decayed) (Table X). If decomposition impedes species level identification, identification will be to genus or at the least a delineation of gymnosperm or angiosperm. Length of each piece of woody debris will be recorded, as well as diameter at intersection and diameter of cavity if the piece is hollow (taken perpendicular to the length of wood). For CWD ≥7.6cm, small- and large-end diameters, in addition to the diameter at intersection will be recorded, as well as general shape (cone, cylinder, elliptical, or other) to aid in volume calculations. Large-end and small-end should be measured as the butt and leader of a log, so it is possible to have a large-end diameter which is less than the small-end diameter. If a sample is intersected longitudinally by two transects, or by one transect more than once, the sample will be counted once for each intersection. If a piece of debris is fractured and would pull apart easily at the intersection with the transect, it will be counted as two pieces, if not, it will be counted as one (Forest Service 2005). In order to be counted, woody debris must intersect the transect through the central axis (Figure X) (Waddell 2002).

For wood samples which are heavily decomposed, only that which can be delineated from the forest soil will be quantified. Heavily decomposed debris which has lost all original shape and form such that it cannot be picked up without crumbling into pieces <3.0cm will not be sampled in the study design.

Volume of woody debris for entire stands will be calculated based on the line intersect sampling method, which uses only debris diameter and transect length to estimate whole stand volumes of DDW (Van Wagner 1968).

$$V = \pi^2 \sum d^2 / 8L$$

Where V = volume of wood per unit area
d = piece diameter
L = length of sample line

Past nutrient calculations from woody debris gathered in 2004 will be compared with a smaller amount of newly collected samples, in order to determine the effectiveness of using past data to obtain nutrient concentrations within woody debris. To obtain samples for analysis of nutrient concentrations, three disks ~5 to 10 cm thick will be cut from CWD logs 4m or greater in length. Disks will be cut for every first combination of species and decay class of CWD (maple-class I, maple-classII, etc.). Disks will be cut from the log so that there is equal spacing among them to accurately capture each region of the log. If the log is less than 4m, only two disks will be cut. Each sample will be placed into an individually labeled paper bag and dried at 60℃ to constant mass (Acker 2006 *unpublished*). Discs will be ground and ashed at 500℃ for use in nutrient analysis. The disks will then be dissolved in 6M HNO_3 and analyzed in an atomic absorption spectrophotometer to determine base cation concentrations (Köster et al. 2015).

Uncertainty associated with measuring wood density has been reportedly high compared to volume estimates (Campbell et al. 2019), for this reason past densities of species x decay class combinations from 2004 will be used and compared with more recent densities reported in the literature (Harmon et al. 2008). Densities for wood of a certain species at a specific decay class should remain relatively stable, aside from any discrepancies associated with assigning discrete classes to a continuous process such as decomposition (Harmon et al. 2008).

Fine Woody Debris Sampling (Summer 2020)

FWD, defined as woody material not including leaf litter or bark <3.0cm will be sampled from 4m^2 nested subplots following past methods within the same stands in 2006. Although exact diameter thresholds for FWD vary within the literature, the Forest Service FIA program uses a range of 0.01 to 7.62cm (Woodall and Monleon 2008). Subplots were only rejected if they occurred on ephemeral or perennial streams (Vadeboncoeur 2006 *unpublished*). Plots will be randomly placed based on a stratified design utilizing permanently marked transects installed for forest floor and litter analysis (Yanai et al. 2000; Yanai et al. 2012). FWD is further delineated into size classes <7.5mm, 7.5-16mm, and 16-30mm.

Within each plot established for FWD sampling, every part of twigs and branches 16-30mm in diameter will be collected. Twigs will be cut with pruning shears where diameter is >30mm, or where the debris crosses the plot boundary. Twigs <16mm will be collected in nested $0.5m^2$ subplots in the same manner. No dead branches attached to living or dead trees will be collected, unless the tree is dead and leaning at an angle <45° from the forest floor. Dead branches suspended above the plot, but not attached to trees will be collected up to 2.5m. All samples will be placed in labeled plastic bags and returned to the lab for drying at 60℃ to constant mass.

Samples will then be re-weighed and Wiley milled to pass a 2mm screen

...To Be Continued

Tentative Statistical Analysis

Linear regression: woody debris (CWD and FWD) properties (biomass, volume, etc.) and stand age

ANOVA and independent t-tests: stands grouped by age using woody debris species composition to define groups

Groups for ANOVA:

Two youngest stands (CC2 and CC3)

35-43 yrs old, (significantly more *Prunus pensylvanica* debris)

≥50 yrs old, (diverse mix of species)

Expected Results - CWD

I expect to find quantifiable differences among the contributions of certain species to the overall pool of coarse woody debris within stands of varying ages. In young stands (<24 years old) I would expect to find residual CWD composed of large diameter debris from coniferous species such as eastern hemlock (*Tsuga canadensis*) and red spruce (*Picea rubens*). Residual CWD is expected to consist of decay resistant species, moderately to heavily decomposed (decay classes >4), due to the time spent on the forest floor (Gore and Patterson 1985). CC2 (31yrs) was described as residual in 2004 (Acker 2006 *unpublished*), however, I expect to now find early-successional CWD within this stand.

I expect to find early-successional CWD in stands ~24-45 years old (CC2-31yrs, H6-36yrs, M6-40yrs, and M5-43yrs). I expect to find a significant contribution of pin cherry (*Prunus pensylvanica*) among the coarse woody debris in early-successional stands. Pin cherry establishes and recruits best in the open, dominating stands for 15-20 yrs following establishment, and actively self thinning to ultimately end up as downed dead wood after ~35yrs (Tierney and Fahey 1998). Red maple (*Acer rubrum*), paper birch (*Betula papyrifera*), yellow birch (*Betula alleghaniensis*), as well as quaking aspen (*Populus tremuloides*) woody debris may also occur in these stands, though it will likely be of small diameter (<20cm). Mortality within stands H6, M6, and M5, would largely be a result of increased competition for resources during stem exclusion (Schwarz et al. 2001).

After ~40-50 yrs a shift may occur to more shade-tolerant and mid-tolerant species that recruit to dominate canopy positions as non-tolerant species succumb to mortality from competition for light and resources (Leak et al. 2014). Heterogeneous disturbances from light and resource competition, as well as windthrow, storm damage and mortality from infestations of pests and disease will be responsible for CWD found in stands ~40-50yrs old (Mid-successional debris). Mid-successional debris is composed of a diverse array of species and decay class, with a significantly larger component of mid-tolerant species. I expect to find mid-successional debris in stands 101, H5, T20, M4, T30, H4, and M3 (aged 50 - 110yrs).

Old-growth CWD pools would consist of downed wood that is greater in diameter than the largest living trees. This was not found previously at any of the sites (woody debris ≤ 40cm diameter, largest living trees >60cm diameter), I expect to possibly find old-growth debris in sites H2 and H3 (~145yrs old) (Table X).

Table X: Chronosequence research sites with stand age and expected woody debris classifications. White Mountains, New Hampshire.

Site	Current age	Woody Debris Classification
CC2	31	Early-Successional
H6	36	Early-Successional
M6	40	Early-Successional
M5	43	Early-Successional
101	50	Mid-Successional
H5	53	Mid-Successional
T20	62	Mid-Successional
M4	70	Mid-Successional
T30	72	Mid-Successional
H4	86	Mid-Successional
M3	110	Mid-Successional
H2	~145	Old-Growth?
H3	~145	Old-Growth?

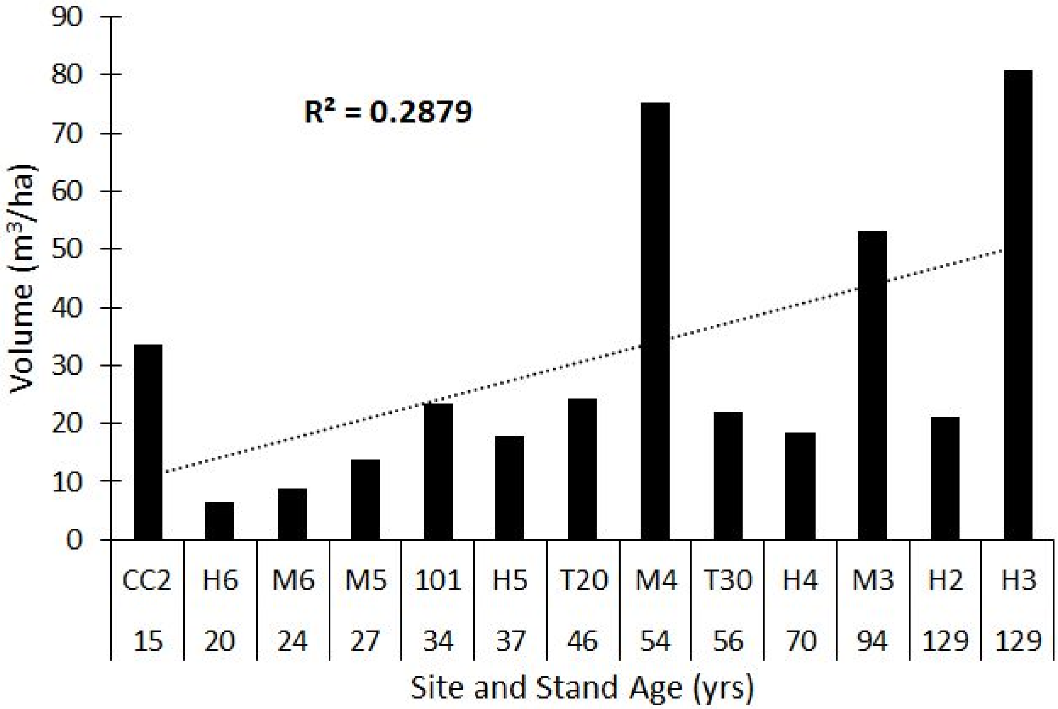

Figure X: Linear regression of woody debris volume (m^3/ha) and site name with stand age in 2004. White Mountains, New Hampshire. (Data from Acker 2006 *unpublished*).

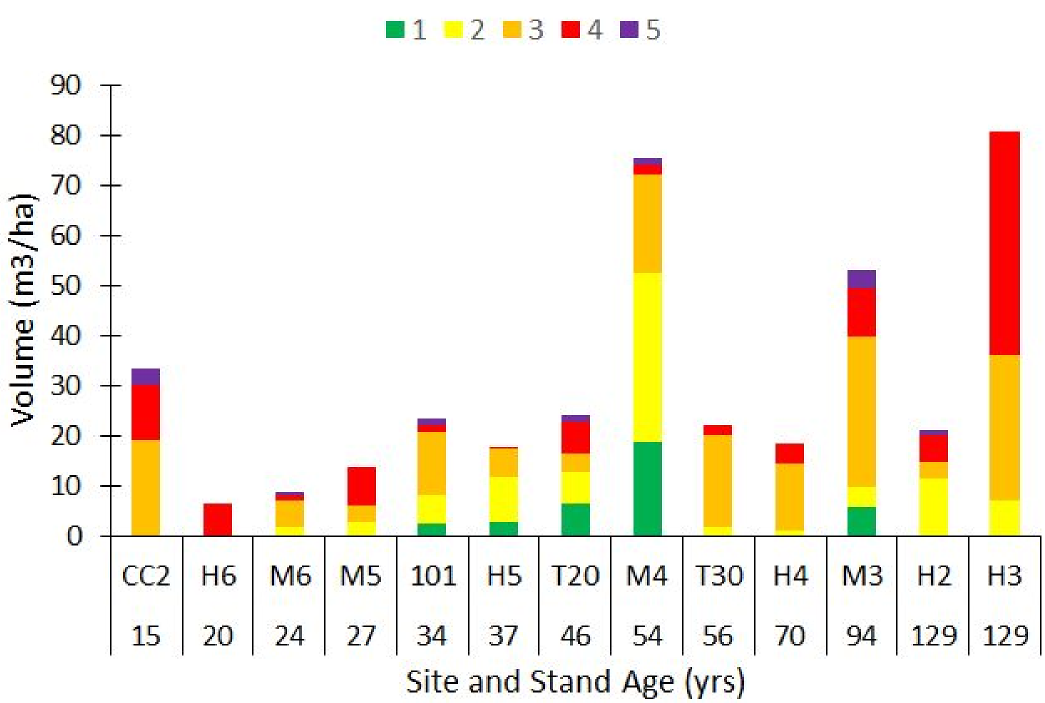

Figure X: Woody debris volume (m3/ha) in each decay class (1-5) found in chronosequence sites with site ages in 2004.White Mountains, New Hampshire. (Data from Acker 2006 *unpublished*).

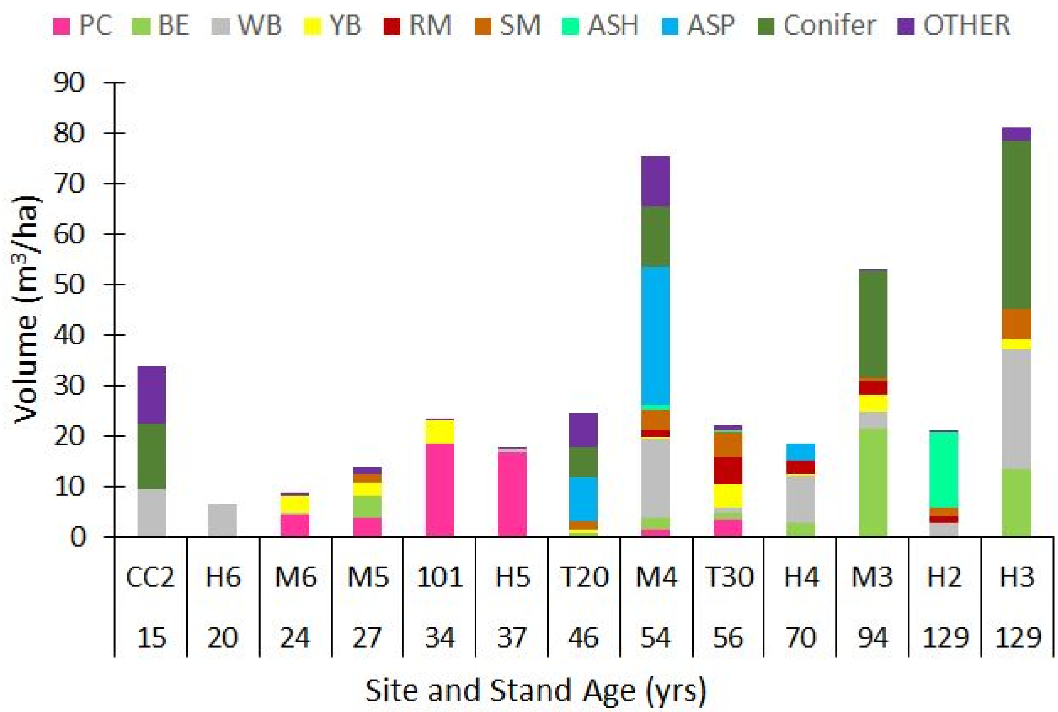

Figure X: Woody debris volume (m^3/ha) of each species found within chronosequence sites with site ages in 2004. White Mountains, New Hampshire. (Data from Acker 2006 *unpublished*).

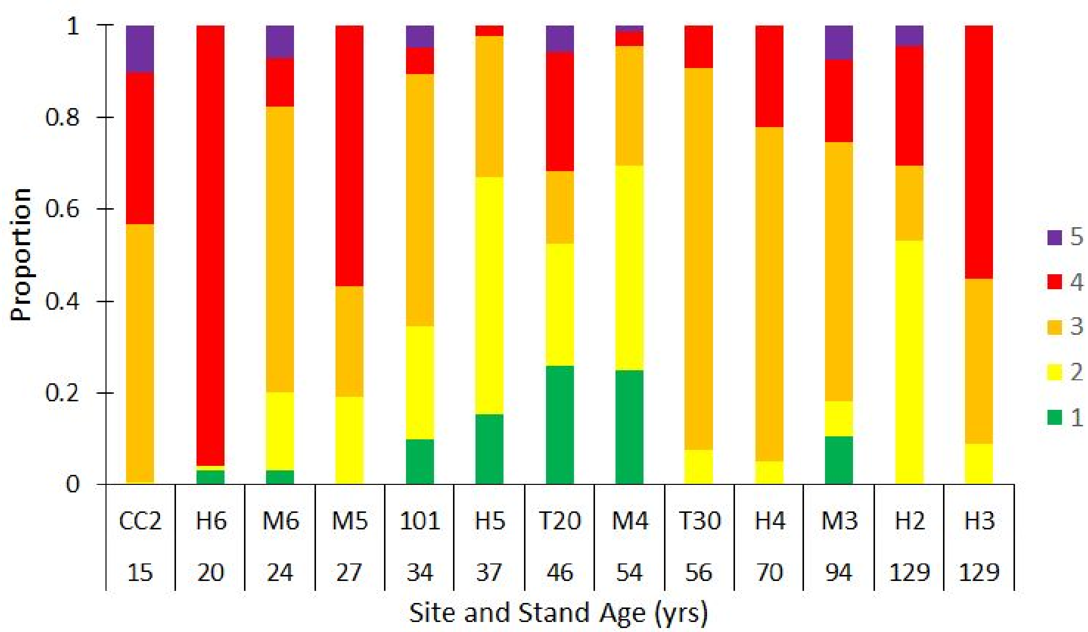

Figure X: Proportion of woody debris in each decay class (1-5), found within chronosequence sites with site ages in 2004. White Mountains, New Hampshire. (Data from Acker 2006 *unpublished*).

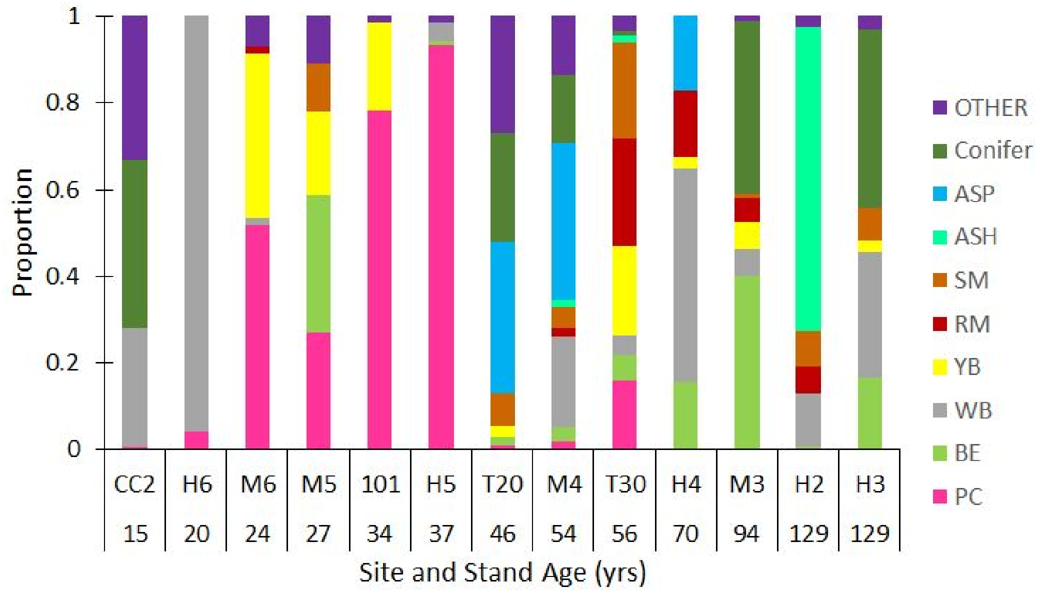

Figure X: Proportion of species contribution to woody debris found within chronosequence sites with site ages in 2004. White Mountains, New Hampshire. (Data from Acker 2006 *unpublished*).

Expected Results - FWD

Based on data obtained in 2006, I expect to see a linear trend in the mass of FWD in stands <40 years old (CC2-31 and H6-36) (Vadeboncoeur 2006) (Figure X). In stands >40 years old, I expect to see a relatively stable and consistent mass of FWD, with higher abundances in the stands where *Fagus grandifolia* is a significant portion of the total basal area due to damage from beech bark disease (Latty et al. 2003).

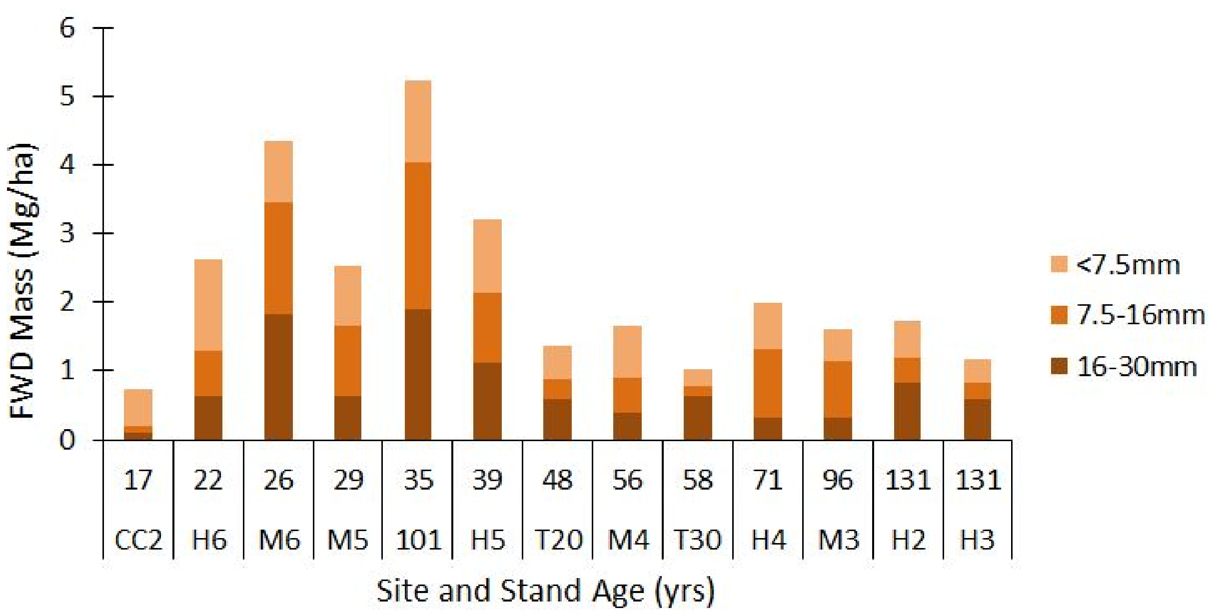

Figure X. Fine woody debris mass (Mg/ha) for each size class within the 13 chronosequence stands with ages in 2006. (Data from Vadeboncoeur 2006 *unpublished*).

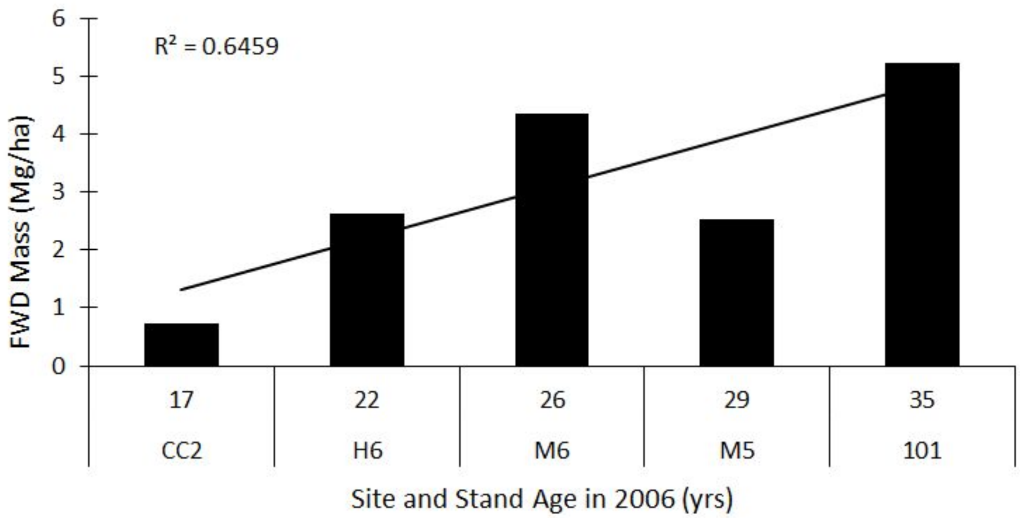

Figure X. Linear regression of total fine woody debris mass (Mg/ha) for sites aged 17-35 (site ages in 2006). (Data from Vadeboncoeur 2006 *unpublished*).

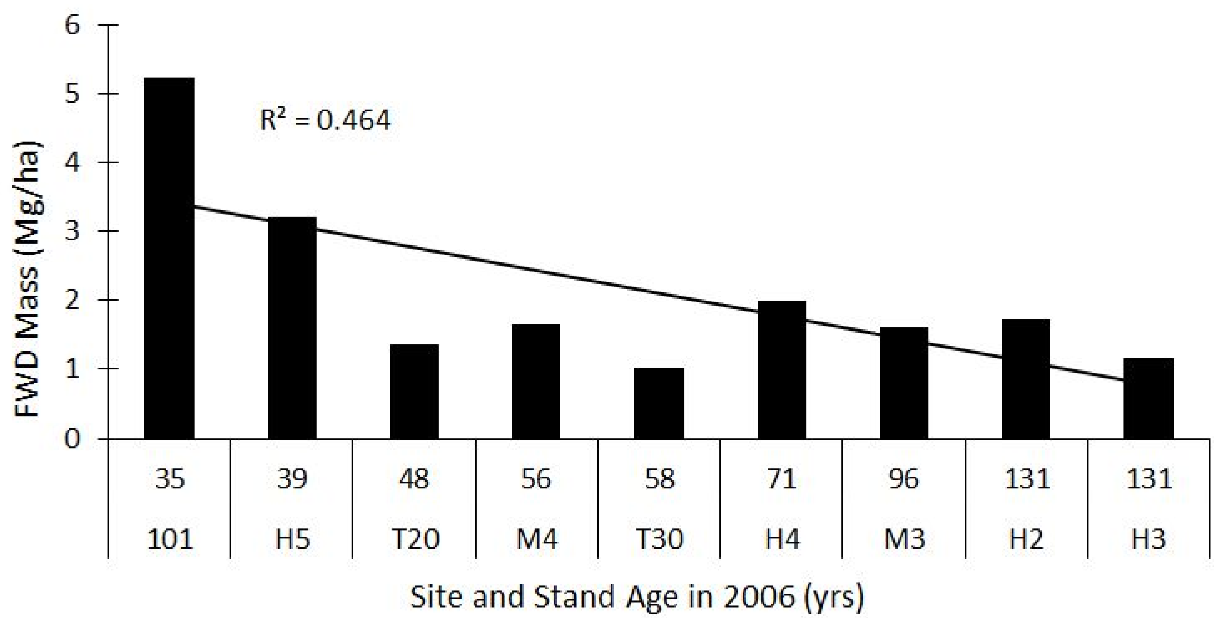

Figure X. Linear regression of total fine woody debris mass (Mg/ha) for sites aged 35-131 (site ages in 2006). (Data from Vadeboncoeur 2006 *unpublished*).

Supplemental Materials

Budget:

18, 6ft Fiberglass stakes for re-monumenting - $18

Field equipment list:

- 25 meter tape
- Diameter tapes
- Calipers
- Data sheets (rite in the rain)
- Clipboard
- Keyhole saw
- Chainsaw
- Pruning shears
- Wood ID book by Hoadley
- Hand lens, razor blade
- Flagging/stakes for re-monumenting
- Balance(s)
- First aid kit

Potential Pitfalls

- Sampling will not shed light on the volume of CWD/FWD embedded within soil.
- Cluster transects may be slightly off the original location due to an inability to locate the exact cluster. Though previous instructions on relocating clusters should provide enough detail for this problem to be avoided, and the transects will still accurately represent the stand.
- Wood decomposition is a continuum, and classifying wood into decay classes, even with a discrete decay classification scale is difficult. For this reason, samples in the same decay class, of the same species, may exhibit different nutrient concentrations.

Appendix

Table X: Site Descriptions. White Mountain National Forest, New Hampshire. Data from Yanai et al. 2000; Acker 2006 *unpublished*.

Site	Lat/Long	Current Age	Silvicultural Treatment	Treatment year	Site Location within The White Mountain National Forest
CC2	44° 04' N 71° 16' W	31	Clearcut	1989	Bear Notch Rd.
H6	44° 03' N 71° 17' W	36	Clearcut, mechanical	Winter 1984	BEF, compartment 23
M6	44° 00' N 71° 25' W	40	Clearcut, mechanical	Winter 1979-80	Sabbaday Falls
M5	44° 13' N 71° 14' W	43	Clearcut, followed by Timber stand improvement thinning	Winter 1976-77	Jackson
101	43° 56' N 71° 44' W	50	Clearcut	November 1970	HBEF, Watershed 101
H5	44° 03' N 71° 17' W	53	Clearcut strips, scarified	1967	BEF, compartment 28
T20	44° 04' N 71° 25' W	62	Heavily cut, with some cull trees girdled	1958	Sawyer River Rd.
M4	44° 09' N 71° 14' W	70	Clearcut, intensity unknown	1949-50	West of Jackson
T30	44° 09' N 71° 14' W	72	Intensity of cut unknown	1948	Iron Mountain Rd.
H4	44° 03' N 71° 17' W	86	Clearcut. Thinning in 1959 - 45% of basal area removed	1933-35	BEF, compartment 22
M3	44° 13' N 71° 15' W	110	Presumed clearcut	1910	Jackson, Ellis River
H2	44° 03 'N 71° 17' W	~145	Clearcut, used as pasture. Thinned in 1936 - 20-30% removed	~1875	BEF, compartment 16
H3	44° 03 'N 71° 17' W	~145	Clearcut, used as pasture	~1875	BEF, compartment 16

Table X: Site elevation (m), aspect, slope (%), and use of standard (cluster) or alternative (box) transect design. White Mountain National Forest, New Hampshire. Data from Acker 2006 *unpublished*.

Site	Elevation (m)	Aspect	Slope (%)	Requires alt. Transect?
CC2	330	Flat to NW	6	Y
H6	330	NNE	12	N
M6	540	WNW	19	N
M5	630	SSW	28	N
101	520	SSW	21	N
H5	360	NNE	18	N
T20	540	ESE	14	Y
M4	460	NNE	9	N
T30	550	NNE	13	N
H4	350	NNE	18	N
M3	580	SSW	26	N
H2	320	Flat	3	N
H3	320	Flat	5	N

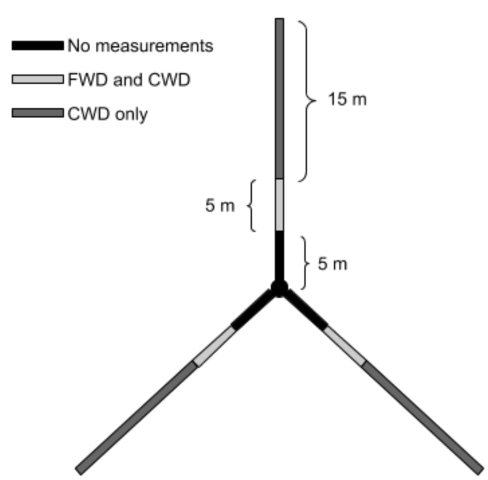

Figure X. Woody debris standard cluster sampling design, three 25 m transects diverging from a center point.

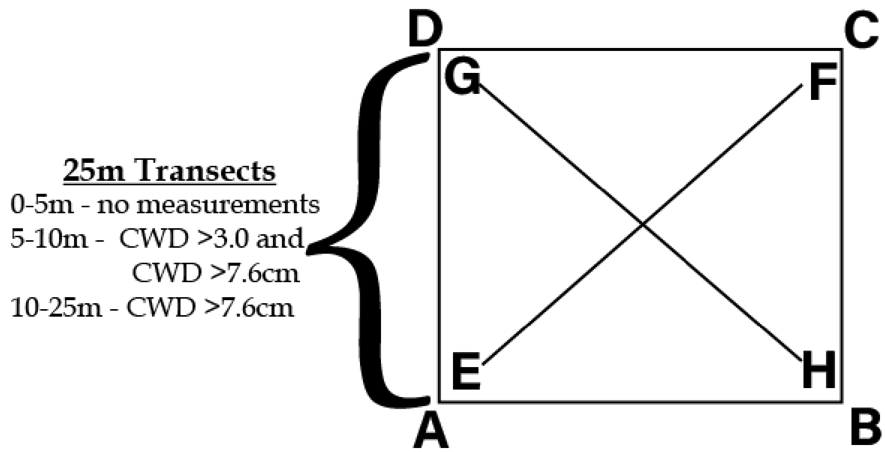

Figure X. Woody debris alternate transect sampling design used in site CC2 due to limited size.

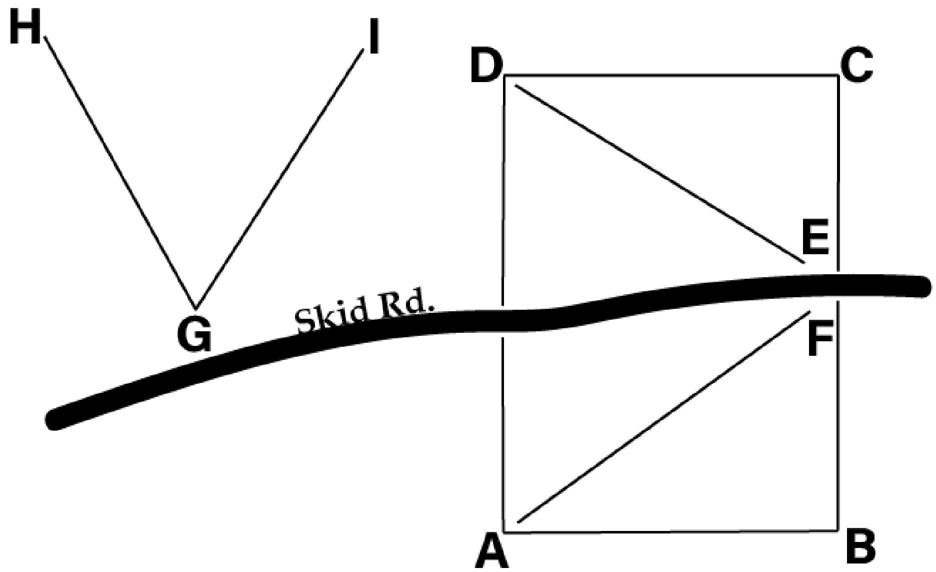

Figure X. Woody debris alternate transect sampling design used in site T20 to avoid skid rd.

Decay classes from Forest Service 2005:

Decay Class	Structural Integrity	Texture of Rotten Portions	Color of Wood	Invading Roots	Branches and Twigs
1	Sound, freshly fallen, intact logs	Intact, no rot; conks of stem decay absent	Original color	Absent	If branches are present, fine twigs are still attached and have tight bark
2	Sound	Mostly intact; sapwood partly soft (starting to decay) but can't be pulled apart by hand	Original color	Absent	If branches are present, many fine twigs are gone and remaining fine twigs have peeling bark
3	Heartwood sound; piece supports its own weight	Hard, large pieces; sapwood can be pulled apart by hand or sapwood absent	Reddish-brown or original color	Sapwood only	Branch stubs will not pull out
4	Heartwood rotten; piece does not support its own weight, but maintains its shape	Soft, small blocky pieces; a metal pin can be pushed into heartwood	Reddish or light brown	Throughout	Branch stubs pull out
5	None, piece no longer maintains its shape, it spreads out on ground	Soft; powdery when dry	Red-brown to dark brown	Throughout	Branch stubs and pitch pockets have usually rotted down

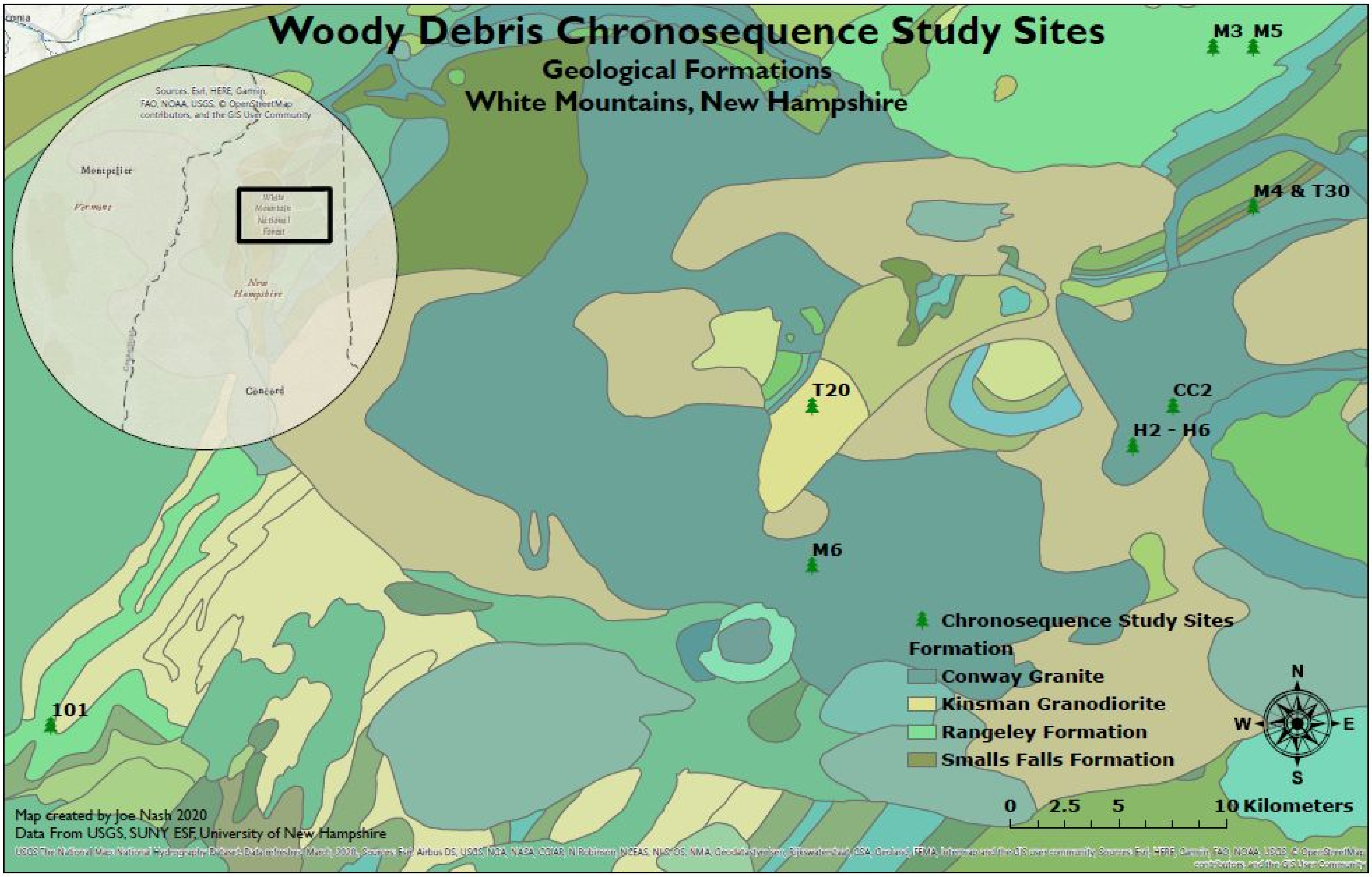

Figure X. Map of chronosequence sites on underlying geological formations. White Mountains, New Hampshire.

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