Canadian Journal of Forest Research
Revue canadienne de recherche forestière

**Changes in mass, carbon, nitrogen and phosphorus in logs
decomposing for 30 years in three Rocky Mountain
coniferous forests**

Journal:	<i>Canadian Journal of Forest Research</i>
Manuscript ID	cjfr-2017-0001.R2
Manuscript Type:	Article
Date Submitted by the Author:	05-Jun-2017
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Keyword:	coarse woody debris, decomposition, mass loss, nutrient, turnover
Is the invited manuscript for consideration in a Special Issue? :	N/A

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3 **Changes in mass, carbon, nitrogen and phosphorus in logs decomposing for**

4 **30 years in three Rocky Mountain coniferous forests**

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Abstract

Estimates of decomposition rates of coarse woody debris (CWD) and fluxes of nutrients therein are essential components of C and nutrient budget models. In a 30-year field experiment, we periodically measured mass remaining and nutrient concentrations in log segments of pine, spruce and fir in natural, mature coniferous forests in Alberta, Canada. The predicted turnover times (t_{95} ; years) were 43-44 years for pine, 42-60 years for spruce and 38-46 years for fir. Extrapolating from best-fit models, we predict that decomposition of these logs would be complete within 50 – 60 years. C:N declined for most of the decomposition period and ratios of the three species converged at <200 at 90% mass loss. Net release of N occurred only after logs had lost 90% of their original C, and C:N had declined to <200 . C:P declined and converged at 500-1000 at 90% mass loss. There was no evidence of net P release from logs even at 90% mass loss. It may be possible to estimate the amounts of N and P that will be incorporated into decaying logs based on the extent to which their initial C:N differs from 200 and initial C:P differs from 500.

Key words: coarse woody debris; decomposition, mass loss, nutrient, turnover

31 Introduction

32 Measurements of decomposition rates of coarse woody debris (CWD) are necessary to estimate
33 carbon stores and rates of CO₂ release in forests, and are components of most C budget models
34 (Magnusson et al. 2016). Coarse woody debris is also essential wildlife habitat, so estimates of
35 the longevity of CWD are also needed to ensure adequate pools for biodiversity conservation
36 (Stokland et al. 2012). Changes in nutrient concentrations are also needed to determine the
37 importance of CWD in the annual nutrient budget of a forest, and establish the point in
38 decomposition at which CWD changes from being a net sink to a net source of nutrients (Laiho
39 and Prescott 2004). Such information is needed to address questions regarding the long-term
40 implications of forest harvesting, salvage removal and extraction of woody residues for
41 bioenergy production for site fertility (Russell et al. 2015).

42 Decomposition of CWD in northern forests usually occurs over several decades, so direct
43 measurements of mass loss and nutrient release are rare. Most estimates of CWD decomposition
44 rates have been derived from indirect measures, such as changes in wood density over time
45 (decay time being estimated via chronosequence or dendrological methods), or scaled up from
46 measures of CO₂ evolution from logs (Russell et al. 2015). Rates of mass loss or density loss
47 often vary during the decay process – initial mass loss is usually slow, which is interpreted as a
48 lag while the wood becomes colonized; this is followed by a period of faster decay (Harmon et
49 al. 2000; Yatskov et al. 2003). In some studies a ‘moderately slow’ final phase is evident
50 (Tarasov and Birdsey 2001; Yatskov et al 2003); in contrast, Makinen et al. (2006) described fast
51 decomposition through to disappearance. Despite the variation in rates, the decline in mass or
52 density is usually described by a negative exponential function, the slope of which (*i.e.* the mass-
53 loss rate constant) is used to compare rates of decomposition among studies.

Concentrations of N and P in wood are initially low, and increase during decay; accordingly C:N and C:P ratios decline throughout the decomposition period. There is often a net increase in the total amounts of N and P in wood as it decomposes; as such decaying CWD acts as a sink and long-term storage site for nutrients. Net release of N and P may occur throughout the process (Palviainen et al 2008, 2010a, 2010b), but is often delayed until late in decomposition, at which point CWD becomes a nutrient source (Laiho and Prescott 2004).

Direct measurements of mass loss and nutrient changes in logs of three dominant tree species have been monitored during a long-term field experiment in three coniferous forests in the Rocky Mountains of Alberta, Canada. Measurements after 14 years (Laiho and Prescott 1999) and 21 years (Hermann and Prescott 2010) indicated distinct patterns of decay of the logs at the three sites and that the logs continued to be a net sink for growth-limiting nutrients (usually N and P), even after decomposing for 21 years and losing more than half of their mass. Here we report the results from the final collection – by which time the logs had been decomposing for 30 years. We address the following questions:

- 1) What is the estimated turnover time of logs of the three species?
- 2) How do nitrogen and phosphorus concentrations and ratios change during decomposition?
- 3) At what point in decomposition do logs become a net source of nitrogen and phosphorus?

Study sites

The three study sites were within 5 km of one another in the Lusk Creek basin, adjacent to the Kananaskis Field Station of the University of Calgary in the Kananaskis Valley, in the Front

76 Range of the Rocky Mountains of southwestern Alberta (51°01'N, 115°02' W). The Kananaskis
77 Valley has a dry continental climate with warm, dry summers and long, cold winters modified by
78 intermittent warm (chinook) winds. According to Environment Canada 30-year climate normals
79 (1981-2010), mean annual temperature at the Kananaskis Field Station is 3.6°C and average
80 monthly temperatures range from -6.2°C in January to 14.5°C in July. Average annual
81 precipitation is 640 mm, of which 256 mm occurs as snow. Soils are well-drained brunisols
82 overlying primarily limestone glacial deposits. Forests in the Kananaskis Valley are
83 predominantly coniferous, with a montane zone of lodgepole pine (*Pinus contorta* Dougl. ex
84 Loud.) and white spruce (*Picea glauca* (Moench Voss) or white x Engelmann spruce hybrids
85 below 1700 m, and an upper subalpine zone of Engelmann spruce (*Picea engelmannii* Parry ex
86 Engelm.) or spruce hybrids, and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.). The three study
87 sites were identified according to the dominant species of overstorey tree in the stand, as Pine,
88 Spruce, or Fir. The sites are described in more detail by Prescott et al. (1989).

89 The Pine site was located on a flat ground moraine of glacial till at 1530 m elevation. The soil
90 was an Orthic Eutric Brunisol of clay loam texture overlying glacial till. Canopy trees were
91 exclusively lodgepole pine, which originated following a severe fire in 1889. Spruce, poplar
92 (*Populus balsamifera* L.) and aspen (*Populus tremuloides* Michx.) dominated the understorey.
93 The shrub layer was composed of *Shepherdia canadensis* (L.) Nutt., *Salix scouleriana* Barr. ex
94 Hook., and *Juniperus communis* L. Ground vegetation was dominated by forbs (*Cornus*
95 *canadensis* L., *Hedysarum sulphurescens* Rydb., *Lathyrus ochroleucus* Hook., *Aster conspicuus*
96 Lindl., *Epilobium angustifolium* L.), and grasses (*Calamagrostis rubescens* Buckl., *Elymus*
97 *innovatus* Beal.). Stand density in the beginning of the study period (1984) was 1716 stems ha⁻¹,
98 stand basal area was 30.5 m² ha⁻¹, and mean dbh was 12.2 cm.

The Spruce site was at the base of a northwest-facing slope at 1500 m elevation with a 3° slope. The soil was an Orthic Eutric Brunisol of sandy loam texture overlying lake deposits. The overstorey was composed of spruce and pine, most of which originated from a fire in 1865. The understorey was also predominantly white spruce, along with aspen, poplar, *S. canadensis*, and green alder (*Alnus crispa* (Ait.) Pursh). Ground vegetation was composed of mosses (*Pleurozium schreberi* (Brid.) Mitt., *Hylocomium splendens* (Hedw.) B.S.G.), *Linnaea borealis* L., and forbs (*A. conspicuus*, *E. angustifolium*, *Arnica cordifolia* Hook., *Mertensias paniculata* (Ait.) G. Don). Stand density was 750 stems ha⁻¹, basal area 39 m² ha⁻¹ and mean dbh 16.4 cm.

The Fir site was situated at 1830 m on a 30° slope facing west-northwest. The soil was an Orthic Eutric Brunisol of clay loam texture overlying colluvial deposits. The overstorey was composed of subalpine fir up to 200 years old and Engelmann spruce up to 350 years old. Spruce and fir were both present in the understorey along with *A. crispa* and mosses (*H. splendens*, *P. schreberi*). Stand density was 1177 stems ha⁻¹, basal area 40 m² ha⁻¹, and mean dbh 11.6 cm.

Methods

Three (pine and spruce) or four (fir) standing dead or recently fallen trees (*i.e.* showing little visible sign of decay) of the dominant species at each site were collected in late August 1984. The logs were approximately 15 cm in diameter at their midpoints. The bark of each log was still intact, and logs included both sapwood and heartwood. Logs were cut into segments 20 cm long with a fine-blade band saw. Three-cm pieces were cut from each end of each log segment, all pieces were weighed, and a metal tag was attached to one of the end pieces. The two end pieces were then reattached to the log with a 4-cm-long screw in order to reduce artificial exposure of the wood in the central piece which was used to determine the rate of decay.

121 Seventy log segments were placed on the litter surface at 3-m intervals within one 20 x 30 m plot
122 at each site in September 1984, coincident with placement of several other litter types (Prescott
123 et al 1993a). Only logs of the one dominant tree species at each site were placed at the site.
124 Unused portions of the harvested logs were used to determine the average moisture content and
125 C, N and P concentrations, hence the original dry mass and C, N and P content of each log
126 segment. Ten log segments were collected from each site 2, 6, 10, 14, 21 and 30 years after
127 placement.

128 For the 30-year harvest, ten log segments at each site were collected in September 2014. All
129 visible fragments of wood and bark from beneath each log were collected and included in the
130 sample. Logs were placed in plastic bags, shipped to the University of British Columbia, and
131 kept cool until processing. Logs were cleaned of litter and vegetation (including roots). By 30
132 years, the case-hardened end-pieces had also decayed and fragmented, such that it was no longer
133 possible to distinguish fragments from end and center sections of the log. This necessitated
134 processing the entire log. Each log was weighed fresh, dried at 80°C to constant mass, and
135 weighed. The entire log was then milled through a hammer mill, mixed well and a subsample
136 was ground through a Wiley mill and used for C, N, and P analyses. When removing the screws
137 holding the segments together, it was clear that there was less decay immediately around the
138 screw (probably as a result of zinc coating). The less-decomposed wood attached to the screw
139 was removed and dried and weighed separately. To correct for the decay inhibition, the dry
140 weight of this section was multiplied by the average mass remaining calculated for the
141 unaffected area of the same log. The amount of N and P remaining in each log after 14, 21 and
142 30 years was calculated by standardizing the original weight of each log to 1.00 kg and

143 multiplying this value by the proportion of mass remaining and concentration of each nutrient in
144 each log at each collection time.

145 The pattern of percent mass remaining over the 30-year study period for each species was fit to
146 linear, polynomial, exponential, sigmoidal and power models and goodness of fit of each model
147 was assessed by R^2 values and Akaike Information Criteria (AIC). Power models had poor fits
148 and are not presented. For all models, turnover time (years) was estimated by calculating the
149 amount of time required for the logs to reach 95% mass loss. This was calculated using the
150 equations in Table 1 and setting y equal to 5. All analyses were conducted in JMP version 12
151 (SAS Institute Inc. 2015).

153 Results

154 *Mass loss*

155 After 30 years, the average percent of the original dry mass remaining of the logs was 13.3% in
156 pine logs, 34.1% in spruce logs and 22.5% in fir logs (Figure 1). Mass loss was slow for the
157 first 6 years but fairly constant thereafter in spruce and fir logs. Pine logs went through a period
158 of rapid mass loss between 2 and 10 years, coincident with channeling of logs by carpenter ants,
159 after which mass declined at a steady rate.

160 *Fig 1 here*

161 Models of mass loss over the 30-year period are presented in Table 1. For pine logs, a
162 polynomial model had the strongest fit (higher R^2), but extrapolation of this model beyond 30
163 years was not biologically reasonable (*sensu* Harmon et al. 2009). Sigmoidal and exponential
164 models best described pine mass loss, with estimated turnover times ($t_{0.95}$) of 43 and 44 years.

Fits for spruce logs were weaker; linear, polynomial and sigmoidal models best described the pattern of mass loss over the 30 years and predicted turnover times of 42 and 60 years, respectively. The exponential model fit less well, and had a predicted a turnover time ($t_{0.95}$) of 84 years. Sigmoidal, polynomial and linear models fit the pattern of mass loss of fir logs over the 30 years better than the exponential model, and predicted turnover times ($t_{0.95}$) of 34 to 46 years, compared to the 55 years predicted by the exponential model. Extrapolating from these models, we predict that decomposition of these logs would be complete within 50 – 60 years.

Table 1 here

Nutrient concentrations

Concentrations of nitrogen and phosphorus (%) generally increased in all three types of logs during decomposition, particularly once the logs had lost 50% of their original mass (Figure 2). C:N and C:P ratios declined during decomposition; by the time logs reached 90% mass loss, C:N ratios were 100-200 and C:P ratios had declined to 500-1000 (Figure 2). N:P ratios remained between 5 and 25 throughout decomposition in pine and spruce, but remained elevated in decomposing fir logs (Figure 2).

Figure 2 here

The P content of logs (*i.e.* total mass of P) became increasingly variable during decomposition, but was rarely less than that in the original (Time 0) logs, indicating no net release of P, even when more than 80% of the original C in the logs had been lost (Figure 3). Nitrogen content also became more variable as decay proceeded, but there was evidence of net loss of N, especially

from pine logs, after more than 75% of the original carbon has been lost (Figure 3). Only N in pine logs showed a significant relationship over time.

Figure 3 here

Discussion

The predicted turnover times (t_{95} ; years) of these logs based on repeated measurement of mass remaining over a 30-year period are 43-44 years for pine, 42-60 years for spruce and 34-46 years for fir. These estimates are similar to predictions of turnover times based on the 14-year data (pine 35 years based on sigmoidal model, spruce 45 years (sigmoidal) and fir 35 years (linear model); Laiho and Prescott 1999). Turnover-time predictions from the data for the first 21 years (based on negative exponential models) were similar for pine (42 years) but were much greater for spruce (123 years) and fir (58 years). This discrepancy in the 21-year estimates may be attributable to use of negative exponential models, as over the 30-year period only mass loss from pine logs was best described by a negative exponential model. Models of mass loss from Scots pine, Norway spruce and silver birch logs in Finland (Makinen et al 2006) also indicated that late-stage mass loss is not slow and prolonged as predicted by exponential decay models – rather, rates declined but decomposition proceeded to disappearance 60-80 years following death. Estimates of turnover times of CWD in northern forests based on negative exponential models (Table 2) are much higher than the values presented here and in Makinen et al. (2006), indicate that the application of negative exponential models may overestimate the length of time required for decomposition of CWD in northern forests.

Table 2 here

207 An initial slow phase of decomposition has been reported by Busse (1994) and Yatskov et al.
208 (2003), and is evident in density-loss curves of Olajuyigbe et al. (2010). Models that include this
209 “lag-time” have been employed (Harmon et al. 1986), and may be especially pertinent when
210 modeling decay that incorporates the period during which the CWD is standing-dead (*i.e.* the
211 ‘snag-time’) (Makinen et al. 2006). However, the three species of logs in this study displayed
212 distinct patterns of mass loss during the first decade: an obvious lag in spruce logs, linear loss in
213 fir logs and rapid loss between 6 and 10 years in pine logs, coincident with the channeling
214 activity of the ants. Although some studies have found a period of slow decomposition late in
215 the process (Yatskov et al. 2003), there was no indication in this study of logs of any species
216 reaching an asymptote (Harmon et al. 2009) or ‘maximum decomposition limit’ (*sensu* Berg et
217 al. 1996;

218 We tried to reduce artificially enhanced access to the logs segments caused by sawing the logs
219 into segments by re-attaching end pieces to cover the ends of each log segment. This appears to
220 have been successful as end pieces were often case-hardened such that access was not enhanced
221 from the ends. Rather, collapsing of logs was common and decomposition was most advanced on
222 the bottom of the logs, where they were in contact with the forest floor. This was especially
223 evident in the pine logs that had ant channels, as these were concentrated in the bottom third of
224 the logs. Despite the ends being firmly attached to the center pieces, the tiny space between the
225 two segments may have improved access to fungi, and thereby hastened decomposition.

226 The necessity of including the end pieces of the logs, which were case-hardened but had decayed
227 and fragmented by the 30-year harvest could have resulted in mass remaining being
228 overestimated at 30 years relative to previous collections. Additionally, although great care was
229 taken during each harvest to identify and collect fragments of bark and wood beneath the logs

which were deemed likely to have derived from the log segment, it is impossible to be certain of the origin of each fragment, which could have led to some error in remaining mass estimates.

Concentrations of N increased throughout decomposition— even as mass loss approached 90%. Relatedly, C:N ratios declined through the decomposition process but leveled out at <200. Other studies have reported declines in C:N ratios of conifer CWD to about this level: from >1000 to 250 (Strukelj et al. 2013), from >500 to about 150 (Saunders et al. 2011), from 352 to 123 (Petrillo et al. 2015), from 277-294 to 91-102 (Krankina et al. 1999), and from 280 to 120 (Olejuyigbe et al. 2011). The consistency of this endpoint C:N (100-200) suggests that it may be possible to estimate the amount of N that will be incorporated into decaying logs based on their initial C:N ratio.

It may also be possible to predict the decomposition stage at which net N release (*i.e.* N content less than initial) will occur based on the initial C:N of the CWD. Our logs entered a phase of net N release only after 90% C loss, once C:N was <200. Strukelj et al. (2012) found net release of N once 70% (fir) and 80% (spruce) of the initial C content had been lost (C:N 250); initial N concentrations were 767 mg/g (fir) and 987 mg/g (spruce). Creed et al. (2004) found no net loss of N until the C content had declined by 80%, at which point the C:N ratios were 203 (red spruce) and 142 (Fraser fir). In contrast, Pavliainen et al. (2008) found net release of N early in the decay process, but the C:N ratios of their logs (pine 294 and spruce 234) were much lower than ours (600-800). The consistency of these values suggest that there may be a consistent critical C:N ratio in wood of about 200, at which point net N mineralization begins.

Measurements of net N mineralization from well-decayed wood in the forest floor are also consistent with the existence of a critical C:N value for wood just below 200: Hart (1999) measured net release of N from well-decayed wood with C:N ratios of 117, while Prescott et al.

(1993b) reported net N release from decayed wood with C:N ratios of 157, 107 and 70, but net immobilization in decayed wood with a C:N of 196. Therefore it may be possible to predict from the initial C:N value both the amount of N that will be incorporated into decaying wood, and the stage of decay at which it will switch from a net sink to a net source of N.

Phosphorus concentrations also climbed throughout decomposition period and C:P ratios declined and converged at 500-1000 at 90% mass loss. There was no evidence of net P release from logs even at 90% mass loss. Similarly, Palviainen et al. (2010b) found that amounts of P in pine and spruce stumps after 40 years of decomposition were double their initial amounts, and their model predicted that P would be released only at about 90% mass loss. The decline and convergence of C:P ratios of wood is strikingly similar to the pattern discovered in decaying foliar litter of 10 species (Moore et al. 2006), in which C:P ratios initially 500-2200 converged to 500 at 80% C loss. The degree to which CWD will be a P sink during decomposition may therefore be predictable by the extent to which the initial C:P is greater than 500. Even fir logs, which had an extremely high initial C:P (50,000) gained sufficient P to have C:P ratios similar to pine and spruce logs by 50% C loss. As P has been shown to be the growth-limiting nutrient at the fir site (Prescott et al. 1989), this finding confirms the suggestion of Laiho and Prescott (2004) that decaying logs are especially large sinks for the nutrient in shortest supply on a site.

Insights into the forms in which these nutrients accumulate during decomposition can be gleaned from observations made while processing the 30-year logs (Plates S1-16). By this stage of decay, it had become difficult to decide which sorts of materials should be included in the 'mass remaining' category – *i.e.* which materials should be considered part of the log and which were extraneous. It was possible to remove moss and lichens growing on the logs, roots growing through the logs, and soil macrofauna that had the misfortune of being in the logs at the time of

276 collection. However, it was not possible to remove the fungal hyphae that permeated most of the
277 logs, nor was this considered appropriate as their tissue was probably largely derived from
278 compounds from the logs. In this sense the carbon and nutrients in the fungi had not been
279 mineralized and removed from the log, rather they had been transformed into fungal material.
280 Similarly, many logs contained considerable masses of faecal pellets of fauna and fine particles
281 of wood that appeared to have been fragmented by soil fauna. If we presume that these were
282 largely produced through the consumption of the wood itself or of the fungi within the wood,
283 excluding the mass of these materials would give the impression that the wood material at the
284 base of this food chain had been decomposed (and the carbon mineralized to CO_2), which was
285 clearly not the case. Not including the mass of faecal material would have caused us to
286 overestimate actual decomposition. The problem of overestimating decomposition rate by not
287 accounting for material which has been consumed by fauna but only minimally mineralized has
288 been noted as a concern when estimating decomposition rates of litter materials. Carcamo et al
289 (2000) noted that 90% of the mass of leaf litter consumed by millipedes was simply transformed
290 into faecal pellets rather than 'decomposed' (if decomposition refers to mineralization to CO_2).
291 Frouz et al (2015) determined that all of the additional mass lost from litters when soil fauna are
292 present could be accounted for in the faecal matter produced by the fauna. This faecal matter, as
293 well as fungal material, both in original form and having undergone further microbial and
294 chemical transformations, are presumably the primary repository of the nutrients in decaying
295 logs, and contribute to the increase in concentrations and contents of some nutrients during
296 decomposition as this material accumulates and the amount of actual 'wood' in the log or litter
297 declines. Elucidation of the nature of this secondary material and the processes through which it

298 is formed are needed to further our understanding of the linked processes of decomposition,
299 humification and transformation.

300

301 Acknowledgements

302 This long-term ecological research was possible because of the support and infrastructure
303 provided by the Kananaskis Field Station of the University of Calgary. We thank Dr. Anders
304 Taeroe for enthusiastic assistance in finding the elusive Fir site. The study was supported by a
305 NSERC Discovery grant to CEP.

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Captions for Figures

Figure 1. Percent mass remaining of decomposing logs of the three species over the 30-year experiment. Mean and standard deviation of 10 samples per collection time are shown.

Figure 2. Nitrogen concentration (A), phosphorus concentration (B), C:N ratio (C), C:P ratio (D) and N:P ratio (E) in relation to mass loss (%) for decomposing logs of the three species. Lines of best fit are plotted for each species (Table S1).

Figure 3. Contents of N and P remaining in decomposing logs of the three species as a function of C mass remaining. Values are standardized to 1.00 kg weight of original log. Lines of best fit are shown where significant (nitrogen in pine logs; Table S2).

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Figure 1. Percent of original mass remaining in decomposing logs of the three species over the 30-year experiment. Mean and standard deviation of 10 samples of each species at each collection time are shown.

Nitrogen concentration (A), phosphorus concentration (B), C:N ratio (C), C:P ratio (D) and N:P ratio (E) in relation to mass loss (%) for decomposing logs of the three species. Lines of best fit are plotted for each species (Table S1).

Contents of N and P remaining in decomposing logs of the three species as a function of C mass remaining. Values are standardized to 1.00 kg weight of original log. Lines of best fit are shown where significant (nitrogen in pine logs; Table S2).

Table S1. Exponential, polynomial, linear and sigmoidal models fit to the percent mass remaining data over the 30-year study period for each tree species. Equations of the best-fit models, associated R^2 values and Akaike Information Criteria (AIC), and turnover times (years to reach 95% mass loss) are shown.

Species	Model	Equation (y=)	R^2	AIC	Turnover time
Pine	Exponential	$104.12e^{-0.069x}$	0.91	528.3	44
	Polynomial	$102.8-5.9x-0.099x^2$	0.91	527.0	NA
	Linear	$92.05-3.04x$	0.84	566.0	29
	Sigmoidal	$237.7/(1+e^{(0.095(x-2.99))})$	0.91	527.9	43
Spruce	Exponential	$103.7e^{-0.030x}$	0.78	543.8	92
	Polynomial	$100.2-1.9x-0.009x^2$	0.8	538.2	42
	Linear	$101.2-2.2x$	0.8	536.3	44
	Sigmoidal	$127.8/(1+e^{(0.074(x-17.3))})$	0.8	538.5	60
Fir	Exponential	$104.2e^{-0.044x}$	0.86	537.8	69
	Polynomial	$101.3-3.30x+0.020x^2$	0.88	530.8	38
	Linear	$99.1-2.7x$	0.87	530.7	34
	Sigmoidal	$133.2/(1+e^{(0.094(x-11.7))})$	0.88	528.2	46

Table S1. Nitrogen concentrations, phosphorus concentrations, C:N ratio and C:P ratios in relation to mass loss (%) over the 30-year study fit with exponential, polynomial and linear models for each log species. Equations of the best-fit models and associated R^2 values and Akaike Information Criteria (AIC) are shown.

Variable	Species	Function	Equation (y=)	R^2	AIC
N (%)	Pine	Exponential	$0.0966e^{0.0162x}$	0.34	-39.9
		Polynomial	$0.048+0.00257x+0.0000165x^2$	0.35	-37.7
		Linear	$0.01488+0.0043x$	0.35	-40.1
	Spruce	Exponential	$0.0373e^{0.0355x}$	0.71	-47.8
		Polynomial	$0.106-0.0041x+0.00013x^2$	0.71	-45.2
		Linear	$-0.0858+0.00716x$	0.61	-38.9
	Fir	Exponential	$0.0853e^{0.0237x}$	0.57	-21.4
		Polynomial	$0.119-0.00123x+8.62e-5x^2$	0.57	-18.9
		Linear	$-0.0626+0.00764x$	0.52	-18.1
P (%)	Pine	Exponential	$0.000122e^{0.0716x}$	0.73	-163.9
		Polynomial	$0.0017-0.00166x+2.48e-6x^2$	0.63	-152.5
		Linear	$-0.0326+0.000966x$	0.39	-139.4
	Spruce	Exponential	$0.000174e^{0.0754x}$	0.62	-184.4
		Polynomial	$.012-0.000699x+1.4619e-5x^2$	0.54	-175.7
		Linear	$-0.01003 + 0.0005723*x$	0.41	-170.5
	Fir	Exponential	$0.0029e^{0.035x}$	0.58	-158.5
		Polynomial	$0.0037-0.000303x+1.105e-5x^2$	0.57	-155.5
		Linear	$-0.0195+0.000833x$	0.51	-153.7
C:N ratio	Pine	Exponential	$756.9e^{-0.0199x}$	0.77	352.6
		Polynomial	$768.96-14.42x+0.0841x^2$	0.78	535.7
		Linear	$600.46 - 5.54x$	0.64	365.9
	Spruce	Exponential	$811.52e^{-0.0217x}$	0.66	389.5
		Polynomial	$737.30-10.13x+0.0214x^2$	0.7	388.6
		Linear	$705.696-8.269x$	0.7	386.2
	Fir	Exponential	$459.0e^{-0.0161x}$	0.37	383.8
		Polynomial	$470.55-7.03x+0.033x^2$	0.38	385.7
		Linear	$400.28-3.59x$	0.36	384.2
C:P ratio	Pine	Exponential	$12370.9e^{-0.024x}$	0.87	510.6
		Polynomial	$11565.7-164.87x+0.508x^2$	0.91	504
		Linear	$10546.96-111.2x$	0.89	506.3
	Spruce	Exponential	$17126.2e^{-0.021x}$	0.21	632.9
		Polynomial	$17725.2-388.4x+2.90x^2$	0.21	635.4
		Linear	$13440.9-136.25x$	0.17	634.2
	Fir	Exponential	$47811.4e^{-0.048x}$	0.73	627.8
		Polynomial	$42013.7- 1169.7x+8.187x^2$	0.71	633.5
		Linear	$24790.09-328.31x$	0.48	648.6

Table S2. Contents of N and P remaining in decomposing logs of the three species in relation to C mass remaining fit with exponential, polynomial and linear models for each log species. Equations of the best-fit models and associated R² values and Akaike Information Criteria (AIC) are shown.

Variable	Species	Function	Equation (y=)	R ²	AIC
N remaining (mg)	Pine	Exponential	$544.3e^{-0.0112x}$	0.22	427.4
		Polynomial	$109.30+36.13x-0.351x^2$	0.38	423
		Linear	$445.76 + 11.26*x$	0.27	425.6
	Spruce	Exponential	$1999.6e^{-0.0132x}$	0.26	452
		Polynomial	$1856.79-18.66x+0.049x^2$	0.26	454.7
		Linear	$1728.66 - 13.37*x$	0.26	452
	Fir	Exponential	$1151.3e^{-0.0013x}$	0.006	456.9
		Polynomial	$278+53.07x-0.606x^2$	0.32	448.2
		Linear	$1135.39 + 1.99*x$	0.01	456.8
P remaining (mg)	Pine	Exponential	$82.5e^{-0.0081x}$	0.08	280.9
		Polynomial	$88.87-1.15x+0.00953x^2$	0.09	283.3
		Linear	$79.73 - 0.477*x$	0.07	281.1
	Spruce	Exponential	$188.9e^{-0.0216x}$	0.28	308.7
		Polynomial	$183.10-3.41x+0.020x^2$	0.28	311.5
		Linear	$130.17 - 1.23*x$	0.25	309.9
	Fir	Exponential	$108.2e^{-0.00696x}$	0.06	322.9
		Polynomial	$43.94-3.29x-0.048x^2$	0.24	319.3
		Linear	$111.52 - 0.73*x$	0.08	322.3

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