MODELLING OF LITTER DECOMPOSITION AND NITROGEN MINERALIZATION

by

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ABSTRACT

A 3-compartment model was formulated to simulate the dynamic development of mass, N concentrations and C/N ratios in decomposing forest litterbags, over time, across a wide range of climate, site and litter type conditions, based on 8 predictor variables and 12 best-fitted parameters. The compartments refer to the fast, slowly and very slowly decomposing fractions of the litter. The model was calibrated with the 1992 to 2000 litterbag data of the Canadian Intersite Decomposition Experiment (CIDET), involving 10 different litter types (Trembling Aspen, American Beech, Douglas Fir, White Birch, Jack Pine, Black Spruce, Tamarack, Western Red Cedar, Bracken Fern, Plains Rough Fescue). These bags were distributed across 21 sites (18 upland and 3 wetland sites), located in 7 provinces and territories (Labrador, Quebec, Ontario, Saskatchewan, Yukon, Alberta, and British Columbia). Annual precipitation across these sites varies from 261 to 1782 mm. Mean annual air temperature ranges from -9.8 to + 9.3 C. The predictor variables refer to water-and acid-extractable portions of the litter (to specify the fast fraction), and to ash content (to specify the slow and very slow fractions). The variables that capture the influence of climate on litter decomposition are mean July and January air temperatures, and annual precipitation. The rate of N mineralization was found to depend on the initial N concentration of the litter, and on the C concentration of the forest floor on which the litterbags were laid. This thesis summarizes: the model, the statistical procedures, the equations, the best-fitted results, and the finalized parameters.

Key words: forest litterbags, organic matter decomposition, N concentrations, climate, litter type, CIDET.

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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

The rate at which forest litter decomposes plays an important role in the carbon cycling of terrestrial ecosystems (Schimel, 1995; Swift et al., 1979). For example, in boreal and temperate forests, 1500 Pg (10^{15}g) of carbon is stored in the mineral soil due to slow decomposition, while 55 Pg are stored in the forest litter layers due to a faster rate of decomposition. Together, these accumulations amount to about 20% and 70% respectively that is stored in boreal and temperate forest (Schlesinger, 1997; Moore, et al., 1999). In Canada, about 12 Pg of carbon are contained in forest vegetation and other plants, while 76 Pg of carbon are stored in soils and decaying plant litter. About 135 Pg have accumulated in forested and non-forested peatlands (Kurz et al., 1992). In general, the rate of forest litter decomposition not only influences the rate of organic matter storage in and on soils, but also influences:

1. the rate at which C is returned to the atmosphere, by way of heterotrophic respiration and the related CO_2 release from the forest floor (Jenkinson et al., 1991).
2. the rate at which nutrients such as N, P, Ca, Mg, and K are released or mineralized from the litter for continued plant (Kimmins, 1977, Aber and Melillo, 1991; Bryant et al., 1998; Swift et al., 1979); in general, soil organic matter (SOM) is a critical source of nutrients, contributes to soil structure, and keeps soils moist;

3. the rate of floral and faunal activities in forest soils: for example, faster decomposing litter leads to thinner forest litter layers while encouraging deeper mull-type layers of organically enriched topsoil; the process that leads to this combination is often due to earthworm-induced biomixing (Tan, 2000);
4. the rate at which heavy metals such as Hg (Eatherall et al., 1998) and organic pollutants become biologically available and toxic (Alberts et al., 1994);
5. the rate at which litter-mineralized nutrients and dissolved organic matter and heavy metals are leached from the soil, and enter small forest streams (Thurman E.M., 1985; Kochy and Wilson, 1997 ; Grigal, 2002; Ravchandran, 2004; Arp and Oja, 1997; Zhu et al., 2003);
6. the rate of change of soil physical properties, such as the build-up of forest litter, the build-up of soil organic matter (SOM) in the mineral soil (Jr. et al., 1999), the type, size and strength of soil mineral structure, the extent of soil moisture retention (Prescott et al., 2000), the extent of soil thermal insulation (Balland, 2003), the extent of cation retention (Meyer and Arp, 1994), and the change in soil bulk density, soil aeration, and soil permeability with increasing soil depth.

Therefore, quantifying and predicting the rate of forest litter decomposition is fundamental to understanding forest ecosystem functioning in general, and is essential for dealing with matters of C storage, nutrient cycling, and soil and water quality within managed and un-managed forest ecosystems (Kimmins, 1977).

With climate change, the mean global surface temperature has steadily increased over the last 150 years, and is rising at a faster rate at high latitude (Hansen et al., 1988; Mcelroy, 1994). With these increases, the rate of carbon cycling and the rate of forest litter decomposition is likely to increase as well. Several field-oriented studies have been initiated for the purpose of to clarifying and quantifying these changes (Gibson and Jordan, 1983; Jenkinson et al., 1991). Among these studies are:

1. the Long-term Intersite Decomposition Experiment Team (LIDET, 1995),
2. the Decomposition Study (DECO) in Europe, and
3. the Canadian Intersite Decomposition Experiment (CIDET) in Canada (Prescott et al., 2000;Trofymow et al., 1995;Trofymow and the CIDET Working Group, 1998).

The Long-Term Intersite Decomposition Experiment Team (LIDET) is a 10-year study that was been initiated to:

1. to examine the long-term rates of decay of approximately 20 types of plant litter on 28 sites covering arctic tundra, warm desert, grassland, tropical and temperate forests, and
2. to compare the results with *a priori* predicted decomposition rates from several soil process models (Long-term Intersite Decomposition Experiment Team (LIDET), 1995; Troyfymow and CIDET Working Group, 1998).

The Decomposition Study (DECO) is a long term litter decomposition research project that is centered on Europe (Long-term Intersite Decomposition Experiment Team (LIDET), 1995; Prescott et al., 2000; Troyfymow and CIDET Working Group, 1998).

The Canadian Intersite Decomposition Experiment (CIDET) in Canada is similar in its design and was initiated to investigate the long-term rates of litter decomposition and nutrient mineralization over all of the ecoclimatic regions in Canada (Long-term Intersite Decomposition Experiment Team (LIDET), 1995; Prescott et al., 2000; Troyfymow and CIDET Working Group, 1998). The CIDET study was initiated in 1992, because data on long-term litter decomposition rates in Canadian forests were needed for the development and calibration of the Carbon Budget Model – Canadian Forest Sector (CBM-CFS) (Trofymow and the CIDET Working Group, 1998). This particular model is the national C budget model to be used for Kyoto and UNFCC reporting, and contains a simple two-compartment formulation for litter decomposition (Kurz et al., 1992). Other models such as CENTURY (CENTURY, 2000; Parton et al., 1987), ROMUL (Chertov et al., 2001) and others (McGill, 1996; Swift et al., 1979) also depend on litter decomposition data for the purpose of site-, litter- and climate-specific model calibrations.

The CIDET study involves the placement of 11,000 litterbags, comprising 10 foliage types, i.e., Trembling Aspen (***Populus Tremuloides***), American Beech (***Fagus Grandifolia***), Douglas Fir (***Pseudotsuga Menziesii***), White Birch (***Betula Papyrifera***), Jack Pine (***Pinus Banksiana***), Black Spruce (***Picea Mariana***), Tamarack (*Larix laricina*), Western Red Cedar (***Thuja Plicata***), Bracken Fern (***Pteridium Aquilinum***), Plains Rough Fescue (***Festuca Hallii***) and wooden blocks of Western Hemlock (***Tsuga Heterophylla),*** placed at 21 sites (18 upland sites, 3 wetland sites), across the major ecoclimate regions of Canada (Trofymow et al. 2002). Thus far, data from 1992 to 1998 have been used to quantify the overall rates of litter decay using climate variables and substrate variables as rate-of-decay predictors (Moore et al., 1999; Moore et al., 2005a; Moore et al., 2005b; Trofymow et al., 2002). For example, the quality of fit between the calculations and the data for mass remaining has been shown to be fairly high with an overall r^2 value of 0.80 and only 7 predictor variables in the final regression equations (Trofymow et al., 2002).

1.2 THESIS OBJECTIVE

The specific objective of this thesis is:

to present and evaluate the performance of a 3-compartment model to calculate the amount of mass remaining, nitrogen concentrations and C/N ratio in the CIDET litterbags over seven years, by litter type and climate region.

This objective is addressed in this Thesis as follows: **Chapter 2** contains a literature review of the forest litter decomposition process, involving laboratories studies, field examinations, and several model formulations. **Chapter 3** provides an overview CIDET. **Chapter 4** describes the litter decomposition model and its assumptions. **Chapter 5** documents the process of the model establishment and calibration and the accuracy of the model to simulate the litter mass and nitrogen concentration of CIDET leaf and wood litter. **Chapter 6** discusses the litter decomposition model about model fit, the relationship between litter quality and litter decomposition, climate factors and litter decomposition, wetland effect on litter decomposition and nitrogen mineralization and the effect of exogenous nitrogen on litter decomposition. **Chapter 7** summarizes conclusions, contributions original to the work, and recommendations for further studies.

Recent discussions and summaries about the utility of 1, 2 or 3-compartment models in terms of capturing the release of CO_2 from soil organic matter degradation with respect to changing climate conditions and litter type can be found in (Knorr et al., 2005; Powlson, 2005). In the model of this Thesis (**Chapter 4,** and **Appendix**), climate is represented by annual precipitation, and mean monthly air temperature in July and January. These temperatures represent the amplitudes of the on-site annual temperature variations. Litter type is represented by initial chemical composition as determined by proximate chemical analysis (water- and acid-extractable fractions, and ash content). The chemical influence of the underlying substrate on the rate of decay and resulting N concentrations within the litterbags is also examined at each site.

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

Litter decomposition generally occurs in two or more phases (Berg et al., 1993; Berg, 2000; Currie and Aber, 1997): the first phase is very fast and occurs within the first year (Berg, 2000; Chertov and Komarov, 1997; Troyfymow and CIDET Working Group, 1998); the second and later phases are slow, and occur over many years. There are two assumptions: one assumption is that the decomposing organic matter gradually changes its chemical composition from one phase to the other, e.g., from the originating litter to the fermented litter and than to humus. The other assumption is that organic matter consists of a mixture of chemical components that decompose at different rates. The components that decompose quickly are mainly due to readily solubilized substances. The more slowly decomposing substances are structural, such as lignin.

Models that have been proposed thus contain various combinations of these two assumptions. For example, the SOMM and ROMUL models (Chertov and Komarov, 1997), and the CANDY (Franko et al., 1995) and CENTURY models (Parton et al., 1987; CENTURY, 2000) mainly follow the first assumption. The latter assumption dominates models such as DOCMOD, MBL_GEN, and GEN_DEC (Moorhead, 1999; Troyfymow and CIDET Working Group, 1998). In all models, N and lignin contents of the litter, and climatic factors such as temperature and precipitation (or soil moisture and temperature conditions), are part of the rate of decay formulation (Chertov and Komarov, 1997; Currie and Aber, 1997; Moorhead and Reynolds, 1991; Preston and Trofymow, 2000).

The models differ in terms of number of organic matter pools under consideration. There are also basic differences in definition. In CENRTURY, the rate of decay calculations refers to the rate of loss from any particular pool. The actual Carbon loss due to heterotrophic CO_2 respiration is a percentage component of the rate of decay. The amount of organic matter converted from pool to pool is the complement. In SOMM, ROMUL, CANDY, and DOCDOM, respiration rates are identified as mineralization rates, and these are, for the most part, calculated separately from the conversion rates.

The objectives of this chapter are:

1. *to review the rate of organic matter decomposition as formulated in the literature;*
2. *to synthesize this review in the context of the model that forms the basis of this Thesis.*

2.2 SOIL ORGANIC MATTER DECOMPOSITION MODELS

Models that have been proposed to model the rate of forest litter decomposition vary in range of complexity, from very simple, assuming non-changing environmental conditions and substrate content, to very elaborate and mechanistic. The earliest model was developed in the 1940s by Jenny (1941), who stated that the rate of forest litter decay should be proportional to the amount of litter on the ground. He then introduced a constant amount of annual litter fall to simulate the amount of litter on the ground, over time:

$$\frac{dX}{dt} = -kX + L \qquad [2.1]$$

where

X --- pool size of C or N (t ha^{-1});

k-----first order rate constant (t^{-1});

L--- rate of litter fall (t ha^{-1}).

In 1963, Olson (Olson, 1963) integrated this equation, and obtained:

$$X = (L/k)(1 - e^{-kt}) \qquad [2.2]$$

This formulation was later incorporated by Arp and McGrath (1987a, b) into 2, 4 and 8 component models regarding forest biomass accumulations, with more parameters being introduced with each component addition to the model, and where the parameters were obtained from field-determined biomass components. In this formulation, components referred to foliage biomass, herbivore biomass, forest floor biomasss, mineral soil biomass, live and dead wood biomass, etc. The benefit of this model was its simplicity, and that it can be used to represent chrono-sequential data for each biomass component quite well (Arp and McGrath, 1987b). The problem was that the best-fitted k values could not – by themselves - be directly linked to changing environmental and substrate conditions. Hence, a model formulation such as this needs separate calibrations across varying climate and substrate conditions in order to be of value beyond the anecdotal curve-fitting step.

Among the models that contain explicit sub-module expressions for the rate of forest litter decomposition are the SOMM, ROMUL, CANDY, CENTURY, DOCDOM, GENDEC, MBL-GEN and CBM-CFS models. The SOMM and ROMUL model were developed for simulating C cycling and biomass in forest ecosystems. The CENTURY and CANDY models were originally developed for agricultural and grassland ecosystems and the CENTURY model was later extended to simulate C-cycling in forest ecosystems. The CBM-CFS was developed to account national or regional C pools and fluxes in Canada's forest ecosystems and forest product sector. The DOCDOM model was developed to simulate the leaching of dissolved organic carbon (DOC) from forest soils. THE GENDEC was developed to examine the interactions between the buried litter, decomposer microorganisms, and C and N pools in the arid ecosystems, especially desert. The MBL-GEN was designed to examine changes in the fluxes and allocation of C and N among foliage, fine roots, stems, and soils in response to changes in atmosphere CO2 concentration, temperature, soil water, irradiance, and inorganic nitrogen inputs.(Chertov et al., 2001; Chertov and Komarov, 1997; Franko et al., 1995; Parton et al., 1987; CENTURY, 2000; Currie and Aber, 1997; Moorhead and Reynolds; 1991; Rastetter et al., 1991; Kurz and Apps, 1999; Palosuo et al., 2003).

These models are reviewed below, with emphasis on general model structure, and basic approach taken to resolve the forest litter decay process. Three of these models (CENTURY, CANDY, and SOMM) were also reviewed in an earlier publication concerning 9 soil organic matter models, to ascertain the ability of these models to simulate soil organic matter levels for select soil types (Smith et al., 1997).

SOMM and ROMUL

The SOMM model (Chertov et al., 2001; Chertov and Komarov, 1997) presents organic matter decomposition in 3 stages (Figure 2.1): at the first stage, fresh organic matter is considered to be consumed by fungi, bacteria and arthropods (fermentation). At this stage, part of the organic matter would be lost through heterotrophic respiration, and part of it is transferred into fermented matter (F layer). At the second stage, the fermented organic matter is consumed by a second set of fungi, bacteria and arthropods, and also by earthworms. At this time, part of the consumed material is again used for heterotrophic respiration, and part of it is then transformed into humus. The third stage is the humus mineralization stage.

At each stage, the litter fermentation rate is determined by the ash and N content of the decaying litter, and by soil temperature and moisture. Furthermore, humus as produced by the earthworms is empirically set to have a C/N ratio of 8. For fermented litter as produced by arthropods, fungi and bacteria, the C/N ratio is set at 15. SOMM uses similar expressions for the C and N turn-over rates, but with the N turn-over rates set to be smaller than the C turn-over rates, since N losses from the decaying litter are proportionately lower than the simultaneous C losses.

The ROMUL model is built on SOMM, by expanding the decomposing litter component into several above- and below-ground "cohorts". Cohorts refer, e.g., to leaf litter, wood litter, root litter (Figure 2.2). There are other innovations as well, such as more elaborate expressions for soil moisture and temperature effects according to season. The time scale of this model can be one day, one month, or one year. Both SOMM and ROMUL can be used to estimate changes not only in C and N, but other nutrient elements as well (P, Ca, Mg, and K).

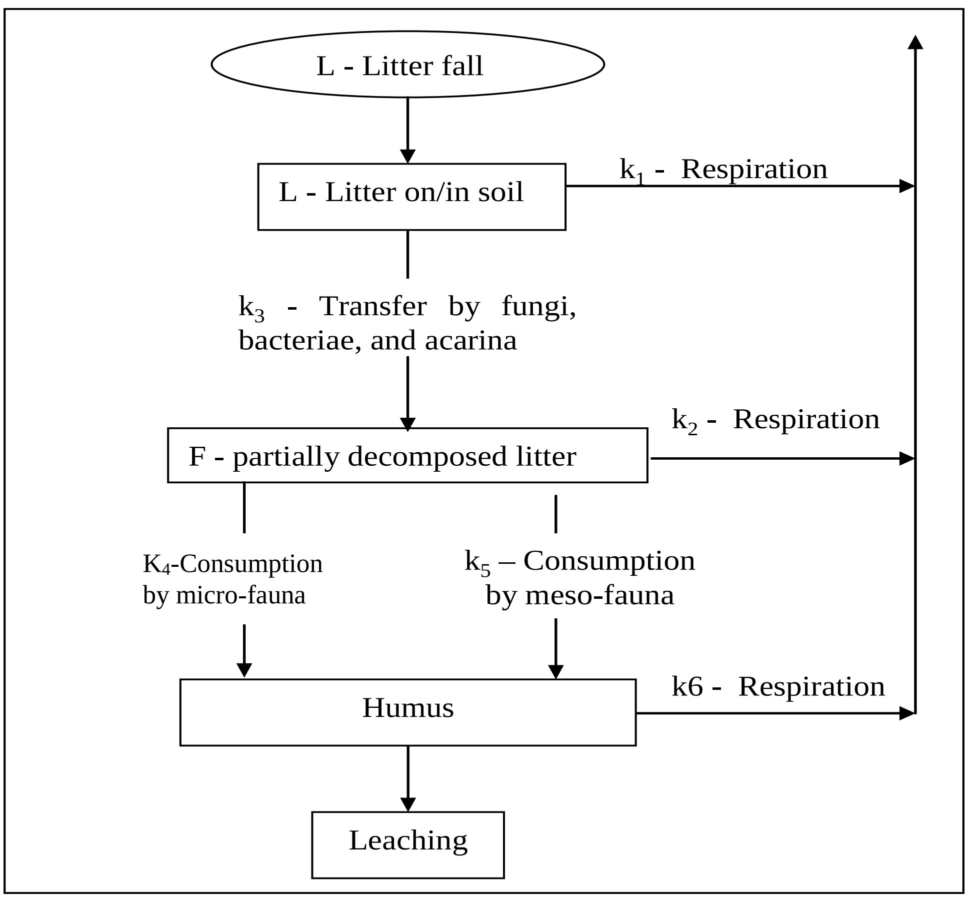

Figure 2.1 Flow chart of the organic matter decomposition for SOMM, or one compartment (cohort) in ROMUL (Chertov and Komarov, 1997).

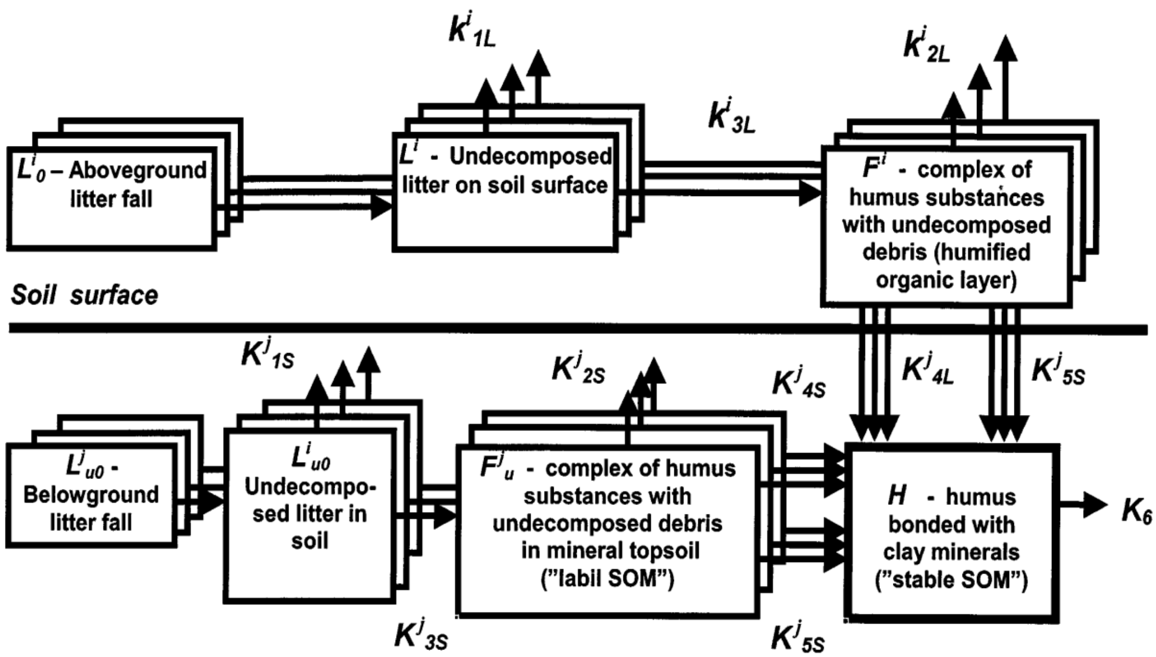

Figure 2.2 Flow chart of the organic matter decomposition in the ROMUL model, including root, wood debris and leaf litter (Chertov et al., 2001).

CANDY

CANDY (Franko et al., 1995) is designed to simulate the effects of soil temperature and soil moisture on C and N cycling, including nutrient uptake and nutrient leaching within the context of changing hydrological conditions of cropped systems. The organic matter decomposition and nitrogen mineralization components of this model are addressed by way of three organic matter pools: the added organic matter (AOM) pool, the biologically active soil organic matter (BOM) pool, and the stabilized soil organic matter (SOM) pool (Figure 2.3). This is, in principle, similar to the SOMM formulation.

Decomposition rates are formulated as a mixture of mineralization and conversions rates, all of which are assumed to be proportional to pool size such that

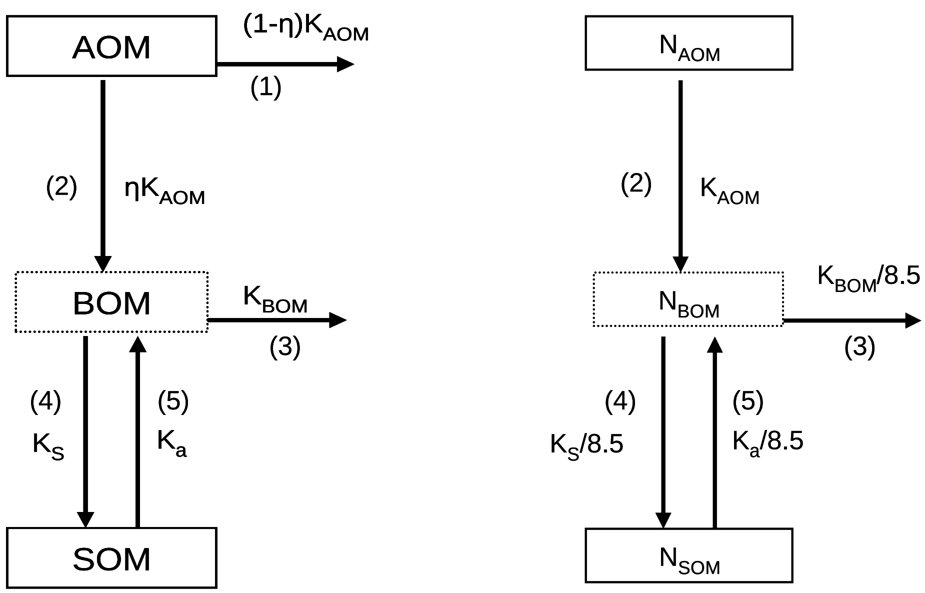

Figure 2.3 Flow chart of C decomposition and N mineralization in the CANDY model. AOM is added organic matter, BOM is biologically active soil organic matter, SOM is stabilized soil organic matter. The model can handle up to 6 AOM pools. KAOM is the decaying rate of AOM pool and η is the conversion fraction. Ks is the transferring rate of BOM to SOM and Ka is the decaying rate of SOM. The nitrogen mineralization processes are deduced from the specific C/N ratio of the C compartments. The C/N ratio of BOM and SOM pools is 8.5. The nitrogen mineralization of the AOM pool depends on the C decomposition of that pool.

$$\frac{dC_{AOM}}{dt} = -k_{AOM} C_{AOM} \qquad [2.3]$$

$$\frac{dC_{BOM}}{dt} = n\,k_{AOM}C_{AOM} - (k_{BOM} + k_s)C_{BOM} + k_a C_{SOM} \qquad [2.4]$$

$$\frac{dC_{SOM}}{dt} = k_s C_{BOM} - k_a C_{SOM} \qquad [2.5]$$

where C is carbon content, and k_{AOM}, k_{BOM}, k_{SOM}, k_a, k_5 and η are moisture and temperature dependent rate coefficients. In the model, the C/N ratio of the BOM and SOM pools are set at 8.5. This ratio is then used to determine the rate of N release from these pools. All of the organic matter conversions are centered on the BOM pool.

CENTURY

The CENTURY (Parton et al., 1987; CENTURY, 2000) model was designed to simulate long-term vegetative biomass and SOM dynamics, and N, P and S cycling at the same time. The SOM component simulates organic matter decomposition above and below ground (Figure 2.4). The above- and below-ground soil components are composed of several pools: a structural pool, a metabolic pool, a microbial or active pool, a slow pool, and a passive pool. The structural and metabolic pools are the litter pools. The metabolic pool is set to decompose fast. The structural pool is set to decompose slowly. The sizes of these pools are determined by the lignin/nitrogen ratio: the higher this ratio, the more organic matter is partitioned into the structural pool. Carbon from the structural, metabolic and microbial pools is set to be converted into CO_2, or becomes part of the slow and passive soil organic carbon pool. The turn-over rate of the microbial pool amounts to several months. The decomposition rate is obtained by reducing a maximum decomposition rate by a multiplicative function that depends on soil moisture, soil temperature, and a cultivation factor.

The decomposition of each of the state variables is calculated using the following equation:

$dC_i/dt = K_i\ M_d\ T_d\ C_i$ [2-6]

where, Ci is the carbon in the state variable;

i=1, 2, 3, 4, 5, 6, 7 for each carbon litter pool;

K_i=the maximum decomposition rate;

M_d= the effect of the ratio of monthly precipitation to potential evapotranspiration on decomposition;

T_d= the effect of monthly average soil temperature on decomposition (derived from poisson function).

The N turn-over process is assumed to have same structure as the soil organic matter turn-over process, as illustrated in Figure 2.5. The C/N ratio of organic matter varies by pool type: 150 for the structural pools, 8 for the active pool, and 11 for the slow and passive pools. N rates entering or leaving the pools are adjusted such that the C/N ratios in each pool remain fixed, as specified. The N content of the metabolic pools, however, are allowed to vary, depending on the amount of N received, with the stipulation that any structural organic matter that is formed in this pool will have a C/N ratio of 150 as well. These calculations, in turn, leached to the production of mineralized

N. The model also addresses external N inputs, via atmospheric deposition, fertilizer applications, and N_2 fixation. N losses from the soil are set to occur in various ways: N volatilization, leaching, and grazing (or harvesting).

DOCDOM

The DOCDOM model (Currie and Aber, 1997) addresses the decay process with 6 pools: lignocellulose (LC), unprotected cellulose (C), acid-soluble extractives (E), woody litter, microbial biomass, and forest floor humus. Ash-free foliage and fine roots enter the LC, C and E pools. Acid-insoluble mass and acid-soluble mass are entered into the LC pool in equal amounts. The remainder of the acid-soluble mass is entered into the C pool. In this model, wood debris is decomposed differently from foliage (Figure 2.6).

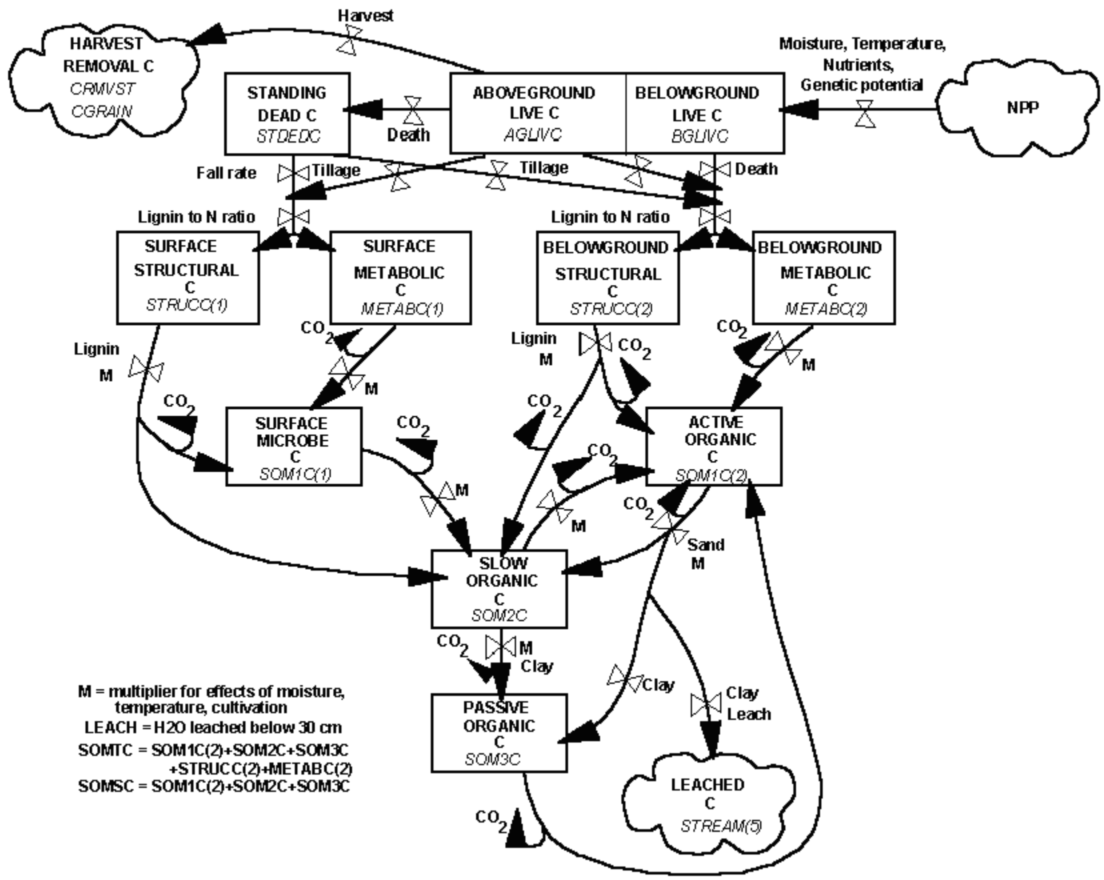

Figure 2.4 Flow chart of litter decomposition in the CENTURY model (Parton et al.,, 1987, CENTURY, 2000).

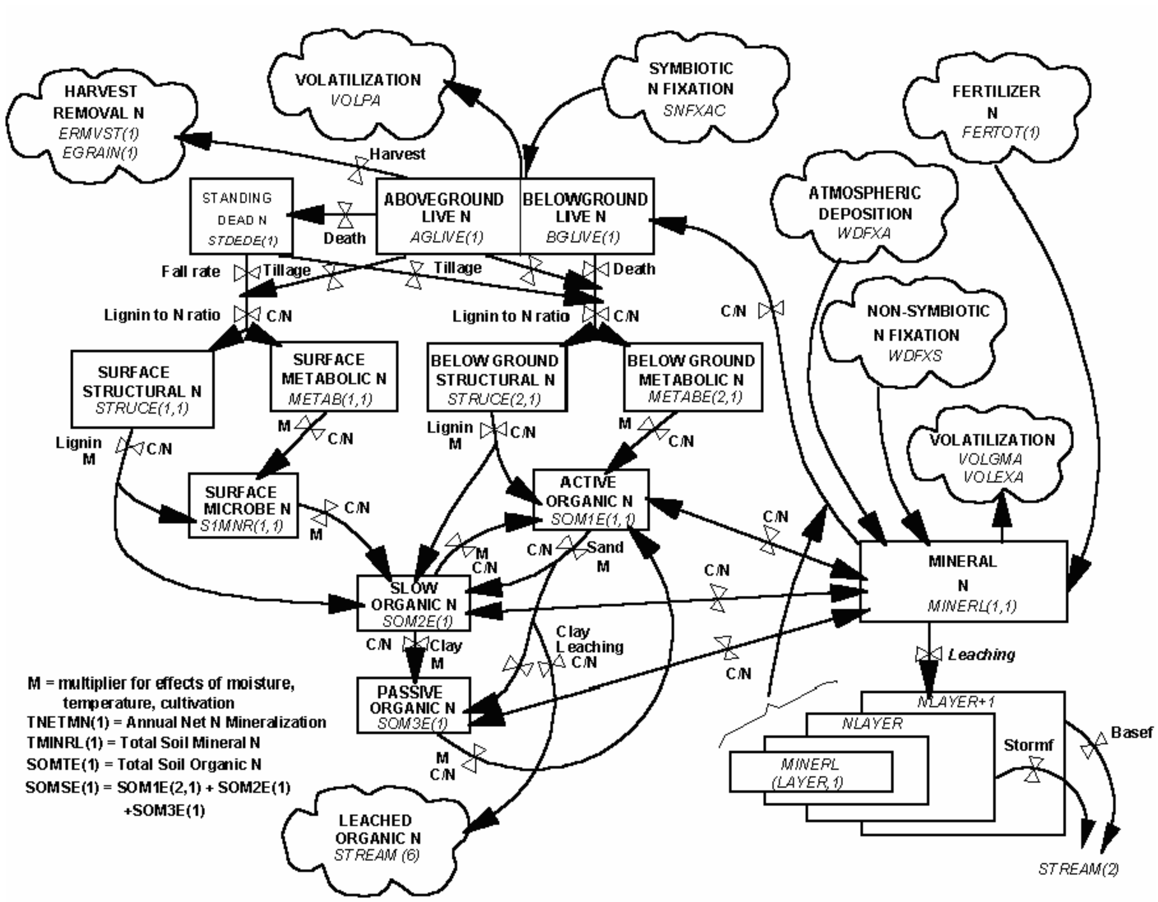

Figure 2.5 Flow chart of litter decomposition in the CENTURY model (Parton et al.,, 1987, CENTURY, 2000).

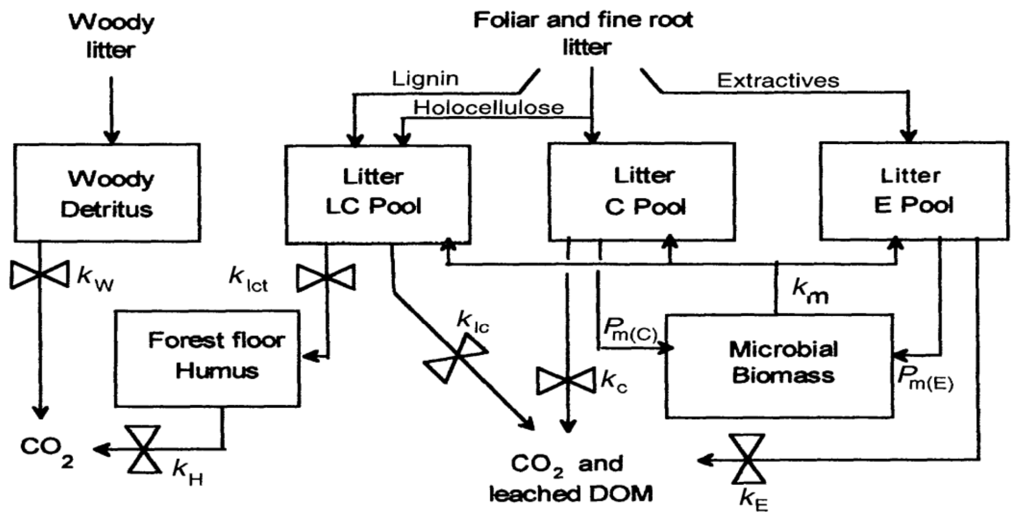

Figure 2.6 Pools and transfers of litter in the DOCDOM model.

The process of N mineralization is combined with the carbon decomposition process. The various N flows addressed in the DOCDOM model are shown in Figure 2.7. Except for the wood, lingo-cellulose and humus pools, N transfer rates are calculated from the corresponding organic matter transfer rates, multiplied by the N concentration of that pool. For the LC pool, provisions are made to absorb N when N concentrations are low, and to mineralize N when the N concentrations are high. For the woody pool, there is no N release until a C/N ratio of 20 is reached. For the humus pool, N is set to be mineralized at a lower rate than the humus mineralization rate, to reach a C/N ratio similar to the end ratio for the woody pool.

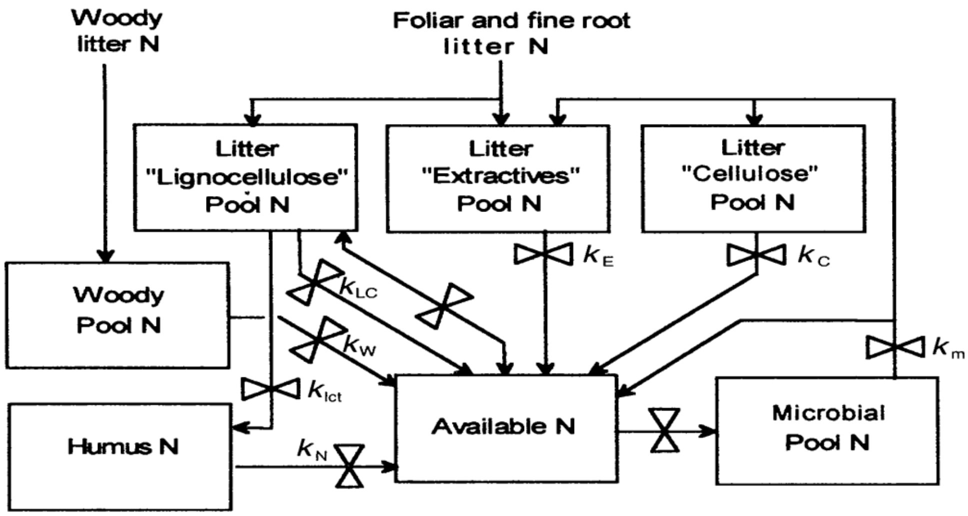

Figure 2.7 Pools and transfers of nitrogen in the DOCDOM model.

GENDEC

The GENDEC (Moorhead and Reynolds, 1991) model also addresses soil C and N pools, by way of 5 parallel C and N pools (Figure 2.8 and 2.9): labile (C1), holocellulose (C2), decay-resistant matter (C3), and dead (C5) and live microbial (C5) biomass pools. The output from each C pool is, once again, set to be proportional to the size of that pool, with rate coefficients adjusted according to soil moisture, soil temperature, and N limitation status. The output from pools C1 to C4 is partitioned into microbial growth and respiration.

In this model, the N dynamics are directly linked to the C dynamics by setting the relative rate of change of each N pool equal to each corresponding C pool, with a prescribed C/N ratio as proportionality coefficient, as follows from C1 to C5: 5/1, 1000/1, 19/1, 9/1, and 9/1. Special provisions are made to absorb N when microbial growth is N limited: any N surplus from internal or external sources is then used for microbial growth. The temperature sensitivity follows the expression

$$\log_{10}S(T) = [(T-25)/10] \log_{10}(Q_{10}) \qquad [2\text{-}7]$$

where S(T) is the multiplier for the rate coefficient, such that S(T) = 1 at 25C, T is temperature, and Q_{10} is the rate of increase for a 10 ºC difference.

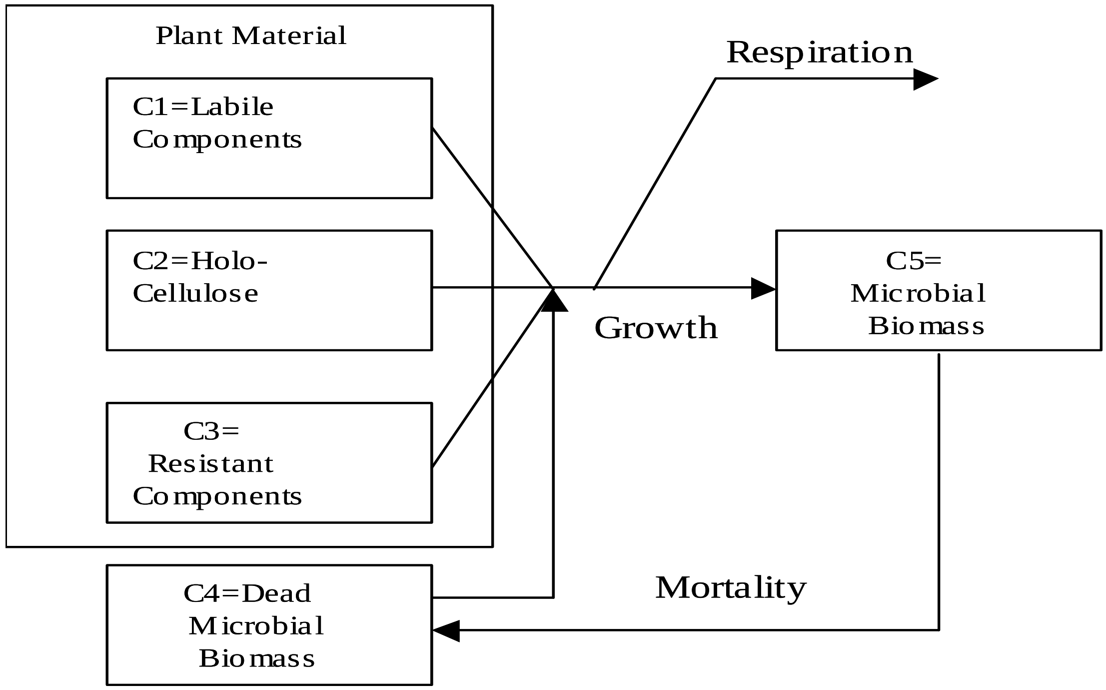

Figure 2.8 The carbon decomposition flow chart of GENDEC model.

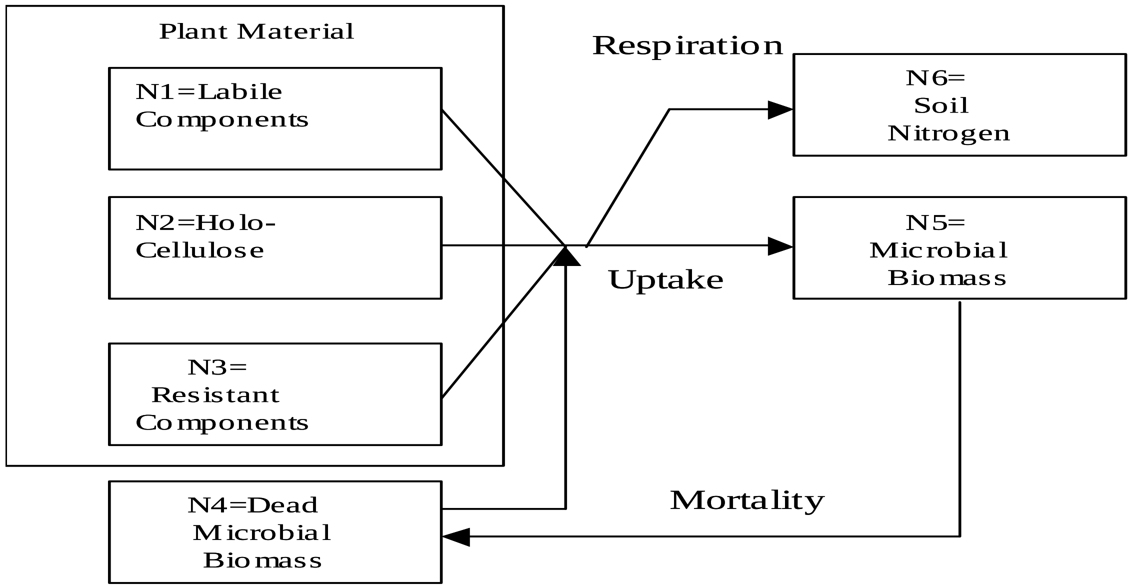

Figure 2.9 The nitrogen decomposition flow chart of GENDEC model

MBL_GEN

The litter decomposition component of the MBL_GEN (Rastetter et al., 1991) model is similar to the GENDEC model in structure. The C and N dynamics are again linked through adherence of prescribed and pool-dependent C/N ratios. The model however, does no address any microbial pools explicitly. The model provides for N absorption in response to external N sources (Figure 2.10).

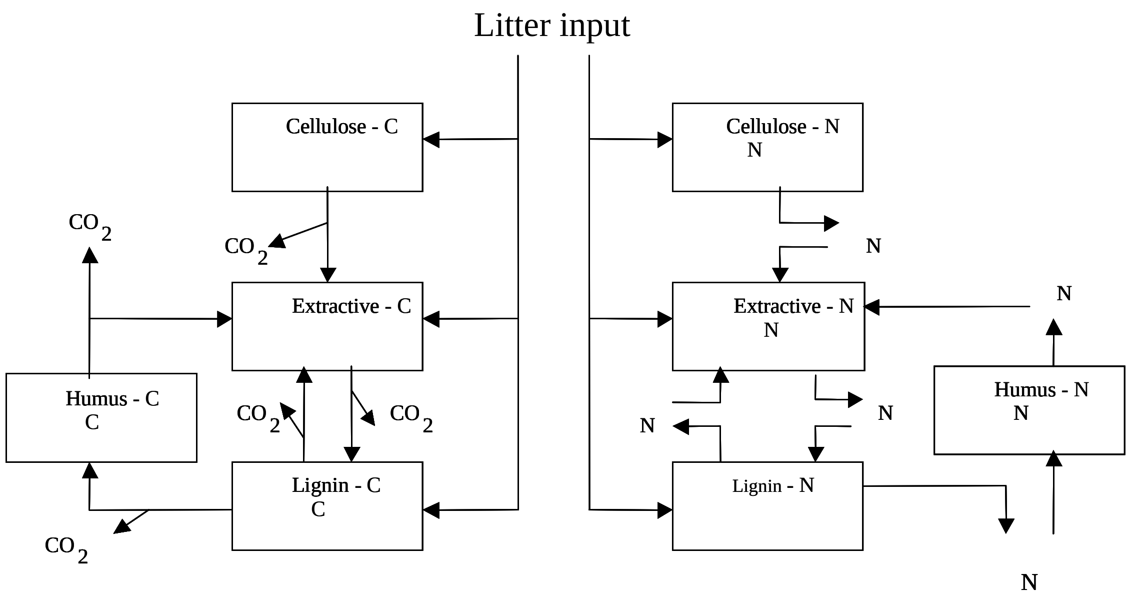

Figure 2.10 The Carbon decomposition and nitrogen mineralization flow chart of MBL-GEN model

CBM-CFS

Dead organic matter decomposition (DOM) in the CBM-CFS model (Kurz and Apps, 1999) is represented in Figure 2.11. DOM build-up and decomposition is addressed by considering 4 pools: a very fast, a fast, a medium and a slow pool. The slow pool refers to humus. 17 % of the combined litter contributions are transferred to the slow DOM pool and the rest enters the atmosphere as CO_2. In time, slow DOM accumulations are also transferred to the atmosphere in the same way. Transfer of organic matter to aquatic environments is considered negligible.

Rate of C release from each pool is modified regionally according to the local mean annual air temperature, by setting

$$k(T) = k(T_0) \exp[0.1 (MAT\text{-}T_0) \ln(Q_{10})], \quad [2.8]$$

where

T_0 is a reference temperature (= 10ºC),

MAT is mean annual temperature, and

Q_{10} = 2 (i.e., the CO_2 release rate from the decomposing litter is expected to double with an average annual increase of 10ºC). This formula makes no provision regarding change in litter decomposition with regional changes in soil moisture (dry to moist to wet), and extent of soil frost. The model allows for temporarily increased soil temperature following forest disturbances such as forest fire and harvesting.

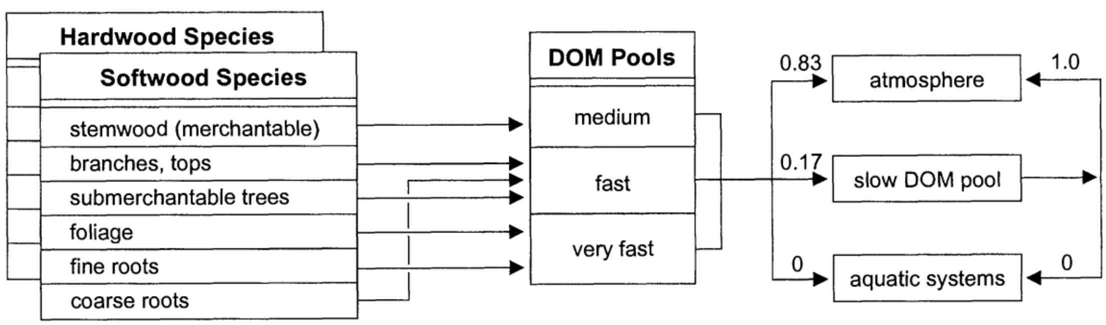

Figure 2.11 Dead organic matter decomposition process in the CBM-CFS model.

The DOM decomposition model in the CBM-CFS model has not been verified.

2.3 MODELS BASED ON THE CIDET DATA

The **Yasso** model was used to examine the leaf-litter portion of the CIDET data (Palosuo et al., 2003). The Yasso model addresses 5 litter pools: soluble, holocellulose, and lignin-like compounds and 2 humus pools (Figure 2.12). The driving force of this model is mean annual temperature, growing season temperature and potential evapotranspiration. The r^2 for mass remaining, actual and predicted, is 0.66 for the first year, and 0.45 for the sixth year.

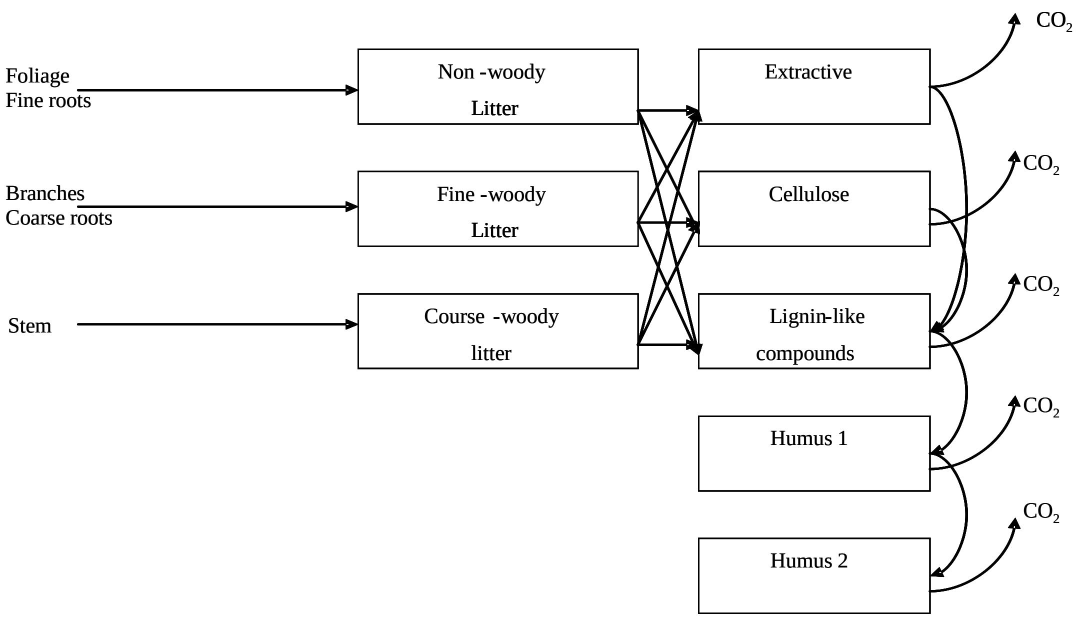

Figure 2.12 Flow chart of the Yasso soil carbon model (Palosuo et al., 2003).

Trofymow et al. (2002) simulated organic matter decomposition based on the 3-compartment exponential decay model:

$$\text{mass remaining} = A \exp(-kt). \qquad [2\text{-}9]$$

where A is the initial mass per compartment, and k is the rate of decay parameter per compartment. This parameter was found to depend on the chemical content of the litter, and on climate, respectively. The r^2 =0.75-0.76 for 7 variable models and r^2 =0.77-0.78 for 9 variable models.

2.4 SYNTHESIS

Organic matter decomposition is a microbial process. The model that appears to be most explicit in this regard is the GENDEC model, which allows for microbial biomass, growth and mortality simulations. The other models assume microbial involvement implicitly through provision of microbial biomass pools with a prescribed C/N ratio of 8 or so (DOCDEM, CANDY, and CENTURY). In SOMM and ROMUL, C/N ratios are mainly used to restrain or direct microbial action: microbial biomass itself is considered negligible.

The number and types of pools used for quantifying litter decay vary with each model. In many cases, distinctions are made among the pools based on functionality, as in CENTURY, with metabolic, active, slow, passive pools; as in SOMM with litter, fermentation, and humus pools; and as in CANDY, with new additions, biologically active, soil organic matter pools. In other cases, distinctions among the pools are made based on structure, as in MBL-GEM with cellulose, extractives, lignin, humus pools, or on a structure-function combinations, as in DOCDOM, with woody, litter lingo-cellulose, cellulose, extractive, microbial pools, and as in GENDEC, with labile, holocellulose, resistant, dead and live microbial pools.

Generally, the rate of decomposition is found to depend on substrate type and weather or climate (i.e., varying soil moisture and temperature conditions). Models also vary in terms of proposed mechanisms to address the transfer of litter mass and N into CO_2, humus and soil N. Typically, the rules used to decide which pools and flows to address, and how to connect these pools and flows, are based on simple suppositions about the microbial litter-to-humus conversion. These suppositions refer to:

- simple first-order kinetics where the rate of decay and transfers from one pool to another are assumed to be proportional to the size of the decaying pool; and
- N transfers which are assumed to be directly proportional to the associated C transfers, with prescribed C/N ratios of the decaying pool being the proportionality coefficients.

Adjustments to the latter supposition are made in terms of allowing N adsorption to occur when excess N becomes available for the microbially active pools, especially when the rate of microbial growth is calculated to be N limited (e.g., GENDEC).

Given the variety and approaches used to model the rate of decay process, several questions come to mind:

1. Which model structure would actually be the most appropriate for assessing the overall forest decomposition process?
2. What level of complexity, or simplicity, would actually be most suited for which particular modeling purpose?
3. How good are the *a priori* determinations (deduced independently from controlled laboratory and field studies) in the context of widely changing and heterogeneous conditions for soil, substrates, and decay organisms?

These questions are important because the type and number of C and N pools and processes to be included in the model formulation are based on a varying combination of theoretical and empirical considerations. In many cases, some of the addressed pools are not easily separable or measurable because of fuzzy overlap and permeation, e.g., humified organic matter within non-humified matter; dead within life microbial biomass, etc. Pool separation and quantification is usually restricted to structural and non-structural pools, e.g., cellulose, lignin, extractives, especially at the initial litter stage. Follow-up studies on the changing composition of the litter as it decays are rare, and are also fairly complex. For example, there are likely considerable differences in the rate of decay according to litter piece size and related variations with respect to incubation times, especially in reference to coarse woody debris, with twigs, branches, logs, or roots of varying diameter. In contrast, leaf litter appears to be sufficiently similar in terms of its general decay dynamics because of its generally open, porous and its already germ-permeated condition at the time of litter fall.

In this thesis, a simple process-based model is developed, tested and calibrated in the context of the above considerations, as follows:

1. The model is structural in the sense that organic matter decays in parallel fashion from three pools: a fast, slow and very slow pool. Originally, conversion processes from the fast to the slow, and from the slow to the very slow pools were also part of the formulation. That part of the formulation, however, was discarded because the data did not permit a quantification of these conversion rates other than setting them

equal to 0. This, in turn, implied that there would be no significant net transfers from one pool to the other. Any such transfers would have likely been lost as CO_2 over the course of each year. In addition, this also implied that there would not be a significantly-sized intermediate microbial pool. This, in turn, affirmed the supposition of the SOMM and ROMUL models, i.e., the actual size of the microbial pool should be negligible in relation to the other pools.

2. Instead of prescribing the rate of N mineralization to be in step with the biomass rate of decay based on a prescribed C/N ratio expectation for each pool, the model does not assume a fixed C/N ratio, but examines N release and retention as a variable concept, with only one condition: that the C/N ratio in the very slow litter pool approaches a final yet-to-be determined number. A steadily increasing N concentration in the decaying litter is an immediate result of this formulation, because the relative turnover rate for N is slower than the relative turn-over rate for C (keeping the C/N ratio constant implies no change in N concentration).
3. Typically, the rate of decay in forest litter bags depends on three factors: initial size of pools, pool type, and environment. Environmental factors, in turn, are determined by climate (or weather), chemical inputs (such as nutrients) from various sources (atmosphere, surrounding substrates). In each of the above models, and the model of this Thesis, environmental factors contribute to the multiplicative formulation of the decay process. Pool type influences the basic rate of decay coefficient.
4. Model initialization, or the specification of the initial pool sizes, is generally an *a priori* process if pool sizes are directly measurable. When they are not, model initialization becomes part of model calibration. Non-measurable components refer to

“fermented”, “humified”, “dead” or “live” microbial, “passive”, “active”, “fast”, “slow”, or “very slow” pools. The approach taken up in this Thesis is to relate the fuzzy “fast”, “slow”, or “very slow” terms to the actual initial composition of the CIDET litterbags, as already reported in the literature.

The general intent of this thesis is to model

the rate of decay and N mineralization as affected by changing conditions in climate and substrates, from uplands to wetlands, from arctic climates to temperate climates, from dry to wet climates, from tree leaf litter to grass and fern litter.

The ensuing analysis therefore focuses on semi-empirically formulating those mechanisms that control the rate of decay, as affected by season, substrate type on which the litter bags are placed, and initial chemical composition. This analysis is only about the rate of decay in litter bags, and therefore does not deal with annual litter inputs, nutrient uptake, and nutrient cycling in general. The main and eventual purpose of this analysis is to develop a submodel that can be used to realistically simulate the build-up of organic matter and N in forest litter layers in forests from temperate to arctic environments, in response to annual leaf litter additions and other inputs.

The performances of the CANDY, CENTURY and SOMM and a number of other similar models were evaluated with long-term soil organic matter data (% values of organic matter content in mineral soils), collected over the course of 29 to 139 years, from 7 intensively studied forest or farm research locations in 5 countries (Smith et al., 1997; Table 2.1). The suite of statistical methods in this evaluation included:

1. Estimates for the total difference between the simulated and measured values were calculated by root mean square error RMSE, given by

$$RMSE = \frac{100}{\bar{O}} \sqrt{\sum_{i=1}^{n} (P_i - O_i)^2 / n}\,, \qquad [2\text{-}10]$$

2. Estimates for the modeling efficiency

$$EF = \frac{(\sum_{i=1}^{n} O_i - \bar{O})^2 - \sum_{i=1}^{n} (P_i - O_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2} \qquad [2\text{-}11]$$

If EF >0, the simulated values describe the trend in the measured data better than the mean of the observations. If EF<0, the simulated values describe the data less well than a mean of the observations.

3. Estimates for the total difference between simulations and measurements were calculated by relative errors (RE) and mean (ME) errors, given by

$$RE = \frac{100}{n} \sum_{i=1}^{n} (P_i - O_i) / O_i \quad \text{and} \qquad [2\text{-}12]$$

$$ME = \sum_{i=1}^{n} (P_i - O_i) / n\,, \qquad [2\text{-}13]$$

4. Estimates if the simulated values follow the same pattern as measured values was calculated by the correlation coefficient between the actual and simulated values, given by

$$r = \frac{\sum_{i=1}^{n} O_i - \bar{O})\ (P_i - O_i)}{\sqrt{\sum_{i=1}^{n} (O_i - \bar{O})^2 \sum_{i=1}^{n} (P_i - O_i)^2}} \qquad [2\text{-}14]$$

In this formulation, *O* refers to actual and *P* refers to simulated values. The bar over *O* and *P* refers to the average value; n is number of data used for model calibration and verification.

Table 2.1 Location of research stations and soil treatments used for model performance evaluations in Smith et al., 1997.

Experiment	Country	Land-use	Crop/plant cover and treatments	Duration years
Bad Lauchstädt	Germany	Arable	Sugar beet-spring barley-potatoes-winter wheat with: (1) organic manure plus NPK fertilizer; (2) no fertilizer	93
Rothamsted Park	UK	Grassland	Permanent grassland with: (1) no fertilizer; (2) organic manure (1905 onwards)	139
Rothamsted Wilderness	UK	Woodland	Naturally regenerated woodland with no fertilization	112
Prague -Ruzyn	Czech Republic	Arable	Sugar beet, spring wheat since 1966 with: (1) organic manure plus inorganic fertilizer; (2) no fertilizer	40
Tamworth	Australia	Arable	(1) Lucerne/clover and cereal with urea or superphosphate; (2) Fallow /cereal with urea or superphosphate	29
Waite	Australia	Arable	(1) Wheat-fallow with superpbosphate; (2) Wheat-oats-pasture fallow with superphosphate	70
Calhoun Exp. Forest	USA	Forestry	Planted loblolly pine, no fertilization	38

The entries in Table 2.2 below are useful for focusing on the RMSE, EF, ME model performance results for CANDY, CENTURY, and SOMM as listed in Smith et al.

(1997) for those locations and treatments for which there were sufficient data for model testing. In comparison, these results indicate a fairly good performance of the CANDY and CENTURY models to simulate soil organic matter concentrations. These results, however, were achieved through calibrating these two models for each treatment and location. In contrast, no calibration was done with SOMM. Hence, for the prediction purposes, SOMM appears to be fairly reliable by location and treatment, with the worst SOMM-EF performance of -60 for the no fertilization treatment at the Calhoun Exp. Forest, and the best SOMM-EF performance of 0.5 at Rothamsted Geeschroft.

Table 2.2 Statistical performance results of the CANDY, CENTURY and SOMM models based on the long-term soil organic matter studies listed in Table 2.1.

		CANDY			CENTURY			SOMM		
Location and Treatment	n	RMSE,%	EF	ME	RMSE,%	EF	ME	RMSE,%	EF	ME
Bad Lauchstiidt										
No Fertilization	7	5	-0.5	3	5	-0.5	0	20	-23	-13
Fertilization	7	6	-0.1	1	5	0.1	-2	14	-5.5	11
Calhoun Experimental Forest										
No Fertilization	8	4	0	1	6	-0.1	1	13	-60	23
Organic Manure	4	7	0.3	2	7	0.3	-1	13	-1.5	9
Prague-Ruzyne										
No Fertilization	21	5	0	0.5	6	-1	0.1	5	0	-0.1
High Fertilization	21	11	-0.75	-8	7.5	0.1	-4	7.5	0	-5
Tamworth										
Fallow Rotation	2	6.2	-0.2	-0.75	5.8	0	0	9	-2	1.75
Lucerne/Clover Rotation	18	5	0.1	-0.3	6	-0.2	0.6	17.5	-13	4
Rothamsted Geescroft	18				11	0.8	2	8	0.5	0.5
Waite										
Wheat-fallow	4	5	1	-0.1	5	1	-0.1	35	-11	-10
wheat-oats-pasture fallow	4	14	-0.3	-3	14.5	-0.3	4	14	-0.2	-4
Average	10.4	6.8	-0.05	-0.5	7.16	0.02	0.05	14.18	-10.5	1.56

In the context of this Thesis, it should be remembered that the above comparisons are for predicting and testing soil organic matter concentrations as these vary from year-to-year as a result of new seasonal inputs, and new and old decay throughout the years. The work of this thesis simply deals with the decay in forest litter bags, with no seasonal additions into the bags, at least not by design. It is hoped, however, that this thesis leads to an improved parameterization of the rate of decay process of forest litter, so that the rate of litter decomposition can be predicted across a wide climate range (temporal to boreal) and simple qualifiers regarding local litter composition. If this can be achieved, then it would become possible to use the following formulation as part of the litter decomposition algorithms in new and old soil organic matter prediction models.

CHAPTER 3 REVIEW OF CIDET

3.1 INTRODUCTION

The CIDET project is a cooperative study with the objectives:

- to study the impact of climate and microclimate on the rates of litter decomposition and nutrient mineralization at all of the ecoclimate provinces in Canada.
- to study the patterns of litter decomposition and nutrient mineralization on a long-term range.
- to examine the impact of substrate on litter decomposition.
- to test specific hypotheses on the litter decay.

Decomposition and N accumulation was hypothesized to occur as follows:

- There would be three fractions: fast, slow, and metastable.
- It would not be possible to address details about the fast decomposition process because of the coarseness of the annual litterbag retrieval rate.
- Initial mass loss and N accumulation of the fast and slow fractions would be determined by climate and initial litter decomposition.
- The rate of mass loss variations of the metastable fraction would mainly due to climate variations.
- There would be microclimate variations due to local changes in soil moisture and temperature.

- The initial rate of mass loss should increase as N exogenous to the litterbags is absorbed.
- The meta-stable phase would not start to decompose until the lignin-to-cellulose ratio exceeds 0.5.

3.2 DISTRIBUTION OF THE CIDET SITES

Based on the idea that the litter decomposition is determined by climate (site), litter type, and time, twenty-one sites (18 uplands, 3 wetlands) close to climate stations and roads were chosen in 1991, to represent the major ecoclimate regions of Canada (Figure 3.1): 7 sites would be located in the boreal region, 6 would be in the cordilleran region, 4 would be in the subarctic region, 2 would be in the temperate region, and 2 would be in the transitional forest-grassland region. In the boreal and temperate regions, most of the upland sites would be podzols; in the cordilleran region, two sites would be podzols, two would be brunisols, and one would be a luvisol; in the subarctic region, the upland sites would represent a cryosol, a gleysol and a brunisol (Table 3.1 and Table 3.2).

3.3 SPECIES SELECTION AND LITTERBAG FIELD LAYOUT

Ten "standard" litterbags involving 10 foliage types (including needles, broadleaves, grasses, ferns), representing the major species of Canada (Table 3.3). All of the fresh litter was collected in 1991. All litter was air- or oven-dried at 40^{o}C to prevent decay, was cleaned by removing branches and other materials, and then thoroughly mixed. A portion of this litter was used to determine the chemical composition of the litter.

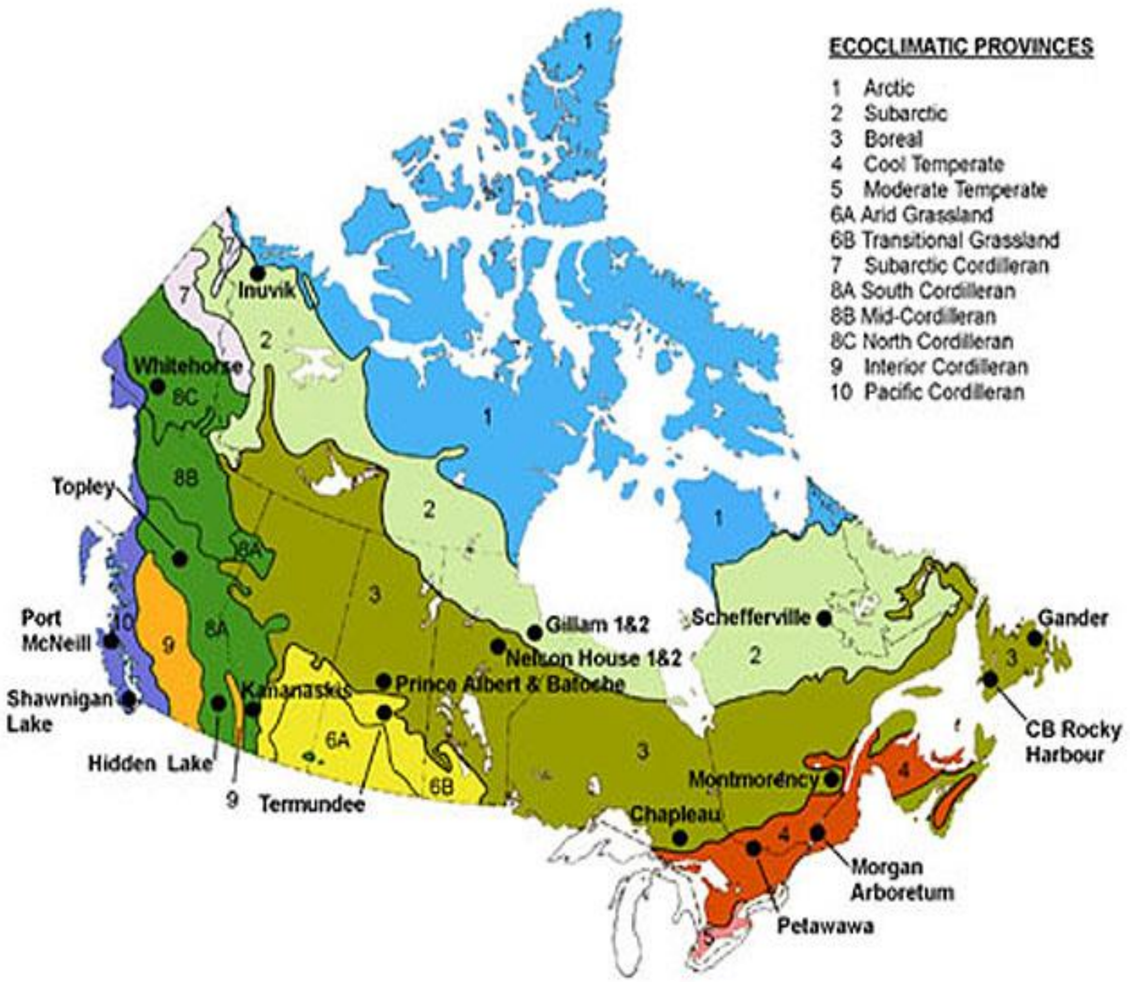

Figure 3.1 Locations of the 18 upland forest sites and their distributions within the ecoclimatic provinces of Canada (Ecoregions Working Group and Canadian Committee on Ecological Land Classification, 1989, Trofymow et al., 2002).

Bag construction followed the U.S. experiment (Long-term Intersite Decomposition Experiment Team (LIDET, 1995) with some modifications. All litterbags were made from a woven polypropylene pool cover/shade cloth fabric with 0.25 x 0.5 mm openings. The bags were 20 x 20 cm in size and filled with approximately 10 g air-dry weight of leaves or needles. Each bag was identified with a unique number and weight, total initial air-dry weight, adjusted oven-dry weight, species, and site replicate number for each litter.

Table 3.1 Site location information (Trofymow and the CIDET Working Group1998)

ECOCLIMR	Site Name	SITE	UW	Prov	Latitude	Longitude
Boreal_Northern_Cordilleran	Whitehorse	WHI	u	YT	60°51'N	135°12'W
Boreal_Southern_Cordilleran	Topley	TOP	u	BC	54°36'N	126°18'W
Coastal_South_Pacific_Cordilleran	Shawnigan LK	SHL	u	BC	48°38'N	123°42'W
High_Subarctic	Inuvik	INU	u	NT	68°19'N	133°32'W
Humid_High_Cool_Temperate	Petawawa	PET	u	ON	45°55'N	77°35'W
Humid_Low_Boreal	Chapleau	CHA	u	ON	47°38'N	83°14'W
Humid_Mid-Cool_Temperate	Morgan Arb	MAR	u	PQ	45°25'N	73°57'W
Low_Subarctic	Gillam	GI1	u	MB	56°19'N	94°51'W
	Gillam	GI2	w	MB	56°19'N	94°51'W
	Schefferville	SCH	u	PQ	54°52'N	66°39'W
Maritime_Low_Boreal	CB_Rocky_Harbour	CBR	u	NF	49°32'N	57°50'W
Maritime_Mid-Boreal	Gander	GAN	u	NF	48°55'N	54°34'W
Maritime_South_Pacific_Cordilleran	Port McNeill	PMC	u	BC	50°36'N	127°20'W
Moist_Montane_Southern_Cordilleran	Hidden Lake	HID	u	BC	50°33'N	118°50'W
Montane_Southern_Cordilleran	Kananaskis	KAN	u	AB	51°00'N	115°00'W
Perhumid_Low_Boreal	Montmorency	MON	u	PQ	47°19'N	71°8'W
Subhumid_High_Boreal	Nelson House	NH1	u	MB	55°55'N	98°37'W
	Nelson House	NH2	w	MB	55°55'N	98°37'W
Subhumid_Low_Boreal	Prince Albert	PAL	u	SK	53°13'N	105°58'W
Transitional_Grassland	Batoche	BAT	w	SK	52°43'N	106°7'W
	Termundee	TER	u	SK	51°50'N	104°55'W

UW—Upland or wetland

The layout of litterbags followed the following design: Four separate 5 x 11 m plots were selected within a minimum stand area of 4 ha and at least 30 m from any stand boundary. Plots were at least 20 m apart from each other (e.g. Figure 3.2a). Each set of bags to be collected in a given year was connected by a 4 m string, and each string was labeled with a unique number. These sets of bags were laid out to trees and approximately 1 m apart in a random order in parallel lines. The bags were no closer than 50 cm to trees. Four replicates of the same string were made for collection of each year.

The location and number of each string of bags were noted on the sketch map for each plot (Figure 3.2b). Litter bags were placed organic layers or moss surface (avoiding visible rocks and logs). The buried wood blocks were inserted into the upper mineral soil at a depth of 10–30 cm (Figure 3.2c). The opposite diagonal corners of the bags were pinned to the ground on those sites where herb or grass growth in subsequent seasons may push up the bags.

3.4 SITE CONDITIONS

Climate data obtained for each CIDET site referred to average January temperature, average July temperature, annual average temperature and annual total precipitation. These data were obtained from weather stations nearest to each CIDET site (Table 3.4). Sites with highest precipitation and temperature occurred near the westerncoast, while sites with lowest precipitation occurred in the sub arctic and transitional grassland region (Table 3.5). Information about topography (elevation, aspect, slope, and surface topography), soils (types, forest floor thickness, soil depth, soil pH, cations and macronutrients) and vegetation types (vegetation cover, species, density and height and age of trees) are summarized in Table 3.6, Table 3.7 and Table 3.8.

Table 3.2 Distribution CIDET site in Soil and Ecological Classes (Trofymow and the CIDET Working Group, 1998).

ECOCLIMATE REGION	SITE CODE	SOIL CLASS	HOLDRIGE LIFEZONE CLASSIFICATION
Boreal_Northern_Cordilleran	WHI	Orthic_Eutric_Brunisol	Cool_Temperate_Subalpine_Moist_Forest/(Dry_Scrub)
Boreal_Southern_Cordilleran	TOP	Hemimor/Orthic_Gray_Luvisol	Cool_Temperate_Subalpine_Moist_Forest
Coastal_South_Pacific_Cordilleran	SHL	Orthic_Drystic_Brunisol	Cool_Temperate_Wet_Forest
High_Subarctic	INU	Cryic_Gleysol	Boreal_Moist_Forest
Humid_High_Cool_Temperate	*PET*	*Humo-Ferric_Podzol*	*Cool_Temperate_Moist_Forest*
Humid_Low_Boreal	CHA	Orthic_Drystic_Brunisol	Cool_Temperate_Subalpine_Wet_Forest
Humid_Mid-Cool_Temperate	MAR	Orthic_Ferro-Humic_Podzol	Cool_Temperate_Moist_Forest
Low_Subarctic	GI1	Brunisolic_Static_Cryosol	Boreal_Moist/Wet_Forest
	GI2	Typic_Fibrisol	Boreal_Moist/Wet_Forest
	SCH	Gleyed_Dystric_Brunisol	Cool_Temperate_Subalpine_Rain_Tundra/Wet_Forest
Maritime_Low_Boreal	*CBR*	*Podzol/(Gleysol)*	*Cool_Temperate_Subalpine_Wet_Forest*
Maritime_Mid-Boreal	GAN	Gleyed_Ferro-Humic_Podzol	Cool_Temperate_Subalpine_Wet_Forest
Maritime_South_Pacific_Cordilleran	PMC	Humo-Ferric_Podzol	Cool_Temperate_Wet_Forest
Moist_Montane_Southern_Cordilleran	HID	Orthic_Humo-Ferric_Podzol	Cool_Temperate_Moist_Forest
Montane_Southern_Cordilleran	KAN	Orthic_Eutric_Brunisol	Warm_Temperate_Subalpine_Wet_Forest
Perhumid_Low_Boreal	*MON*	*Orthic_Ferro-Humic_Podzol*	*Cool_Temperate_Subalpine_Rain_Forest*
Subhumid_High_Boreal	NH1	Orthic_Dystric_Brunisol	Cool_Temperate_Subalpine_Moist/Wet_Forest
	NH2	Typic_Fibrisol	Cool_Temperate_Subalpine_Moist/Wet_Forest
Subhumid_Low_Boreal	PAL	Orthic_Regosol	Cool_Temperate_Moist_Forest
Transitional_Grassland	*BAT*	*Limno_Mesisol*	*Cool_Temperate_Steppe*
	TER	Chernozem/Gleysol	Cool_Temperate_Steppe

Table 3.3 Species code, species binomial, common name, place of collection, (Trofymow and the CIDET Working Group, 1998)

Species binomial	Common name	Place of collection
Pseudotsuga Menziesii	Douglas Fir	Shawnigan Lk BC
Larix Laricina	Tamarack	Batoche SK
Pinus Banksiana	Jack Pine	Petawawa ON
Picea Mariana	Black Spruce s	Batoche SK
Thuja Plicata	Western Redcedar	Maple Ridge UBC Res For BC
Fagus Grandifolia	American Beech	Morgan Arb St-Anne-Bellevue PQ
Betula Papyrifera	White Birch	Badger NF
Populus Tremuloides	Trembling Aspen	Kananaskis Valley AB
Pteridium Aquilinum	Bracken Fern	Petawawa ON
Festuca Hallii	Plains Rough Fescue	Termundee SK

3.5 CHEMICAL ELEMENTS CHARACTERIZATION

Chemical elements of litters were analyzed using three methods: total elemental analysis, wet chemical proximate analysis, and ^{13}C CPMAS NMR analysis of C fractions. Elemental analyses were done to determine total N, C, and S by combustion, and to determine total P through wet oxidation and using a Technicon Autoanalyzer. Total Ca, Mg, and K levels were determined by atomic absorption spectroscopy. Proximate chemical analyses were used to determine levels of:

1. non-polar extractables (soluble fats, waxes, and oils) with dicholormethane (Tappi, 1976),
2. water-soluble extractables (i.e., simple sugars, water-soluble phenolics) with hot water (Tappi, 1981),

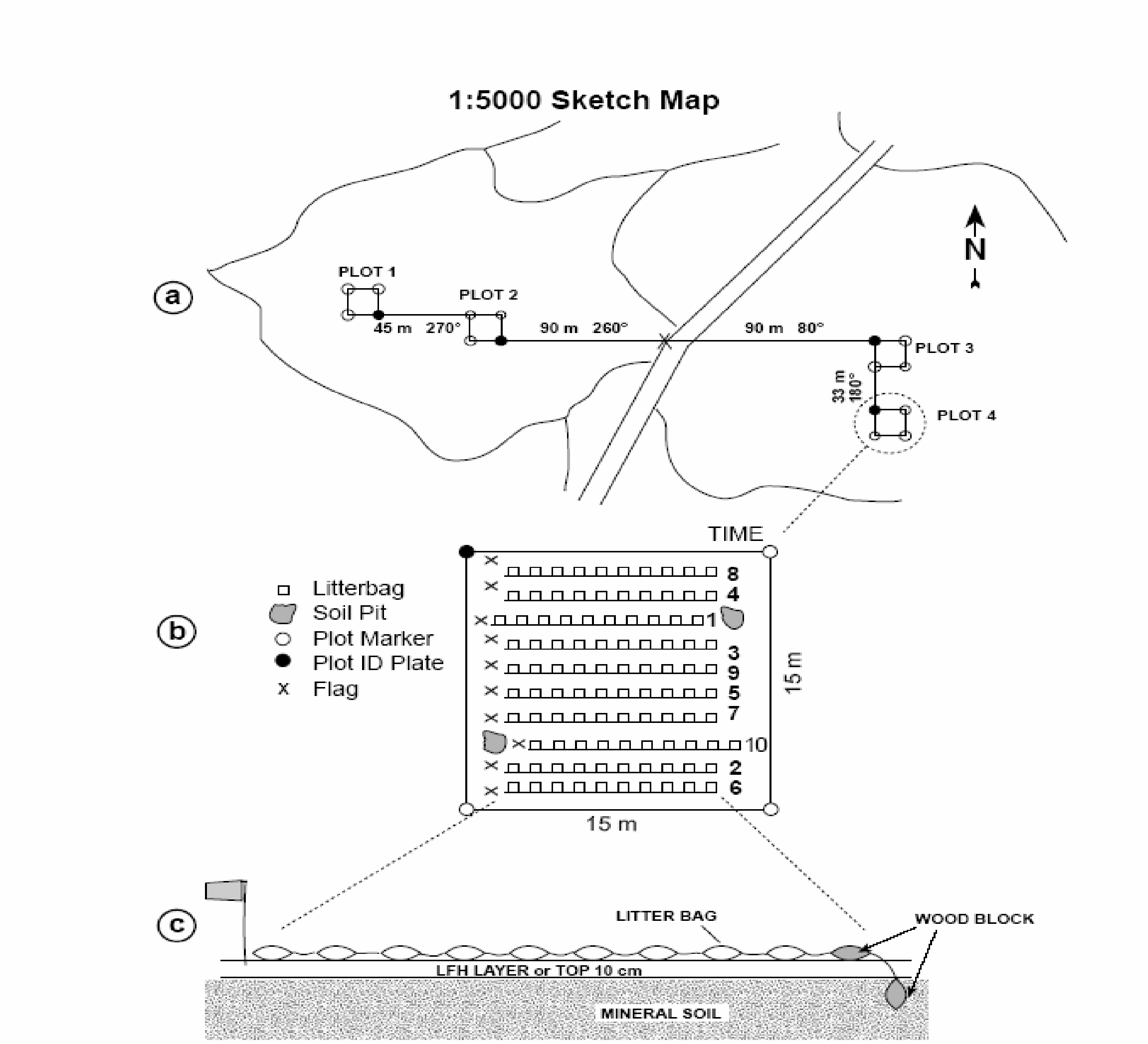

Figure 3.2 The sketch map of the location of CIDET sites. (a), grid plot of litterbag layout (b), and arrangement of litterbag strings (c); (Long-term Intersite Decomposition Experiment Team (LIDET), 1995; Troyfymow and CIDET Working Group, 1998).

3. acid soluble carbohydrates (i.e., cellulose and hemicellulose) by way of sulfuric acid hydrolysis,
4. the remaining mass of acid-insoluble residue, and the ash content by ashing portions of the litter samples with a muffle furnace set at 450° C for eight hours.

Solid-state ^{13}C CPMAS NMR was used to characterize the chemical composition of the litter in terms of the following groups: alkyl groups (representing fats and waxes) at 0–50 ppm; methoxyl groups (representing side chains of lignin and tannin) at 50–60 ppm, O-alkyl groups (representing cellulose and sugars) at 60–92 ppm, aromatic groups (confirming presence and amounts of lignin and tannin) at 92–140 ppm, phenolic groups (also representing lignin and tannin) at 140–163 ppm, and carboxylic groups (representing hemicelluose and amino acids) at 163–185 ppm. The elemental and proximate chemical analysis results are shown in Table 3.9.

The litter bags and wood blocks were collected annually each fall, from 1993 onward. The litterbags were air- or oven-dried (55°C) to stabilize the samples, and to prevent further microbial growth. Buried wood blocks were rinsed with distilled water to remove adhering soil. Mosses, lichens, fine roots, or other plant parts growing into the bags were removed before drying. The four replicates of the litterbags were mixed to yield one composite sample for each litter type for each site. Every composite sample was analyzed for total C, total N, total P and total S using combustion and wet chemical methods as described above.

Table 3.4 Correspondence of CIDET sites and AES Weather Stations. (Trofymow and the CIDET Working Group, 1998).

SITE	UW	SITENAME	LAD	LAM	LOD	LOM	ELEV	WSTNNUM	WEATHSTN	WLAT	WLONG	WELEV
BAT	w	Batoche	52	43	106	7	472	4056240	Prince_Albert_Airport	53.13	105.41	428
CBR	u	CB_Rocky_Harbour	49	32	57	50	50	8403096	Rocky_Harbour	49.35	57.54	40
CBR	u	CB_Rocky_Harbour	49	32	57	50	50	8403097	Rocky_Harbour	49.34	57.55	40
CHA	u	Chapleau	47	38	83	14	460	6061361	Chapleau_Airport	47.49	83.21	446
GAN	u	Gander	48	55	54	34	115	8401700	Gander_Int'l_Airport	48.57	54.34	151
GI1	u	Gillam_1	56	19	94	51	140	5061001	Gillam_Airport	56.21	94.42	145
GI2	w	Gillam_2	56	19	94	30	125	5061001	Gillam_Airport	56.21	94.42	145
HID	u	Hidden_Lake	50	33	118	50	650	1164730	Lumby_Sigalet_Rd	50.22	118.46	560
HID	u	Hidden_Lake	50	33	118	50	650	1160483	Armstrong_Hullcar	50.3	119.13	505
HID	u	Hidden_Lake	50	33	118	50	650	1169729	Lumby	50.23	118.95	500
INU	u	Inuvik	68	19	133	32	73	2202570	Inuvik_Airport	68.18	133.29	68
KAN	u	Kananaskis	51	0	115	0	1530	3053600	Kananaskis	51.02	115.02	1391
MAR	u	Morgan_Arboretum	45	25	73	57	48	7025250	Montreal/Dorval_Int_A	45.28	73.45	31
MAR	u	Morgan_Arboretum	45	25	73	57	48	7027280	Ste_Genevieve	45.3	73.51	23
MON	u	Montmorency	47	19	71	8	670	7042388	Foret_Montmorency	47.19	71.09	790
NH1	u	Nelson_House1	55	55	98	37	288	5062922	Thompson_Airport	55.48	97.52	215
NH2	w	Nelson_House2	55	55	98	25	260	5062922	Thompson_Airport	55.48	97.52	215
PAL	u	Prince_Albert	53	13	105	58	476	4056240	Prince_Albert_Airport	53.13	105.41	428
PET	u	Petawawa	45	55	77	35	173	6106400	Petawawa_Nat_Forestry	46	77.26	168
PET	u	Petawawa	45	55	77	35	173	610FC98	Petawawa_Hoffman	45.53	77.15	153
PMC	u	Port_McNeill	50	36	127	20	100	1026270	Port_Hardy_Airport	50.41	127.22	22
SCH	u	Schefferville	54	52	66	39	500	7117825	Schefferville_Airport	54.48	66.49	522
SCH	u	Schefferville	54	52	66	39	500	7093GJ3	La_Grande_IV_A	53.45	73.4	306
SCH	u	Schefferville	54	52	66	39	500	8504175	Wabush_Lake_A	52.56	66.52	551
SHL	u	Shawnigan_lake	48	38	123	42	355	1017230	Shawnigan_Lake	48.39	123.37	137
TER	u	Termundee	51	50	104	55	537	4057180	Saskatoon_SRC	52.09	106.36	497
TER	u	Termundee	51	50	104	55	537	4057202	Saskatoon_Water_TP	52.07	106.41	483
TOP	u	Topley	54	36	126	18	1100	1078209	Topley_Landing	54.49	126.1	722
WHI	u	Whitehorse	60	51	135	12	667	2101300	Whitehorse_Airport	60.43	135.04	703

Table 3.5 Site climate information (Trofymow and the CIDET Working Group, 1998).

ECOCLIMR	SITE	JANUARY	JULY	AVERAGE	TOTP
Boreal_Northern_Cordilleran	WHI	-20.7	14.1	-1.2	261.2
Boreal_Southern_Cordilleran	TOP	-12.3	14.1	2.5	512.9
Coastal_South_Pacific_Cordilleran	SHL	1.8	17.1	9.3	1215.3
High_Subarctic	INU	-29.6	13.6	-9.8	266.1
Humid_High_Cool_Temperate	PET	-12.9	16.6	4.3	821.7
Humid_Low_Boreal	CHA	-16.9	16.8	1.1	834
Humid_Mid-Cool_Temperate	MAR	-10.6	21	6.1	863.3
Low_Subarctic	GI1	-28	15	-5.2	484.8
	GI2	-28	15	-5.2	484.8
	SCH	-22.8	12.6	-4.8	768.7
Maritime_Low_Boreal	CBR	-5.7	15.7	4.2	1199.7
Maritime_Mid-Boreal	GAN	-6.2	16.5	4.3	1130.1
Maritime_South_Pacific_Cordilleran	PMC	2.4	13.6	7.9	1782.8
Moist_Montane_Southern_Cordilleran	HID	-5.7	18.1	6.3	547.4
Montane_Southern_Cordilleran	KAN	-10.2	14.1	2.8	657.4
Perhumid_Low_Boreal	MON	-14.7	12.6	0.6	1494.2
Subhumid_High_Boreal	NH1	-26.6	15.6	-3.9	542.4
	NH2	-26.6	15.6	-3.9	542.4
Subhumid_Low_Boreal	PAL	-21.5	17.4	0.1	398.4
Transitional_Grassland	BAT	-21.5	17.4	0.1	398.4
	TER	-19.1	18.4	1.8	370.5

Note: TOTP---total precipitation in one year

Table 3.6 Microtopography information of the sites (Trofymow and the CIDET Working Group, 1998)

ECOCLIMR	SITE	UW	Altitude(m)	ASP	SLOP	ELEV	MAC	MES	SURF	MIC
Boreal_Northern_Cordilleran	WHI	u	667	185	2	667	f	g	c	a
Boreal_Southern_Cordilleran	TOP	u	1100	315	7	1100	f	e	c	a
Coastal_South_Pacific_Cordilleran	SHL	u	355	360	5	355	d	c	b	b
High_Subarctic	INU	u	73	220	5	73	e	d	c	f
Humid_High_Cool_Temperate	*PET*	*u*	173	*-1*	*0*	*173*	*g*	*g*	*c*	*a*
Humid_Low_Boreal	CHA	u	460	-1	0	460	g	g	c	b
Humid_Mid-Cool_Temperate	MAR	u	48	-1	0	48	a	a	b	c
Low_Subarctic	GI1	u	140	90	1	140	g	g	c	e
	GI2	w	125	-1	0	125	g	g	c	d
	SCH	u	500	-1	0	500	a	g	c	c
Maritime_Low_Boreal	*CBR*	*u*	50	*270*	*41*	*50*	*d*	*c*	*c*	*d*
Maritime_Mid-Boreal	GAN	u	115	215	10	115	d	c	c	cd
Maritime_South_Pacific_Cordillera	PMC	u	100	-1	3.5	100	g	g	c	e
Moist_Montane_Southern_Cordille	HID	u	650	-1	0	650	e	e	c	b
Montane_Southern_Cordilleran	KAN	u	1530	80	0	1530	d	g	c	c
Perhumid_Low_Boreal	*MON*	*u*	670	*232*	*8*	*670*	*e*	*c*	*a*	*b*
Subhumid_High_Boreal	NH1	u	280	5	5	288	g	g	c	a
	NH2	w	260	-1	0	260	g	g	c	c
Subhumid_Low_Boreal	PAL	u	476	90	5	476	g	c	c	a
Transitional_Grassland	*BAT*	*w*	472	*40*	*20*	*472*	*g*	*d*	*c*	*c*
	TER	u	536.5	152.5	3.25	537	g	d	c	b

Table 3.7 Basic mensuration data of CIDET sites, (Trofymow and the CIDET Working Group, 1998).

ECOCLIMR	SITE	UW	SPEC1	MDENSITY	BAREA	MDBH	MHEIGHT	MAXHEIGH	MAGE
Boreal_Northern_Cordilleran	WHI	u	Pinucont	1198	17.9	12	10.3	20.2	103
Boreal_Southern_Cordilleran	TOP	u	Pinucont	634	27.4	23.5	21.8	28	5
Coastal_South_Pacific_Cordilleran	SHL	u	Pseumenz	2080	48.6	16.4	18.2	23.5	42
High_Subarctic	INU	u	Picemari	3300	3.5	3.8	3.1	8	160
Humid_High_Cool_Temperate	PET	u	Pinubank	1370	17.5	16.9	13.7	19	53
Humid_Low_Boreal	CHA	u	Pinubank	1902	41.9	16.1	15.8	21	70
Humid_Mid-Cool_Temperate	MAR	u	Fagugran	256	26	33.5	25	34	150
Low_Subarctic	GI1	u	Picemari	5055	12.1	7.3	5.8	9.8	94
	GI2	w	no_trees	.	.	.	.	.	.
	SCH	u	Picemari	614	99.8	12.2	6.8	10.6	78
Maritime_Low_Boreal	CBR	u	Abiebals	6271	18.2	5.3	9	11.8	36
Maritime_Mid-Boreal	GAN	u	Picemari	6914	63.2	10	10.6	13.8	85
Maritime_South_Pacific_Cordilleran	PMC	u	Tsughete	484	86.9	40	42.5	137.1	85
Moist_Montane_Southern_Cordilleran	HID	u	Tsughete	600	45.1	26	18.1	28.8	101
Montane_Southern_Cordilleran	KAN	u	Pinucont	1716	30.5	14.4	15	.	90
Perhumid_Low_Boreal	MON	u	Abiebals	3549	60.5	14.3	8.9	13.8	39
Subhumid_High_Boreal	NH1	u	Pinubank	2477	14.9	9.9	10.1	13.4	60
	NH2	w	no_trees	.	.	.	.	.	.
	PAL	u	Pinubank	966	14.1	15.2	12	14.6	65
Transitional_Grassland	BAT	w	no_trees	.	.	.	.	.	.
	TER	u	Poputrem	5659	35	8.5	8.7	11.6	37

Note: The italic regions are not incuded in this study

Table 3.8 Forest floor and soil information of CIDET sites (Trofymow and the CIDET Working Group, 1998).

ECOCLIMR	SITE	UW	HORIZON	LFHDEPTH	MCPCT	MNPCT	MPPCT	MCAPPM	MMGPPM	MNAPPM	MKPPM	MCECCMKG
Boreal_Northern_Cordilleran	WHI	u	LFq	5	33.03	1.1513	0.1369	3901.3	447.13	12.7	224.88	44.96
Boreal_Southern_Cordilleran	TOP	u	LF	8	39.65	1.0538	0.156	2315	364.63	8.17	300.75	23.48
Coastal_South_Pacific_Cordilleran	SHL	u	LFH	5.1	41.24	0.845	0.1181	4313.3	365.33	18.65	462.73	38.71
High_Subarctic	INU	u	O	6.1	41.69	0.9752	0.1511	2000	478.63	29.13	222.25	38.58
Humid_High_Cool_Temperate	PET	u	LFH	5.5	41.88	1.2175	0.1019	2868.6	327.47	64.25	709.47	30.75
Humid_Low_Boreal	CHA	u	LFH	8.5	35.72	1.0238	0.086	1072.5	151.38	7.38	248.25	19.81
Humid_Mid-Cool_Temperate	MAR	u	LFH	4.6	31.59	1.1331	0.0802	1715.6	210.21	15.2	239.45	25.24
Low_Subarctic	GI1	u	H	.	34.09	1.1025	0.078	10000	1298	5	46	144.75
	GI2	w	Of	10	42.05	1.035	0.0644	3359.4	425	133.98	211.88	16.95
	SCH	u	LFH	4.3	36.64	0.7594	0.0788	198.8	107.13	1.88	152.88	12.1
Maritime_Low_Boreal	CBR	u	LFH	8.2	43.2	1.2038	0.1067	2148.8	436.88	54.69	212.5	39.11
Maritime_Mid-Boreal	GAN	u	LFH	9.5	45.77	0.7369	0.0675	634.4	257.88	4.38	175.44	25.4
Maritime_South_Pacific_Cordilleran	PMC	u	LF	9.3	46.99	1.1156	0.0655	748.4	298.25	35.13	134	30.79
Moist_Montane_Southern_Cordilleran	HID	u	LFH	11	38.76	1.1213	0.0977	3945	332.13	51.36	341	49.39
Montane_Southern_Cordilleran	KAN	u	LFH	6	38.3	1.1625	0.1035	3610	442.75	8.29	309.63	49.8
Perhumid_Low_Boreal	MON	u	H	2.3	41.95	0.8944	0.15	476.3	102.25	26	155	23.25
Subhumid_High_Boreal	NH1	u	LF	1	30.66	0.5265	0.057	780	103.6	8.8	149.3	22.08
	NH2	w	Of	10	43.37	0.8531	0.1054	3013.1	809.5	10.38	617.13	45.33
	PAL	u	LFH	2.5	28.12	0.5955	0.0572	2259	315.9	31.69	157	26.71
Transitional_Grassland	BAT	w	LF(H)	10	24.35	0.8063	0.069	6302.5	1051.25	65.88	164.5	48.91
	TER	u	LFH	5.8	15.04	0.9038	0.0968	3785	818.5	33.34	267.13	45.88

Table 3.9 Chemical elements information of each CIDET species (Trofymow and the CIDET Working Group, 1998)

TYPE	COMMON	C	N	P	S	Ca	Mg	K	NPEA	WSEA	ACIDA	LIGA
ASPEN	Trembling Aspen	468	6.7	1.3	1.6	20.5	1.6	12.3	87.5	354.2	337	144
BEECH	American Beech	470	7.1	0.4	2.0	9.9	2.5	0.8	72.5	129.0	453	280
BRFERN	Bracken Fern	463	8.8	0.7	1.2	7.7	3.1	4.3	22.6	90.4	491	329
BSPRUCE	Black Spruce	495	7.3	0.8	2.8	6.6	0.9	2.2	109.2	198.5	370	283
DFIR	Douglas Fir	496	7.0	1.1	2.7	12.8	1.1	1.6	102.7	114.8	416	303
FESCUE	Plains Rough Fescue	438	7.1	0.6	1.5	3.7	1.3	5.0	90.6	128.6	585	112
JPINE	Jack Pine	497	12.8	1.3	1.4	45.5	1.2	2.7	69.7	152.4	424	328
TAMM	Tamarack	488	5.9	0.2	3.2	6.6	2.5	3.1	93.5	311.0	301	240
WBIRCH	White Birch	480	7.2	0.4	1.0	8.5	2.4	2.6	65.2	359.4	303	240
WRCEDAR	Red Cedar	497	6.4	0.5	1.2	16.8	0.9	1.1	107.2	105.1	365	356

Table 3.9 Chemical elements information of each CIDET species (continued) (Trofymow and the CIDET Working Group, 1998).

TYPE	COMMON	ASH	ALKY	METH	OALK	DIOAL	AROM
ASPEN	Trembling Aspen	83.8	106.9	6.8	197	57.3	34.2
BEECH	American Beech	70.5	73.6	14.9	229	55.9	45.3
BRFERN	Bracken Fern	72.1	52.2	16.3	252	56.9	34.8
BSPRUCE	Black Spruce	41.6	112.8	9.9	218	48.4	51.4
DFIR	Douglas Fir	67.4	115.2	7.6	224	43.1	46.7
FESCUE	Plains Rough Fescue	92.2	38.6	7.0	281	63.5	22.5
JPINE	Jack Pine	26.5	116.4	11.0	223	52.2	42.9
TAMM	Tamarack	58.9	77.3	8.5	211	80.6	38.9
WBIRCH	White Birch	33.8	124.0	11.6	210	56.3	34.1
WRCEDAR	Red Cedar	72.0	133.1	10.3	203	54.8	35.2

CHAPTER 4 MODEL DESCRIPTION

4.1 INTRODUCTION

Development and application of mathematical models provide a framework to test hypotheses, integrate experimental results, capture the system characteristics, investigate the system configuration, project the future from the past, understand the relationships among different components of the complex study object and replicate the processes under the influence of environmental factors (Tiktak and Vangrinsven, 1995). The model represented below is based on an earlier 3-compartment model suggestion (Long-term Intersite Decomposition Experiment Team (LIDET), 1995; Minderman, 2005;Parton et al., 1987; Paul and Voroney, 1980) that net annual changes in mass and nutrient contents in forest litterbags can be described as the sum of exponential decay of each of three theoretical compartments (Figure 4.1). These compartments represent:

- a fast decomposing fraction, representing the easily metabolized and solubilized components of fresh litter, such as sugar, soluble organic acid, proteins, and other metabolically active organic and mineral substances;
- a slowly decomposing fraction, which would mainly be composed of cellulose, hemicellulose and other structure-supporting materials of organic and mineral origin;

- a very slow (metastable) fraction, mainly consisting of humifying organic matter, and fairly insoluble inorganic debris.

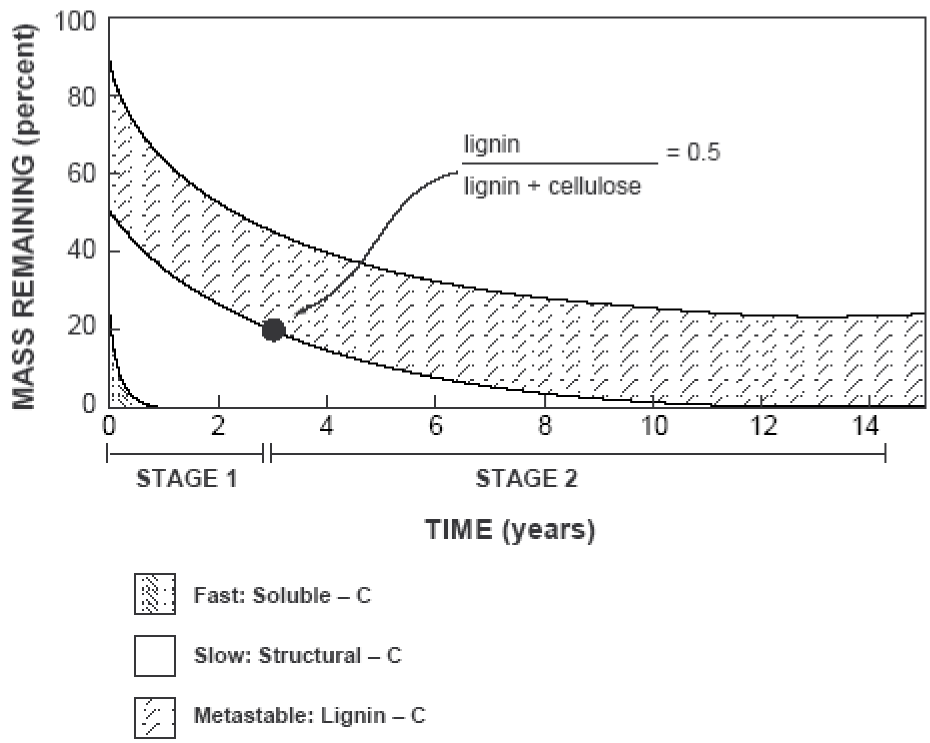

Figure 4.1 The three phases and two stages of fine litter decomposition (LIDET, 1995).

A state-dependent first-order kinetic expression for this 3-compartment model is given by:

$dM_i(t)/dt = -k_i(S)\,M_i(t)$ [4-1]

and

$M(t) = M_1(t) + M_2(t) + M_3(t)$ [4-2]

is the total mass remaining at any time t, and where:

i = 1, 2, 3 denotes the fast, slow and very slow compartments, respectively;

$M_i(t)$ is the mass remaining in the ith compartment at time t;

$k_i(S)$ is the substrate independent but climate dependent part of the rate of change function for the ith compartment; and S refers to the state of the litterbag, as defined by litter type, nutrient content, moisture content, and temperature.

For the N content of the litterbags, it is hypothesized that the rate of change of N_i, in analogy to M_i, is proportional to N_i, i.e.,

$$dN_i(t)/dt = -n_i(S)\ N_i(t) \qquad [4\text{-}3]$$

where $n_i(S)$ is the time-independent but state-dependent part of the net N mineralization process. It is further specified that

$$[N(t)] = \{[N_1(t)]\ M_1 + [N_2(t)]\ M_2 + [N_3(t)]\ M_3\} / M(t) \qquad [4\text{-}4]$$

is the total N concentration in the litterbag at any time t, and

$$[N_i(t)] = N_i(t)/M_i(t)$$

$[N_i(t)]$ are the N concentrations of each compartment.

For the purpose of model initialization, it is set:

$$M_1(t=0) = M(t=0)\ g \qquad [4\text{-}5]$$

$$M_2(t=0) = M(t=0)\ (1 - g)\ e \qquad [4\text{-}6]$$

$$M_3(t=0) = M(t=0)\ (1 - g)\ (1 - e) \qquad [4\text{-}7]$$

where g and e are the partitioning coefficients, i.e., g is the fraction of the fast-decomposing component of the litter, and e sets the proportion between the slow and the very slow decomposing fraction.

As decomposition proceeds, it is needed to ensure that the C/N ratio of the calculated mass remaining inside in litterbags will approach a C/N ratio that is normal for well-humified forest litter, i.e., CN_{final}. Hence,

$$dM_1(t)/dt = - k_1(S)\ M_1(t) \qquad [4\text{-}8]$$

$$dM_2(t)/dt = - k_2(S)\ M_2(t) \qquad [4\text{-}9]$$

$$dM_3(t)/dt = - k_3(S)\ M_3(t)\ \{1 - OM_C\ CN_{final}\ [N_3(t)]\ (1- n_3(S)/k_3(S))\} \qquad [4\text{-}10]$$

where OM_C is a parameter that converts carbon mass into litter mass.

For the rate of N mineralization, it is set

$N_1(t=0) = N(t=0)\ g$,

$N_2(t=0) = e\ N(t=0)\ (1-g)$,

$N_3(t=0) = (1-e)\ N(t=0)\ (1-g)$,

thereby assuming that N(t) is portioned in the same way as M(t), and it is set

$$dN_1(t)/dt = - n_1(S)\ N_1(t) = n_1(S) / k_1(S)\ [N_1(t)]\ dM_1(t)/dt \qquad [4\text{-}11]$$

$$dN_2(t)/dt = - n_2(S)\ N_2(t) = n_2(S) / k_2(S)\ [N_2(t)]\ dM_2(t)/dt \qquad [4\text{-}12]$$

$$dN_3(t)/dt = - n_3(S)\ N_3(t) = n_3(S) / k_3(S)\ [N_3(t)]\ dM_3(t)/dt$$
$$/ [1 - OM_C\ CN_{final}\ [N_3](t)\ (1- n_3(S)/k_3(S))\ ] \qquad [4\text{-}13]$$

In this formulation, the rate of N loss is not only directly proportional to the amount of N in the litterbag, but also directly proportional to the rate of mass loss. This implies that when the relative mass and N losses are equal [i.e., when $n_i(S) = k_i(S)$, i.e., $dM_i(t)/M_i(t) = dN_i(t)/N_i$], N concentration would generally remain unchanged. When $n_i(S) < k_i(S)$, litterbags would be more conservative with respect to N_i loss than to M_i loss, and N_i concentrations would therefore increase over time, as reported by Berg et al. (1999). The opposite occurs when $n_i(S) > k_i(S)$.

The model requires explicit expressions for $k_i(S)$ and $n_i(S)$. In this, it is assumed that the rate parameters for litter decomposition and N mineralization are primarily independent of mass and nitrogen remaining in each compartment, but are affected by local substrate and climate conditions. It is assumed that local climate conditions more or less dictate the rate of microbial activity regardless of microbial community type. Certainly, there is little microbial activity when the litter is frozen. As the temperature increases, microbial activities become more and more active, depending on the prevailing soil moisture conditions, from dry to wet, with moist conditions being optimal. It is therefore set

$$k_i(S) = k_i\ f(\text{climate}) \text{ and } n_i(S) = n_i\ k_i(S) = n_i\ k_i\ f(\text{climate}) \qquad [4\text{-}14]$$

where f(climate) is the climate dependent part of $k_i(S)$ and $n_i(S)$, and k_i and n_i are simple proportionality coefficients. With this, it is assumed that:

- both $k_i(S)$ and $n_i(S)$ relate to changes in climate in the same way,
- $n_i(S)$ is proportional to $k_i(S)$,
- k_i and n_i are climate-independent but litter-specific rate constants.

The f(climate) is formulated such that this function reflects expected regional changes in soil moisture (from dry to wet, and from unfrozen to frozen), and in soil temperature as follows:

$$f(\text{climate}) = \{ [\min(1, ppt / p1) + T_{Jan} / p2] \exp[-(Ea/R) (1/ (T_{July}+273)-1/288)] \} \quad [4\text{-}15]$$

where p1 and p2 are parameters, Ea is activation energy of the overall decay process, and R is the universal gas constant (= 8.31 J $mole^{-1}$ C^{-1}). In this, annual precipitation (ppt, in mm) and mean January air temperature (T_{Jan}, in ^{o}C) are used to capture the effect of frost and of low soil moisture content on the annual rate of decomposition, as affected by precipitation and extent of soil frost at each site. It is assumed that rate of decay will not be affected by high rates of precipitation once these rates exceed a certain threshold when soil moisture contents are sufficiently high. In Equation [4-14], this threshold is denoted by p1. An exception to this may occur when annual precipitation inputs are very high, i.e., in excess of 2000 mm (Schuur, 2001). The exponential term in this equation is intended to capture the effect of soil temperature on the rate of decomposition, with mean July temperature (T_{July}, in ^{o}C) as a surrogate variable for the soil temperature. Therefore, f(climate) is set to become 1 when: ppt = p1, T_{Jan} = 0 ^{o}C, and T_{July} = 15 ^{o}C. For a recent discussion about general trends, see Prescott et al. (2004).

The long-term implication of the above formulation is such that, as t approaches infinity:

- dM(t) / dN(t) and M(t)/ N(t) approach CN_{final} , and
- both N(t) and M(t) approach 0.

For the fast and slow fractions (i = 1 and 2), the half-lives for mass remaining are given by

$$t_{i,1/2} = - \ln(0.5) / [k_i \, f(\text{climate})]. \qquad [4\text{-}16]$$

For the very slow fraction, the half-life is given by

$$t_{3,1/2} = - \ln(0.5) /\{ k_3 \, f(\text{climate}) \, [1 - OM_C \, CN_{final} \, [N_3](t) \;\; (1- n_3/k_3)] \} \qquad [4\text{-}17]$$

Hence, $t_{3,1/2}$ changes not only with climate condition and litter type, but also with time towards the final value given by

$$t_{3,1/2} = - \ln(0.5) /[n_3 \, f(\text{climate})]. \qquad [4\text{-}18]$$

The above model formulation implies that the N mineralization process is gradually becoming the rate-limiting component of the overall litter decomposition process.

Since the amount of N remaining in the litterbags is coupled to the remaining mass, it is instructive to follow the changes in the C/N ratio of the decomposing litter over time by litter type and location. In the model, this ratio is calculated by setting

$$[C/N](t) = C(t)/N(t) =[M(t)/ OM_C]/ N(t) \qquad [4\text{-}19]$$

All of the above assumes that there would be no exogenous N absorption within the litterbags.

A diagrammatic view of the model, as realized in Stella (1998), is presented in Figure 4.2. Here, boxes refer to the mass and N reservoirs, broad arrows represent annual losses from these reservoirs, and light arrows show logical connections, such as:

- the influence of the decomposition rate and N mineralization, by compartment, and
- the combining of the mass and nitrogen reservoirs to compute total mass and nitrogen remaining as the sum of each of these reservoirs, by litter type, and by site.

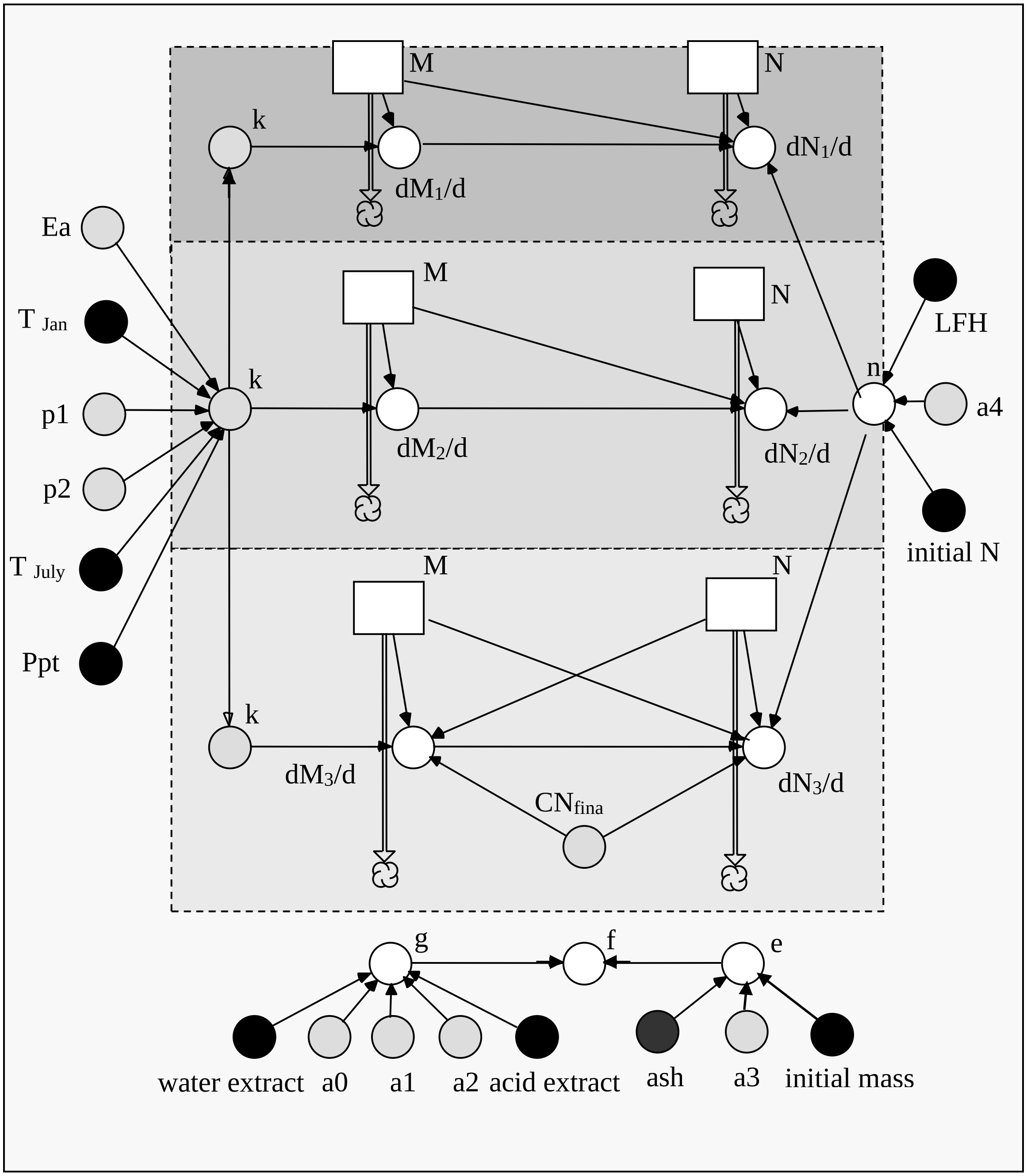

Figure 4.2 Overview of the 3-compartment model designed to evaluate mass loss and N concentrations in CIDET litterbags and wooden blocks. Square represents mass and N pools within each compartment. Broad arrows denote input or output of mass or N from pools. Circles refer to entry points for specific information dealing with model control, such as specification of the rate equations and the required parameter values. Model tracks pool sizes over time, starting from initial values.

CHAPTER 5 MODEL CALIBRATION

5.1 INTRODUCTION

The objective of the Chapter is to summarize the steps that are needed for detailed CIDET model calibrations. A compilation of the CIDET experimental design, methods and data essential to consider in terms of model initialization and calibration has already been presented in Chapter 3 by way of Tables 3.1 to Table 3.9.

5.2 MODEL OPTIMIZATION

In principle, there is no way to determine any of the above model parameters and their associated functions *a priori*. Furthermore, $M_i(t)$ and $N_i(t)$ are not easily quantified by way of actual measurements due to the fuzziness of the 3-compartment concept, and the chemical and biological uncertainties that are associated with specifying actual fast, slow, and very slow fractions. Nevertheless, model calibrations can be done by comparing model output with actual M(t), [N](t), C(t) and [C/N](t) values over time, by litter type, and by climate condition. To do this, the following two steps are adopted to match model output with field determined values. The main idea of the Step 1 process is to generate a model that can be used to predict how the weather influences litter decomposition, the partition of the total litter into the fast, slow and very slow pools, and the rate of litter decomposition among the three pools and if there is litter transferring from the fast pool to the slow pool and from the slow pool to the very slow pool with each specific litter type only. The main idea of the Step 2 process is to establish the relationship between the litter chemical elements and the initial weight of each fast, slow and very slow pool and calibrate the parameters of the whole model across the litter types and sites.

STEP 1

Parameters p_1, p_2, Ea, and CN_{final} were assumed to be common across litter type, site and compartment. The k_i parameters were assumed to be constant across litter type and site, but were expected to vary by compartment such that $k_1 > k_2 > k_3$, by definition. Parameters n_i, e, and g, were also kept constant across site, but were considered to be litter-specific. The litter-specific OM_c parameter was obtained from the Table 3.9 entries, by noting that

$$OM_c = (1.49 +/- 0.09) + (0.0088+/-0.0002) \text{ acid\_extractable\_fraction } (\%) +$$

$$(0.0060+/- \ 0.0001) \text{ water\_extractable\_fraction } (\%),\ r^2 = 0.76 \qquad [5\text{-}1]$$

Based on these specifications, 57 parameters remained unknown: 30 (3 compartments * 10 litter types) for n_i, 10 each for e and g, plus k_i, p_1, p_2, Ea, and CN_{final}. To further reduce the number of unknown parameters, the patterns of similarity for n_i across the 3 compartments are searched for by way of preliminary Step-1 optimizations. The following was found:

- N losses from the fast and slow fractions were both found to have the same mineralization rate such that $n_1(S) = n_2(S) = n_2\,k_2(S)$;
- N losses from N2 and N3 were found to have the same N retention rate $n_2 = n_3$, hence $n_2\,(S) = n_2\,k_2(S)$ and $n_3\,(S) = n_2\,k_3\,(S)$.

This implied that parameters n_1 and n_3 could simply be derived from n_2, thereby reducing the number of Step-1 adjustable parameters to 37.

STEP 2

The resulting Step-1 parameters were re-evaluated, and how the values for n_i, e and g relate to differences by litter type were examined, based on the initial litter composition, as displayed in Table 3.9, and by substrate type, as displayed in Table 3.8. During this process, variables and equations were identified through regression analysis, for the purpose of:

- further decreasing the overall number of adjustable parameters needed to represent the inherent variability of M(t), N(t) and [C/N](t) ;
- interpreting the rate of mass loss and N mineralization in the litterbags in an ecologically meaningful way, in the context of litter chemical element type, changing climate and changing forest floor conditions.

The numerical phase of optimization process was done by re-formulating the model as Step-1 and Step-2 models within the (ModelMaker, 1999) modeling framework, and by using the built-in least-squares fitting routines (Simplex and Marquardt) for parameter optimization and for statistical reporting. The total sample size for each of the M(t), N(t), and [C/N](t) analyses was 1470 (= 21 sites x 10 litter types x 7 collection years), with one composite litter sample from each site. Obvious outliers (i.e., a sudden and one-time spikes or drops in mass or N concentration) were replaced by linear interpolation between the values of the preceding and the following year. Since M(t) values ranged from about 0.1 to 10 g, N(t) values ranged from 0.5% to 2.5%, and [C/N](t) values ranged from about 15 to 100, the default weighting was changed for optimizing the [C/N](t) values from 0.15 to 1. Doing so gave top priority to the least-squares fitting of M(t), and roughly equal secondary priority to the least-squares fitting of the [N](t) and [C/N](t). All values were subject to least-squares fitting at the same time.

5.3 STEP-1 CALIBRATION RESULT

Preliminary calculations with 37 adjustable parameters revealed that the [N(t)] fit could be further generalized across sites by setting:

$$n_2 = n_a \, LFH\_C\,(\%)\, N\,(t{=}0) \,/\, M\,(t{=}0) \qquad [5\text{-}2]$$

where n_a is a parameter, dependent on litter type but independent of climate; LFH_C (%) is the C content of the forest floor substrate on which the bags were placed. This formulation implies that litterbags would lose slightly more N to surrounding LFH substrates with high rather than low %C values.

The resulting best-fitted Step-1 values for k_1, k_2, k_3, n_a, p_1, p_2, Ea, e, g, and CN_{final} are listed in Table 5.1 (top part). These results indicate that the Step-1 calibration was quite effective in capturing the substrate- and climate-related variations of the CIDET data, with r^2 = 0.93 for M(t), r^2 = 0.84 for [N(t)], and r^2 = 0.83 for the [C/N](t) values. This was further coupled with a fairly low error of estimate for all the best-fitted parameter values, with average error estimates at

9.6% for e (range (5.3% to 17.2%);

6.3% for g (range 0% to 13.4%);

12.2% for n_a (range 6.6% to 24.1%);

10.3%, 5.8%, and 9.5% for k_1, k_2 and k_3, respectively;

14.8 % for CN_{final}; and

2.5%, 1.4%, and 3.7% for the climate-related p1, p2, and Ea parameters.

Due to the unavoidable propagation of error, r^2 values for [N(t)] and [C(t)/N(t)] were generally lower than for M(t). Failure in correctly fitting the M(t) values invariably compromised the fitting of the [N(t)] and [C(t)/N(t)] values.

The inclusion of the LFH_C (%) term in Equation [5-2] improved the [N](t) fit by increasing r^2 from 0.78 to 0.84. Using C/N values instead of LFH_C (%) values also brought an improvement, but only from r^2 = 0.78 to 0.81.

Shown in Table 5.2 are details about the best-fitted residuals, as calculated by species type (top), and by site (bottom). These residuals generally clustered about 0 within the standard deviations of the residuals. For the M(t) residuals by species, all residuals were insignificantly different from 0, with p(ME=0)>0.247. For [N(t)] residuals by species, 3 of the 10 entries remained insignificantly different from 0, while the others showed a small negative bias, meaning that the model would slightly under-predict the actual [N](t) values. For the [C/N](t) residuals by species, 8 of the 10 entries had a small positive bias. For the M(t) and [N(t)] residuals by site, about 1/3 of the residuals remained insignificantly different from 0. For [C/N](t) residuals by site, 18 of the 21 entries had a small positive bias.

Note that the presence or absence of a bias depends in part on the SD precision of the calculations: larger SD values led to a lower incidence of bias, as shown by the Western red cedar entries. In general, the Step-1 results suggest that the species-specific model calculations were generally consistent with the M(t), [N(t)], and [C/N](t) data at any CIDET site.

5.4 STEP-2 CALIBRATION RESULT

Examining the e and g results in Table 5.1 in relation to the initial litter composition by litter type (Table 3.9) produced:

- an equation for determining the initial fraction of the fast decomposing litter:

$$g = \exp[\, a0 + a1 \text{ acid\_extractable\_fraction } (\%) + a2 \text{ water\_extractable\_fraction } (\%)], \text{ and} \qquad [5\text{-}3]$$

- an equation for determining the proportion between the slow and very slow fraction:

$$e = \exp\{- a3\, [ash(t=0)]\} \qquad [5\text{-}4]$$

where [ash(t=0)] is the initial ash fraction (in %), and a0, a1, a2, and a3 are regression coefficients. Determining these coefficients and re-determining all the other parameters again, led to the results listed in the bottom part of Table 5.1. These results revealed that:

- the values for g (fast-decomposing fraction) and for OM_c (organic matter per carbon) both increase with increasing water- and acid-extractable components of the litter mass;
- the numbers for g in Table 5.1 imply that White birch and Trembling aspen have the most mass in the fast fraction, while litter from Western red cedar and Douglas fir has the least mass (0) in this fraction (Figure 5.1).

The positive number for a3 in Equation [5-4] implies that increasing ash content would decrease the mass in the slow fraction, and increase the mass in the very slow fraction. Therefore, Plains rough fescue, White birch and Black spruce have the least, and Western red cedar and American beech have the highest amount of mass in very slow fraction (Figure5.1, Table 5.1).

Larger positive numbers for n_a in Equation [5-1] imply faster rates of N mineralization relative to mass remaining. For any given n_a value, calculated N mineralization rates further depend on the initial N concentration in the litterbag, and also on the C concentration of the soil next to the litterbags. In particular, N mineralization rates (relative to mass loss from the slow fraction) were calculated to be slowest for American beech and Tamarack, but highest for Jack pine, Black spruce, and Plains rough fescue (Figure 5.1). As a result, N concentrations in the slowly decomposing American beech and Tamarack litter were observed and calculated to increase at a rate similar to that of the other faster decomposing litter types.

A visual presentation of the goodness-of-fit achieved after the Step-2 calibration for M(t), [N(t)], and [C/N](t) is provided in Figures 5.2 to 5.4 for White birch, American beech, Black spruce, and Plains rough fescue, respectively. In general, the Step-2 model calculated M(t), [N](t), and [C/N](t) with an ME of 0.67 g, 0.20%, and 7.7, respectively (Table 5.1).

The Step-2 model also captured the overall M(t), [N(t) and [C/N](t) variations by litter type and location fairly consistently, as indicated by the residual plots of Figure 5.5, and by the best-fitted r^2 values and associated mean errors in Table 5.3. As with the Step-1 calculations, r^2 values for [N(t)] and [C/N](t) were lower than for M(t), due to the unavoidable propagation of error. The changes in the N concentrations were least well captured at the PMC, SHL and TER sites. For the three wetlands (BAT, GL2, NH2), best-fitted N concentrations were generally slightly below actual values. This indicated that the N mineralization rates of the litterbags were lower on the wetland sites than the upland sites. In contrast, there were no consistent M(t) differences between the upland and wetland litterbags: ME<0 at BAT, and ME>0 at GL1 and GL2.

In all cases, absolute ME values were less than the associated standard deviation values of error (SD), as shown in Table 5.3 by species, and by site. This Table shows

Table 5.1 CIDET litterbag analysis: parametric values, and goodness-of-fit descriptors for the Srtep-1 and Step-2 calculations.

Step-1 results	Litter-type specific parameters						Parameters held in common				Goodness of fit			
	e		g		n_a							M(t)	[N(t)]	[C/N](t)
Litter type	estimate	+/- error	estimate	+/- error	estimate	+/- error		unit	estimate	+/- error		gram	%	
Trembling Aspen	0.395	0.038	0.226	0.009	0.99	0.15	k1	1/year	7.46	0.77	ME	-0.03	-0.04	2.6
American Beech	0.374	0.038	0.063	0.008	0.75	0.18	k2	1/year	0.405	0.023	SD	0.60	0.18	7.3
Bracken Fern	0.431	0.042	0.110	0.009	1.54	0.15	k3	1/year	0.124	0.012	r^2	0.93	0.84	0.83
Black Spruce	0.652	0.034	0.117	0.010	1.94	0.13								
Douglas Fir	0.567	0.037	0	-	1.41	0.16								
Plains Rough Fescue	0.280	0.048	0.454	0.009	1.89	0.15	p1	1/°C	88.4	2.0				
Jack Pine	0.565	0.043	0.102	0.009	1.46	0.11	p2	1/mm	824.6	10	Sample size	1470	1470	1470
Tamarack	0.375	0.040	0.079	0.009	1.32	0.25	Ea	J/mole	62462	2064				
White Birch	0.622	0.033	0.223	0.018	1.27	0.09					Parameters	26	10	1
Western Red Cedar	0.284	0.040	0	-	2.91	0.37	CN_{final}		25.6	3.8				
Step-2 results														
Trembling Aspen	0.376	-	0.26	-	1.44	0.05	k1	1/year	19.8	2.0	ME	-0.02	-0.04	2.4
American Beech	0.439	-	0.10	-	"	"	k2	1/year	0.377	0.014	SD	0.67	0.20	7.7
Bracken Fern	0.431	-	0.10	-	"	"	k3	1/year	0.292	0.023	r^2	0.92	0.80	0.81
Black Spruce	0.615	-	0.08	-	"	"								
Douglas Fir	0.455	-	0.06	-	"	"								
Plains Rough Fescue	0.341	-	0.45	-	"	"	p1	1/°C	87.8	2.2				
Jack Pine	0.734	-	0.09	-	"	"	p2	1/mm	830.8	11.4	Sample size	1470	1470	1470
Tamarack	0.503	-	0.11	-	"	"	Ea	J/mole	61690	2312				
White Birch	0.674	-	0.19	-	"	"					Parameters	10	1	1
Western Red Cedar	0.432	-	0.03	-	"	"	CN_{final}		25.8	2.5				

Predictor equations across litter type, with common parameters

e = exp[- (0.117+/-0.011) ash(%)]

SD is the standard deviation of error

ME is mean error

Table 5.2 CIDET litterbag study: Step-1 error analysis, by species (top) and site (bottom).

Species	Mass remaining (g)				N concentration (%)				C/N			
	ME	SD	r^2	p(ME=0)	ME	SD	r^2	p(ME=0)	ME	SD	r^2	p(ME=0)
Trembling Aspen	-0.03	0.54	0.94	0.513	-0.05	0.19	0.77	0.002	2.1	7.2	0.76	0.001
American Beech	-0.01	0.60	0.91	0.779	-0.03	0.16	0.78	0.029	3.3	8.1	0.69	0.000
Bracken Fern	-0.01	0.61	0.93	0.868	-0.09	0.14	0.81	0.000	5.5	6.1	0.82	0.000
Black Spruce	-0.06	0.67	0.93	0.285	-0.18	0.22	0.78	0.000	4.6	5.5	0.85	0.000
Douglas Fir	-0.03	0.53	0.94	0.476	-0.04	0.21	0.69	0.018	-0.1	3.4	0.68	0.790
Plains Rough Fescue	-0.04	0.48	0.96	0.354	0.00	0.20	0.73	0.774	3.7	4.6	0.88	0.000
Jack Pine	0.00	0.66	0.90	0.947	-0.03	0.12	0.82	0.014	2.7	8.2	0.78	0.000
Tamarack	-0.07	0.71	0.88	0.247	-0.01	0.15	0.64	0.378	1.9	12.0	0.56	0.056
White Birch	-0.02	0.64	0.91	0.769	0.02	0.14	0.77	0.171	2.1	5.5	0.69	0.000
Western Red Cedar	-0.03	0.57	0.95	0.557	-0.02	0.14	0.84	0.051	0.2	7.0	0.75	0.766

Site	Mass remaining (g)				N concentration (%)				C/N			
	ME	SD	r^2	p(ME=0)	ME	SD	r^2	p(ME=0)	ME	SD	r^2	p(ME=0)
BAT	-0.09	0.70	0.87	0.266	-0.06	0.17	0.80	0.006	5.9	8.6	0.81	0.000
CBR	0.21	0.48	0.96	0.000	-0.17	0.15	0.90	0.000	6.1	5.1	0.90	0.000
CHA	0.22	0.55	0.96	0.001	-0.09	0.18	0.86	0.000	4.8	7.2	0.80	0.000
GAN	-0.05	0.40	0.97	0.312	-0.02	0.14	0.88	0.344	2.0	4.2	0.93	0.000
GI1	-0.65	0.61	0.88	0.000	0.07	0.11	0.88	0.000	-2.3	7.5	0.82	0.011
GI2	0.12	0.47	0.93	0.045	-0.07	0.16	0.82	0.001	3.2	7.3	0.81	0.000
HID	-0.11	0.49	0.96	0.057	-0.02	0.13	0.92	0.219	2.2	4.3	0.93	0.000
INU	0.03	0.40	0.90	0.480	0.05	0.10	0.86	0.000	-3.9	9.5	0.77	0.001
KAN	-0.63	0.53	0.93	0.000	0.01	0.12	0.93	0.442	0.5	5.0	0.91	0.359
MAR	-0.04	0.69	0.94	0.648	-0.08	0.19	0.88	0.000	3.6	4.6	0.93	0.000
MON	0.00	0.38	0.97	0.996	-0.19	0.19	0.84	0.000	7.3	5.2	0.89	0.000
NH1	0.02	0.41	0.94	0.746	-0.01	0.11	0.91	0.566	1.8	6.8	0.83	0.034
NH2	0.28	0.47	0.92	0.000	-0.14	0.15	0.82	0.000	8.9	5.0	0.89	0.000
PAL	-0.23	0.42	0.94	0.000	-0.04	0.14	0.89	0.015	3.0	5.6	0.89	0.000
PET	-0.52	0.66	0.93	0.000	-0.03	0.16	0.92	0.097	1.5	4.4	0.93	0.006
PMC	0.38	0.75	0.90	0.000	-0.02	0.22	0.70	0.393	2.6	6.3	0.84	0.001
SCH	-0.08	0.50	0.93	0.191	0.08	0.14	0.84	0.000	-3.0	7.9	0.77	0.002
SHL	0.14	0.41	0.97	0.005	0.08	0.21	0.77	0.001	0.4	6.1	0.86	0.586
TER	0.38	0.65	0.91	0.000	-0.18	0.24	0.71	0.000	9.2	8.5	0.75	0.000
TOP	0.18	0.64	0.92	0.019	-0.06	0.18	0.85	0.011	1.8	6.2	0.86	0.019
WHI	-0.18	0.37	0.93	0.000	0.01	0.13	0.86	0.664	-0.7	7.2	0.85	0.449

ME: mean error = best-fitted - actual

SD: mean standard deviation

Sample size for each species:148; for each site: 70

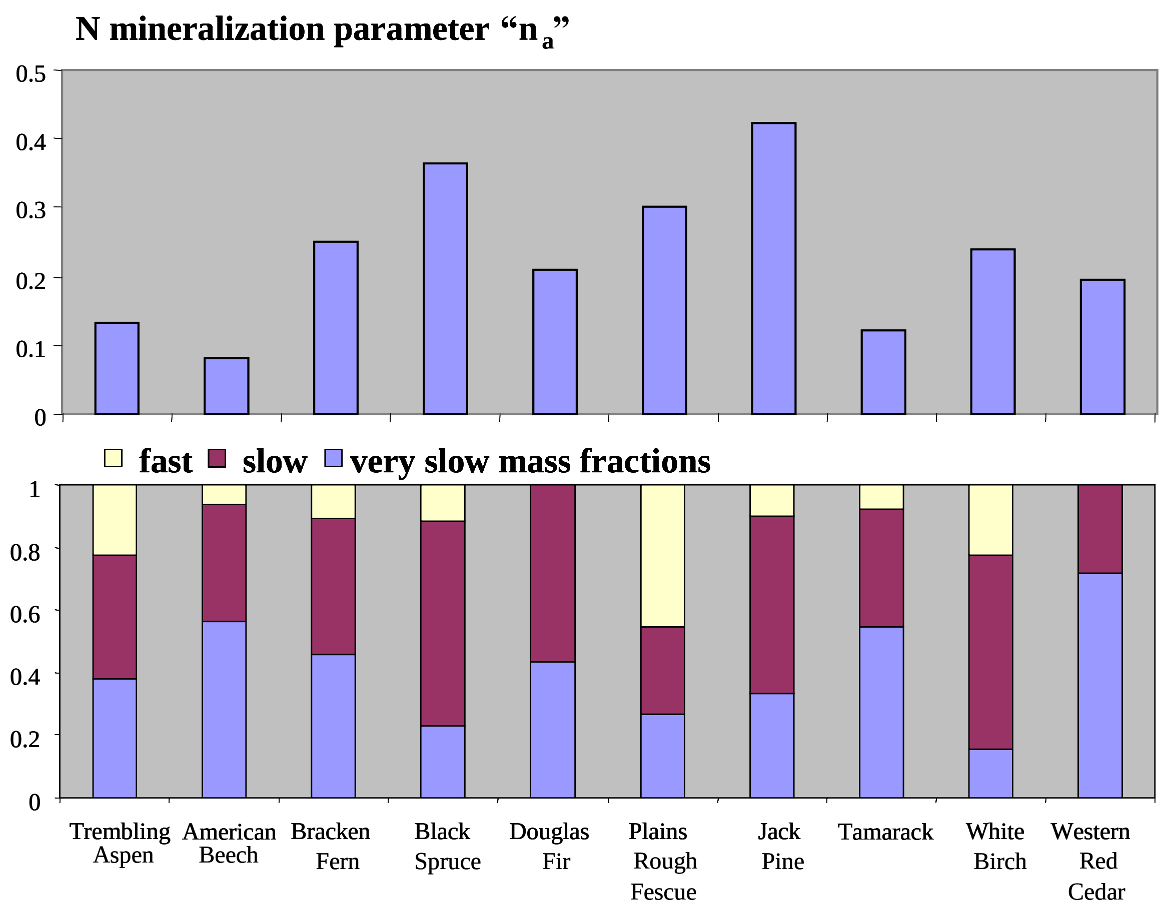

Figure 5.1 Distribution of fast, slow, and very slow fractions in CIDET litterbags, by species, according to model calculations.

that the use of constant parameters across species introduced or added a small positive or negative bias for M(T), [N](t) and [C/N](t) calculations, by species and by site.

5.5 STEP 1– STEP 2 SUMMARY

The Step-1 and Step-2 calibration results were reasonably consistent with one another, in spite of the drop of adjustable parameters from 37 to 12 (Table 5.1). A detailed comparison of the Step-1 and Step-2 residuals against M(t), [N](t), and [C/N](t) confirmed that the Step-2 residuals were only slightly larger than the Step-1 residuals, thereby implying that the gain in generality achieved with the Step-2 process did not compromise the overall model performance (Table 5.1). In summary, the above procedures identified:

- mean monthly air temperatures for January and July, and annual precipitation as suitable predictor variables to estimate the effect of climate on litter decomposition;
- initial water- and acid-extractable portions as indicators to specify the fast decomposing litter portion;
- initial ash content as a means to specify the proportion between the slow and very slow fractions;
- the initial N concentration of the litter, and the C% content of the surrounding substrate, as additional input for capturing the overall C and N retention or release dynamics over time.
- The ratios among the decomposition rate parameters k_1, k_2 and k_3 of the fast, slow and very slow pools, respectively, are constant.
- From the modeling, there are no matter flow from the fast to slow or from the slow to the very slow.

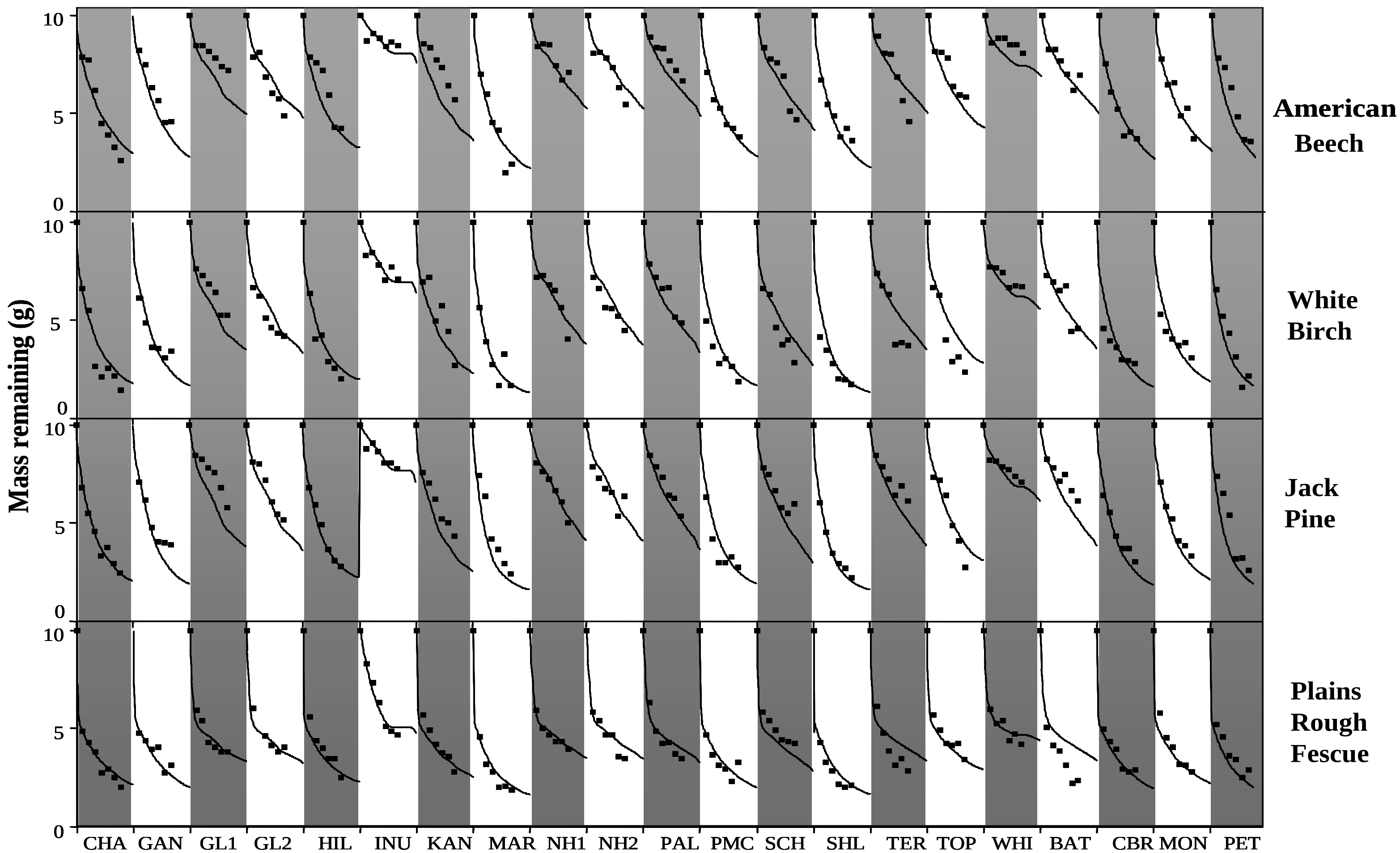

Figure 5.2 Comparison of best-fitted versus actual values of mass remaining in CIDET litterbags, over time (by year), for American Beech, White Birch, Jack Pine, and Plains Rough Fescue, with each plot starting in 1992, by litter type and site.

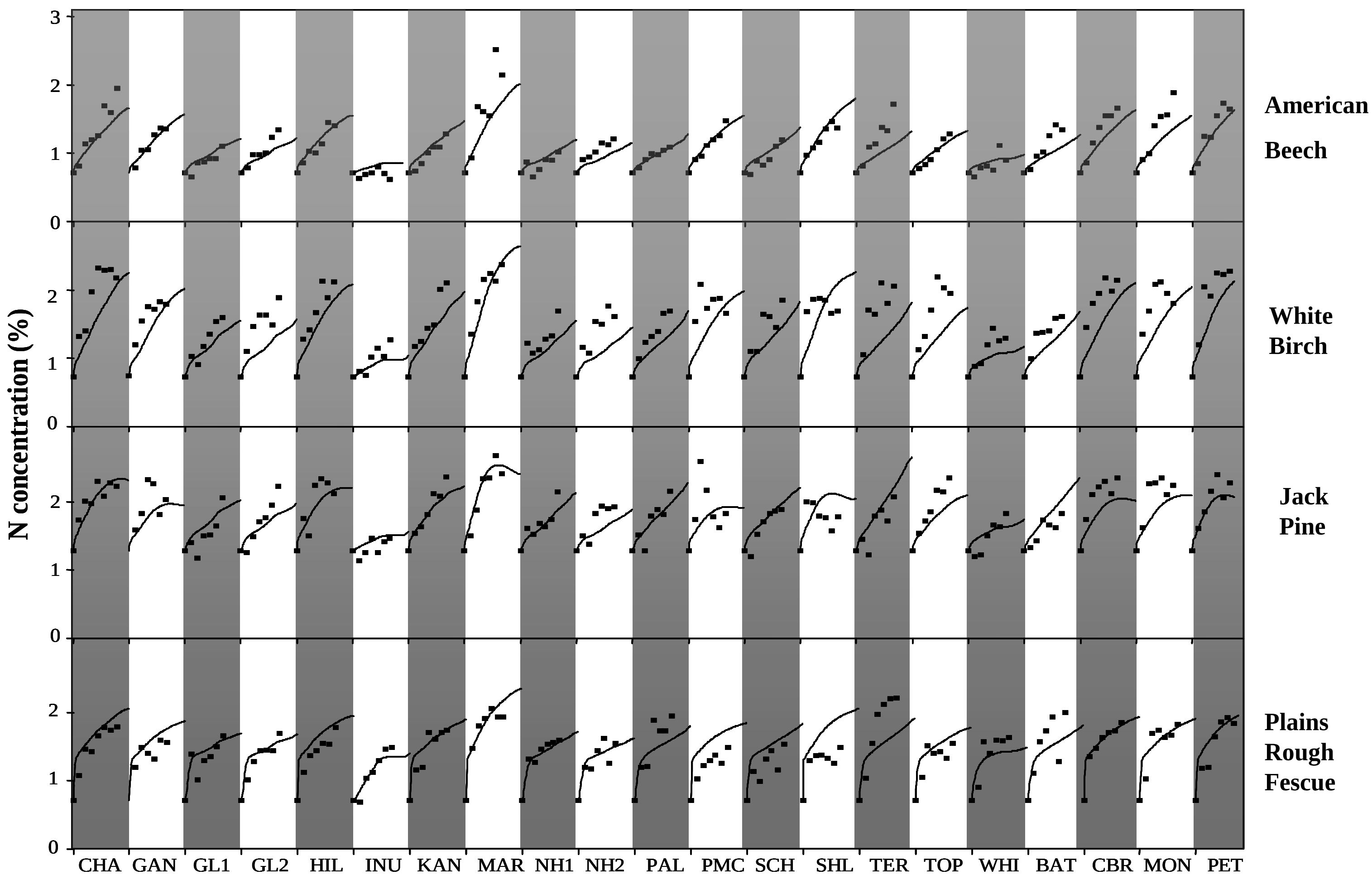

Figure 5.3 Comparison of best-fitted versus actual values of N concentrations in CIDET litterbags, over time (by year), for American Beech, White Birch, Jack Pine, and Plains Rough Fescue, with each plot starting in 1992, by litter type and site.

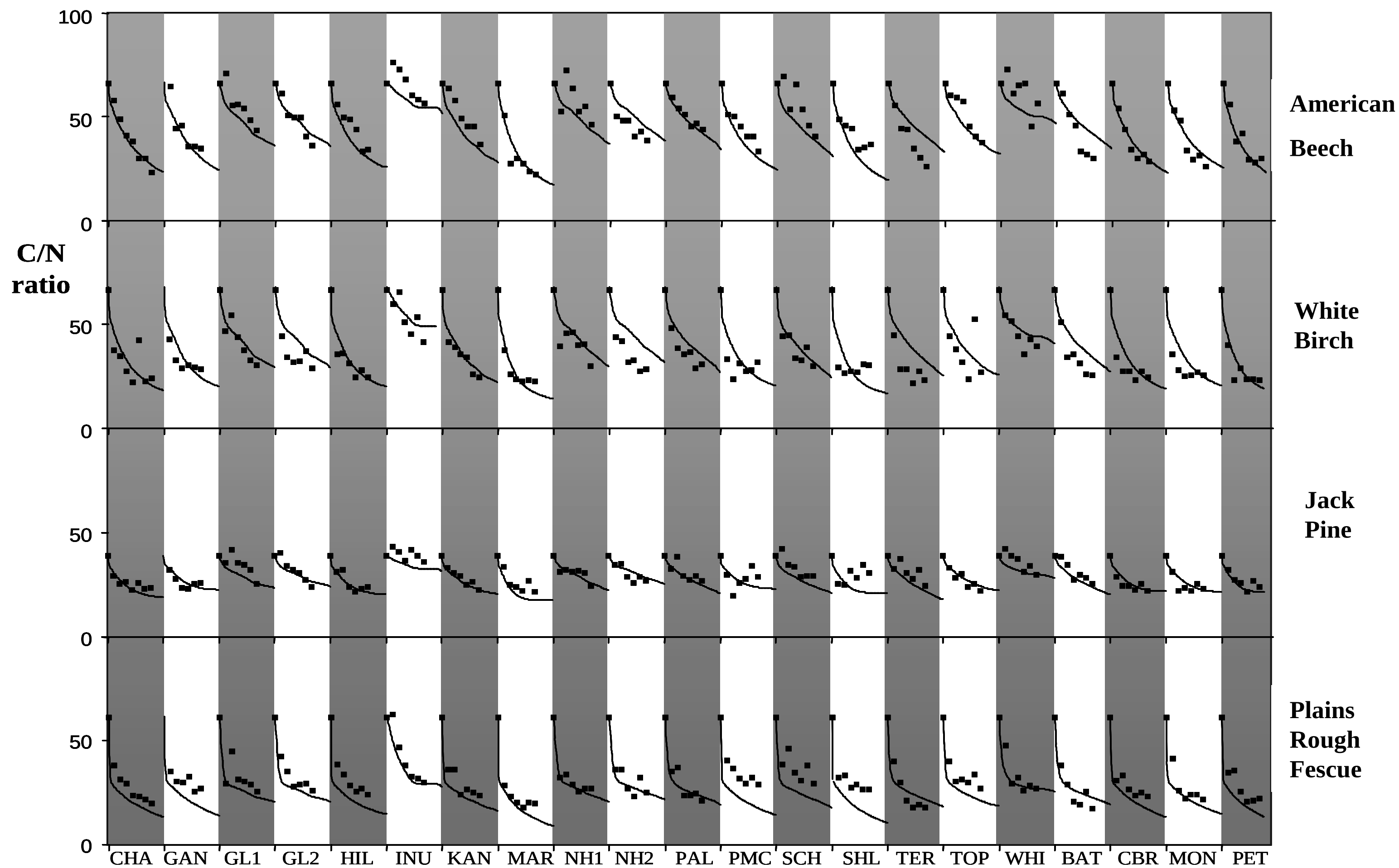

Figure 5.4 Comparison of best-fitted versus actual C/N ratios in CIDET litterbags, over time (by year), for American Beech, White Birch, Jack Pine, and Plains Rough Fescue, with each plot starting in 1992, by litter type and site.

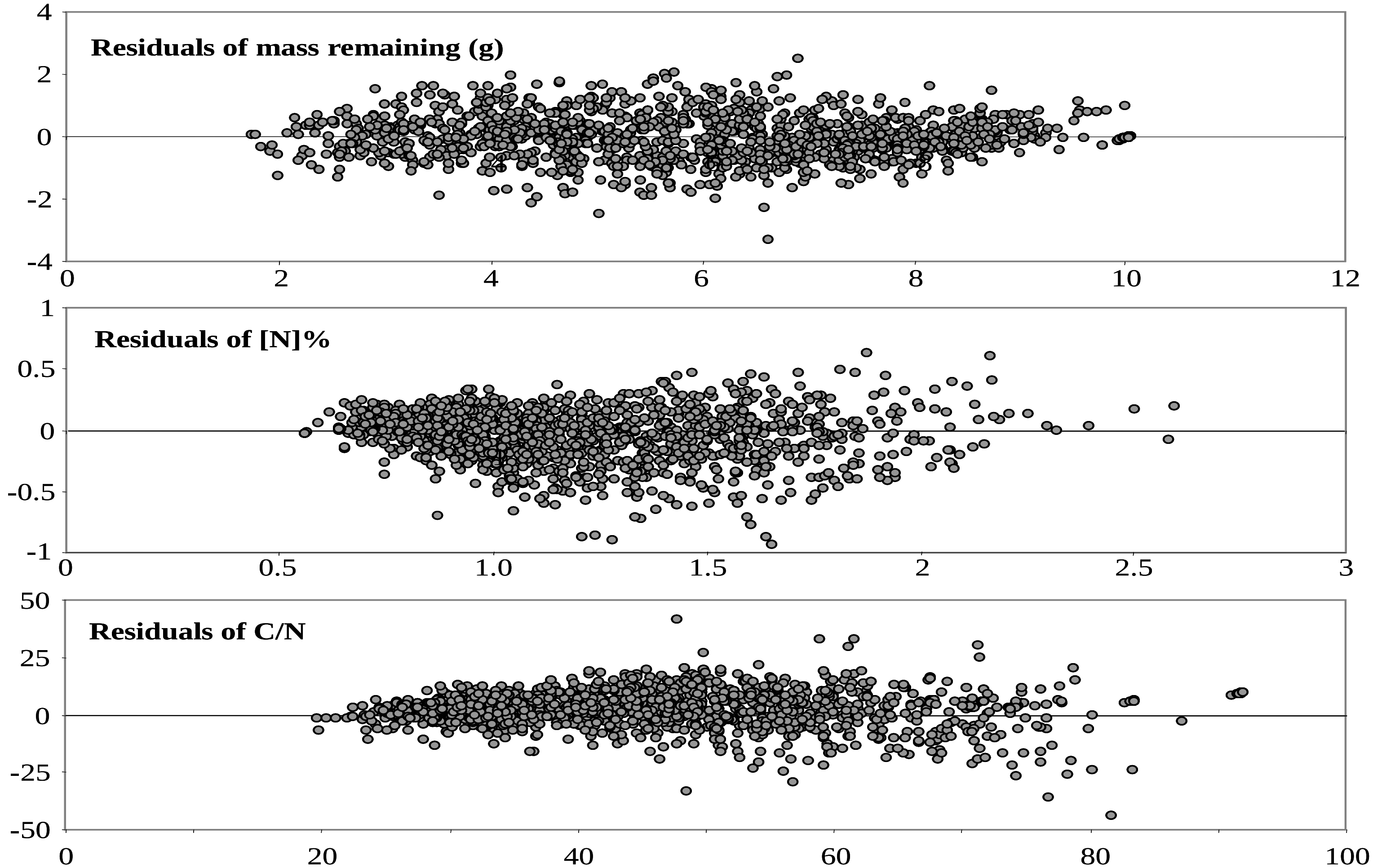

Figure 5.5 Comparison of residuals between actual and best-fitted values for mass remaining (top) and N concentrations (bottom) in CIDET litterbags, resulting from the Step-1 calculations.

Table 5.3 CIDET litterbag study: Step-2 error analysis, by species (top) and site (bottom)

Species	Mass remaining (g)				N concentration (%)				C/N			
	ME	SD	r^2	p(ME=0)	ME	SD	r^2	p(M=0)	ME	SD	r^2	p(M=0)
Trembling Aspen	-0.14	0.56	0.93	0.004	-0.07	0.20	0.77	0.000	2.2	7.3	0.75	0.000
American Beech	-0.29	0.61	0.91	0.000	-0.04	0.16	0.79	0.008	3.2	8.2	0.69	0.000
Bracken Fern	0.18	0.65	0.91	0.003	0.00	0.15	0.76	0.000	2.7	5.5	0.69	0.000
Black Spruce	0.45	0.60	0.94	0.038	-0.04	0.15	0.82	0.000	1.2	6.9	0.76	0.000
Douglas Fir	0.16	0.64	0.93	0.000	-0.12	0.15	0.82	0.021	6.1	6.1	0.83	0.890
Plains Rough Fescue	-0.01	0.48	0.96	0.727	0.06	0.21	0.71	0.001	2.7	4.7	0.88	0.000
Jack Pine	-0.29	0.57	0.94	0.000	-0.04	0.22	0.66	0.093	0.0	3.5	0.66	0.620
Tamarack	-0.07	0.71	0.90	0.000	-0.01	0.12	0.82	0.000	2.9	8.3	0.77	0.000
White Birch	0.12	0.67	0.93	0.001	-0.25	0.24	0.77	0.685	6.7	5.7	0.84	0.000
Western Red cedar	-0.34	0.74	0.87	0.000	0.09	0.14	0.64	0.001	-4.1	11.9	0.54	0.032

Site	Mass remaining (g)				N concentration (%)				C/N			
	ME	SD	r^2	p(M=0)	ME	SD	r^2	p(M=0)	ME	SD	r^2	p(M=0)
BAT	-0.09	0.78	0.83	0.337	-0.06	0.18	0.78	0.007	5.7	9.0	0.79	0.000
CBR	0.22	0.57	0.94	0.002	-0.17	0.19	0.84	0.000	5.8	5.1	0.89	0.000
CHA	0.23	0.63	0.94	0.003	-0.09	0.20	0.82	0.000	4.5	6.5	0.83	0.000
GAN	-0.04	0.55	0.95	0.498	-0.02	0.17	0.82	0.411	1.6	5.6	0.87	0.017
GI1	-0.64	0.67	0.85	0.000	0.06	0.13	0.85	0.000	-2.5	8.4	0.77	0.016
GI2	0.13	0.50	0.92	0.035	-0.07	0.18	0.77	0.001	3.1	7.8	0.78	0.002
HID	-0.10	0.60	0.93	0.177	-0.02	0.15	0.87	0.265	1.9	4.8	0.91	0.001
INU	0.04	0.43	0.88	0.390	0.05	0.10	0.85	0.000	-3.9	9.8	0.75	0.001
KAN	-0.63	0.62	0.91	0.000	0.01	0.15	0.89	0.571	0.3	6.3	0.86	0.700
MAR	-0.04	0.80	0.92	0.688	-0.08	0.22	0.84	0.006	3.2	5.0	0.91	0.000
MON	0.00	0.45	0.96	0.952	-0.19	0.21	0.81	0.000	6.9	4.9	0.90	0.000
NH1	0.02	0.48	0.92	0.739	-0.01	0.12	0.89	0.516	1.6	7.4	0.80	0.072
NH2	0.28	0.52	0.91	0.000	-0.14	0.16	0.78	0.000	8.7	5.3	0.87	0.000
PAL	-0.22	0.54	0.91	0.001	-0.04	0.15	0.86	0.018	2.9	6.6	0.85	0.000
PET	-0.51	0.75	0.92	0.000	-0.03	0.20	0.86	0.186	1.1	5.7	0.89	0.100
PMC	0.39	0.70	0.91	0.000	-0.02	0.24	0.64	0.407	2.2	5.9	0.85	0.003
SCH	-0.07	0.64	0.88	0.373	0.07	0.16	0.78	0.000	-3.2	9.2	0.69	0.005
SHL	0.15	0.49	0.96	0.012	0.08	0.23	0.68	0.004	0.0	6.7	0.82	0.993
TER	0.38	0.74	0.88	0.000	-0.18	0.25	0.67	0.000	9.1	8.3	0.75	0.000
TOP	0.19	0.71	0.90	0.027	-0.06	0.20	0.80	0.018	1.6	6.7	0.84	0.051
WHI	-0.19	0.44	0.90	0.001	0.01	0.14	0.84	0.715	-0.8	7.7	0.83	0.365

ME: mean error = best-fitted - actual

SD: standard deviation of error

Sample size for each species:148; for each site: 70

CHAPTER 6 DISCUSSION

6.1 MODEL FIT

While the model is able to represent the CIDET data for mass remaining, N concentrations, and C/N ratio quite well, there is the possibility that even better and perhaps less-biased calibrations could be achieved if the above-ground specifications for air temperature and precipitation were to be substituted by estimates for the actual moisture and temperature conditions within the litterbags. In the absence of actual measurements, this substitution would involve transforming the above-ground weather or climate data as used above into below-ground soil temperature and soil moisture estimates. This substitution would likely produce only a small but perhaps consistently unbiased improvement for fitting M(t), N(t) and [C/N](t) by species and by site, and may also lead to significantly better estimates for Ea, CN_{final}, k_i. The detailed regression analysis conducted by Trofymow et al. (2002) also suggested that inclusion of additional climate variables such as summer and winter precipitation add to the capturing of the climate-related variabilities within the CIDET data. What emerges from all of this is that most of the net annual variability of M(t), [N(t)] and [C/N](t) can in fact be linked to a very broad characterization of climate and chemical composition of litter and LFH substrate. Other factors such as local microtopography, drainage, soil pH, soil drainage and differences in forest floor type, microbial communities, and atmospheric deposition would all be additional contributors to the litter decay and N retention and mineralization processes. The analysis of this thesis, however, suggests that these other factors would only provide minor adjustments to the overall C and N retention and release projections.

6.2 COMPARISONS TO CIDET STUDY HYPOTHESES

It has been hypothesized (Trofymow and the CIDET Working Group, 1998) that the decay of fast and slow decomposing compartments would be determined by climate and initial chemical composition of the litter. The Step-1 and Step-2 procedures revealed that the rate of decay would indeed be strongly and commonly affected by these factors. However, litter type was shown to mainly affect the initial partitioning of mass into the fast, slow and very slow compartments, while climate was shown to affect the relative rate of change after the compartment initialization.

It has further been hypothesized (Trofymow and the CIDET Working Group, 1998) that the annual CIDET sampling procedures would be limited to quantify the slow and very slow decay process, because the fast-decaying fraction would be lost within a year. While this was found to be true at southern locations (e.g., Hidden Lake, Morgan Arboretum, Port McNeill, Shawnigan Lake), this was not the case for the northern locations (i.e., Inuvik, Whitehorse, Gillam, Nelson House, Prince Albert, Schefferville, Termundee, Topley).

It has also been hypothesized (Trofymow and the CIDET Working Group, 1998) that the decomposing litter will eventually enter a metastable phase, i.e., once the lignocellulose ratio exceeds 0.5 and the very slowly decay process dominates. The Step-1 and Step-2 optimization procedures, however, did not identify a threshold demarcation from fast to slow, and from slow to very slow, at least not within the period of measurement. In addition, the Step-1 and Step-2 procedures did not isolate chemically derived variables as strong rate-of-decay predictors. Instead, these procedures identified ash content as the most significant determinant to separate the slow from the very slow fraction, i.e., litter with the least ash (e.g., Jack pine, White birch, and Black spruce) would have the largest slowly decomposing fraction, and the least very slowly decaying fraction. In the extreme, ash% = 0 implied that there would be no very slow fraction in the litter. Whether this suggestion is generally true needs to be checked with other litter types.

6.3 CLIMATE EFFECTS

Potential climate effects have recently been discussed in reference to the rate of decomposition of mineral soil organic matter, and in the context of the temperature sensitivity (or the lack thereof) and related activation energies of the decay of the fast, slow and very slow fractions (Knorr et al., 2005). These authors found Ea to increase from 43,000 to 76,000 J mole^{-1} from the fast to the very slow fraction, respectively. The best-fitted Step-1 and Step-2 estimates for Ea amounted to 62,000 J mole^{-1} for all three fractions, respectively. Optimizing Ea separately for each of the three fractions did not produce significantly different Ea numbers per fraction, thereby justifying the assumption that climate affects the decay parameters of each of the three fractions similarly, at least at the net annual scale. The Ea values for the fast and slow fractions, however, might change to smaller values when measurements are taken at a finer time scale of days and months rather than years, as was the case in the methods described by Knorr et al. (2005). However, Borken et al. (2003) reported an Ea value of 73,700 J $mole^{-1}$ based on weekly soil respiration measurements over the course of 150 days. For the same situation, these authors also reported a linear increase in the rate of soil respiration with increasing soil moisture content, after accounting for the temperature effect. These measurements involved organic and mineral soil layers, with a moisture range from < 10 to 250 %, and 10 to 30%, respectively.

At the hourly to daily scale, soil CO_2 would generally be released during a short-lived pulse after wetting, with peak and duration of each pulse increasing with the amount of water received (Borken et al., 2003). Over the course of a year, the numerical accumulation of these pulses would likely accentuate the linearity between net litter mass loss and total soil moisture input. In fact, allowing for a curvilinear response between net annual litter mass loss and annual precipitation by, e.g., replacing the expression “ppt/p1” by “1-exp(-ppt/p1)” in Equation [4-15] noticeably reduced the quality of the Step-1 and Step-2 fit for M(t), N(T), and [C/N](t) (details not shown).

The rate of litter decay may be decreasing as the rate of annual precipitation increases beyond 2000 to about 5000mm, according to Schuur (2001). In the model, this effect can be implemented by replacing the “min(1, ppt/p1)“ expression by “min(1, ppt/p1) [1- b max(0, ppt/p1-1)”, with b as a parameter. The range of the CIDET annual precipitation values is, however, too small to evaluate b.

The climate-affected half–lives for the decomposition fraction generally varied between 1 and 15 years for the slow fraction, from the southern to northern locations, respectively. For the fast fraction, these numbers ranged from 0.08 to 1.2 years. For the very slow fraction, the numbers varied from 8 to 105 years initially. The final values can be derived from equation 4-18 and Table 5.1.

6.4 ABOUT THE WETLAND SITES

There were no consistent M(t) differences between the litterbags that were placed on the upland and the wetland sites. Laiho et al. (2004) reported similar results for the case of Scots pine litterbags placed along a drainage gradient in peatland forests. These authors suggested that the general moisture and temperature conditions at and within the top portion of forested peatland soils are similar to those of forested upland soils, and this would therefore explain the general lack of difference in the rate of decay from the upland to the wetland litterbags.

While rate of mass loss was not consistently affected by the upland and wetland placement of the litterbags, [N(t)] values were significantly higher on the wetland than the upland sites. This increase implied a lower rate of N mineralization on the wetland sites. Subsequent calculations with the CIDET data led to the following result:

n_a(wetlands) / n_a(uplands) = 0.53 +/- 0.14.

Lower wetland rates for N mineralization have already been reported by (Ohrui et al., 1999) and others (e.g., (Grigal and Homann, 1994). These lower N mineralization rates would likely not be due to increased moisture contents in the litterbags, because increased moisture content should increase the overall decomposition rate according to the above formulation. Instead, the lowered N mineralization rate is likely due to an allelopathic suppression of the N-mineralization process. This suppression has already been reported to be induced by the leaf-litter leachates from shrubby vegetation such as *Kalmia Angustifolia* (Yamasaki et al., 2002), and *Ledum Palustre* (Labrador Tea) and *Empetrum Hermaphrodium* (Crowberry) (Castells et al., 2005). In contrast, leachates from bryophytes such as *Sphagnum* sp. and *Hylocomium Splendens* did not affect the N mineralization rate (Castells et al., 2005).

6.5 MORE ABOUT N CONCENTRATIONS AND C/N RATIOS

Over the first 7 years since litterbag placement, field-determined values for [C/N](t) dropped quickly from about 70 into the general C/N range of the forest floor substrates on which the litterbags were placed (see Table 3.6 for C/N ratios of the forest floor substrates, and Figures 5.2, 5.3 and 5.4 for actual and modeled values). The best-fitted value for the final C/N ratio was about 25.8 +/-2.5 (Table 5.1). This number is generally lower than what is shown in Table 3.8 in reference to the CN ratios of the LFH substrates of the CIDET sites, with the TER site (C/N = 16) as a notable exception. In well-humified organic matter of mineral soils, C/N ratios are even lower (Berg et al., 1999). For actual forest floor samples, such low values are unlikely, even for well-humified litter, because of new leave, twig, log and root inputs, and additional inputs derived from physical disturbances such as tree uprooting and faunal biomixing. There also remains a numerical uncertainty about what the actual CIDET-derived value for CN_{final} should be: using values from 20 to 30 did not affect the overall model fit.

Increased N concentrations with increasing mass loss over time have already been reported and discussed elsewhere, notably by Berg et al. (1999) and Limpens and Berendse (2003). Model-derived plots of how mass, N concentrations, and C/N ratios change over the course of 25 years with changing climate locations and/or conditions (cool to warm, dry to wet) are presented in Figure 6.1 for the Black spruce and Jack pine litterbags. According to these calculations, N concentrations and C/N ratios would not always be increasing or decreasing with increasing time since litterbag placement: litter similar to that derived from Jack pine, with similar portions in the slow and very slow fractions and a fairly high N mineralization rate for the slow fraction, would show a rapid increase in [N(t)], followed by a temporary decline until approaching a final value for C/N.

Apart from the above considerations, there are also other factors that would further complicate the overall data analysis of the litterbags with increasing time after field deployment. Some of these factors refer to: new mass build-up inside the bags due to bag-internal root growth and/or gradual mineral deposition, notably Ca and Fe deposits. Mineral deposits are expected to occur in locations receiving mineral-enriched seepage water, or from mineral-rich water that accumulates at or near the soil surface in arid regions.

6.6 EFFECTS OF EXOGENOUS N ON DECOMPOSITION

(Berg and E.Matzner, 1997) suggested that exogenous N may influence the rate of decay. Hobbie (2000), Hobbie (2002) and Prescott et al. (2004) found N-accelerated decay, but only for the fast fraction when the decay process is N limited. Hagedorn et al. (2003) found a N-decreased rate of decay for well-humified organic matter, but only when N availability was increased by at least an order of magnitude or so. Limpens and Berendse (2003) reported that incubating sphagnum litter with and without N deposition treatments (from 0 to 80 kg ha-1 yr-1) did not affect mass loss. The Step-1 and Step-2 calculations also suggest that exogenous N would likely not have a strong influence on the rate of decay: allowing for exogenous N input into the litterbags forced the model-calculated Step-1 and Step-2 N concentrations to increase faster than the actual concentration.

6.7 MODEL PERFORMANCE COMPARISONS: THE MODEL OF THIS THESIS VERSUS CANDY, CENTURY AND SOMM

The RMSE, ME, and EF model performance indicators of the CANDY, CENTURY and SOMM models - based on the various soil organic matter simulations in Chapter 2 by location - were also evaluated for the Step-2 M(t), [N(t)] and C/N calculations of the preceding Chapter. The results so obtained (mean values, and ranges of RMSE, EF and ME values) are listed in Table 6.1. Also shown in this table are the number of data points that are part of the calculations, and the number of calibrations done with each model for each location or data set. As mentioned before, there were no calibrations with SOMM. Nevertheless, the SOMM calculations generally fell within -42 to + 26 % of the actual mean values of each location. Calculations were more precise, to within -22 to + 5 % with the model calibrations with CANDY and CENTURY for each location. On average, however, the estimated model efficiencies remained quite low. In contrast, the Step-2 results for M(t), [N(t)] and C/N achieved more or less the same precision, but with only one calibration for all the data (21 locations with 10 litter types, and an overall sample size of 1470). In addition, the estimated EF values were quite high, thereby indicating that the Step-2 process is fairly effective in capturing the trend of the data, across litter type and climate condition.

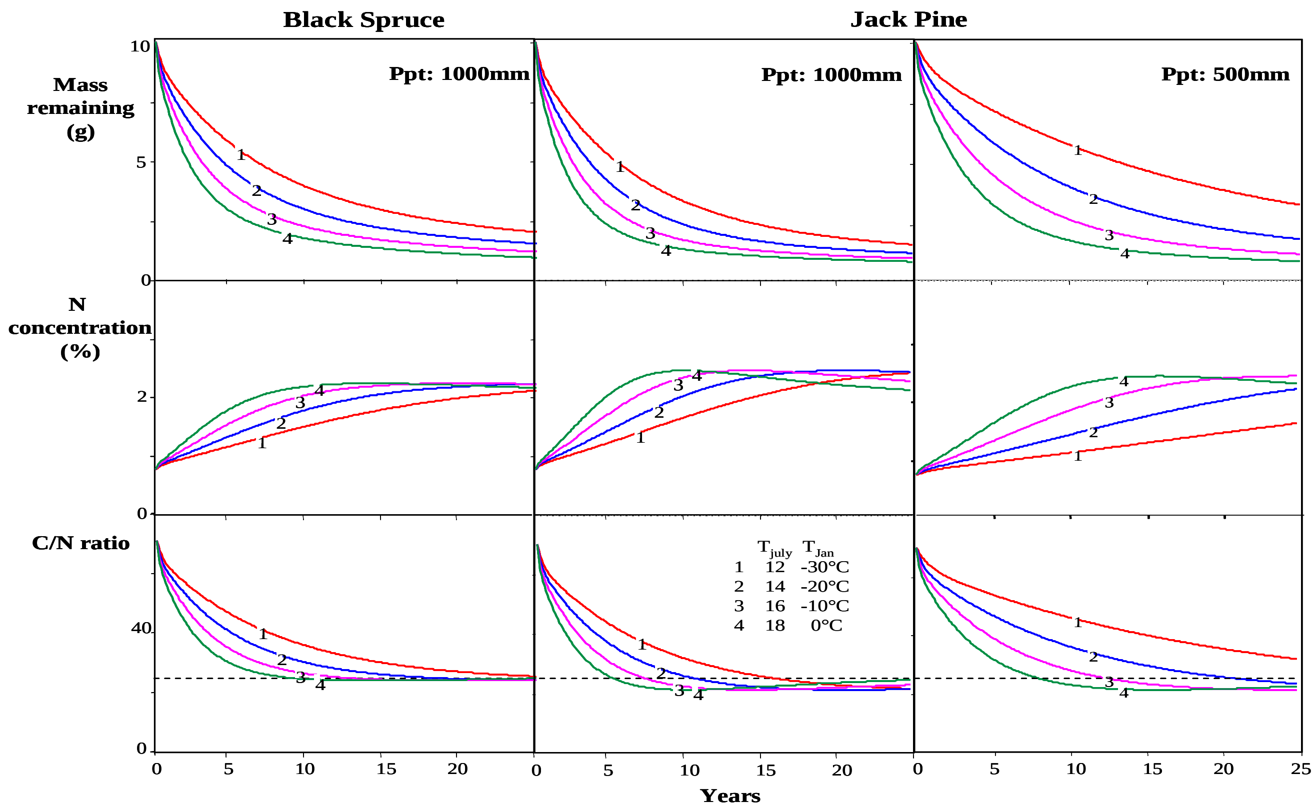

Figure 6.1 Comparison of mass remaining (top), N concentration (middle) and CN ratio (bottom) in Black Spruce and Jack pine litterbags, for 25 years, with varying climate conditions (annual precipitation 1000 or 500 mm, as marked), for several temperature conditions, varying upwards (1 to 4), from Tjuly = 12ºC and Tjan = 30º C.

Table 6.1 Model performance comparisons for CANDY, CENTURY, SOMM and the model of this Thesis.

Model performance indicator		Soil organic carbon %						Mass (g)		[N] (%)		C/N	
		CANDY		CENTURY		SOMM		THIS MODEL		THIS MODEL		THIS MODEL	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Root mean square error	RMSE, %	6.8	4 - 14	7.2	5 - 14.5	14.2	5 - 35	10.4	5 - 16.4	16.2	11.6-24.3	17.0	11.9 - 29.1
Mean error	ME	1.6	-10 - 4	0.6	-4 - 10	-1.1	-45 - 28	1.70	-9.1 - 10.8	-0.85	-11.3-9.5	8.80	-0.4 - 34.7
Relative error	RM, %	-2.5	-22 - 5	0.5	-11 - 11.4	-1.2	-42 - 26	-0.2	-6.6 - 3.4	-0.40	-1.9 - 0.8	0.20	-0.4-0.9
Modelling efficiency	EF	-0.045	-0.8 - 1	0.018	-1 - 1	-10.5	-60 - 0.5	0.90	0.7 - 0.96	0.75	0.5 - 0.75	0.76	0.45 -1
Number of samples	n	112		116		114		1470		1470		1470	
Number of calibrations	N	10		11		0		1		1		1	

CHAPTER 7 CONCLUSIONS

7.1 SUMMARIZING REMARKS

Holding all parameters constant across litter type and site reduced the overall fraction of the explained variations for mass remaining, for the N concentrations, and for the C/N ratios, only by a small amount. In turn, this small loss led to a considerable gain in terms of model generality, i.e., specifications about annual precipitation, mean July and January temperature, initial N concentration, and initial fractions of the fast, slow and very slow fractions were found to be sufficient to estimate mass and N remaining in decomposing litter over many years, across the wide range of climate conditions on the 21 CIDET sites. This model may therefore serve as a useful means to predict mass loss, N concentrations and C/N ratios of forest litter across Canada and other countries with similar climate conditions.

In recent literature discussions, it has been suggested that an accurate quantification of the slow and very slow fractions of soil organic matter is very important for assessing the impact of climate warming on the release of additional CO_2 from soils. This is because the pool sizes of the slow and very slow fractions are quite large, and because of the suggestion that the very slow fraction has a greater thermal sensitivity than the slow and fast fractions (Knorr et al., 2005). This paper demonstrates that:

- for forest litter, there is no significant change in the thermal sensitivity from the fast to the very slow fractions, at least not at the net annual scale (Ea values are similarly high for all three fractions, at 62,000 J mole-1); Borken et al. (2003) suggested that this would also be so at the daily scale;
- under changing climate conditions, highest rates of change of CO_2 release from decaying litter can be expected to occur in regions where cool summers change to warm summers, where dry regions become moist on account of increased precipitation, and where cold winters become more temperate;
- in addition to being sensitive to climate and the surrounding LFH substrate, the rates of mass and N release from the litter were calculated to vary by the initial amount and type of the fast, slow, and very slow decaying fractions (see Table 6.1);
- the decaying litter was found to be quite conservative in terms of N release, thus leading to increasing N concentrations, with highest concentrations observed and calculated for those substrates and conditions that favor fast decay; the model calculations also showed that absorption of exogenous N inside the litterbags would likely be insignificant, at least not on a net annual basis, and within the general precision of the best-fitted model calculations;
- altogether, the interplay between litter decomposition, N mineralization was calculated to produce a wide spectrum of N concentrations and C/N ratios within the decaying litter of the CIDET study, as affected by substrate type and climatic conditions, over time.

It should be remembered that all of the above refers to observed and expected trends for leaf- litter only. For other types of litter, such as coarse woody debris and roots, trends associated with the C and N sink and source dynamics may differ considerably over time, and with changing climate, and type and size of debris (Creed et al., 2004). The CIDET data may further reveal some of this in reference to examining the mass and N concentrations remaining in the western hemlock wood blocks.

7.2 ORIGINAL CONTRIBUTIONS

The following items are original to this Thesis:

- The processes used for model establishment and calibration regarding organic matter decomposition and N mineralization in litter bags were found to be very effective, and fairly unique, as detailed in the literature review (Chapter 2).
- This is the first time that rate of litter decomposition and N mineralization in litter bags has been represented fairly efficiently and systematically using only 3 components (fast, slow and very slow), from temperate to boreal conditions, for various litter types.
- While organic matter and N may be transferred from one pool to the other, the analysis of this Thesis revealed such transfers would be negligible, at the annual scale.
- The formulation suggests a gradual change in litter decomposition from an initially C-limited situation to a final N-limited situation. Existing models tend to be

prescriptive in this regard, using fixed C/N ratios to guide at least some of the calculations, for some of the pools.

- The model predicts the litter decomposition and N mineralization rates with climate change and substrate type, with fairly high reliability; this includes detecting no difference in the rate of decay of the litter bags when placed on top of the soil of the upland and wetland sites, and detecting a difference instead for the rate of N mineralization (less in wetlands than on uplands).
- With the model and the data, the Thesis established several new findings:

  a. there is no threshold in the decay from fast to slow to very slow;
  b. there is no transfer of mass and N between the fast, slow and very slow pools, at the annual scale, except for the fast N pool, which appears to become part of the slow N pool within the first year, at most locations; at the coolest locations, a small part of the fast N pool may be subject to a leaching loss.
  c. absorption of exogenous N within the litterbags is unlikely, or not a major process
  d. the rate parameters for decay and N mineralization for the fast, slow and very slow pools are affected only by local climate and substrate conditions; litter type, however, matters in terms of knowing the initial size of the fast, slow and very slow pools for mass and N.

7.3 SUGGESTIONS FOR FURTHER WORK

There are many questions that lead to further work:

- Will the model performance improve once actual or simulated soil temperature and soil moisture values are used in the regression analysis, instead of the climate-based functions suggested above?
- Are there conditions during which the forest litter inside the bags become a N sink (i.e., when exogenous N is immobilized)?
- Are the rates of N mineralization, as calculated with the model, consistent with rates of N mobilization under field conditions?
- Can the model be used to capture the mineralization rates of other nutrients? If so, what modifications need to be made, for each specific element, such as, e.g., phosphorus?
- Can the leaf litter decomposition model be used to simulate wood litter decomposition?
- Can this model be developed further to simulate litter accumulation and decomposition dynamics of the forest floor itself?
- To what extent will the model, as formulated, be sufficient to simulate litter decay and N mineralization in other data similar to the CIDET data?
- Will the performance of other C models improve once the algorithms of this Thesis are part of these models?

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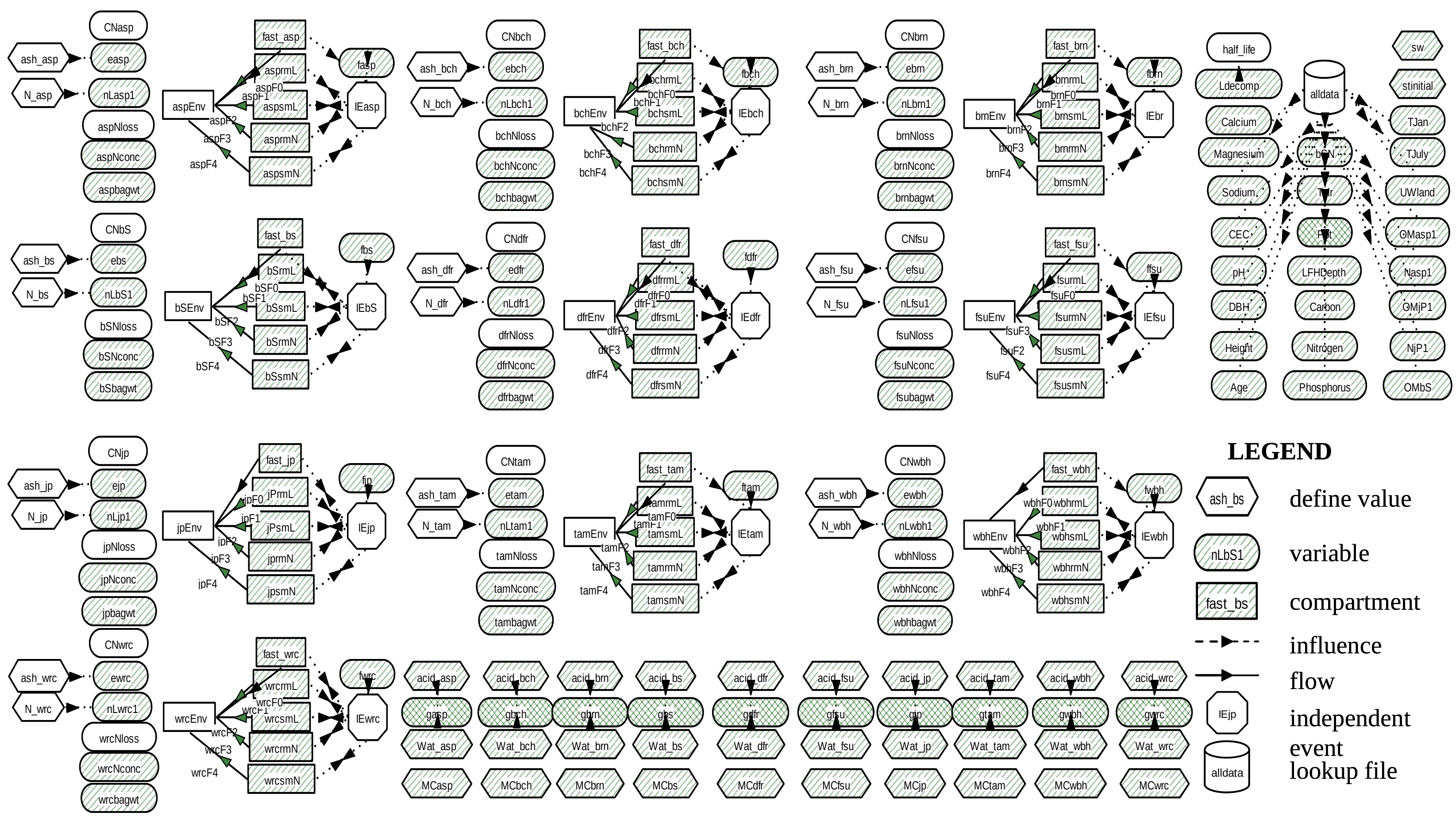
APPENDIX I LITTER DECOMPOSITION MODEL, IN MODEL-MAKER



APPENDIX. II MODEL EQUATIONS

parameter: t	2178.79999999983	0
Main		
parameter: a0	-6.62000436533501	0.203498730508045
parameter: a1	0.116164441370396	0.00260318497149414
parameter: a2	0.103694191109753	0.00288021253712003
parameter: a4	1.44113135839379	0.0543349658812696
parameter: a3	0.116850634186642	0.0112701961974184

variable: Age Unconditional Global;Age = age1

define value: ash_asp Unconditional; ash_asp = 8.38

define value: ash_bch Unconditional; ash_bch = 7.05

define value: ash_brn Unconditional;ash_brn = 7.21

define value: ash_bs Unconditional; ash_bs = 4.16

define value: ash_dfr Unconditional; ash_dfr = 6.74

define value: ash_fsu Unconditional; ash_fsu = 9.22

define value: ash_jp Unconditional; ash_jp = 2.65

define value: ash_tam Unconditional; ash_tam = 5.89

define value: ash_wbh Unconditional; ash_wbh = 3.38

define value: ash_wrc Unconditional; ash_wrc = 7.2

variable: aspbagwt Unconditional Global
aspbagwt = aspsmL+asprmL+fast_asp

compartment: aspEnv Unconditional; daspEnv/dt = +aspF1+aspF2+aspF3+aspF4+aspF0; Initial Value = 0.0

flow: aspF0 Unconditional; Flow from fast_asp to aspEnv; aspF0 = k1* fast_asp*Ldecomp

flow: aspF1 Unconditional Global; Flow from asprmL to aspEnv
aspF1 = Ldecomp* asprmL

flow: aspF2 Unconditional Global; Flow from aspsmL to aspEnv
aspF2 = (aspsmL-MCasp*CNfinal*aspsmN*(1-nLasp1*(1-fasp)))*k3*Ldecomp

flow: aspF3 Unconditional Global; Flow from asprmN to aspEnv
aspF3 = aspF1*(asprmN/asprmL)*nLasp1*fasp

flow: aspF4 Unconditional Global; Flow from aspsmN to aspEnv
aspF4 = k3*Ldecomp*aspsmN*nLasp1*(1-fasp)

variable: aspNconc Unconditional Global; aspNconc = (aspsmN+asprmN)/(aspsmL+asprmL+fast_asp)*100 variable: aspNloss Unconditional; aspNloss = aspF3+aspF4

compartment: asprmL Unconditional Global; dasprmL/dt = -aspF1; Initial Value = 1

compartment: asprmN Unconditional Global; dasprmN/dt = -aspF3; Initial Value = 0.01

compartment: aspsmL Unconditional Global; daspsmL/dt = -aspF2; Initial Value = 1

compartment: aspsmN Unconditional Global; daspsmN/dt = -aspF4; Initial Value = 0.01

variable: bchbagwt Unconditional Global; bchbagwt = bchsmL+bchrmL+fast_bch

compartment: bchEnv Unconditional; dbchEnv/dt = +bchF1+bchF2+bchF3+bchF4+bchF0; Initial Value = 0.0

flow: bchF0 Unconditional; Flow from fast_bch to bchEnv; bchF0 = k1 * fast_bch*Ldecomp

flow: bchF1 Unconditional Global; Flow from bchrmL to bchEnv; bchF1 = Ldecomp*bchrmL

flow: bchF2 Unconditional Global; Flow from bchsmL to bchEnv;
bchF2 = (bchsmL-MCbch*CNfinal*bchsmN*(1-nLbch*(1-fbch)))*k3*Ldecomp

flow: bchF3 Unconditional Global; Flow from bchrmN to bchEnv; bchF3 =
bchF1*(bchrmN/bchrmL)*nLbch*fbch

flow: bchF4 Unconditional Global; Flow from bchsmN to bchEnv; bchF4 =
k3*Ldecomp*bchsmN*nLbch*(1-fbch)

variable: bchNconc Unconditional Global; bchNconc =
(bchsmN+bchrmN)/(bchsmL+bchrmL+fast_bch)*100

variable: bchNloss Unconditional; bchNloss = bchF3+bchF4

compartment: bchrmL Unconditional Global; dbchrmL/dt = -bchF1; Initial Value = 1

compartment: bchrmN Unconditional Global; dbchrmN/dt = -bchF3; Initial Value = 0.01

compartment: bchsmL Unconditional Global; dbchsmL/dt = -bchF2; Initial Value = 1

compartment: bchsmN Unconditional Global; dbchsmN/dt = -bchF4; Initial Value = 0.01

variable: brnbagwt Unconditional Global; brnbagwt = brnsmL+brnrmL+fast_brn

compartment: brnEnv Unconditional; dbrnEnv/dt = +brnF1+brnF2+brnF3+brnF4+brnF0; Initial Value = 0.0

flow: brnF0 Unconditional; Flow from fast_brn to brnEnv; brnF0 = k1 * fast_brn*Ldecomp

flow: brnF1 Unconditional Global; Flow from brnrmL to brnEnv; brnF1 = Ldecomp*brnrmL

flow: brnF2 Unconditional Global; Flow from brnsmL to brnEnv;
brnF2 = (brnsmL-MCbrn*CNfinal*brnsmN*(1-nLbrn*(1-fbrn)))*k3*Ldecomp

flow: brnF3 Unconditional Global; Flow from brnrmN to brnEnv; brnF3 =
brnF1*(brnrmN/brnrmL)*nLbrn*fbrn

flow: brnF4 Unconditional Global; Flow from brnsmN to brnEnv; brnF4 =
k3*Ldecomp*brnsmN*nLbrn1*(1-fbrn)

variable: brnNconc Unconditional Global; brnNconc =
(brnsmN+brnrmN)/(brnsmL+brnrmL+fast_brn)*100

variable: brnNloss Unconditional; brnNloss = brnF3+brnF4

compartment: brnrmL Unconditional Global; dbrnrmL/dt = -brnF1; Initial Value = 1

compartment: brnrmN Unconditional Global; dbrnrmN/dt = -brnF3; Initial Value = 0.01

compartment: brnsmL Unconditional Global; dbrnsmL/dt = -brnF2; Initial Value = 1

compartment: brnsmN Unconditional Global; dbrnsmN/dt = -brnF4; Initial Value = 0.01

variable: bSbagwt Unconditional Global; bSbagwt = bSsmL+bSrmL+fast_bs

compartment: bSEnv Unconditional; dbSEnv/dt = +bSF1+bSF3+bSF4+bSF2+bSF0; Initial Value = 0.0

flow: bSF0 Unconditional; Flow from fast_bs to bSEnv; bSF0 = k1 * fast_bs*Ldecomp

flow: bSF1 Unconditional Global; Flow from bSrmL to bSEnv; bSF1 = Ldecomp* bSrmL

flow: bSF2 Unconditional Global; Flow from bSsmL to bSEnv;
bSF2 = (bSsmL-MCbs*CNfinal*bSsmN*(1-nLbS1*(1-fbs)))*k3*Ldecomp

flow: bSF3 Unconditional Global; Flow from bSrmN to bSEnv; bSF3 = bSF1*(bSrmN/
bSrmL)*nLbS1*fbs

flow: bSF4 Unconditional Global; Flow from bSsmN to bSEnv; bSF4 = k3*Ldecomp*bSsmN*nLbS1*(1-fbs)

variable: bSN Unconditional Global; bSN = NbS

variable: bSNconc Unconditional Global; bSNconc = (bSsmN+bSrmN)/(bSsmL+bSrmL+fast_bs)*100

variable: bSNloss Unconditional; bSNloss = bSF3+bSF4

compartment: bSrmL Unconditional Global; dbSrmL/dt = -bSF1; Initial Value = 1

compartment: bSrmN Unconditional Global; dbSrmN/dt = -bSF3; Initial Value = 0.01

compartment: bSsmL Unconditional Global; dbSsmL/dt = -bSF2; Initial Value = 1

compartment: bSsmN Unconditional Global; dbSsmN/dt = -bSF4; Initial Value = 0.01

variable: Calcium Unconditional Global; Calcium = Calcium1

variable: Carbon Unconditional Global; Carbon = carbon1

variable: CEC Unconditional Global; CEC = cec1

variable: CNasp Unconditional; CNasp = 1/(aspNconc*MCasp)

variable: CNbch Unconditional; CNbch = 1/(bchNconc*MCbch)

variable: CNbrn Unconditional; CNbrn = 1/(brnNconc*MCbrn)

variable: CNbS Unconditional; CNbS = 1/(bSNconc*MCbs)

variable: CNdfr Unconditional; CNdfr = 1/(dfrNconc*MCdfr)

parameter: CNfinal   25.8499986711704   2.54876393548328

variable: CNfsu Unconditional; CNfsu = 1/(fsuNconc*MCfsu)

variable: CNjp Unconditional; CNjp = 1/(jpNconc*MCjp)

variable: CNtam Unconditional; CNtam = 1/(tamNconc*MCtam)

variable: CNwbh Unconditional; CNwbh = 1/(wbhNconc*MCwbh)

variable: CNwrc Unconditional; CNwrc = 1/(wrcNconc*MCwrc) variable: DBH Unconditional Global; DBH = dbh1

variable: dfrbagwt Unconditional Global; dfrbagwt = dfrsmL+dfrrmL+fast_dfr

compartment: dfrEnv Unconditional; ddfrEnv/dt = +dfrF1+dfrF2+dfrF3+dfrF4+dfrF0; Initial Value = 0.0

flow: dfrF0 Unconditional; Flow from fast_dfr to dfrEnv; dfrF0 = k1* fast_dfr*Ldecomp

flow: dfrF1 Unconditional Global; Flow from dfrrmL to dfrEnv; dfrF1 = Ldecomp*dfrrmL

flow: dfrF2 Unconditional Global; Flow from dfrsmL to dfrEnv;
dfrF2 = (dfrsmL-MCdfr*CNfinal*dfrsmN*(1-nLdfr1*(1-fdfr)))*k3*Ldecomp

flow: dfrF3 Unconditional Global; Flow from dfrrmN to dfrEnv; dfrF3 =
dfrF1*(dfrrmN/dfrrmL)*nLdfr1*fdfr

flow: dfrF4 Unconditional Global; Flow from dfrsmN to dfrEnv; dfrF4 =

k3*Ldecomp*dfrsmN*nLdfr1*(1-fdfr)

variable: dfrNconc Unconditional Global; dfrNconc = (dfrsmN+dfrrmN)/(dfrsmL+dfrrmL+fast_dfr)*100

variable: dfrNloss Unconditional; dfrNloss = dfrF3+dfrF4

compartment: dfrrmL Unconditional Global; ddfrrmL/dt = -dfrF1; Initial Value = 1

compartment: dfrrmN Unconditional Global; ddfrrmN/dt = -dfrF3; Initial Value = 0.01

compartment: dfrsmL Unconditional Global; ddfrsmL/dt = -dfrF2; Initial Value = 1

compartment: dfrsmN Unconditional Global; ddfrsmN/dt = -dfrF4; Initial Value = 0.01

independent event: IEbS Active Reset
; Period: 9; stinitial; Actions:
fast_bs=10*gbs; bSrmL=10*(1- gbs)*ebS; bSsmL=10*(1- gbs)*(1-ebS); bSrmN=0.073*fbs;
bSsmN=0.073*(1-fbs);

parameter: Ea   61690.445265898   2312.3442611794

variable: easp Unconditional Global; easp = exp(-a3*ash_asp)

independent event: IEjp Active Reset; Period: 9; stinitial Actions:
fast_jp=10*gjp; jPrmL=10*(1- gjp)*ejp; jPsmL=10*(1- gjp)*(1-ejp); jprmN=0.128*fjp; jpsmN=0.128*(1-
fjp);

variable: ebch Unconditional Global; ebch = exp(-a3*ash_bch)

variable: ebrn Unconditional Global; ebrn = exp(-a3*ash_brn)

variable: ebs Unconditional Global; ebs = exp(-a3*ash_bs)

independent event: IEasp Active Reset; Period: 9; stinitial; Actions:
fast_asp=10*gasp; asprmL=10*(1-gasp)*easp; aspsmL=10*(1-gasp)*(1-easp); asprmN=0.067*fasp;
aspsmN=0.067*(1-fasp);

variable: edfr Unconditional Global; edfr = exp(-a3*ash_dfr)

variable: efsu Unconditional Global; efsu = exp(-a3*ash_fsu)

variable: ejp Unconditional Global; ejp = exp(-a3*ash_jp)

independent event: IEwbh Active Reset; Period: 9; stinitial; Actions:
fast_wbh=10*gwbh; wbhrmL=10*(1-gwbh)*ewbh; wbhsmL=10*(1-gwbh)*(1-ewbh);
wbhrmN=0.072*fwbh;
wbhsmN=0.072*(1-fwbh);

independent event: IEtam Active Reset; Period: 9; stinitial; Actions:
fast_tam=10*gtam; tamrmL=10*(1-gtam)*etam; tamsmL=10*(1-gtam)*(1-etam); tamrmN=0.059*ftam; tamsmN=0.059*(1-ftam);

independent event: IEbch Active Reset; Period: 9; stinitial;Actions:
fast_bch=10*gbch; bchrmL=10*(1-gbch)*ebch; bchsmL=10*(1-gbch)*(1-ebch); bchrmN=0.071*fbch; bchsmN=0.071*(1-fbch);

independent event: IEbr Active Reset; Period: 9; stinitial; Actions:
fast_brn=10*gbrn; brnrmL=10*(1-gbrn)*ebrn; brnsmL=10*(1-gbrn)*(1-ebrn); brnrmN=0.088*fbrn; brnsmN=0.088*(1-fbrn);

independent event: IEdfr Active Reset; Period: 9; stinitial; Actions:
fast_dfr=10*gdfr; dfrrmL=10*(1-gdfr)*edfr; dfrsmL=10*(1-gdfr)*(1-edfr); dfrrmN=0.07*fdfr; dfrsmN=0.07*(1-fdfr);

independent event: IEfsu Active Reset; Period: 9; stinitial; Actions:
fast_fsu=10*gfsu; fsurmL=10*(1- gfsu)*efsu; fsusmL=10*(1- gfsu)*(1-efsu); fsurmN=0.071*ffsu; fsusmN=0.071*(1-ffsu);

variable: etam Unconditional Global; etam = exp(-a3*ash_tam)

variable: ewbh Unconditional Global; ewbh = exp(-a3*ash_wbh)

independent event: IEwrc Active Reset; Period: 9; stinitial; Actions:
fast_wrc=10*gwrc; wrcrmL=10*(1-gwrc)*ewrc; wrcsmL=10*(1-gwrc)*(1-ewrc); wrcrmN=0.064*fwrc; wrcsmN=0.064*(1-fwrc);

variable: ewrc Unconditional Global; ewrc = exp(-a3*ash_wrc)

variable: fasp Unconditional Global; fasp = gasp*(1-easp)+easp

compartment: fast_asp Unconditional Global; dfast_asp/dt = -aspF0; Initial Value = 1

compartment: fast_bch Unconditional Global; dfast_bch/dt = -bchF0; Initial Value = 0.0

compartment: fast_brn Unconditional Global; dfast_brn/dt = -brnF0; Initial Value = 0.0

compartment: fast_bs Unconditional Global; dfast_bs/dt = -bSF0; Initial Value = 1

compartment: fast_dfr Unconditional Global; dfast_dfr/dt = -dfrF0; Initial Value = 0.0

compartment: fast_fsu Unconditional Global; dfast_fsu/dt = -fsuF0; Initial Value = 0.0

compartment: fast_jp Unconditional Global; dfast_jp/dt = -jpF0; Initial Value = 0.0

compartment: fast_tam Unconditional Global; dfast_tam/dt = -tamF0; Initial Value = 0.0

compartment: fast_wbh Unconditional Global; dfast_wbh/dt = -wbhF0; Initial Value = 0.0

compartment: fast_wrc Unconditional Global; dfast_wrc/dt = -wrcF0; Initial Value = 0.0

variable: fbch Unconditional Global; fbch = gbch*(1-ebch)+ebch

variable: fbrn Unconditional Global; fbrn = gbrn*(1-ebrn)+ebrn

variable: fbs Unconditional Global; fbs = gbs*(1-ebs)+ebs

variable: fdfr Unconditional Global; fdfr = gdfr*(1-edfr)+edfr

variable: ffsu Unconditional Global; ffsu = gfsu*(1-efsu)+efsu

variable: fjp Unconditional Global; fjp = gjp*(1-ejp)+ejp variable: fsubagwt Unconditional Global; fsubagwt = fsusmL+fsurmL+fast_fsu

compartment: fsuEnv Unconditional; dfsuEnv/dt = +fsuF1+fsuF2+fsuF3+fsuF4+fsuF0; Initial Value = 0.0

flow: fsuF0 Unconditional; Flow from fast_fsu to fsuEnv; fsuF0 = k1 * fast_fsu*Ldecomp

flow: fsuF1 Unconditional Global; Flow from fsurmL to fsuEnv; fsuF1 = Ldecomp*fsurmL

flow: fsuF2 Unconditional Global; Flow from fsusmL to fsuEnv;
fsuF2 = (fsusmL-MCfsu*CNfinal*fsusmN*(1-nLfsu*(1-ffsu)))*k3*Ldecomp

flow: fsuF3 Unconditional Global; Flow from fsurmN to fsuEnv; fsuF3 =
fsuF1*(fsurmN/fsurmL)*nLfsu*ffsu

flow: fsuF4 Unconditional Global; Flow from fsusmN to fsuEnv; fsuF4 =
k3*Ldecomp*fsusmN*nLfsu*(1-ffsu)

variable: fsuNconc Unconditional Global; fsuNconc = (fsusmN+fsurmN)/(fsusmL+fsurmL+fast_fsu)*100

variable: fsuNloss Unconditional; fsuNloss = fsuF3+fsuF4

compartment: fsurmL Unconditional Global; dfsurmL/dt = -fsuF1; Initial Value = 1

compartment: fsurmN Unconditional Global; dfsurmN/dt = -fsuF3; Initial Value = 0.01

compartment: fsusmL Unconditional Global; dfsusmL/dt = -fsuF2; Initial Value = 1

compartment: fsusmN Unconditional Global; dfsusmN/dt = -fsuF4; Initial Value = 0.01

variable: ftam Unconditional Global; ftam = gtam*(1-etam)+etam

variable: fwbh Unconditional Global; fwbh = gwbh*(1-ewbh)+ewbh

variable: fwrc Unconditional Global; fwrc = gwrc*(1-ewrc)+ewrc

variable: gasp Unconditional Universal; gasp = exp(a0+a1*acid_asp+a2*Wat_asp)/10

variable: gbch Unconditional Universal; gbch = exp(a0+a1*acid_bch+a2*Wat_bch)/10

variable: gbrn Unconditional Universal; gbrn = exp(a0+a1*acid_brn+a2*Wat_brn)/10

variable: gbs Unconditional Universal; gbs = exp(a0+a1*acid_bs+a2*Wat_bs)/10

variable: gdfr Unconditional Universal; gdfr = exp(a0+a1*acid_dfr+a2*Wat_dfr)/10

variable: gfsu Unconditional Universal; gfsu = exp(a0+a1*acid_fsu+a2*Wat_fsu)/10

variable: gjp Unconditional Universal; gjp = exp(a0+a1*acid_jp+a2*Wat_jp)/10

variable: gtam Unconditional Universal; gtam = exp(a0+a1*acid_tam+a2*Wat_tam)/10

variable: gwbh Unconditional Universal; gwbh = exp(a0+a1*acid_wbh+a2*Wat_wbh)/10

variable: gwrc Unconditional Universal; gwrc = exp(a0+a1*acid_wrc+a2*Wat_wrc)/10

variable: half_life Unconditional; half_life = min(100,-ln(0.5)/(Ldecomp*k3+0.0001))

variable: Height Unconditional Global; Height = height1

variable: jpbagwt Unconditional Global; jpbagwt = jPsmL+jPrmL+fast_jp

compartment: jpEnv Unconditional; djpEnv/dt = +jpF1+jpF2+jpF3+jpF4+jpF0; Initial Value = 0.0

flow: jpF0 Unconditional; Flow from fast_jp to jpEnv; jpF0 = k1* fast_jp*Ldecomp

flow: jpF1 Unconditional Global; Flow from jPrmL to jpEnv; jpF1 = Ldecomp*jPrmL

flow: jpF2 Unconditional Global; Flow from jPsmL to jpEnv;
jpF2 = (jPsmL-MCjp*CNfinal*jpsmN*(1-nLjp1*(1-fjp)))*k3*Ldecomp

flow: jpF3 Unconditional Global; Flow from jprmN to jpEnv; jpF3 = jpF1*(jprmN/jPrmL)*nLjp1*fjp

flow: jpF4 Unconditional Global; Flow from jpsmN to jpEnv; jpF4 = k3*Ldecomp*jpsmN*nLjp1*(1-fjp)

variable: jpNconc Unconditional Global; jpNconc = (jpsmN+jprmN)/(jPsmL+jPrmL+fast_jp)*100

variable: jpNloss Unconditional; jpNloss = jpF3+jpF4

compartment: jPrmL Unconditional Global; djPrmL/dt = -jpF1; Initial Value = 1

compartment: jprmN Unconditional Global; djprmN/dt = -jpF3; Initial Value = 0.01

compartment: jPsmL Unconditional Global; djPsmL/dt = -jpF2; Initial Value = 1

compartment: jpsmN Unconditional Global; djpsmN/dt = -jpF4; Initial Value = 0.01

parameter: k1   19.8420950879234   2.00448118258888

parameter: k2   0.37706100272869   0.0139222452683166

parameter: k3   0.292152098268689   0.0231086925626961

lookup file: alldata C:\Documents and Settings\chengfu\Desktop\work\CNModels\Paul\bagalladopt.txt

t Control

TJan1 Controlled by: t; Linear interpolation

TJuly1 Controlled by: t; Linear interpolation

ppt1 Controlled by: t; Linear interpolation

lfhdepth1 Controlled by: t; Linear interpolation

carbon1 Controlled by: t; Linear interpolation

nitrogen1 Controlled by: t; Linear interpolation

phosphorus1 Controlled by: t; Linear interpolation

Calcium1 Controlled by: t; Linear interpolation

magenesium1 Controlled by: t; Linear interpolation

sodium1 Controlled by: t; Linear interpolation

potassium1 Controlled by: t; Linear interpolation

cec1 Controlled by: t; Linear interpolation

ph1 Controlled by: t; Linear interpolation

dbh1 Controlled by: t; Linear interpolation

height1 Controlled by: t; Linear interpolation

age1 Controlled by: t; Linear interpolation

UWland1 Controlled by: t; Linear interpolation

variable: Ldecomp Unconditional Global;
Ldecomp = k2*max(0,(min(1,Ppt/p2)+TJan/p1)*exp(-(Ea/8.31)*(1/(TJuly+273)-1/288)))

variable: LFHDepth Unconditional Global; LFHDepth = lfhdepth1

variable: Magnesium Unconditional Global; Magnesium = magenesium1

define value: MCasp Unconditional Global; MCasp = 1.488+0.0088*acid_asp+0.0060*Wat_asp

define value: MCbch Unconditional Global; MCbch = 1.488+0.0088*acid_bch+0.0060*Wat_bch define value: MCbrn Unconditional Global; MCbrn = 1.488+0.0088*acid_brn+0.0060*Wat_brn

define value: MCbs Unconditional Global; MCbs = 1.488+0.0088*acid_bs+0.0060*Wat_bs

define value: MCdfr Unconditional Global; MCdfr = 1.488+0.0088*acid_dfr+0.0060*Wat_dfr

define value: MCfsu Unconditional Global; MCfsu = 1.488+0.0088*acid_fsu+0.0060*Wat_fsu

define value: MCjp Unconditional Global; MCjp = 1.488+0.0088*acid_jp+0.0060*Wat_jp

define value: MCtam Unconditional Global; MCtam = 1.488+0.0088*acid_tam+0.0060*Wat_tam

define value: MCwbh Unconditional Global; MCwbh = 1.488+0.0088*acid_wbh+0.0060*Wat_wbh

define value: MCwrc Unconditional Global; MCwrc = 1.488+0.0088*acid_wrc+0.0060*Wat_wrc

define value: N_asp Unconditional; N_asp = 6.7/1000

define value: N_bch Unconditional; N_bch = 7.1/1000

define value: N_brn Unconditional; N_brn = 8.8/1000

define value: N_bs Unconditional; N_bs = 7.3/1000

define value: N_dfr Unconditional; N_dfr = 7.0/1000

define value: N_fsu Unconditional; N_fsu = 7.1/1000

define value: N_jp Unconditional; N_jp = 12.8/1000

define value: N_tam Unconditional; N_tam = 5.9/1000

define value: N_wbh Unconditional; N_wbh = 7.2/1000

define value: N_wrc Unconditional; N_wrc = 6.4/1000

variable: Nasp1 Unconditional Global; Nasp1 = Nasp

variable: Nitrogen Unconditional Global; Nitrogen = nitrogen1

variable: NjP1 Unconditional Global; NjP1 = NjP

variable: nLasp Unconditional Global; nLasp = a4*N_asp *Carbon

variable: nLbch Unconditional Global; nLbch = a4*N_bch*Carbon

variable: nLbrn Unconditional Global; nLbrn = a4*N_brn*Carbon

variable: nLbS Unconditional Global; nLbS = a4*N_bs*Carbon

variable: nLdfr Unconditional Global; nLdfr = a4*N_dfr*Carbon

variable: nLfsu Unconditional Global; nLfsu = a4*N_fsu*Carbon

variable: nLjp Unconditional Global; nLjp = a4*N_jp*Carbon

variable: nLtam Unconditional Global; nLtam = a4*N_tam*Carbon

variable: nLwbh Unconditional Global; nLwbh = a4*N_wbh*Carbon

variable: nLwrc Unconditional Global; nLwrc = a4*N_wrc*Carbon

parameter: p1 87.7910845169475 2.15682838425585

parameter: p2 830.838751144665 11.4499755133072

variable: Ppt Unconditional Universal; Ppt = ppt1

variable: Sodium Unconditional Global; Sodium = sodium1

define value: stinitial Unconditional Global; stinitial = 1991.9

variable: Tair Unconditional Global; Tair = tair1 variable: tambagwt Unconditional Global; tambagwt = tamsmL+tamrmL+fast_tam

compartment: tamEnv Unconditional; dtamEnv/dt = +tamF1+tamF2+tamF3+tamF4+tamF0; Initial Value = 0.0

flow: tamF0 Unconditional; Flow from fast_tam to tamEnv; tamF0 = k1 * fast_tam*Ldecomp

flow: tamF1 Unconditional Global; Flow from tamrmL to tamEnv; tamF1 = Ldecomp*tamrmL

flow: tamF2 Unconditional Global; Flow from tamsmL to tamEnv;
tamF2 = (tamsmL-MCtam*CNfinal*tamsmN*(1-nLtam1*(1-ftam)))*k3*Ldecomp

flow: tamF3 Unconditional Global; Flow from tamrmN to tamEnv; tamF3 = tamF1*(tamrmN/tamrmL)*nLtam1*ftam

flow: tamF4 Unconditional Global; Flow from tamsmN to tamEnv; tamF4 = k3*Ldecomp*tamsmN*nLtam1*(1-ftam)

variable: tamNconc Unconditional Global; tamNconc = (tamsmN+tamrmN)/(tamsmL+tamrmL+fast_tam)*100

variable: tamNloss Unconditional; tamNloss = dfrF3+dfrF4

compartment: tamrmL Unconditional Global; dtamrmL/dt = -tamF1; Initial Value = 1

compartment: tamrmN Unconditional Global; dtamrmN/dt = -tamF3; Initial Value = 0.01

compartment: tamsmL Unconditional Global; dtamsmL/dt = -tamF2; Initial Value = 1

compartment: tamsmN Unconditional Global; dtamsmN/dt = -tamF4; Initial Value = 0.01

variable: TJan Unconditional Global; TJan = TJan1

variable: TJuly Unconditional Global; TJuly = TJuly1

variable: UWland Unconditional Global; UWland = UWland1

define value: Wat_asp Unconditional Global; Wat_asp = 35.42

define value: Wat_bch Unconditional Global; Wat_bch = 12.9

define value: Wat_brn Unconditional Global; Wat_brn = 9.04

define value: Wat_bs Unconditional Global; Wat_bs = 19.85

define value: Wat_dfr Unconditional Global; Wat_dfr = 11.48

define value: Wat_fsu Unconditional Global; Wat_fsu = 12.86

define value: Wat_jp Unconditional Global; Wat_jp = 15.24

define value: Wat_tam Unconditional Global; Wat_tam = 31.1

define value: Wat_wbh Unconditional Global; Wat_wbh = 35.94

define value: Wat_wrc Unconditional Global; Wat_wrc = 10.51

variable: wbhbagwt Unconditional Global; wbhbagwt = wbhsmL+wbhrmL+fast_wbh

compartment: wbhEnv Unconditional; dwbhEnv/dt = +wbhF1+wbhF2+wbhF3+wbhF4+wbhF0; Initial Value = 0.0

flow: wbhF0 Unconditional; Flow from fast_wbh to wbhEnv; wbhF0 = k1 * fast_wbh*Ldecomp

flow: wbhF1 Unconditional Global; Flow from wbhrmL to wbhEnv; wbhF1 = Ldecomp*wbhrmL

flow: wbhF2 Unconditional Global; Flow from wbhsmL to wbhEnv;
wbhF2 = (wbhsmL-MCwbh*CNfinal*wbhsmN*(1-nLwbh1*(1-fwbh)))*k3*Ldecomp

flow: wbhF3 Unconditional Global; Flow from wbhrmN to wbhEnv;
wbhF3 = wbhF1*(wbhrmN/wbhrmL)*nLwbh1*fwbh

flow: wbhF4 Unconditional Global; Flow from wbhsmN to wbhEnv;
wbhF4 = k3*Ldecomp*wbhsmN*nLwbh1*(1-fwbh)

variable: wbhNconc Unconditional Global; wbhNconc =

(wbhsmN+wbhrmN)/(wbhsmL+wbhrmL+fast_wbh)*100

variable: wbhNloss Unconditional; wbhNloss = dfrF3+dfrF4

compartment: wbhrmL Unconditional Global; dwbhrmL/dt = -wbhF1; Initial Value = 1

compartment: wbhrmN Unconditional Global; dwbhrmN/dt = -wbhF3; Initial Value = 0.01

compartment: wbhsmL Unconditional Global; dwbhsmL/dt = -wbhF2; Initial Value = 1

compartment: wbhsmN Unconditional Global; dwbhsmN/dt = -wbhF4; Initial Value = 0.01

variable: wrcbagwt Unconditional Global; wrcbagwt = wrcsmL+wrcrmL+fast_wrc

compartment: wrcEnv Unconditional; dwrcEnv/dt = +wrcF1+wrcF2+wrcF3+wrcF4+wrcF0; Initial Value = 0.0

flow: wrcF0 Unconditional; Flow from fast_wrc to wrcEnv; wrcF0 = k1* fast_wrc*Ldecomp

flow: wrcF1 Unconditional Global; Flow from wrcrmL to wrcEnv; wrcF1 = Ldecomp*wrcrmL

flow: wrcF2 Unconditional Global; Flow from wrcsmL to wrcEnv;
wrcF2 = (wrcsmL-MCwrc*CNfinal*wrcsmN*(1-nLwrc1*(1-fwrc)))*k3*Ldecomp

flow: wrcF3 Unconditional Global; Flow from wrcrmN to wrcEnv; wrcF3 =
wrcF1*(wrcrmN/wrcrmL)*nLwrc1*fwrc

flow: wrcF4 Unconditional Global; Flow from wrcsmN to wrcEnv; wrcF4 =
k3*Ldecomp*wrcsmN*nLwrc1*(1-fwrc)

variable: wrcNconc Unconditional Global; wrcNconc =

(wrcsmN+wrcrmN)/(wrcsmL+wrcrmL+fast_wrc)*100

variable: wrcNloss Unconditional; wrcNloss = wrcF3+wrcF4

compartment: wrcrmL Unconditional Global; dwrcrmL/dt = -wrcF1; Initial Value = 1

compartment: wrcrmN Unconditional Global; dwrcrmN/dt = -wrcF3; Initial Value = 0.01

compartment: wrcsmL Unconditional Global; dwrcsmL/dt = -wrcF2; Initial Value = 1

compartment: wrcsmN Unconditional Global; dwrcsmN/dt = -wrcF4; Initial Value = 0.01

APPENDIX III. SYMBOL EXPLANATION

Symbol	Definition
_Env	Litter of one species decomposed into environment(g)
_Env	N of one species mineralized into the environment (g)
_bagwt	Simulated litter bag weight of one species(g)
_Nconc	N one species concentration of one species(%)
_Nloss	N one species mineralized into the environment (g)
_rmL	Slow litter pool weight of one species (g)
_rmN	Slow N pool weight of one species (g)
_smL	Very slow litter pool weight of one species (g)
_smN	Very slow N pool weight of one species (g)
a0	parameter in equation 6-3
a1	parameter in equation 6-3
a2	parameter in equation 6-3
a3	parameter in equation 6-4
a4	n_a in equation 6-1 and 6-2
acid_	Acid soluable carbohydrate
Age | age1	Forest age of of the CIDET site
ash	Ash content%
asp_	Trembling aspen
bch_	American beech
brn_	Bracken fern
bs_	Black spruce
Calcium | C	Calcium concentration of forest floor (mg/kg)
Carbon | car	Mean Carbon content of forest floor(%)
CEC | cec1	Mean cation exchangeable capacity (cmol/kg)
CN_	C and N ratio of one species
CNfinal	The final C and N ratio of decomposed litter
DBH | dbh1	Diameter of breadth height (cm)
dfr_	Douglas fir
e_	The original ratio of slow pool and the very slow pool of one species
Ea	Active energy
f_	The N original ratio between (fast pool + the slow pool)---
	---and the very slow pool of one species
F0	Litter decomposed from the fast pool(g/year); dM1/dt in equation 4-1;
F1	Litter decomposed from the slow pool(g/year); dM2/dt in equation 4-1;
F2	Litter decomposed from the very slow pool(g/year); dM3/dt in equation 4-1;
F3	N mineralized from the fast and slow pool(g/year); dN1/dt in equation 4-3;
F4	N mineralized from the very slow pool(g/year); dN2/dt in equation 4-3;
fast_	Fast litter pool weight of one species (g)
fsu__	Plains rough fescue
g_	The original ratio of fast pool and the slow pool of one species
Height |hei	Average forest height (m)
IE_	independent event for one species
jp_	Jack pine
k1	parameter in equation 4-14
k2	parameter in equation 4-14
k3	parameter in equation 4-14
Ldecomp	f(climate) in equation 4-15

Symbol explanation(continue)

Symbol	Actual meaning
LFHDepth |	LFH depth (cm)
Magenesiun	Magenesium concentration of forest floor (mg/kg)
MC_	Litter carbon ratio of one species
N_ | N___1	Original N concentration of one litter species (%)
Nitrogen | ni	Forest floor N concentration (%)
nL_	N mineralization rate of one speices
p1	parameter in equation 4-14
p2	parameter in equation 4-14
ph1 | pH	pH of forest floor
Phosphorus	Phosphorus concentration of forest floor (mg/kg)
Ppt | ppt1	Yearly total precipitation(mm)
Sodium | So	Sodium concentration of forest floor (mg/kg)
t	year
Tair | Tair1	Yearly average temperature (^{O}C)
tam_	Tamarack
Tjan | TJan1	Average temperature of January (^{O}C)
Tjuly | TJuly	Average temperature of July (^{O}C)
Uwland | U	Wetness of the site condition
Wat_	Water soluble extractables(mg/g)
wbh_	White birch
wrc_	Western red cedar

APPENDIX IV. YEARLY WEATHER INFORMATION AND INITIAL SITE CONDITIONS

Yearly weather information and initial site condition of CIDET

Locatior	YEAR	Tair	Tjan	Tjul	Ppt	Fdepth	C	N	P	Ca	Mg	S	K	CEC	pH	DBH	Height	Age	UWLand
		°C	°C	°C	mm	cm	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	cmol/kg		cm	m	A	0-u;1-w
CHA	1992	1.1	-14.4	13.7	737.1	8.5	35.7	1.0	0.1	1072.5	151.4	7.4	248.3	19.8	4.3	16.1	15.8	71	0
CHA	1993	1.2	-14.3	17.3	878.0	8.5	35.7	1.0	0.1	1072.5	151.4	7.4	248.3	19.8	4.3	16.1	15.8	72	0
CHA	1994	1.9	-23.0	16.9	737.1	8.5	35.7	1.0	0.1	1072.5	151.4	7.4	248.3	19.8	4.3	16.1	15.8	73	0
CHA	1995	1.4	-13.2	17.3	988.6	8.5	35.7	1.0	0.1	1072.5	151.4	7.4	248.3	19.8	4.3	16.1	15.8	74	0
CHA	1996	0.7	-17.9	15.2	1041.9	8.5	35.7	1.0	0.1	1072.5	151.4	7.4	248.3	19.8	4.3	16.1	15.8	75	0
CHA	1997	1.3	-18.1	17.2	695.2	8.5	35.7	1.0	0.1	1072.5	151.4	7.4	248.3	19.8	4.3	16.1	15.8	76	0
CHA	1998	3.9	-13.8	17.2	874.8	8.5	35.7	1.0	0.1	1072.5	151.4	7.4	248.3	19.8	4.3	16.1	15.8	77	0
GAN	1992	2.8	-8.2	12.3	1306.5	9.5	45.8	0.7	0.1	634.4	257.9	4.4	175.4	25.4	3.8	10.0	10.6	85	0
GAN	1993	2.6	-10.2	12.1	1343.1	9.5	45.8	0.7	0.1	634.4	257.9	4.4	175.4	25.4	3.8	10.0	10.6	86	0
GAN	1994	3.5	-8.4	16.5	1319.3	9.5	45.8	0.7	0.1	634.4	257.9	4.4	175.4	25.4	3.8	10.0	10.6	87	0
GAN	1995	3.6	-6.6	16.3	1467.8	9.5	45.8	0.7	0.1	634.4	257.9	4.4	175.4	25.4	3.8	10.0	10.6	88	0
GAN	1996	4.9	-7.2	16.6	1192.2	9.5	45.8	0.7	0.1	634.4	257.9	4.4	175.4	25.4	3.8	10.0	10.6	89	0
GAN	1997	3.3	-6.6	15.8	1143.6	9.5	45.8	0.7	0.1	634.4	257.9	4.4	175.4	25.4	3.8	10.0	10.6	90	0
GAN	1998	4.8	-6.7	17.5	1236.0	9.5	45.8	0.7	0.1	634.4	257.9	4.4	175.4	25.4	3.8	10.0	10.6	91	0
GI1	1992	-5.0	-23.3	12.5	499.8	15.0	38.3	1.1	0.1	7733.3	1022.1	5.9	147.3	103.6	6.6	7.3	5.8	94	0
GI1	1993	-4.1	-21.7	15.3	629.4	15.0	38.3	1.1	0.1	7733.3	1022.1	5.9	147.3	103.6	6.6	7.3	5.8	95	0
GI1	1994	-3.9	-31.2	14.5	539.8	15.0	38.3	1.1	0.1	7733.3	1022.1	5.9	147.3	103.6	6.6	7.3	5.8	96	0
GI1	1995	-4.4	-21.4	14.0	491.4	15.0	38.3	1.1	0.1	7733.3	1022.1	5.9	147.3	103.6	6.6	7.3	5.8	97	0
GI1	1996	-4.7	-28.9	16.6	618.6	15.0	38.3	1.1	0.1	7733.3	1022.1	5.9	147.3	103.6	6.6	7.3	5.8	98	0
GI1	1997	-4.1	-26.5	17.8	694.0	15.0	38.3	1.1	0.1	7733.3	1022.1	5.9	147.3	103.6	6.6	7.3	5.8	99	0
GI1	1998	-1.9	-27.7	16.4	452.6	15.0	38.3	1.1	0.1	7733.3	1022.1	5.9	147.3	103.6	6.6	7.3	5.8	100	0
GI2	1992	-5.0	-23.3	12.5	499.8	10.0	42.1	1.0	0.1	3359.4	425.0	134.0	211.9	17.0	0.0	0.0	0.0	0	1
GI2	1993	-4.1	-21.7	15.3	629.4	10.0	42.1	1.0	0.1	3359.4	425.0	134.0	211.9	17.0	0.0	0.0	0.0	0	1
GI2	1994	-3.9	-31.2	14.5	539.8	10.0	42.1	1.0	0.1	3359.4	425.0	134.0	211.9	17.0	0.0	0.0	0.0	0	1
GI2	1995	-4.4	-21.4	14.0	491.4	10.0	42.1	1.0	0.1	3359.4	425.0	134.0	211.9	17.0	0.0	0.0	0.0	0	1
GI2	1996	-4.7	-28.9	16.6	618.6	10.0	42.1	1.0	0.1	3359.4	425.0	134.0	211.9	17.0	0.0	0.0	0.0	0	1
GI2	1997	-4.1	-26.5	17.8	694.0	10.0	42.1	1.0	0.1	3359.4	425.0	134.0	211.9	17.0	0.0	0.0	0.0	0	1
GI2	1998	-1.9	-27.7	16.4	452.6	10.0	42.1	1.0	0.1	3359.4	425.0	134.0	211.9	17.0	0.0	0.0	0.0	0	1
HID	1992	7.9	-1.3	18.0	726.7	11.0	38.8	1.1	0.1	3945.0	332.1	51.4	341.0	49.4	5.9	26.0	18.1	101	0
HID	1993	6.4	-10.6	16.0	679.2	11.0	38.8	1.1	0.1	3945.0	332.1	51.4	341.0	49.4	5.9	26.0	18.1	102	0
HID	1994	7.7	-0.3	19.8	583.8	11.0	38.8	1.1	0.1	3945.0	332.1	51.4	341.0	49.4	5.9	26.0	18.1	103	0
HID	1995	6.6	-4.1	18.0	587.6	11.0	38.8	1.1	0.1	3945.0	332.1	51.4	341.0	49.4	5.9	26.0	18.1	104	0
HID	1996	4.8	-8.5	18.3	647.4	11.0	38.8	1.1	0.1	3945.0	332.1	51.4	341.0	49.4	5.9	26.0	18.1	105	0
HID	1997	6.6	-5.4	16.9	592.2	11.0	38.8	1.1	0.1	3945.0	332.1	51.4	341.0	49.4	5.9	26.0	18.1	106	0
HID	1998	8.3	-5.8	21.0	430.9	11.0	38.8	1.1	0.1	3945.0	332.1	51.4	341.0	49.4	5.9	26.0	18.1	107	0
INU	1992	-8.9	-28.5	14.2	313.1	6.1	41.7	1.0	0.2	2000.0	478.6	29.1	222.3	38.6	5.2	3.8	3.1	160	0
INU	1993	-6.0	-21.8	15.1	263.7	6.1	41.7	1.0	0.2	2000.0	478.6	29.1	222.3	38.6	5.2	3.8	3.1	161	0
INU	1994	-8.1	-31.9	18.3	348.0	6.1	41.7	1.0	0.2	2000.0	478.6	29.1	222.3	38.6	5.2	3.8	3.1	162	0
INU	1995	-6.8	-23.1	14.4	309.6	6.1	41.7	1.0	0.2	2000.0	478.6	29.1	222.3	38.6	5.2	3.8	3.1	163	0
INU	1996	-8.1	-25.2	14.0	452.5	6.1	41.7	1.0	0.2	2000.0	478.6	29.1	222.3	38.6	5.2	3.8	3.1	164	0
INU	1997	-7.2	-27.9	14.4	315.3	6.1	41.7	1.0	0.2	2000.0	478.6	29.1	222.3	38.6	5.2	3.8	3.1	165	0
INU	1998	-4.5	-31.0	16.9	290.2	6.1	41.7	1.0	0.2	2000.0	478.6	29.1	222.3	38.6	5.2	3.8	3.1	166	0
KAN	1992	4.2	-1.1	12.5	792.5	6.0	38.3	1.2	0.1	3610.0	442.8	8.3	309.6	49.8	5.0	14.4	15.0	90	0
KAN	1993	3.4	-10.6	11.0	843.0	6.0	38.3	1.2	0.1	3610.0	442.8	8.3	309.6	49.8	5.0	14.4	15.0	91	0
KAN	1994	4.0	-5.2	15.4	493.4	6.0	38.3	1.2	0.1	3610.0	442.8	8.3	309.6	49.8	5.0	14.4	15.0	92	0
KAN	1995	3.2	-6.0	14.2	842.1	6.0	38.3	1.2	0.1	3610.0	442.8	8.3	309.6	49.8	5.0	14.4	15.0	93	0
KAN	1996	1.5	-13.3	14.7	639.3	6.0	38.3	1.2	0.1	3610.0	442.8	8.3	309.6	49.8	5.0	14.4	15.0	94	0
KAN	1997	4.1	-9.4	14.6	488.1	6.0	38.3	1.2	0.1	3610.0	442.8	8.3	309.6	49.8	5.0	14.4	15.0	95	0
KAN	1998	4.4	-9.5	16.7	813.7	6.0	38.3	1.2	0.1	3610.0	442.8	8.3	309.6	49.8	5.0	14.4	15.0	96	0

Yearly weather information and initial site condition of CIDET (continued)

Locatior	YEAR	Tair	TJan	Tjul	Ppt	Fdepth	C	N	P	Ca	Mg	S	K	CEC	pH	DBH	Height	Age	UWLand
		°C	°C	°C	mm	cm	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	cmol/kg		cm	m	A	0-u;1-w
MAR	1992	5.1	-11.9	17.7	905.1	4.6	31.6	1.1	0.1	1715.6	210.2	15.2	239.5	25.2	4.0	33.5	25.0	150	0
MAR	1993	5.1	-8.9	21.0	1089.1	4.6	31.6	1.1	0.1	1715.6	210.2	15.2	239.5	25.2	4.0	33.5	25.0	151	0
MAR	1994	5.5	-17.7	21.3	950.2	4.6	31.6	1.1	0.1	1715.6	210.2	15.2	239.5	25.2	4.0	33.5	25.0	152	0
MAR	1995	6.3	-6.5	21.7	976.5	4.6	31.6	1.1	0.1	1715.6	210.2	15.2	239.5	25.2	4.0	33.5	25.0	153	0
MAR	1996	6.2	-11.5	19.9	1175.1	4.6	31.6	1.1	0.1	1715.6	210.2	15.2	239.5	25.2	4.0	33.5	25.0	154	0
MAR	1997	5.8	-10.3	19.4	1139.3	4.6	31.6	1.1	0.1	1715.6	210.2	15.2	239.5	25.2	4.0	33.5	25.0	155	0
MAR	1998	6.2	-10.8	20.2	1099.2	4.6	31.6	1.1	0.1	1715.6	210.2	15.2	239.5	25.2	4.0	33.5	25.0	156	0
NH1	1992	-3.4	-21.4	13.5	416.4	1.0	30.7	0.5	0.1	780.0	103.6	8.8	149.3	22.1	4.8	9.9	10.1	60	0
NH1	1993	-3.3	-22.4	15.3	468.4	1.0	30.7	0.5	0.1	780.0	103.6	8.8	149.3	22.1	4.8	9.9	10.1	61	0
NH1	1994	-3.1	-30.8	15.1	413.2	1.0	30.7	0.5	0.1	780.0	103.6	8.8	149.3	22.1	4.8	9.9	10.1	62	0
NH1	1995	-3.4	-20.9	13.6	511.4	1.0	30.7	0.5	0.1	780.0	103.6	8.8	149.3	22.1	4.8	9.9	10.1	63	0
NH1	1996	-4.2	-28.4	16.8	517.1	1.0	30.7	0.5	0.1	780.0	103.6	8.8	149.3	22.1	4.8	9.9	10.1	64	0
NH1	1997	-3.1	-25.9	17.6	583.8	1.0	30.7	0.5	0.1	780.0	103.6	8.8	149.3	22.1	4.8	9.9	10.1	65	0
NH1	1998	-1.0	-25.5	16.8	448.9	1.0	30.7	0.5	0.1	780.0	103.6	8.8	149.3	22.1	4.8	9.9	10.1	66	0
NH2	1992	-3.4	-21.4	13.5	416.4	10.0	43.4	0.9	0.1	3013.1	809.5	10.4	617.1	45.3	4.8	0.0	0.0	0	1
NH2	1993	-3.3	-22.4	15.3	468.4	10.0	43.4	0.9	0.1	3013.1	809.5	10.4	617.1	45.3	4.8	0.0	0.0	0	1
NH2	1994	-3.1	-30.8	15.1	413.2	10.0	43.4	0.9	0.1	3013.1	809.5	10.4	617.1	45.3	4.8	0.0	0.0	0	1
NH2	1995	-3.4	-20.9	13.6	511.4	10.0	43.4	0.9	0.1	3013.1	809.5	10.4	617.1	45.3	4.8	0.0	0.0	0	1
NH2	1996	-4.2	-28.4	16.8	517.1	10.0	43.4	0.9	0.1	3013.1	809.5	10.4	617.1	45.3	4.8	0.0	0.0	0	1
NH2	1997	-3.1	-25.9	17.6	583.8	10.0	43.4	0.9	0.1	3013.1	809.5	10.4	617.1	45.3	4.8	0.0	0.0	0	1
NH2	1998	-1.0	-25.5	16.8	448.9	10.0	43.4	0.9	0.1	3013.1	809.5	10.4	617.1	45.3	4.8	0.0	0.0	0	1
PAL	1992	1.7	-13.4	16.1	349.9	2.5	28.1	0.6	0.1	2259.0	315.9	31.7	157.0	26.7	6.2	15.2	12.0	65	0
PAL	1993	1.6	-20.4	15.7	419.3	2.5	28.1	0.6	0.1	2259.0	315.9	31.7	157.0	26.7	6.2	15.2	12.0	66	0
PAL	1994	0.9	-23.3	17.3	515.2	2.5	28.1	0.6	0.1	2259.0	315.9	31.7	157.0	26.7	6.2	15.2	12.0	67	0
PAL	1995	0.6	-16.8	17.0	429.2	2.5	28.1	0.6	0.1	2259.0	315.9	31.7	157.0	26.7	6.2	15.2	12.0	68	0
PAL	1996	-0.7	-24.6	17.6	426.2	2.5	28.1	0.6	0.1	2259.0	315.9	31.7	157.0	26.7	6.2	15.2	12.0	69	0
PAL	1997	1.9	-23.0	18.6	435.6	2.5	28.1	0.6	0.1	2259.0	315.9	31.7	157.0	26.7	6.2	15.2	12.0	70	0
PAL	1998	2.9	-19.3	18.4	411.8	2.5	28.1	0.6	0.1	2259.0	315.9	31.7	157.0	26.7	6.2	15.2	12.0	71	0
PMC	1992	9.1	5.3	14.5	1903.5	9.3	47.0	1.1	0.1	748.4	298.3	35.1	134.0	30.8	3.5	40.0	42.5	85	0
PMC	1993	8.6	0.7	14.2	1501.2	9.3	47.0	1.1	0.1	748.4	298.3	35.1	134.0	30.8	3.5	40.0	42.5	86	0
PMC	1994	8.8	6.4	14.3	2181.6	9.3	47.0	1.1	0.1	748.4	298.3	35.1	134.0	30.8	3.5	40.0	42.5	87	0
PMC	1995	9.0	4.5	14.6	1851.6	9.3	47.0	1.1	0.1	748.4	298.3	35.1	134.0	30.8	3.5	40.0	42.5	88	0
PMC	1996	8.0	2.8	13.7	2040.1	9.3	47.0	1.1	0.1	748.4	298.3	35.1	134.0	30.8	3.5	40.0	42.5	89	0
PMC	1997	9.2	3.4	14.8	2551.5	9.3	47.0	1.1	0.1	748.4	298.3	35.1	134.0	30.8	3.5	40.0	42.5	90	0
PMC	1998	9.1	3.5	14.8	1778.3	9.3	47.0	1.1	0.1	748.4	298.3	35.1	134.0	30.8	3.5	40.0	42.5	91	0
SCH	1992	-4.6	-22.1	11.6	777.2	4.3	36.6	0.8	0.1	198.8	107.1	1.9	152.9	12.1	4.9	12.2	6.8	78	0
SCH	1993	-3.4	-20.8	16.1	651.4	4.3	36.6	0.8	0.1	198.8	107.1	1.9	152.9	12.1	4.9	12.2	6.8	79	0
SCH	1994	-3.3	-30.5	13.8	568.8	4.3	36.6	0.8	0.1	198.8	107.1	1.9	152.9	12.1	4.9	12.2	6.8	80	0
SCH	1995	-2.5	-19.6	13.2	652.6	4.3	36.6	0.8	0.1	198.8	107.1	1.9	152.9	12.1	4.9	12.2	6.8	81	0
SCH	1996	-2.7	-25.1	15.5	645.6	4.3	36.6	0.8	0.1	198.8	107.1	1.9	152.9	12.1	4.9	12.2	6.8	82	0
SCH	1997	-3.0	-22.6	16.0	582.0	4.3	36.6	0.8	0.1	198.8	107.1	1.9	152.9	12.1	4.9	12.2	6.8	83	0
SCH	1998	-0.3	-21.3	14.5	587.6	4.3	36.6	0.8	0.1	198.8	107.1	1.9	152.9	12.1	4.9	12.2	6.8	84	0
SHL	1992	10.8	4.8	18.0	1118.3	5.1	41.2	0.8	0.1	4313.3	365.3	18.7	462.7	38.7	5.1	16.4	18.2	42	0
SHL	1993	9.7	-0.6	16.1	913.0	5.1	41.2	0.8	0.1	4313.3	365.3	18.7	462.7	38.7	5.1	16.4	18.2	43	0
SHL	1994	10.2	6.0	18.6	1267.8	5.1	41.2	0.8	0.1	4313.3	365.3	18.7	462.7	38.7	5.1	16.4	18.2	44	0
SHL	1995	10.5	3.4	18.4	1432.3	5.1	41.2	0.8	0.1	4313.3	365.3	18.7	462.7	38.7	5.1	16.4	18.2	45	0
SHL	1996	9.2	2.6	18.5	1362.5	5.1	41.2	0.8	0.1	4313.3	365.3	18.7	462.7	38.7	5.1	16.4	18.2	46	0
SHL	1997	10.2	2.6	17.6	1630.1	5.1	41.2	0.8	0.1	4313.3	365.3	18.7	462.7	38.7	5.1	16.4	18.2	47	0
SHL	1998	10.6	3.2	19.0	1489.2	5.1	41.2	0.8	0.1	4313.3	365.3	18.7	462.7	38.7	5.1	16.4	18.2	48	0

Yearly weather information and initial site condition of CIDET (continued)

Locatior	YEAR	Tair	TJan	Tjul	Ppt	Fdepth	C	N	P	Ca	Mg	S	K	CEC	pH	DBH	Height	Age	UWLand
		°C	°C	°C	mm	cm	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	cmol/kg		cm	m	A	0-u;1-w
TER	1992	3.5	-9.6	17.4	369.8	5.8	15.0	0.9	0.1	3785.0	818.5	33.3	267.1	45.9	7.0	8.5	8.7	37	0
TER	1993	3.1	-17.9	16.5	383.9	5.8	15.0	0.9	0.1	3785.0	818.5	33.3	267.1	45.9	7.0	8.5	8.7	38	0
TER	1994	3.3	-19.1	18.9	403.4	5.8	15.0	0.9	0.1	3785.0	818.5	33.3	267.1	45.9	7.0	8.5	8.7	39	0
TER	1995	2.8	-13.5	18.3	370.1	5.8	15.0	0.9	0.1	3785.0	818.5	33.3	267.1	45.9	7.0	8.5	8.7	40	0
TER	1996	1.2	-21.2	19.1	401.1	5.8	15.0	0.9	0.1	3785.0	818.5	33.3	267.1	45.9	7.0	8.5	8.7	41	0
TER	1997	4.2	-19.8	20.0	372.8	5.8	15.0	0.9	0.1	3785.0	818.5	33.3	267.1	45.9	7.0	8.5	8.7	42	0
TER	1998	5.2	-16.0	20.2	350.0	5.8	15.0	0.9	0.1	3785.0	818.5	33.3	267.1	45.9	7.0	8.5	8.7	43	0
TOP	1992	4.1	-3.8	15.2	456.8	8.0	39.7	1.1	0.2	2315.0	364.6	8.2	300.8	23.5	4.8	23.5	21.8	5	0
TOP	1993	3.6	-17.7	13.8	558.7	8.0	39.7	1.1	0.2	2315.0	364.6	8.2	300.8	23.5	4.8	23.5	21.8	6	0
TOP	1994	3.6	-6.5	15.9	589.8	8.0	39.7	1.1	0.2	2315.0	364.6	8.2	300.8	23.5	4.8	23.5	21.8	7	0
TOP	1995	3.3	-10.4	14.1	580.8	8.0	39.7	1.1	0.2	2315.0	364.6	8.2	300.8	23.5	4.8	23.5	21.8	8	0
TOP	1996	0.8	-16.9	13.6	633.7	8.0	39.7	1.1	0.2	2315.0	364.6	8.2	300.8	23.5	4.8	23.5	21.8	9	0
TOP	1997	3.8	-12.7	14.0	649.2	8.0	39.7	1.1	0.2	2315.0	364.6	8.2	300.8	23.5	4.8	23.5	21.8	10	0
TOP	1998	4.4	-10.7	16.7	516.9	8.0	39.7	1.1	0.2	2315.0	364.6	8.2	300.8	23.5	4.8	23.5	21.8	11	0
WHI	1992	0.0	-8.2	14.2	325.8	5.0	33.0	1.2	0.1	3901.3	447.1	12.7	224.9	45.0	5.6	12.0	10.3	103	0
WHI	1993	1.3	-17.7	14.4	299.1	5.0	33.0	1.2	0.1	3901.3	447.1	12.7	224.9	45.0	5.6	12.0	10.3	104	0
WHI	1994	-0.4	-17.0	15.5	330.9	5.0	33.0	1.2	0.1	3901.3	447.1	12.7	224.9	45.0	5.6	12.0	10.3	105	0
WHI	1995	-3.5	-14.9	15.4	280.1	5.0	33.0	1.2	0.1	3901.3	447.1	12.7	224.9	45.0	5.6	12.0	10.3	106	0
WHI	1996	-0.4	-10.8	13.8	304.6	5.0	33.0	1.2	0.1	3901.3	447.1	12.7	224.9	45.0	5.6	12.0	10.3	107	0
WHI	1997	0.9	-21.0	15.4	260.8	5.0	33.0	1.2	0.1	3901.3	447.1	12.7	224.9	45.0	5.6	12.0	10.3	108	0
WHI	1998	0.3	-19.6	14.8	167.5	5.0	33.0	1.2	0.1	3901.3	447.1	12.7	224.9	45.0	5.6	12.0	10.3	109	0
BAT	1992	1.7	-13.4	16.1	349.9	10.0	24.4	0.8	0.1	6302.5	1051.3	65.9	164.5	48.9	4.3	0.0	0.0	0	1
BAT	1993	1.6	-20.4	15.7	419.3	10.0	24.4	0.8	0.1	6302.5	1051.3	65.9	164.5	48.9	4.3	0.0	0.0	0	1
BAT	1994	0.9	-23.3	17.3	515.2	10.0	24.4	0.8	0.1	6302.5	1051.3	65.9	164.5	48.9	4.3	0.0	0.0	0	1
BAT	1995	0.6	-16.8	17.0	429.2	10.0	24.4	0.8	0.1	6302.5	1051.3	65.9	164.5	48.9	4.3	0.0	0.0	0	1
BAT	1996	-0.7	-24.6	17.6	426.2	10.0	24.4	0.8	0.1	6302.5	1051.3	65.9	164.5	48.9	4.3	0.0	0.0	0	1
BAT	1997	1.9	-23.0	18.6	435.6	10.0	24.4	0.8	0.1	6302.5	1051.3	65.9	164.5	48.9	4.3	0.0	0.0	0	1
BAT	1998	2.9	-19.3	18.4	411.8	10.0	24.4	0.8	0.1	6302.5	1051.3	65.9	164.5	48.9	4.3	0.0	0.0	0	1
CBR	1992	2.4	-6.5	16.0	715.7	8.2	43.2	1.2	0.1	2148.8	436.9	54.7	212.5	39.1	4.3	5.3	9.0	36	0
CBR	1993	2.4	-7.9	16.0	791.5	8.2	43.2	1.2	0.1	2148.8	436.9	54.7	212.5	39.1	4.3	5.3	9.0	37	0
CBR	1994	1.7	-7.2	16.0	872.6	8.2	43.2	1.2	0.1	2148.8	436.9	54.7	212.5	39.1	4.3	5.3	9.0	38	0
CBR	1995	1.5	-5.6	16.8	791.4	8.2	43.2	1.2	0.1	2148.8	436.9	54.7	212.5	39.1	4.3	5.3	9.0	39	0
CBR	1996	0.2	-6.0	16.3	801.2	8.2	43.2	1.2	0.1	2148.8	436.9	54.7	212.5	39.1	4.3	5.3	9.0	40	0
CBR	1997	2.8	-4.8	16.8	727.0	8.2	43.2	1.2	0.1	2148.8	436.9	54.7	212.5	39.1	4.3	5.3	9.0	41	0
CBR	1998	3.6	-5.0	18.0	779.8	8.2	43.2	1.2	0.1	2148.8	436.9	54.7	212.5	39.1	4.3	5.3	9.0	42	0
MON	1992	3.3	-14.1	15.1	1492.9	2.3	42.0	0.9	0.2	476.3	102.3	26.0	155.0	23.3	4.0	14.3	8.9	39	0
MON	1993	3.5	-14.5	15.1	1063.0	2.3	42.0	0.9	0.2	476.3	102.3	26.0	155.0	23.3	4.0	14.3	8.9	40	0
MON	1994	4.1	-19.7	15.7	1641.6	2.3	42.0	0.9	0.2	476.3	102.3	26.0	155.0	23.3	4.0	14.3	8.9	41	0
MON	1995	4.8	-10.1	16.3	1676.4	2.3	42.0	0.9	0.2	476.3	102.3	26.0	155.0	23.3	4.0	14.3	8.9	42	0
MON	1996	5.8	-14.1	14.6	1559.1	2.3	42.0	0.9	0.2	476.3	102.3	26.0	155.0	23.3	4.0	14.3	8.9	43	0
MON	1997	4.1	-13.9	14.8	1438.6	2.3	42.0	0.9	0.2	476.3	102.3	26.0	155.0	23.3	4.0	14.3	8.9	44	0
MON	1998	6.0	-10.8	14.7	1704.3	2.3	42.0	0.9	0.2	476.3	102.3	26.0	155.0	23.3	4.0	14.3	8.9	45	0
PET	1992	0.5	-12.0	16.6	1904.0	5.5	41.9	1.2	0.1	2868.6	327.5	64.3	709.5	30.8	4.1	16.9	13.7	53	0
PET	1993	0.7	-10.7	20.2	2175.9	5.5	41.9	1.2	0.1	2868.6	327.5	64.3	709.5	30.8	4.1	16.9	13.7	54	0
PET	1994	0.9	-17.8	20.0	2037.4	5.5	41.9	1.2	0.1	2868.6	327.5	64.3	709.5	30.8	4.1	16.9	13.7	55	0
PET	1995	1.6	-6.7	20.2	2032.3	5.5	41.9	1.2	0.1	2868.6	327.5	64.3	709.5	30.8	4.1	16.9	13.7	56	0
PET	1996	1.5	-11.4	18.9	2136.4	5.5	41.9	1.2	0.1	2868.6	327.5	64.3	709.5	30.8	4.1	16.9	13.7	57	0
PET	1997	0.8	-11.5	20.0	1798.8	5.5	41.9	1.2	0.1	2868.6	327.5	64.3	709.5	30.8	4.1	16.9	13.7	58	0
PET	1998	3.0	-7.5	19.7	1880.0	5.5	41.9	1.2	0.1	2868.6	327.5	64.3	709.5	30.8	4.1	16.9	13.7	59	0

APPENDIX V. ACTUAL DATA, AND STEP 2 MODEL SIMULATED RESULTS
(Bag weight; N concentration and C/N ratio)

Actual litterbag weight (g) and simulated weight (g)

Location	Year	Aspena	Aspenp	Beecha	Beechp	Bferna	BFernp	Sprucea	Sprucep	Dfira	DFirp	Fescua	Fescup	Jpinea	JPinep	Tama	Tamp	Bircha	Birchp	Cedara	Cedarp
CHA	1992	10.00	9.72	10.00	9.97	10.00	9.97	10.00	9.72	10.00	9.97	10.00	9.97	10.00	9.97	10.00	9.97	10.00	9.97	10.00	9.97
CHA	1993	6.11	6.27	7.90	7.61	7.63	7.62	6.77	7.46	8.10	7.94	4.86	4.76	6.79	7.17	7.56	7.38	6.61	6.44	8.56	8.21
CHA	1994	6.02	5.39	7.73	6.44	6.24	6.48	5.68	6.02	7.08	6.68	4.28	4.14	5.48	5.63	6.90	6.12	5.51	5.10	7.84	6.93
CHA	1995	4.70	4.71	6.19	5.55	3.59	5.61	4.05	4.96	6.24	5.73	3.82	3.66	4.59	4.52	5.49	5.18	2.64	4.13	6.44	5.96
CHA	1996	3.09	4.17	4.50	4.85	3.34	4.94	2.63	4.17	4.05	4.99	2.75	3.28	3.34	3.70	4.69	4.45	2.11	3.41	4.70	5.20
CHA	1997	3.12	3.77	3.92	4.35	3.50	4.45	2.62	3.62	3.58	4.45	2.91	2.99	3.77	3.16	3.80	3.94	2.56	2.92	4.88	4.65
CHA	1998	3.53	3.43	3.27	3.91	2.85	4.03	2.36	3.17	3.25	3.99	2.51	2.74	2.92	2.73	2.64	3.50	2.15	2.52	3.43	4.17
GAN	1992	10.00	9.98	10.00	9.98	10.00	9.98	10.00	9.98	10.00	9.98	10.00	9.99	10.00	9.99	10.00	9.98	10.00	9.99	10.00	9.98
GAN	1993	6.83	6.42	8.23	7.80	7.72	7.80	7.12	7.71	8.12	8.15	4.79	4.87	7.12	7.44	7.82	7.59	6.15	6.67	8.72	8.41
GAN	1994	6.35	5.57	7.51	6.68	7.07	6.70	5.77	6.32	6.96	6.94	4.37	4.28	6.16	5.95	7.06	6.38	4.88	5.39	8.19	7.20
GAN	1995	5.46	4.76	6.31	5.61	4.72	5.66	4.07	5.05	5.22	5.80	3.94	3.70	4.80	4.61	4.83	5.26	3.62	4.23	6.96	6.04
GAN	1996	4.45	4.14	5.64	4.81	5.00	4.88	2.96	4.14	3.79	4.94	4.03	3.26	4.04	3.67	3.79	4.42	3.57	3.40	5.54	5.16
GAN	1997	3.81	3.66	4.53	4.20	4.11	4.29	2.97	3.49	3.66	4.30	2.72	2.91	4.00	3.03	3.63	3.81	3.09	2.82	4.32	4.50
GAN	1998	3.10	3.27	4.60	3.72	3.81	3.81	2.67	2.99	3.17	3.79	3.11	2.63	3.88	2.56	3.53	3.32	3.44	2.38	3.97	3.96
GI1	1992	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.99
GI1	1993	7.77	6.88	8.45	8.36	8.23	8.34	8.43	8.40	8.97	8.73	5.94	5.27	8.45	8.18	8.57	8.20	7.62	7.34	9.14	8.99
GI1	1994	7.56	6.33	8.46	7.68	8.36	7.68	8.30	7.55	8.91	8.01	5.42	4.81	8.26	7.27	8.37	7.46	7.30	6.52	9.39	8.28
GI1	1995	7.19	6.01	8.17	7.26	7.85	7.27	7.70	7.03	8.77	7.56	4.31	4.58	7.85	6.70	7.99	7.00	6.88	6.03	9.12	7.82
GI1	1996	6.79	5.64	7.84	6.76	7.10	6.79	6.94	6.43	8.23	7.03	4.03	4.32	7.60	6.05	7.77	6.48	6.41	5.47	8.80	7.29
GI1	1997	5.91	5.16	7.37	6.13	6.15	6.18	6.41	5.67	6.28	6.35	3.83	3.98	6.81	5.25	5.28	5.81	5.25	4.77	9.92	6.60
GI1	1998	5.96	4.80	7.20	5.67	5.86	5.73	5.54	5.12	6.55	5.86	3.83	3.73	5.78	4.67	7.17	5.32	5.25	4.27	8.11	6.10
GI2	1992	10.00	9.99	10.00	9.98	10.00	9.98	10.00	9.98	10.00	9.98	10.00	9.99	10.00	9.98	10.00	9.98	10.00	9.98	10.00	9.98
GI2	1993	7.26	6.88	7.87	8.35	7.49	8.33	7.49	8.39	8.58	8.72	6.03	5.27	8.13	8.17	7.67	8.19	6.67	7.32	8.91	8.98
GI2	1994	7.07	6.32	8.10	7.67	7.68	7.67	7.36	7.54	7.96	8.00	5.03	4.80	8.04	7.25	7.90	7.45	6.24	6.51	9.03	8.27
GI2	1995	6.20	6.00	6.86	7.25	7.22	7.26	6.52	7.02	7.57	7.55	4.63	4.58	7.21	6.69	6.55	6.99	5.12	6.02	8.21	7.81
GI2	1996	5.25	5.63	6.04	6.75	6.50	6.78	5.70	6.42	6.43	7.02	4.14	4.32	6.09	6.04	6.05	6.47	4.62	5.47	7.82	7.27
GI2	1997	5.40	5.15	5.73	6.12	6.81	6.16	5.18	5.66	5.53	6.34	3.80	3.98	5.46	5.23	5.22	5.80	4.33	4.77	7.20	6.59
GI2	1998	4.86	4.79	4.87	5.66	6.48	5.71	4.82	5.11	4.68	5.85	4.07	3.73	5.16	4.66	5.19	5.31	4.19	4.27	5.27	6.08
HID	1992	10.00	9.95	10.00	9.93	10.00	9.94	10.00	9.93	10.00	9.93	10.00	9.96	10.00	9.93	10.00	9.93	10.00	9.94	10.00	9.93
HID	1993	6.33	6.11	7.88	7.39	7.48	7.40	6.08	7.19	8.10	7.70	5.61	4.65	6.83	6.89	7.42	7.14	6.39	6.19	8.24	7.96
HID	1994	5.42	5.28	7.60	6.29	5.97	6.33	5.45	5.86	6.26	6.53	4.40	4.07	5.93	5.45	7.20	5.97	4.06	4.96	7.58	6.77
HID	1995	4.68	4.58	7.21	5.38	5.78	5.45	5.38	4.79	5.06	5.56	4.01	3.58	4.93	4.34	5.91	5.02	4.22	3.98	6.73	5.79
HID	1996	5.10	4.09	5.93	4.74	4.33	4.83	3.72	4.07	5.14	4.88	3.47	3.22	3.66	3.60	5.65	4.35	2.87	3.32	5.22	5.09
HID	1997	3.59	3.70	4.30	4.26	3.28	4.36	2.19	3.54	3.93	4.36	3.46	2.94	3.06	3.08	4.27	3.86	2.56	2.85	4.68	4.55
HID	1998	4.07	3.41	4.22	3.89	3.69	4.00	1.90	3.16	3.00	3.97	2.52	2.73	2.77	2.72	3.31	3.49	2.01	2.52	3.99	4.15
INU	1992	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
INU	1993	8.39	8.89	8.70	9.51	8.38	9.50	8.79	9.58	8.90	9.67	8.33	8.21	8.79	9.50	8.96	9.48	8.30	9.13	8.93	9.77
INU	1994	8.74	8.03	9.09	9.10	8.95	9.08	9.09	9.21	9.40	9.36	7.35	6.88	9.09	9.06	8.99	9.04	8.44	8.43	9.59	9.55
INU	1995	7.92	7.43	8.87	8.76	8.64	8.74	8.64	8.86	9.20	9.09	6.31	5.99	8.64	8.67	8.69	8.66	7.85	7.90	9.77	9.32
INU	1996	7.48	6.90	8.41	8.36	7.83	8.34	8.08	8.40	8.51	8.72	5.12	5.31	8.08	8.17	8.15	8.20	7.06	7.34	8.86	8.98
INU	1997	7.64	6.63	8.66	8.07	8.23	8.06	8.07	8.05	8.82	8.42	4.89	5.05	8.07	7.79	8.27	7.89	7.71	6.98	8.96	8.69
INU	1998	7.24	6.59	8.46	8.01	8.04	8.00	7.79	7.98	8.46	8.36	4.69	5.01	7.79	7.71	8.41	7.83	7.11	6.91	9.01	8.63
KAN	1992	10.00	9.93	10.00	9.90	10.00	9.90	10.00	9.88	10.00	9.89	10.00	9.95	10.00	9.87	10.00	9.89	10.00	9.89	10.00	9.89
KAN	1993	7.20	6.38	8.56	7.75	7.96	7.75	7.66	7.64	8.71	8.09	5.71	4.85	7.60	7.37	8.31	7.53	6.97	6.60	8.91	8.36
KAN	1994	6.57	5.76	8.38	6.92	8.24	6.95	7.14	6.61	7.96	7.20	4.91	4.41	7.05	6.26	8.08	6.64	7.18	5.65	8.80	7.46
KAN	1995	6.70	5.15	7.71	6.12	7.18	6.17	5.66	5.65	7.12	6.34	4.20	3.98	6.21	5.23	7.07	5.79	4.95	4.76	8.08	6.59
KAN	1996	5.88	4.62	7.35	5.43	6.47	5.50	5.64	4.84	6.39	5.61	3.77	3.60	5.19	4.39	6.88	5.06	5.76	4.02	7.53	5.84
KAN	1997	5.06	4.30	6.43	5.02	5.06	5.10	3.76	4.37	5.26	5.17	3.57	3.38	5.02	3.91	5.02	4.64	4.46	3.60	6.80	5.39
KAN	1998	4.08	3.95	5.72	4.57	5.63	4.66	3.62	3.87	3.99	4.69	2.79	3.12	4.35	3.41	4.86	4.17	2.71	3.15	5.13	4.89

Note: Aspen-Trembling aspen; Cedar-Western red cedar; Fescu-Plains rough fescue; Beech-American beech
Birch-White birch; Bfern-Bracken fern; Dfir-Douglas fir; Jpine-Jack pine; Spruce-Black spruce; Tam-Tamarack

a--is actual data
p--is simulated data

Actual litterbag weight (g) and simulated weight (g) (continued)

Location	Year	Aspena	Aspenp	Beecha	Beechp	Bferna	BFernp	Sprucea	Sprucep	Dfira	DFirp	Fescua	Fescup	Jpinea	JPinep	Tama	Tamp	Bircha	Birchp	Cedara	Cedarp
MAR	1992	10.00	9.97	10.00	9.96	10.00	9.96	10.00	9.96	10.00	9.96	10.00	9.98	10.00	9.97	10.00	9.96	10.00	9.97	10.00	9.96
MAR	1993	6.04	5.79	7.03	6.97	7.32	7.00	6.67	6.67	7.69	7.25	4.58	4.43	7.44	6.33	7.53	6.69	5.65	5.71	8.23	7.51
MAR	1994	5.12	4.65	5.99	5.47	5.76	5.54	5.58	4.86	6.14	5.64	3.16	3.62	6.37	4.42	6.70	5.09	3.91	4.05	7.66	5.87
MAR	1995	3.06	3.85	4.55	4.44	4.16	4.55	3.84	3.71	4.40	4.55	2.80	3.05	4.17	3.26	4.38	4.03	2.75	3.01	6.55	4.75
MAR	1996	2.20	3.29	4.16	3.74	3.06	3.88	2.35	2.99	2.20	3.82	2.01	2.65	3.66	2.57	4.21	3.32	1.67	2.36	5.17	3.98
MAR	1997	2.92	2.93	1.94	3.30	1.84	3.45	1.79	2.57	1.72	3.35	2.06	2.38	2.95	2.19	1.40	2.89	3.25	2.00	4.08	3.49
MAR	1998	1.77	2.64	2.42	2.95	2.10	3.11	1.94	2.26	1.98	2.99	1.85	2.17	2.40	1.93	3.11	2.56	1.67	1.74	3.68	3.10
NH1	1992	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
NH1	1993	7.41	7.20	8.43	8.62	8.13	8.60	8.17	8.70	8.69	8.98	5.93	5.66	8.05	8.51	8.40	8.49	7.18	7.69	8.97	9.22
NH1	1994	7.23	6.69	8.54	8.14	8.06	8.13	7.98	8.12	8.78	8.50	5.03	5.09	7.65	7.88	8.38	7.95	7.32	7.06	9.14	8.76
NH1	1995	7.43	6.39	8.50	7.76	7.67	7.76	7.53	7.65	8.50	8.10	4.66	4.86	7.24	7.37	8.15	7.54	6.79	6.61	8.96	8.36
NH1	1996	6.31	6.02	7.43	7.27	7.43	7.29	6.92	7.05	7.96	7.57	4.34	4.59	6.67	6.72	7.59	7.02	6.51	6.04	8.60	7.84
NH1	1997	5.04	5.62	6.73	6.74	4.81	6.77	5.79	6.39	6.43	7.00	4.33	4.31	6.07	6.01	6.66	6.44	5.65	5.43	7.86	7.25
NH1	1998	5.57	5.27	7.08	6.28	4.99	6.33	5.44	5.83	6.11	6.51	3.95	4.06	5.00	5.42	6.33	5.95	4.07	4.92	7.60	6.75
NH2	1992	10.00	9.99	10.00	9.98	10.00	9.98	10.00	9.98	10.00	9.98	10.00	9.99	10.00	9.98	10.00	9.98	10.00	9.98	10.00	9.98
NH2	1993	7.16	7.19	8.06	8.60	7.87	8.58	7.20	8.68	8.29	8.96	5.86	5.66	7.88	8.49	8.14	8.47	7.20	7.67	9.27	9.21
NH2	1994	6.41	6.67	8.12	8.12	8.00	8.11	6.49	8.10	8.17	8.48	5.40	5.08	7.28	7.86	8.01	7.93	6.64	7.04	9.03	8.74
NH2	1995	5.99	6.37	7.84	7.74	7.68	7.74	6.63	7.63	7.40	8.08	4.67	4.84	6.78	7.35	6.83	7.52	5.67	6.59	8.57	8.34
NH2	1996	4.97	6.00	7.36	7.25	7.27	7.26	6.19	7.03	7.12	7.55	4.66	4.58	6.55	6.69	7.44	7.00	5.58	6.03	8.23	7.81
NH2	1997	4.69	5.59	6.35	6.71	7.05	6.73	5.64	6.37	6.42	6.97	3.57	4.29	5.35	5.99	6.81	6.42	5.22	5.42	7.79	7.23
NH2	1998	4.63	5.24	5.47	6.24	7.00	6.28	5.25	5.81	4.85	6.47	3.47	4.04	6.37	5.39	6.43	5.93	4.49	4.90	7.47	6.72
PAL	1992	10.00	9.98	10.00	9.98	10.00	9.98	10.00	9.97	10.00	9.97	10.00	9.99	10.00	9.97	10.00	9.98	10.00	9.98	10.00	9.97
PAL	1993	7.70	7.09	8.92	8.53	8.52	8.51	8.35	8.60	9.12	8.89	6.34	5.53	8.47	8.40	8.92	8.39	7.90	7.56	9.34	9.14
PAL	1994	7.53	6.49	8.34	7.89	8.15	7.89	7.83	7.81	8.64	8.24	4.87	4.93	7.86	7.55	8.42	7.68	7.21	6.76	9.21	8.51
PAL	1995	6.56	6.03	8.31	7.29	7.39	7.31	7.05	7.07	8.37	7.59	4.26	4.60	7.35	6.74	7.98	7.03	6.64	6.07	8.93	7.86
PAL	1996	6.39	5.70	7.68	6.85	6.16	6.88	5.64	6.52	7.65	7.12	4.28	4.37	6.44	6.15	7.44	6.56	6.67	5.56	8.45	7.37
PAL	1997	5.23	5.42	7.18	6.47	5.61	6.52	5.10	6.07	6.88	6.72	3.69	4.17	6.30	5.67	7.48	6.16	5.18	5.14	7.24	6.97
PAL	1998	5.51	5.12	6.67	6.09	4.86	6.15	4.65	5.61	6.96	6.31	3.49	3.96	5.35	5.18	6.32	5.75	4.89	4.71	7.64	6.55
PMC	1992	10.00	9.95	10.00	9.93	10.00	9.94	10.00	9.93	10.00	9.93	10.00	9.96	10.00	9.93	10.00	9.93	10.00	9.94	10.00	9.93
PMC	1993	5.62	6.07	7.11	7.35	7.06	7.35	5.85	7.14	6.43	7.65	4.67	4.63	6.35	6.83	6.28	7.09	4.97	6.15	7.42	7.92
PMC	1994	5.08	5.19	5.68	6.17	6.01	6.21	3.66	5.71	5.87	6.40	3.65	4.00	4.20	5.31	4.77	5.84	3.64	4.83	5.12	6.64
PMC	1995	4.50	4.48	5.24	5.25	5.54	5.31	2.93	4.64	4.75	5.42	3.12	3.50	2.99	4.19	3.36	4.88	2.79	3.85	3.77	5.64
PMC	1996	4.04	3.96	4.45	4.58	5.39	4.65	2.68	3.89	3.58	4.70	2.94	3.13	2.98	3.43	3.76	4.19	3.02	3.18	3.69	4.91
PMC	1997	4.15	3.54	4.26	4.05	5.84	4.14	2.98	3.34	3.85	4.15	2.30	2.83	3.29	2.88	4.14	3.66	2.62	2.69	3.33	4.34
PMC	1998	3.85	3.19	3.83	3.61	4.17	3.71	2.21	2.90	3.63	3.69	3.26	2.57	2.72	2.47	2.98	3.23	1.85	2.30	2.76	3.85
SCH	1992	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.99
SCH	1993	7.17	6.60	8.38	8.05	7.99	8.04	7.50	8.01	8.37	8.40	5.82	5.01	7.83	7.77	8.00	7.85	6.60	6.95	8.78	8.67
SCH	1994	6.83	6.08	7.80	7.36	8.01	7.37	6.83	7.15	8.07	7.67	5.41	4.64	7.49	6.84	7.79	7.11	6.32	6.15	8.80	7.93
SCH	1995	6.22	5.71	7.59	6.86	6.84	6.88	5.42	6.54	6.81	7.13	4.91	4.37	6.67	6.18	7.19	6.57	4.63	5.58	8.22	7.39
SCH	1996	5.66	5.28	6.90	6.29	5.26	6.33	4.85	5.85	6.94	6.52	4.42	4.07	5.77	5.45	7.01	5.97	3.75	4.95	7.50	6.77
SCH	1997	4.95	4.90	5.11	5.79	4.69	5.85	4.70	5.27	5.05	5.99	4.36	3.80	5.52	4.83	6.65	5.45	4.00	4.41	6.47	6.23
SCH	1998	5.11	4.59	4.66	5.39	4.62	5.46	3.83	4.80	5.29	5.56	4.23	3.58	5.99	4.34	6.41	5.03	2.85	3.98	5.33	5.79
SHL	1992	10.00	9.95	10.00	9.94	10.00	9.94	10.00	9.94	10.00	9.93	10.00	9.96	10.00	9.94	10.00	9.94	10.00	9.94	10.00	9.93
SHL	1993	5.24	5.81	6.73	6.99	6.72	7.01	5.58	6.70	6.25	7.27	4.27	4.44	6.05	6.36	6.52	6.71	4.13	5.74	7.37	7.53
SHL	1994	4.46	4.78	5.44	5.64	5.84	5.70	4.01	5.08	4.90	5.83	3.26	3.72	4.51	4.65	6.18	5.28	3.46	4.25	6.60	6.07
SHL	1995	4.10	3.96	4.89	4.58	4.29	4.67	2.88	3.88	5.64	4.70	2.83	3.13	3.45	3.42	4.05	4.18	2.77	3.17	4.54	4.91
SHL	1996	3.59	3.39	3.80	3.86	3.75	3.97	2.47	3.13	3.04	3.95	2.18	2.72	2.94	2.69	4.19	3.46	2.00	2.50	4.05	4.12
SHL	1997	3.15	2.98	4.22	3.36	3.08	3.47	2.23	2.64	2.87	3.42	2.00	2.42	2.69	2.24	3.50	2.97	1.98	2.07	3.36	3.57
SHL	1998	2.89	2.65	3.62	2.97	2.98	3.09	1.96	2.29	2.78	3.01	2.13	2.18	2.21	1.94	2.82	2.59	1.71	1.78	3.62	3.13

Note: Aspen-Trembling aspen; Cedar-Western red cedar; Fescu-Plains rough fescue; Beech-American beech
Birch-White birch; Bfern-Bracken fern; Dfir-Douglas fir; Jpine-Jack pine; Spruce-Black spruce; Tam-Tamarack

a--is actual data
p--is simulated data

Actual litterbag weight (g) and simulated weight (g) (continued)

Location	Year	Aspena	Aspenp	Beecha	Beechp	Bferna	BFernp	Sprucea	Sprucep	Dfira	DFirp	Fescua	Fescup	Jpinea	JPinep	Tama	Tamp	Bircha	Birchp	Cedara	Cedarp
TER	1992	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.99	10.00	10.00	10.00	10.00	10.00	9.99	10.00	10.00	10.00	9.99
TER	1993	7.05	6.93	8.95	8.40	8.20	8.39	7.90	8.44	8.97	8.77	6.12	5.32	8.45	8.23	8.38	8.24	7.39	7.38	8.68	9.03
TER	1994	6.51	6.45	8.09	7.85	7.29	7.85	6.91	7.75	7.39	8.19	4.80	4.90	7.88	7.48	8.01	7.63	6.76	6.70	8.58	8.45
TER	1995	5.36	6.04	8.01	7.30	7.20	7.33	6.21	7.06	7.37	7.60	3.85	4.61	7.24	6.74	7.60	7.03	6.33	6.06	7.87	7.86
TER	1996	4.88	5.68	6.87	6.83	4.40	6.87	5.06	6.48	5.92	7.10	3.12	4.36	6.40	6.12	5.58	6.53	3.77	5.52	7.80	7.35
TER	1997	4.19	5.39	5.63	6.43	6.12	6.50	4.42	6.01	4.77	6.67	3.49	4.15	6.90	5.61	6.71	6.11	3.86	5.08	6.09	6.92
TER	1998	3.90	5.11	4.56	6.07	4.66	6.14	4.30	5.56	5.41	6.28	2.86	3.95	6.12	5.14	5.20	5.72	3.69	4.67	6.23	6.52
TOP	1992	10.00	9.97	10.00	9.96	10.00	9.97	10.00	9.96	10.00	9.96	10.00	9.98	10.00	9.96	10.00	9.96	10.00	9.96	10.00	9.96
TOP	1993	6.68	6.70	8.16	8.16	7.80	8.14	7.33	8.15	8.00	8.52	5.70	5.09	7.33	7.92	7.92	7.97	6.65	7.09	8.50	8.79
TOP	1994	6.52	6.07	8.12	7.34	7.93	7.35	7.03	7.13	7.62	7.65	4.94	4.63	7.20	6.82	7.77	7.09	6.29	6.13	8.82	7.91
TOP	1995	6.04	5.48	7.82	6.56	7.60	6.59	5.61	6.18	7.41	6.81	4.24	4.22	6.40	5.80	7.10	6.26	4.02	5.25	7.05	7.07
TOP	1996	5.19	5.06	6.38	6.01	5.94	6.06	3.67	5.52	5.41	6.22	4.14	3.92	4.86	5.09	4.80	5.67	2.90	4.64	6.03	6.47
TOP	1997	5.31	4.69	5.95	5.52	5.01	5.58	3.68	4.94	4.46	5.70	4.22	3.65	4.09	4.49	5.07	5.16	3.14	4.12	4.78	5.93
TOP	1998	4.17	4.33	5.84	5.06	3.74	5.13	2.77	4.42	3.79	5.21	3.40	3.40	2.76	3.96	4.24	4.68	2.35	3.64	5.15	5.43
WHI	1992	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.98	10.00	9.98	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.99	10.00	9.98
WHI	1993	7.50	7.39	8.61	8.74	8.04	8.72	8.14	8.83	8.81	9.08	6.01	5.92	8.20	8.65	8.38	8.62	7.73	7.86	9.07	9.31
WHI	1994	7.55	6.86	8.83	8.32	8.40	8.31	8.28	8.35	9.08	8.69	5.24	5.26	8.15	8.13	8.77	8.16	7.69	7.29	9.49	8.95
WHI	1995	7.09	6.56	8.86	7.98	8.12	7.98	7.73	7.93	8.81	8.33	5.40	4.99	7.90	7.67	8.36	7.78	7.46	6.87	9.44	8.60
WHI	1996	6.82	6.33	8.53	7.68	7.57	7.68	7.59	7.55	8.43	8.01	4.39	4.81	7.74	7.26	8.12	7.45	6.67	6.52	9.14	8.28
WHI	1997	6.84	6.15	8.52	7.45	7.61	7.46	7.20	7.27	8.61	7.76	4.73	4.69	7.40	6.96	8.13	7.21	6.75	6.25	9.25	8.03
WHI	1998	5.98	6.12	8.09	7.40	7.65	7.41	6.23	7.21	7.86	7.71	4.21	4.66	7.12	6.89	7.83	7.16	6.70	6.20	8.47	7.98
BAT	1992	10.00	9.97	10.00	9.97	10.00	9.97	10.00	9.96	10.00	9.96	10.00	9.98	10.00	9.95	10.00	9.96	10.00	9.96	10.00	9.96
BAT	1993	6.92	7.09	8.26	8.52	8.02	8.51	7.69	8.58	8.71	8.88	5.09	5.52	8.26	8.38	8.13	8.38	7.32	7.55	8.68	9.13
BAT	1994	6.55	6.48	8.27	7.89	8.12	7.89	7.26	7.80	8.70	8.23	4.14	4.93	7.84	7.54	8.35	7.67	6.98	6.75	9.19	8.50
BAT	1995	6.18	6.03	7.68	7.29	7.25	7.31	7.09	7.06	8.42	7.59	3.86	4.60	7.16	6.73	8.89	7.03	6.54	6.06	9.38	7.85
BAT	1996	5.26	5.70	7.01	6.85	7.28	6.88	6.53	6.51	7.36	7.12	3.14	4.37	7.49	6.15	8.50	6.55	6.75	5.55	8.37	7.37
BAT	1997	5.08	5.42	6.16	6.47	5.91	6.52	4.65	6.06	6.19	6.72	2.20	4.17	6.68	5.66	6.89	6.16	4.42	5.13	8.07	6.97
BAT	1998	5.43	5.13	6.94	6.09	5.88	6.16	5.77	5.60	5.51	6.31	2.33	3.96	6.15	5.18	7.51	5.75	4.59	4.71	8.84	6.55
CBR	1992	10.00	9.96	10.00	9.94	10.00	9.94	10.00	9.94	10.00	9.94	10.00	9.97	10.00	9.94	10.00	9.94	10.00	9.94	10.00	9.94
CBR	1993	5.78	6.17	7.52	7.47	7.13	7.48	6.00	7.30	7.18	7.79	4.98	4.70	6.41	6.99	7.03	7.23	4.56	6.29	7.99	8.05
CBR	1994	4.20	5.25	6.10	6.25	5.12	6.29	4.41	5.81	5.57	6.48	4.33	4.05	5.57	5.40	5.41	5.93	3.96	4.91	7.46	6.73
CBR	1995	4.08	4.52	5.19	5.30	4.86	5.36	4.28	4.69	3.80	5.46	3.97	3.53	4.34	4.23	5.24	4.93	3.59	3.89	5.46	5.69
CBR	1996	3.51	3.96	3.85	4.58	3.98	4.66	2.54	3.89	3.74	4.71	2.93	3.13	3.73	3.43	4.22	4.19	2.96	3.17	4.80	4.91
CBR	1997	3.64	3.54	4.03	4.05	4.36	4.15	2.92	3.33	4.79	4.14	2.78	2.83	3.69	2.88	4.48	3.66	2.92	2.67	3.78	4.33
CBR	1998	3.37	3.18	3.72	3.61	3.30	3.71	2.26	2.89	2.83	3.68	2.89	2.57	3.03	2.46	3.87	3.22	2.81	2.28	3.71	3.84
MON	1992	10.00	9.98	10.00	9.98	10.00	9.98	10.00	9.99	10.00	9.98	10.00	9.99	10.00	9.99	10.00	9.98	10.00	9.99	10.00	9.98
MON	1993	5.85	6.25	7.78	7.58	7.50	7.58	6.65	7.43	7.59	7.91	5.81	4.76	7.10	7.14	7.41	7.35	5.31	6.41	8.09	8.17
MON	1994	4.70	5.44	6.47	6.50	6.48	6.53	5.58	6.11	6.75	6.75	4.52	4.18	5.86	5.72	6.54	6.19	4.45	5.19	7.33	7.00
MON	1995	4.41	4.75	6.59	5.60	5.84	5.66	4.23	5.04	5.39	5.79	4.06	3.70	5.19	4.60	6.22	5.24	4.03	4.21	6.47	6.03
MON	1996	3.74	4.21	4.85	4.90	4.80	4.97	3.51	4.24	4.90	5.04	3.18	3.31	4.10	3.78	5.07	4.51	3.69	3.48	5.44	5.26
MON	1997	3.78	3.81	5.27	4.40	4.21	4.48	3.46	3.69	4.51	4.51	3.11	3.02	3.85	3.23	4.75	4.00	3.86	2.99	4.67	4.71
MON	1998	2.52	3.48	3.71	3.97	4.16	4.07	2.89	3.25	3.56	4.06	2.79	2.78	3.33	2.80	4.03	3.57	3.08	2.60	4.33	4.24
PET	1992	10.00	9.98	10.00	9.97	10.00	9.97	10.00	9.98	10.00	9.97	10.00	9.98	10.00	9.98	10.00	9.97	10.00	9.98	10.00	9.97
PET	1993	6.67	5.91	7.85	7.12	7.59	7.14	7.27	6.86	8.43	7.42	5.19	4.51	7.37	6.53	8.11	6.86	6.57	5.89	8.65	7.68
PET	1994	6.21	4.81	7.35	5.67	5.55	5.73	6.00	5.12	6.92	5.87	4.59	3.74	6.52	4.68	7.40	5.32	5.20	4.29	7.62	6.10
PET	1995	3.88	4.03	6.32	4.67	5.88	4.75	4.64	3.98	5.60	4.79	3.62	3.18	5.42	3.51	6.52	4.27	4.35	3.25	7.48	5.00
PET	1996	4.02	3.46	4.83	3.95	2.67	4.05	3.44	3.22	4.36	4.03	3.41	2.77	3.19	2.77	4.67	3.55	3.14	2.57	4.85	4.22
PET	1997	2.75	3.05	3.65	3.45	2.23	3.56	2.34	2.72	2.72	3.51	2.48	2.47	3.23	2.31	3.65	3.05	1.56	2.14	3.72	3.66
PET	1998	2.65	2.71	3.55	3.04	2.24	3.15	2.25	2.35	3.27	3.08	2.87	2.22	2.57	1.99	3.35	2.66	2.17	1.83	3.58	3.21

Note: Aspen-Trembling aspen; Cedar-Western red cedar; Fescu-Plains rough fescue; Beech-American beech
Birch-White birch; Bfern-Bracken fern; Dfir-Douglas fir; Jpine-Jack pine; Spruce-Black spruce; Tam-Tamarack

a--is actual data
p--is simulated data

Actual N concentration (%) and N concentration (%) in litterbag

Location	Year	Aspena	Aspenp	Beecha	Beechp	Bferna	BFernp	Sprucea	Sprucep	Dfira	DFirp	Fescua	Fescup	Jpinea	JPinep	Tama	Tamp	Bircha	Birchp	Cedara	Cedarp
CHA	1992	0.67	0.69	0.71	0.71	0.88	0.88	0.73	0.75	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
CHA	1993	1.05	1.03	0.81	0.90	0.99	1.10	0.96	0.93	0.86	0.85	1.08	1.42	1.72	1.58	0.73	0.77	1.32	1.05	0.63	0.76
CHA	1994	1.20	1.15	1.13	1.02	1.33	1.24	1.22	1.09	1.15	0.97	1.46	1.54	2.00	1.77	1.15	0.90	1.40	1.23	0.64	0.87
CHA	1995	1.46	1.26	1.19	1.14	1.52	1.36	1.45	1.24	1.15	1.09	1.43	1.65	1.97	1.94	1.06	1.02	1.98	1.42	0.87	0.97
CHA	1996	1.76	1.36	1.25	1.25	1.63	1.47	1.75	1.40	1.64	1.21	1.65	1.75	2.30	2.10	1.20	1.14	2.32	1.60	1.01	1.08
CHA	1997	1.73	1.45	1.69	1.35	1.23	1.56	1.58	1.53	1.44	1.30	1.77	1.82	2.08	2.21	1.22	1.25	2.28	1.76	1.62	1.17
CHA	1998	1.62	1.54	1.59	1.44	1.63	1.65	1.84	1.66	1.69	1.40	1.74	1.89	2.27	2.30	1.62	1.35	2.30	1.91	1.39	1.27
GAN	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
GAN	1993	0.88	1.00	0.78	0.87	0.99	1.07	0.86	0.89	0.87	0.83	1.20	1.38	1.59	1.50	0.73	0.75	1.20	1.00	0.60	0.73
GAN	1994	1.12	1.10	1.04	0.97	1.33	1.18	1.24	1.02	1.00	0.93	1.49	1.47	1.82	1.62	0.79	0.85	1.55	1.14	0.75	0.83
GAN	1995	1.12	1.21	1.04	1.09	1.29	1.30	1.31	1.17	1.14	1.05	1.40	1.57	2.32	1.75	1.05	0.98	1.75	1.32	0.78	0.94
GAN	1996	1.30	1.31	1.27	1.21	1.43	1.41	1.27	1.33	1.48	1.16	1.32	1.65	2.26	1.86	1.11	1.10	1.71	1.49	0.89	1.05
GAN	1997	1.22	1.40	1.36	1.31	1.45	1.50	1.43	1.46	1.34	1.27	1.60	1.72	1.81	1.94	1.22	1.22	1.82	1.64	0.78	1.15
GAN	1998	1.43	1.48	1.35	1.40	1.65	1.58	1.40	1.58	1.68	1.36	1.56	1.77	2.03	1.99	1.15	1.32	1.79	1.77	1.01	1.25
GI1	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
GI1	1993	0.78	0.95	0.65	0.83	0.93	1.03	0.78	0.85	0.81	0.79	1.39	1.31	1.39	1.47	0.66	0.71	1.02	0.95	0.54	0.70
GI1	1994	0.81	1.02	0.85	0.89	0.91	1.09	0.74	0.91	0.81	0.84	1.01	1.40	1.17	1.55	0.52	0.76	0.91	1.03	0.54	0.75
GI1	1995	0.93	1.06	0.86	0.93	1.05	1.14	0.90	0.96	1.10	0.88	1.29	1.44	1.50	1.61	0.74	0.80	1.17	1.09	0.66	0.78
GI1	1996	0.99	1.10	0.91	0.98	1.22	1.19	0.95	1.03	0.93	0.93	1.35	1.49	1.51	1.68	0.73	0.85	1.35	1.16	0.65	0.83
GI1	1997	1.03	1.17	0.91	1.05	1.30	1.27	0.94	1.12	0.91	1.00	1.50	1.56	1.64	1.78	0.79	0.93	1.53	1.27	0.69	0.90
GI1	1998	1.18	1.23	1.10	1.11	1.32	1.33	1.29	1.20	1.09	1.06	1.66	1.61	2.05	1.86	0.80	0.99	1.59	1.36	0.62	0.95
GI2	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
GI2	1993	0.72	0.95	0.78	0.83	0.99	1.03	0.75	0.84	0.73	0.79	1.02	1.31	1.26	1.46	0.66	0.71	1.09	0.95	0.57	0.70
GI2	1994	1.28	1.01	0.97	0.89	1.16	1.09	0.94	0.91	0.93	0.84	1.28	1.39	1.49	1.54	0.66	0.76	1.46	1.03	1.02	0.75
GI2	1995	1.05	1.05	0.97	0.92	1.18	1.13	1.03	0.96	0.95	0.88	1.44	1.43	1.70	1.58	0.82	0.80	1.63	1.08	0.67	0.78
GI2	1996	1.27	1.10	1.00	0.97	1.41	1.18	1.16	1.02	1.26	0.93	1.45	1.48	1.76	1.64	0.76	0.85	1.63	1.15	0.69	0.83
GI2	1997	1.08	1.16	1.23	1.04	1.42	1.25	0.93	1.11	1.20	1.00	1.44	1.54	1.95	1.73	0.91	0.92	1.49	1.25	0.74	0.89
GI2	1998	1.52	1.22	1.34	1.10	1.30	1.31	1.46	1.19	1.48	1.05	1.69	1.59	2.22	1.80	1.05	0.98	1.89	1.34	1.04	0.94
HID	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
HID	1993	1.00	1.04	0.86	0.91	0.96	1.12	1.16	0.95	0.93	0.87	1.13	1.42	1.75	1.58	0.81	0.79	1.27	1.07	0.69	0.77
HID	1994	1.32	1.15	1.02	1.03	1.45	1.24	1.01	1.09	1.20	0.98	1.37	1.54	1.50	1.75	0.74	0.91	1.41	1.24	0.80	0.88
HID	1995	1.37	1.27	1.00	1.15	1.30	1.37	1.29	1.25	1.14	1.10	1.43	1.64	2.23	1.91	0.96	1.03	1.67	1.42	0.85	0.99
HID	1996	1.41	1.36	1.13	1.25	1.56	1.47	1.36	1.40	1.32	1.21	1.55	1.73	2.33	2.03	0.98	1.14	2.13	1.59	1.04	1.09
HID	1997	1.62	1.44	1.44	1.34	1.54	1.55	1.45	1.52	1.41	1.30	1.54	1.79	2.27	2.13	1.26	1.25	1.89	1.73	0.95	1.18
HID	1998	1.70	1.51	1.40	1.42	1.56	1.62	1.73	1.62	1.54	1.38	1.78	1.85	2.11	2.19	1.31	1.33	2.11	1.85	1.16	1.25
INU	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
INU	1993	0.60	0.75	0.63	0.74	0.72	0.92	0.60	0.76	0.62	0.72	0.69	0.86	1.14	1.33	0.54	0.62	0.81	0.78	0.43	0.65
INU	1994	0.72	0.83	0.68	0.77	0.73	0.96	0.59	0.79	0.67	0.74	1.03	1.02	1.26	1.38	0.48	0.65	0.74	0.84	0.48	0.67
INU	1995	0.85	0.89	0.71	0.80	0.88	0.99	0.77	0.81	0.72	0.76	1.12	1.17	1.46	1.42	0.63	0.67	1.01	0.89	0.54	0.68
INU	1996	0.90	0.95	0.79	0.83	1.10	1.03	0.80	0.84	0.84	0.79	1.29	1.30	1.26	1.46	0.62	0.71	1.15	0.95	0.65	0.70
INU	1997	0.84	0.98	0.69	0.86	1.03	1.05	0.81	0.87	0.83	0.81	1.46	1.35	1.42	1.49	0.80	0.73	1.02	0.98	0.54	0.72
INU	1998	0.98	0.99	0.61	0.86	1.00	1.06	0.92	0.88	0.86	0.81	1.48	1.36	1.46	1.50	0.74	0.73	1.27	0.99	0.74	0.72
KAN	1992	0.67	0.67	0.71	0.71	0.88	0.89	0.73	0.74	0.70	0.71	0.71	0.71	1.28	1.29	0.59	0.59	0.72	0.72	0.64	0.65
KAN	1993	0.84	1.01	0.74	0.88	0.96	1.09	0.81	0.91	0.80	0.84	1.15	1.39	1.53	1.54	0.63	0.76	1.17	1.02	0.57	0.74
KAN	1994	1.06	1.09	0.84	0.96	1.00	1.17	0.76	1.01	1.00	0.91	1.19	1.47	1.63	1.66	0.91	0.84	1.24	1.14	0.66	0.81
KAN	1995	1.05	1.17	1.00	1.05	1.15	1.27	1.10	1.13	1.01	1.00	1.71	1.56	1.81	1.78	0.85	0.93	1.44	1.27	0.72	0.90
KAN	1996	1.23	1.26	1.08	1.15	1.46	1.36	1.16	1.25	1.24	1.10	1.61	1.64	2.12	1.91	0.90	1.03	1.49	1.42	0.75	0.98
KAN	1997	1.35	1.32	1.08	1.21	1.53	1.43	1.35	1.34	1.25	1.16	1.71	1.70	2.08	1.99	1.11	1.10	2.01	1.52	0.86	1.04
KAN	1998	1.57	1.39	1.28	1.29	1.32	1.50	1.49	1.44	1.43	1.24	1.74	1.76	2.36	2.08	1.17	1.18	2.10	1.64	0.87	1.12

Note: Aspen-Trembling aspen; Cedar-Western red cedar; Fescu-Plains rough fescue; Beech-American beech
Birch-White birch; Bfern-Bracken fern; Dfir-Douglas fir; Jpine-Jack pine; Spruce-Black spruce; Tam-Tamarack

a--is actual data
p--is simulated data

Actual N concentration (%) and N concentration (%) in litterbag (continued)

Location	Year	Aspena	Aspenp	Beecha	Beechp	Bferna	BFernp	Sprucea	Sprucep	Dfira	DFirp	Fescua	Fescup	Jpinea	JPinep	Tama	Tamp	Bircha	Birchp	Cedara	Cedarp
MAR	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
MAR	1993	1.11	1.09	0.93	0.97	1.02	1.18	1.02	1.01	0.96	0.92	1.47	1.49	1.50	1.71	0.78	0.84	1.35	1.15	0.64	0.82
MAR	1994	1.45	1.29	1.67	1.16	1.57	1.39	1.06	1.28	1.37	1.12	1.80	1.69	1.87	2.04	1.30	1.05	1.83	1.47	0.86	1.00
MAR	1995	1.88	1.46	1.61	1.35	1.80	1.58	1.67	1.55	1.58	1.31	1.91	1.85	2.33	2.32	1.16	1.25	2.15	1.79	0.94	1.17
MAR	1996	1.87	1.61	1.55	1.52	1.86	1.73	1.91	1.78	1.79	1.48	2.06	1.98	2.34	2.51	1.28	1.44	2.24	2.07	1.17	1.34
MAR	1997	1.86	1.73	2.52	1.64	2.25	1.84	1.77	1.95	2.39	1.61	1.93	2.07	2.67	2.59	1.92	1.58	2.12	2.26	1.36	1.47
MAR	1998	2.14	1.82	2.14	1.75	1.99	1.93	2.06	2.07	1.73	1.72	1.93	2.13	2.41	2.60	1.64	1.71	2.37	2.40	1.52	1.58
NH1	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
NH1	1993	1.05	0.92	0.87	0.81	1.20	1.01	0.93	0.83	0.93	0.77	1.32	1.23	1.61	1.45	0.81	0.69	1.22	0.92	0.75	0.69
NH1	1994	0.82	0.98	0.65	0.86	1.00	1.06	0.76	0.87	0.86	0.81	1.26	1.36	1.53	1.52	0.68	0.73	1.07	0.98	0.60	0.72
NH1	1995	0.79	1.02	0.76	0.89	1.12	1.09	0.84	0.92	0.82	0.84	1.46	1.40	1.67	1.58	0.64	0.76	1.12	1.03	0.57	0.75
NH1	1996	0.96	1.07	0.90	0.94	1.12	1.15	0.92	0.98	0.94	0.89	1.53	1.46	1.63	1.66	0.65	0.81	1.28	1.11	0.63	0.79
NH1	1997	1.15	1.12	0.89	0.99	1.13	1.21	1.08	1.05	1.04	0.95	1.56	1.52	1.74	1.76	0.78	0.87	1.33	1.20	0.71	0.84
NH1	1998	1.13	1.18	1.01	1.05	1.33	1.27	1.19	1.13	1.16	1.00	1.59	1.58	2.14	1.86	0.86	0.92	1.69	1.28	0.66	0.89
NH2	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
NH2	1993	1.14	0.92	0.90	0.81	1.20	1.01	1.03	0.82	0.97	0.77	1.20	1.23	1.50	1.43	0.79	0.69	1.15	0.91	0.72	0.69
NH2	1994	1.20	0.97	0.94	0.85	1.37	1.05	1.03	0.87	0.94	0.80	1.16	1.34	1.38	1.48	0.74	0.72	1.07	0.97	0.66	0.72
NH2	1995	1.28	1.01	1.01	0.88	1.22	1.08	1.09	0.90	1.07	0.83	1.44	1.38	1.82	1.52	0.82	0.75	1.53	1.01	0.83	0.74
NH2	1996	1.40	1.05	1.15	0.92	1.34	1.13	1.21	0.95	1.22	0.88	1.62	1.43	1.93	1.57	0.92	0.80	1.50	1.07	0.66	0.78
NH2	1997	1.55	1.10	1.12	0.98	1.17	1.18	1.19	1.02	1.17	0.93	1.26	1.48	1.89	1.64	0.87	0.85	1.76	1.15	0.81	0.83
NH2	1998	1.46	1.15	1.21	1.03	1.31	1.23	1.30	1.08	1.27	0.98	1.54	1.52	1.92	1.70	0.91	0.90	1.61	1.22	0.84	0.87
PAL	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
PAL	1993	0.90	0.93	0.78	0.82	0.99	1.02	0.87	0.84	0.81	0.78	1.20	1.27	1.51	1.47	0.69	0.70	0.99	0.93	0.54	0.69
PAL	1994	1.14	1.01	0.90	0.88	0.99	1.08	0.97	0.90	0.88	0.83	1.21	1.39	1.28	1.57	0.71	0.75	1.23	1.02	0.60	0.74
PAL	1995	1.14	1.07	0.98	0.94	1.22	1.15	0.99	0.98	0.89	0.89	1.89	1.46	1.78	1.68	0.72	0.81	1.32	1.11	0.66	0.79
PAL	1996	1.16	1.12	0.98	0.99	1.36	1.20	1.16	1.04	1.01	0.94	1.73	1.52	1.89	1.76	0.89	0.86	1.39	1.19	0.61	0.83
PAL	1997	1.16	1.16	1.04	1.03	1.17	1.25	1.45	1.10	1.04	0.98	1.72	1.57	1.81	1.85	1.27	0.90	1.66	1.26	0.79	0.87
PAL	1998	1.25	1.21	1.08	1.08	1.13	1.31	1.43	1.17	1.05	1.03	1.95	1.62	2.15	1.94	0.84	0.96	1.69	1.34	0.66	0.92
PMC	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
PMC	1993	1.08	1.03	0.90	0.91	1.11	1.11	1.07	0.94	0.97	0.86	1.02	1.41	1.74	1.54	0.87	0.78	1.53	1.05	0.67	0.77
PMC	1994	1.16	1.14	0.95	1.02	0.94	1.23	1.02	1.08	1.18	0.98	1.21	1.51	2.59	1.66	0.81	0.90	2.08	1.21	0.73	0.88
PMC	1995	1.31	1.25	1.11	1.14	1.29	1.34	1.54	1.23	1.28	1.09	1.29	1.60	2.16	1.77	1.18	1.03	1.73	1.38	0.97	0.98
PMC	1996	1.36	1.34	1.19	1.24	1.31	1.44	1.61	1.36	1.59	1.20	1.37	1.67	1.78	1.85	1.23	1.14	1.86	1.53	1.14	1.08
PMC	1997	1.37	1.41	1.25	1.33	1.24	1.52	1.49	1.48	1.34	1.29	1.26	1.72	1.62	1.92	1.07	1.24	1.87	1.65	1.07	1.17
PMC	1998	1.45	1.48	1.47	1.41	1.48	1.59	1.56	1.58	1.43	1.38	1.49	1.76	1.82	1.96	1.30	1.33	1.66	1.77	1.20	1.26
SCH	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
SCH	1993	0.77	0.99	0.69	0.86	0.84	1.06	0.94	0.88	0.74	0.81	1.14	1.37	1.20	1.51	0.64	0.73	1.10	0.99	0.51	0.72
SCH	1994	0.98	1.05	0.88	0.92	0.91	1.13	0.78	0.95	0.87	0.87	0.99	1.43	1.52	1.61	0.76	0.79	1.10	1.08	0.62	0.78
SCH	1995	0.88	1.10	0.82	0.97	1.06	1.18	1.01	1.02	0.91	0.92	1.32	1.49	1.70	1.68	0.75	0.84	1.65	1.15	0.66	0.82
SCH	1996	0.91	1.16	0.90	1.04	1.20	1.25	1.09	1.10	0.97	0.99	1.44	1.55	1.83	1.78	0.86	0.91	1.61	1.25	0.69	0.88
SCH	1997	1.14	1.22	1.10	1.10	1.20	1.32	1.05	1.19	1.04	1.05	1.15	1.61	1.86	1.87	0.88	0.98	1.45	1.35	0.63	0.94
SCH	1998	1.06	1.27	1.20	1.16	1.06	1.38	1.22	1.27	1.16	1.11	1.53	1.66	1.88	1.95	0.79	1.04	1.85	1.44	0.66	0.99
SHL	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
SHL	1993	1.15	1.07	0.96	0.95	1.11	1.16	1.08	0.99	1.08	0.90	1.29	1.45	2.00	1.62	0.85	0.82	1.68	1.11	0.69	0.80
SHL	1994	1.61	1.22	1.08	1.10	1.27	1.32	1.20	1.19	1.22	1.06	1.37	1.60	1.98	1.82	0.70	0.99	1.86	1.34	0.72	0.95
SHL	1995	1.50	1.37	1.16	1.27	1.37	1.48	1.43	1.41	1.26	1.23	1.37	1.72	1.78	2.00	1.15	1.17	1.87	1.60	0.95	1.10
SHL	1996	1.62	1.49	1.35	1.41	1.57	1.60	1.56	1.60	1.52	1.37	1.33	1.82	1.76	2.11	1.05	1.32	1.85	1.81	1.07	1.24
SHL	1997	1.52	1.59	1.46	1.52	1.47	1.70	1.48	1.74	1.37	1.49	1.26	1.88	1.57	2.17	1.34	1.45	1.65	1.97	1.06	1.36
SHL	1998	1.59	1.68	1.36	1.61	1.49	1.77	1.38	1.85	1.36	1.59	1.48	1.92	1.77	2.17	1.39	1.57	1.69	2.08	1.00	1.47

Note: Aspen-Trembling aspen; Cedar-Western red cedar; Fescu-Plains rough fescue; Beech-American beech
Birch-White birch; Bfern-Bracken fern; Dfir-Douglas fir; Jpine-Jack pine; Spruce-Black spruce; Tam-Tamarack

a--is actual data
p--is simulated data

Actual N concentration (%) and N concentration (%) in litterbag (continued)

Location	Year	Aspena	Aspenp	Beecha	Beechp	Bferna	BFernp	Sprucea	Sprucep	Dfira	DFirp	Fescua	Fescup	Jpinea	JPinep	Tama	Tamp	Bircha	Birchp	Cedara	Cedarp
TER	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
TER	1993	0.87	0.96	0.81	0.84	0.87	1.04	0.89	0.86	0.88	0.79	1.03	1.32	1.45	1.52	0.72	0.71	1.05	0.96	0.60	0.70
TER	1994	1.26	1.02	1.08	0.89	1.03	1.10	0.94	0.92	1.09	0.84	1.54	1.42	1.21	1.64	0.76	0.76	1.71	1.05	1.12	0.75
TER	1995	1.50	1.09	1.13	0.95	1.41	1.17	1.21	1.00	1.11	0.90	1.97	1.50	1.79	1.77	0.95	0.82	1.64	1.15	0.88	0.80
TER	1996	1.63	1.14	1.37	1.01	1.45	1.24	1.36	1.08	1.41	0.96	2.12	1.57	1.87	1.91	1.07	0.88	2.10	1.24	0.82	0.85
TER	1997	1.59	1.20	1.33	1.07	1.28	1.30	1.50	1.16	1.49	1.01	2.20	1.63	1.71	2.04	1.08	0.94	1.80	1.34	0.98	0.90
TER	1998	1.72	1.26	1.72	1.12	1.49	1.36	1.70	1.24	1.52	1.07	2.21	1.70	2.07	2.18	1.19	0.99	2.05	1.44	1.06	0.95
TOP	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
TOP	1993	0.88	0.97	0.76	0.85	0.96	1.05	0.90	0.86	0.87	0.80	1.05	1.35	1.53	1.49	0.63	0.72	1.13	0.97	0.60	0.71
TOP	1994	1.15	1.05	0.84	0.92	1.13	1.12	0.78	0.95	0.96	0.87	1.51	1.43	1.72	1.58	0.58	0.79	1.31	1.07	0.65	0.78
TOP	1995	1.05	1.12	0.90	1.00	1.01	1.21	1.16	1.05	0.91	0.95	1.41	1.50	1.85	1.69	0.85	0.87	1.70	1.19	0.75	0.85
TOP	1996	1.33	1.18	1.05	1.06	1.29	1.28	1.47	1.14	1.27	1.01	1.42	1.56	2.16	1.78	0.86	0.94	2.19	1.28	0.84	0.91
TOP	1997	1.19	1.24	1.21	1.13	1.46	1.34	1.33	1.22	1.29	1.08	1.33	1.62	2.14	1.86	0.96	1.01	2.03	1.38	0.97	0.97
TOP	1998	1.41	1.31	1.28	1.20	1.35	1.41	1.62	1.32	1.39	1.15	1.54	1.68	2.34	1.95	1.12	1.08	1.94	1.49	1.00	1.03
WHI	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
WHI	1993	0.66	0.90	0.64	0.80	0.73	1.00	0.70	0.82	0.67	0.76	0.90	1.18	1.20	1.43	0.54	0.68	0.88	0.90	0.48	0.68
WHI	1994	0.81	0.96	0.78	0.84	1.17	1.04	0.77	0.85	0.75	0.79	1.57	1.32	1.22	1.49	0.60	0.71	0.91	0.96	0.66	0.71
WHI	1995	0.97	0.99	0.81	0.87	1.08	1.07	0.84	0.89	0.82	0.82	1.41	1.37	1.50	1.54	0.66	0.74	1.20	1.00	0.57	0.73
WHI	1996	0.88	1.02	0.74	0.89	1.22	1.10	0.88	0.92	0.98	0.85	1.59	1.41	1.65	1.58	0.67	0.77	1.44	1.04	0.66	0.75
WHI	1997	1.01	1.04	1.11	0.92	1.25	1.12	0.96	0.95	0.85	0.87	1.58	1.43	1.63	1.61	0.62	0.79	1.25	1.07	0.67	0.77
WHI	1998	1.12	1.05	0.89	0.92	1.35	1.13	1.08	0.95	1.02	0.87	1.63	1.44	1.83	1.62	0.68	0.79	1.29	1.08	0.72	0.78
BAT	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
BAT	1993	0.81	0.94	0.76	0.82	0.78	1.02	0.66	0.84	0.63	0.78	1.11	1.27	1.33	1.48	0.67	0.70	0.99	0.94	0.45	0.70
BAT	1994	1.21	1.01	0.95	0.88	1.03	1.09	0.76	0.91	0.89	0.83	1.57	1.40	1.43	1.59	0.65	0.75	1.36	1.03	0.67	0.74
BAT	1995	1.14	1.07	1.02	0.94	1.40	1.16	1.08	0.99	0.90	0.89	1.73	1.47	1.73	1.70	0.80	0.81	1.38	1.12	0.75	0.79
BAT	1996	1.46	1.12	1.26	0.99	1.41	1.21	1.18	1.05	1.22	0.94	1.93	1.53	1.66	1.80	0.94	0.86	1.40	1.20	0.74	0.84
BAT	1997	1.38	1.17	1.41	1.04	1.40	1.26	1.30	1.12	1.33	0.99	1.28	1.58	1.62	1.90	0.93	0.91	1.58	1.28	0.90	0.88
BAT	1998	1.38	1.22	1.34	1.09	1.40	1.32	1.30	1.19	1.46	1.04	1.99	1.64	1.82	2.00	0.97	0.97	1.61	1.37	0.78	0.93
CBR	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
CBR	1993	1.11	1.03	0.85	0.90	1.08	1.11	1.09	0.93	1.03	0.86	1.35	1.41	1.74	1.55	0.75	0.78	1.45	1.04	0.72	0.76
CBR	1994	1.29	1.15	1.14	1.02	1.40	1.23	1.33	1.08	1.31	0.98	1.47	1.52	2.11	1.69	1.03	0.90	1.80	1.22	1.57	0.87
CBR	1995	1.80	1.26	1.38	1.15	1.55	1.36	1.43	1.25	1.24	1.10	1.63	1.62	2.21	1.83	1.10	1.03	1.95	1.40	0.91	0.99
CBR	1996	1.67	1.36	1.55	1.26	1.72	1.46	1.65	1.39	1.52	1.21	1.70	1.70	2.30	1.95	1.26	1.15	2.17	1.57	1.00	1.10
CBR	1997	1.83	1.44	1.55	1.35	1.74	1.55	1.74	1.52	1.63	1.31	1.72	1.77	2.11	2.02	1.14	1.26	1.98	1.72	1.16	1.19
CBR	1998	2.04	1.52	1.66	1.44	1.94	1.63	1.67	1.64	1.77	1.41	1.85	1.82	2.34	2.08	1.44	1.37	2.14	1.85	1.18	1.29
MON	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
MON	1993	1.11	1.02	0.90	0.89	1.00	1.10	1.04	0.92	1.02	0.85	1.02	1.40	1.62	1.55	0.81	0.77	1.35	1.04	0.63	0.75
MON	1994	1.66	1.12	0.98	1.00	1.27	1.21	1.20	1.05	1.15	0.95	1.70	1.50	2.26	1.68	1.00	0.88	1.70	1.19	0.97	0.85
MON	1995	1.70	1.22	1.40	1.11	1.65	1.32	1.57	1.20	1.47	1.06	1.74	1.60	2.28	1.81	1.11	0.99	2.08	1.35	1.03	0.95
MON	1996	1.83	1.32	1.53	1.21	1.68	1.42	1.73	1.34	1.53	1.17	1.63	1.68	2.34	1.93	1.38	1.10	2.11	1.51	1.04	1.05
MON	1997	1.34	1.40	1.56	1.30	1.60	1.50	1.56	1.45	1.59	1.26	1.67	1.74	2.11	2.01	1.59	1.20	1.95	1.64	1.17	1.13
MON	1998	2.10	1.47	1.88	1.38	1.82	1.58	1.74	1.56	1.68	1.34	1.83	1.79	2.24	2.08	1.47	1.29	1.80	1.76	1.48	1.22
PET	1992	0.67	0.67	0.71	0.71	0.88	0.88	0.73	0.73	0.70	0.70	0.71	0.71	1.28	1.28	0.59	0.59	0.72	0.72	0.64	0.64
PET	1993	0.93	1.06	0.84	0.94	0.93	1.14	0.90	0.97	0.82	0.89	1.18	1.44	1.60	1.60	0.69	0.81	1.20	1.09	0.63	0.79
PET	1994	0.98	1.22	1.25	1.10	1.12	1.31	1.13	1.18	1.06	1.05	1.20	1.59	1.85	1.80	0.80	0.98	2.05	1.34	0.62	0.94
PET	1995	1.75	1.35	1.23	1.25	1.28	1.46	1.46	1.39	1.18	1.21	1.65	1.71	2.16	1.97	1.09	1.15	1.91	1.57	0.89	1.09
PET	1996	1.69	1.47	1.55	1.38	1.80	1.58	1.48	1.57	1.59	1.35	1.86	1.80	2.40	2.08	1.24	1.30	2.25	1.78	1.04	1.22
PET	1997	2.00	1.57	1.73	1.49	1.60	1.67	1.87	1.71	1.67	1.46	1.92	1.86	2.05	2.14	1.25	1.42	2.23	1.93	1.25	1.34
PET	1998	1.96	1.65	1.64	1.59	1.86	1.75	1.90	1.82	1.78	1.56	1.84	1.91	2.27	2.15	1.50	1.54	2.27	2.05	1.16	1.44

Note: Aspen-Trembling aspen; Cedar-Western red cedar; Fescu-Plains rough fescue; Beech-American beech
Birch-White birch; Bfern-Bracken fern; Dfir-Douglas fir; Jpine-Jack pine; Spruce-Black spruce; Tam-Tamarack

a--is actual data
p--is simulated data

Actual C/N ratio and simulated C/N ratio

Location	Year	Aspena	Aspenp	Beecha	Beechp	Bferna	BFernp	Sprucea	Sprucep	Dfira	DFirp	Fescua	Fescup	Jpinea	JPinep	Tama	Tamp	Bircha	Birchp	Cedara	Cedarp
CHA	1992	69.85	72.72	66.20	71.57	52.61	57.44	67.67	68.98	70.86	74.14	61.55	67.59	38.83	39.94	82.54	87.22	66.67	70.37	77.50	83.29
CHA	1993	45.85	48.72	57.80	56.65	43.12	45.87	53.24	55.80	57.31	61.14	38.07	33.97	29.27	32.45	64.58	66.79	37.53	48.49	78.10	70.60
CHA	1994	42.43	43.68	22.96	49.88	40.48	40.98	42.14	47.68	43.75	53.49	31.25	31.23	25.40	29.01	45.06	57.57	34.59	41.28	28.62	61.65
CHA	1995	34.93	39.79	40.76	44.71	29.36	37.27	35.66	41.59	46.01	47.67	29.37	29.15	26.50	26.40	47.70	50.58	27.39	35.86	60.02	54.79
CHA	1996	27.78	36.72	37.92	40.66	27.48	34.40	29.77	36.93	30.52	43.11	23.27	27.53	22.78	24.44	38.50	45.14	22.07	31.72	48.61	49.37
CHA	1997	29.63	34.50	29.69	37.78	37.97	32.37	35.80	33.72	33.89	39.86	23.04	26.39	25.77	23.17	41.42	41.30	42.51	28.88	31.85	45.47
CHA	1998	31.54	32.60	29.69	35.32	27.12	30.68	28.10	31.11	29.49	37.10	21.49	25.44	23.00	22.25	29.20	38.06	22.61	26.59	37.34	42.12
GAN	1992	69.85	74.82	66.20	71.76	52.61	57.62	67.67	70.98	70.86	74.34	61.55	67.84	38.83	40.08	82.54	87.45	66.67	70.63	77.50	83.48
GAN	1993	55.66	50.12	64.91	58.36	44.94	47.24	58.86	58.00	58.23	63.02	35.12	34.96	32.43	34.07	65.35	69.00	42.82	50.64	83.11	72.68
GAN	1994	44.85	45.70	44.28	52.32	37.76	42.97	39.84	50.84	52.65	56.17	30.36	32.72	27.87	31.66	65.15	60.67	32.71	44.42	66.14	64.58
GAN	1995	46.12	41.43	45.59	46.53	36.00	38.90	40.31	44.04	47.10	49.60	30.06	30.60	23.49	29.31	46.37	52.73	28.64	38.48	66.45	56.78
GAN	1996	37.69	38.19	35.59	42.16	32.03	35.88	40.55	39.03	32.57	44.65	32.65	29.06	22.83	27.59	44.41	46.79	30.53	34.09	56.97	50.85
GAN	1997	43.23	35.78	35.66	38.94	34.09	33.68	37.46	35.46	35.90	40.99	25.52	27.96	25.57	26.46	42.10	42.43	29.14	30.99	65.94	46.41
GAN	1998	36.57	33.85	34.52	36.40	27.88	32.00	38.50	32.80	29.55	38.11	27.05	27.15	26.11	25.74	42.52	39.03	28.55	28.72	52.38	42.85
GI1	1992	69.85	74.76	66.20	71.72	52.61	57.57	67.67	70.90	70.86	74.30	61.55	67.75	38.83	40.02	82.54	87.40	66.67	70.53	77.50	83.45
GI1	1993	60.77	52.48	71.01	61.10	47.42	49.15	64.18	61.15	61.48	66.05	29.38	36.64	35.80	34.80	78.30	72.94	46.57	53.46	92.41	76.23
GI1	1994	58.44	49.23	55.48	57.24	54.70	46.34	66.44	56.56	64.13	61.78	44.64	34.35	41.82	32.97	92.37	67.58	54.42	49.22	90.91	71.31
GI1	1995	53.72	47.45	56.15	54.85	44.79	44.62	60.56	53.71	49.09	59.08	31.31	33.39	35.74	31.83	65.19	64.32	43.69	46.69	79.24	68.14
GI1	1996	49.49	45.37	54.18	52.05	37.87	42.61	55.16	50.38	56.02	55.92	30.44	32.28	34.44	30.49	68.63	60.51	37.48	43.75	79.08	64.43
GI1	1997	48.74	42.69	81.64	48.45	41.22	40.04	56.40	46.13	54.16	51.86	28.71	30.85	32.38	28.76	60.79	55.63	32.90	39.97	76.56	59.65
GI1	1998	40.17	40.71	43.27	45.82	34.55	38.16	39.92	43.04	45.90	48.88	25.36	29.81	25.22	27.49	63.13	52.06	30.25	37.23	80.97	56.14
GI2	1992	69.85	74.72	66.20	71.66	52.61	57.53	67.67	70.84	70.86	74.22	61.55	67.74	38.83	40.02	82.54	87.32	66.67	70.48	77.50	83.37
GI2	1993	68.80	52.53	61.39	61.14	47.77	49.20	68.94	61.24	67.85	66.08	42.18	36.71	40.38	34.99	72.23	72.97	44.23	53.57	96.84	76.25
GI2	1994	37.56	49.36	50.87	57.37	43.12	46.49	55.47	56.79	52.63	61.92	35.21	34.50	34.21	33.35	76.03	67.72	34.06	49.48	46.67	71.43
GI2	1995	48.71	47.64	49.79	55.05	39.85	44.83	52.63	54.03	57.38	59.28	27.74	33.59	32.02	32.34	62.27	64.54	31.99	47.06	77.05	68.33
GI2	1996	39.29	45.63	49.80	52.32	32.77	42.88	45.43	50.80	40.89	56.19	28.62	32.55	30.68	31.13	65.39	60.81	32.45	44.22	74.93	64.69
GI2	1997	49.17	43.03	40.33	48.81	35.24	40.39	61.18	46.66	42.01	52.22	29.15	31.21	27.37	29.57	61.55	56.03	37.24	40.58	74.36	60.00
GI2	1998	33.09	41.12	36.34	46.24	36.54	38.58	36.51	43.66	32.66	49.31	26.09	30.23	23.96	28.43	47.33	52.53	28.78	37.93	50.00	56.55
HID	1992	69.85	74.66	66.20	71.52	52.61	57.45	67.67	70.72	70.86	74.06	61.55	67.80	38.83	40.02	82.54	87.13	66.67	70.44	77.50	83.14
HID	1993	59.96	48.07	55.91	55.68	49.48	45.24	43.12	54.72	52.53	60.02	38.67	33.74	31.24	32.32	59.09	65.41	35.74	47.64	72.86	69.22
HID	1994	35.33	43.45	49.46	49.46	34.73	40.78	49.16	47.31	38.81	52.99	33.87	31.28	32.47	29.34	68.83	56.93	35.96	41.08	61.38	60.96
HID	1995	36.72	39.56	48.55	44.28	35.41	37.08	40.40	41.23	46.46	47.14	28.54	29.24	24.22	26.87	51.99	49.91	31.50	35.69	60.28	54.05
HID	1996	36.95	36.82	43.81	40.65	27.82	34.53	37.65	37.08	37.49	43.04	25.35	27.84	21.80	25.22	50.10	45.03	24.46	32.01	49.90	49.17
HID	1997	31.09	34.72	33.40	37.90	31.54	32.62	36.41	34.05	34.39	39.95	26.97	26.79	23.26	24.10	39.64	41.37	28.00	29.34	52.47	45.43
HID	1998	28.65	33.15	34.14	35.87	30.13	31.23	29.02	31.88	31.71	37.65	24.21	26.04	23.98	23.39	35.88	38.67	24.27	27.45	43.19	42.63
INU	1992	69.85	74.74	66.20	71.71	52.61	57.56	67.67	70.89	70.86	74.29	61.55	67.73	38.83	40.02	82.54	87.39	66.67	70.50	77.50	83.45
INU	1993	78.63	66.64	76.27	68.42	61.56	54.89	84.11	68.25	81.46	72.04	62.79	55.88	43.28	38.41	89.98	83.14	60.02	64.75	125.58	81.77
INU	1994	66.94	60.49	73.10	65.71	71.31	52.72	83.76	65.91	74.62	70.06	46.61	47.08	41.21	37.10	107.55	79.51	65.77	60.22	104.39	80.14
INU	1995	58.46	56.23	68.12	63.55	54.49	51.02	70.82	63.85	75.83	68.30	38.11	41.26	36.62	36.07	80.35	76.50	51.29	56.87	98.52	78.54
INU	1996	57.89	52.70	60.38	61.16	42.45	49.21	70.63	61.28	62.71	66.06	32.71	37.01	41.98	34.98	82.90	73.08	45.30	53.64	82.00	76.20
INU	1997	64.47	51.09	72.77	59.54	49.17	48.04	67.73	59.40	61.37	64.34	31.58	35.59	38.93	34.26	68.54	70.80	53.62	51.78	100.75	74.25
INU	1998	52.14	50.83	81.64	59.23	48.60	47.81	58.37	59.05	60.68	63.99	29.73	35.40	36.30	34.12	70.68	70.38	41.65	51.44	71.62	73.85
KAN	1992	69.85	74.42	66.20	71.22	52.61	57.22	67.67	70.31	70.86	73.73	61.55	67.64	38.83	39.85	82.54	86.72	66.67	70.06	77.50	82.78
KAN	1993	55.66	49.51	63.54	57.63	45.36	46.62	62.55	57.01	61.89	62.22	36.14	34.51	33.09	33.17	75.71	68.08	41.57	49.63	90.53	71.82
KAN	1994	45.83	46.03	58.01	52.93	47.65	43.25	65.57	51.39	47.50	56.92	36.30	32.63	30.70	30.92	56.48	61.66	39.26	44.68	75.57	65.61
KAN	1995	48.29	42.63	49.35	48.38	36.07	39.98	48.23	45.99	52.57	51.77	24.16	30.82	29.49	28.72	59.84	55.47	35.52	39.89	73.82	59.56
KAN	1996	39.11	39.67	45.56	44.43	31.71	37.17	44.48	41.38	39.19	47.32	26.21	29.27	25.14	26.83	53.78	50.13	34.16	35.79	70.27	54.29
KAN	1997	24.09	37.90	45.32	42.10	30.95	35.52	39.33	38.69	39.57	44.68	25.09	28.35	26.28	25.75	45.01	46.99	25.80	33.41	61.87	51.15
KAN	1998	31.78	35.96	36.72	39.54	35.38	33.73	36.24	35.81	34.83	41.80	23.28	27.37	22.71	24.63	41.79	43.56	24.62	30.86	60.57	47.69

Note: Aspen-Trembling aspen; Cedar-Western red cedar; Fescu-Plains rough fescue; Beech-American beech
Birch-White birch; Bfern-Bracken fern; Dfir-Douglas fir; Jpine-Jack pine; Spruce-Black spruce; Tam-Tamarack

a--is actual data
p--is simulated data

Actual C/N ratio and simulated C/N ratio (continued)

Location	Year	Aspena	Aspenp	Beecha	Beechp	Bferna	BFernp	Sprucea	Sprucep	Dfira	DFirp	Fescua	Fescup	Jpinea	JPinep	Tama	Tamp	Bircha	Birchp	Cedara	Cedarp
MAR	1992	69.85	74.73	66.20	71.65	52.61	57.54	67.67	70.87	70.86	74.20	61.55	67.80	38.83	40.05	82.54	87.30	66.67	70.54	77.50	83.32
MAR	1993	43.06	45.78	50.70	52.73	43.14	42.98	49.26	50.99	50.42	56.73	28.59	32.30	33.89	30.03	60.85	61.47	37.44	44.18	82.14	65.48
MAR	1994	31.66	38.95	27.36	43.71	30.70	36.43	45.21	40.27	35.23	46.58	23.26	28.50	25.01	25.12	36.55	49.30	25.83	34.57	52.31	53.60
MAR	1995	25.33	34.24	29.75	37.60	24.03	32.07	32.07	33.33	31.45	39.73	20.03	25.94	23.85	22.05	42.44	41.18	23.45	28.36	52.02	45.46
MAR	1996	25.35	31.02	27.61	33.52	22.74	29.22	26.70	29.00	26.03	35.15	17.91	24.26	22.09	20.42	37.34	35.83	22.46	24.54	36.84	39.92
MAR	1997	25.91	29.01	23.60	31.01	22.48	27.53	29.80	26.57	27.32	32.33	19.94	23.26	26.84	19.81	34.45	32.59	23.14	22.48	36.62	36.43
MAR	1998	22.38	27.46	22.15	29.11	21.66	26.29	26.02	24.94	28.10	30.21	19.53	22.53	21.58	19.70	29.33	30.19	22.53	21.15	33.62	33.74
NH1	1992	69.85	74.76	66.20	71.73	52.61	57.58	67.67	70.91	70.86	74.31	61.55	67.75	38.83	40.03	82.54	87.41	66.67	70.53	77.50	83.47
NH1	1993	44.90	54.45	52.64	62.50	36.61	50.17	54.73	62.63	52.69	67.38	32.30	38.93	31.40	35.25	58.71	74.96	39.42	55.23	65.15	77.66
NH1	1994	58.61	51.03	72.63	59.53	49.55	47.94	64.88	59.22	58.36	64.35	33.81	35.43	32.31	33.65	71.64	70.81	45.85	51.53	80.43	74.35
NH1	1995	50.57	49.21	63.90	57.29	41.12	46.29	62.65	56.52	65.32	61.86	28.78	34.23	31.06	32.43	82.39	67.74	46.21	49.05	86.27	71.48
NH1	1996	52.40	47.01	52.56	54.38	43.13	44.17	57.72	53.01	54.67	58.59	25.49	32.97	31.96	30.83	78.15	63.80	39.84	45.90	83.81	67.68
NH1	1997	42.45	44.60	55.03	51.18	40.95	41.83	49.67	49.18	46.55	54.99	26.68	31.61	31.00	29.07	62.68	59.48	40.30	42.46	73.63	63.48
NH1	1998	44.69	42.52	46.14	48.43	35.49	39.83	44.37	45.89	43.03	51.89	26.86	30.45	24.72	27.55	58.72	55.77	29.82	39.51	76.82	59.86
NH2	1992	69.85	74.71	66.20	71.66	52.61	57.53	67.67	70.83	70.86	74.22	61.55	67.74	38.83	40.03	82.54	87.31	66.67	70.48	77.50	83.36
NH2	1993	43.27	54.62	50.28	62.66	36.68	50.35	48.45	62.92	51.28	67.55	36.04	39.13	34.85	35.73	63.68	75.15	43.85	55.58	71.91	77.80
NH2	1994	39.62	51.38	48.35	59.90	34.94	48.31	45.25	59.80	51.54	64.73	36.34	35.78	35.37	34.53	65.49	71.22	41.71	52.21	63.24	74.69
NH2	1995	37.62	49.72	48.22	57.83	38.18	46.83	48.81	57.37	49.11	62.43	26.67	34.73	28.74	33.67	60.83	68.36	31.90	50.01	63.19	72.01
NH2	1996	32.64	47.74	40.35	55.15	34.03	44.92	42.48	54.20	42.48	59.39	23.27	33.68	26.17	32.54	51.96	64.68	32.80	47.23	74.85	68.44
NH2	1997	31.68	45.57	43.04	52.20	40.73	42.83	44.22	50.71	42.21	56.05	32.40	32.56	28.68	31.28	57.01	60.64	27.44	44.17	64.89	64.50
NH2	1998	33.77	43.69	38.68	49.66	35.34	41.03	41.54	47.71	39.07	53.17	24.74	31.60	26.77	30.18	53.52	57.17	28.51	41.54	59.29	61.08
PAL	1992	69.85	74.67	66.20	71.61	52.61	57.49	67.67	70.77	70.86	74.17	61.55	67.71	38.83	39.98	82.54	87.25	66.67	70.42	77.50	83.31
PAL	1993	52.44	53.63	59.62	61.87	40.30	49.69	57.93	61.92	60.82	66.77	35.25	38.00	32.89	34.85	72.75	74.10	48.23	54.40	90.37	77.02
PAL	1994	40.60	49.70	53.83	57.95	50.20	46.75	51.08	57.28	54.59	62.61	37.00	34.49	38.61	32.64	71.39	68.64	38.36	49.72	77.67	72.36
PAL	1995	42.05	46.93	51.07	54.32	40.34	44.08	52.59	52.88	60.95	58.53	23.70	32.86	29.46	30.56	74.48	63.72	35.71	45.74	76.86	67.64
PAL	1996	39.48	44.89	45.51	51.62	32.06	42.10	45.34	49.63	49.21	55.50	23.47	31.70	27.20	29.02	54.72	60.09	36.47	42.82	83.28	64.11
PAL	1997	43.71	43.17	46.59	49.34	40.19	40.44	36.71	46.91	46.44	52.94	24.38	30.72	29.22	27.72	40.71	57.03	28.92	40.36	63.99	61.13
PAL	1998	38.96	41.39	43.80	47.00	40.62	38.73	35.59	44.14	48.48	50.32	21.03	29.71	27.07	26.39	58.93	53.90	30.77	37.86	78.33	58.07
PMC	1992	69.85	74.72	66.20	71.58	52.61	57.51	67.67	70.81	70.86	74.12	61.55	67.88	38.83	40.15	82.54	87.20	66.67	70.56	77.50	83.19
PMC	1993	44.62	48.42	51.22	56.02	44.77	45.61	48.26	55.27	49.38	60.35	40.69	34.14	29.71	33.36	54.61	65.74	33.12	48.33	72.70	69.50
PMC	1994	41.82	43.81	50.16	49.72	54.51	41.18	49.02	47.83	41.45	53.20	36.66	31.85	19.50	30.90	60.67	57.06	23.63	41.87	66.30	61.02
PMC	1995	40.52	40.17	45.39	44.77	38.85	37.73	36.26	42.07	40.53	47.58	31.91	30.09	26.03	28.96	41.32	50.28	31.48	36.83	52.17	54.33
PMC	1996	37.06	37.50	40.50	41.17	36.03	35.26	31.24	37.99	30.90	43.50	29.12	28.85	27.81	27.62	38.70	45.39	27.37	33.27	40.70	49.40
PMC	1997	35.62	35.43	40.34	38.41	40.76	33.41	37.30	34.99	36.80	40.37	32.19	27.95	33.95	26.72	47.66	41.67	27.64	30.67	46.23	45.58
PMC	1998	41.24	33.72	33.20	36.15	34.32	31.93	34.17	32.65	35.27	37.80	28.99	27.26	29.01	26.14	37.31	38.64	31.93	28.69	42.00	42.39
SCH	1992	69.85	74.76	66.20	71.72	52.61	57.57	67.67	70.91	70.86	74.30	61.55	67.76	38.83	40.02	82.54	87.40	66.67	70.54	77.50	83.45
SCH	1993	58.93	50.74	69.77	59.25	53.99	47.78	26.38	58.94	66.35	64.05	38.49	35.19	42.40	33.82	73.29	70.34	44.61	51.32	96.27	73.97
SCH	1994	51.48	47.78	53.68	55.32	55.04	44.94	64.77	54.23	56.01	59.62	46.52	33.53	34.56	31.89	63.78	64.97	44.91	47.13	78.96	68.80
SCH	1995	61.89	45.64	65.53	52.45	43.07	42.87	56.58	50.81	59.58	56.38	34.83	32.37	33.92	30.47	74.23	61.07	33.90	44.09	80.12	65.00
SCH	1996	55.93	43.20	53.78	49.19	39.17	40.52	49.08	46.94	52.64	52.70	30.76	31.06	28.85	28.84	60.12	56.64	32.55	40.65	75.51	60.68
SCH	1997	50.92	41.05	45.85	46.33	39.93	38.47	55.06	43.57	47.41	49.47	38.30	29.91	29.15	27.42	60.88	52.78	38.94	37.65	86.58	56.88
SCH	1998	50.00	39.30	40.58	44.01	46.60	36.82	45.08	40.87	46.41	46.86	29.35	28.98	29.31	26.29	67.47	49.65	29.73	35.24	77.58	53.79
SHL	1992	69.85	74.75	66.20	71.62	52.61	57.54	67.67	70.86	70.86	74.16	61.55	67.88	38.83	40.11	82.54	87.26	66.67	70.59	77.50	83.25
SHL	1993	41.68	46.61	48.85	53.67	40.76	43.84	46.25	52.35	45.68	57.72	32.14	33.04	25.51	31.67	53.51	62.59	29.31	45.63	67.01	66.48
SHL	1994	31.29	40.99	45.92	46.09	41.79	38.45	52.47	43.39	39.26	49.16	33.28	30.13	25.18	28.21	75.18	52.26	26.48	37.74	69.63	56.38
SHL	1995	35.29	36.53	44.41	40.16	35.57	34.29	38.97	36.59	40.45	42.45	27.31	27.89	31.65	25.63	43.67	44.24	27.45	31.73	55.51	48.36
SHL	1996	27.16	33.53	34.07	36.22	28.34	31.61	33.21	32.35	30.72	38.01	28.95	26.48	28.58	24.24	44.29	38.99	26.81	28.02	45.14	42.96
SHL	1997	34.26	31.45	35.03	33.55	31.52	29.85	37.03	29.70	35.14	34.98	26.51	25.58	34.80	23.65	36.64	35.47	30.77	25.79	43.42	39.19
SHL	1998	30.94	29.89	36.76	31.56	31.74	28.60	39.06	27.96	37.56	32.74	26.49	24.98	30.62	23.56	34.39	32.90	30.47	24.42	52.80	36.32

Note: Aspen-Trembling aspen; Cedar-Western red cedar; Fescu-Plains rough fescue; Beech-American beech
Birch-White birch; Bfern-Bracken fern; Dfir-Douglas fir; Jpine-Jack pine; Spruce-Black spruce; Tam-Tamarack

a--is actual data
p--is simulated data

Actual C/N ratio and simulated C/N ratio (continued)

Location	Year	Aspena	Aspenp	Beecha	Beechp	Bferna	BFernp	Sprucea	Sprucep	Dfira	DFirp	Fescua	Fescup	Jpinea	JPinep	Tama	Tamp	Bircha	Birchp	Cedara	Cedarp
TER	1992	69.85	74.73	66.20	71.70	52.61	57.55	67.67	70.88	70.86	74.28	61.55	67.72	38.83	40.01	82.54	87.38	66.67	70.50	77.50	83.43
TER	1993	53.79	52.17	55.56	60.70	48.05	48.73	56.27	60.47	54.19	65.62	39.94	36.37	32.67	33.71	65.51	72.51	44.67	52.70	80.83	75.84
TER	1994	36.97	48.90	44.35	57.02	52.47	45.94	49.79	55.98	43.97	61.62	30.05	33.81	37.81	31.27	64.11	67.49	28.22	48.36	41.13	71.34
TER	1995	31.04	46.12	43.99	53.43	32.48	43.24	43.93	51.56	45.19	57.60	21.10	32.10	30.74	28.86	52.41	62.68	28.54	44.31	61.85	66.73
TER	1996	26.32	43.74	34.60	50.34	29.72	40.92	36.10	47.80	32.84	54.14	17.78	30.66	27.86	26.80	43.18	58.56	21.71	40.87	61.34	62.75
TER	1997	30.93	41.73	6.25	47.74	35.08	38.98	35.47	44.68	31.43	51.25	18.93	29.44	32.11	25.10	46.20	55.13	27.41	38.01	49.13	59.41
TER	1998	27.33	39.85	25.93	45.32	28.93	37.17	30.06	41.79	32.34	48.54	17.78	28.30	24.69	23.52	39.58	51.92	22.98	35.36	48.30	56.28
TOP	1992	69.85	74.70	66.20	71.62	52.61	57.51	67.67	70.81	70.86	74.17	61.55	67.78	38.83	40.09	82.54	87.25	66.67	70.50	77.50	83.29
TOP	1993	54.41	51.40	60.34	60.00	46.35	48.36	51.33	59.90	57.26	64.87	39.90	35.72	33.29	34.44	76.67	71.36	44.27	52.26	91.99	74.88
TOP	1994	41.05	47.90	59.57	55.44	45.92	45.08	63.65	54.44	51.82	59.74	30.40	33.68	28.50	32.33	87.33	65.07	37.82	47.41	75.73	68.88
TOP	1995	52.91	44.66	57.68	51.05	50.35	41.94	48.71	49.23	57.61	54.78	31.10	31.96	30.47	30.27	59.72	59.09	31.82	42.80	72.36	63.06
TOP	1996	37.22	42.33	45.24	47.93	36.12	39.71	35.58	45.53	38.29	51.25	29.72	30.74	23.94	28.80	56.16	54.84	23.70	39.53	61.31	58.89
TOP	1997	45.19	40.24	40.43	45.15	32.99	37.73	41.38	42.29	37.92	48.11	33.63	29.65	25.48	27.50	52.66	51.08	52.66	36.66	55.88	55.17
TOP	1998	36.60	38.30	37.66	42.56	34.30	35.91	32.84	39.31	35.68	45.19	27.01	28.66	22.22	26.32	44.02	47.59	27.01	34.02	53.00	51.70
WHI	1992	69.85	74.72	66.20	71.67	52.61	57.54	67.67	70.85	70.86	74.24	61.55	67.73	38.83	40.01	82.54	87.34	66.67	70.49	77.50	83.39
WHI	1993	72.80	55.79	73.09	63.29	61.89	50.80	74.57	63.47	75.96	68.08	47.72	40.67	42.20	35.74	86.27	76.07	54.76	56.42	104.58	78.34
WHI	1994	55.38	52.22	61.22	60.72	46.27	48.84	62.45	60.65	65.46	65.62	29.30	36.51	38.85	34.41	81.70	72.45	51.70	53.00	71.78	75.75
WHI	1995	52.95	50.35	65.35	58.70	45.36	47.35	64.20	58.26	64.80	63.43	32.38	34.98	37.56	33.35	82.19	69.64	44.45	50.67	90.14	73.27
WHI	1996	53.52	48.96	65.95	56.94	37.87	46.06	59.55	56.13	51.69	61.46	25.85	34.13	31.15	32.43	75.97	67.23	35.63	48.75	77.58	70.98
WHI	1997	50.99	47.95	45.50	55.60	38.36	45.09	57.75	54.52	59.15	59.95	28.38	33.55	34.15	31.72	85.53	65.41	42.86	47.30	78.51	69.22
WHI	1998	44.55	47.74	56.52	55.32	36.15	44.88	47.13	54.19	50.39	59.63	26.87	33.43	29.78	31.57	79.56	65.03	39.30	47.00	73.33	68.86
BAT	1992	69.85	74.61	66.20	71.52	52.61	57.42	67.67	70.66	70.86	74.07	61.55	67.67	38.83	39.92	82.54	87.13	66.67	70.31	77.50	83.20
BAT	1993	58.17	53.50	61.34	61.72	56.56	49.55	75.08	61.70	79.01	66.60	37.91	37.90	38.32	34.64	71.03	73.90	51.16	54.17	113.17	76.85
BAT	1994	39.35	49.51	51.05	57.72	49.08	46.55	60.42	56.95	54.49	62.37	28.91	34.32	34.64	32.28	73.47	68.36	34.21	49.37	71.39	72.12
BAT	1995	36.92	46.67	45.81	54.01	30.74	43.81	48.20	52.44	57.87	58.21	20.50	32.63	27.56	30.04	57.23	63.36	35.56	45.28	66.49	67.32
BAT	1996	26.71	44.57	33.33	51.26	30.78	41.77	39.66	49.12	38.87	55.13	19.12	31.41	29.88	28.39	43.09	59.67	31.21	42.27	63.65	63.74
BAT	1997	32.20	42.80	31.63	48.94	28.68	40.06	37.54	46.34	35.21	52.52	25.60	30.38	28.44	26.99	51.94	56.57	25.90	39.75	55.31	60.72
BAT	1998	23.12	40.98	29.70	46.57	26.21	38.31	35.46	43.51	30.00	49.86	17.24	29.33	25.38	25.58	43.40	53.39	25.34	37.18	60.26	57.62
CBR	1992	69.85	74.69	66.20	71.57	52.61	57.49	67.67	70.78	70.86	74.11	61.55	67.83	38.83	40.11	82.54	87.18	66.67	70.51	77.50	83.20
CBR	1993	42.91	48.66	54.28	56.41	40.67	45.83	45.05	55.68	45.98	60.82	30.91	34.17	29.03	33.12	63.64	66.35	34.09	48.57	66.76	70.11
CBR	1994	39.60	43.72	43.88	49.70	37.21	41.06	38.14	47.72	37.75	53.22	33.13	31.62	24.42	30.22	49.85	57.16	27.40	41.60	31.72	61.14
CBR	1995	28.23	39.80	34.33	44.43	29.04	37.35	38.84	41.55	42.16	47.25	26.39	29.65	24.55	27.93	45.83	49.97	27.63	36.17	58.48	54.05
CBR	1996	30.30	36.86	29.94	40.50	24.48	34.62	31.33	37.10	32.34	42.81	23.59	28.22	22.57	26.33	36.98	44.67	23.13	32.26	49.30	48.72
CBR	1997	28.80	34.68	31.87	37.63	28.02	32.67	31.89	33.97	31.04	39.56	25.07	27.21	25.28	25.31	44.74	40.81	27.45	29.53	44.98	44.76
CBR	1998	24.80	32.89	28.49	35.28	23.40	31.11	32.46	31.55	28.31	36.90	23.24	26.43	22.05	24.67	33.75	37.69	24.53	27.47	44.92	41.48
MON	1992	69.85	74.80	66.20	71.76	52.61	57.61	67.67	70.96	70.86	74.33	61.55	67.81	38.83	40.05	82.54	87.45	66.67	70.60	77.50	83.48
MON	1993	45.68	49.03	53.17	56.94	43.53	46.18	50.24	56.23	47.79	61.43	41.22	34.32	31.19	33.13	58.96	67.08	35.80	49.02	78.22	70.85
MON	1994	28.41	44.63	48.37	50.97	38.00	41.92	39.72	49.13	42.14	54.67	25.72	32.02	21.90	30.49	49.75	58.89	27.89	42.80	48.46	62.89
MON	1995	31.63	40.91	33.64	45.96	28.05	38.37	33.76	43.24	35.29	49.00	22.15	30.11	23.33	28.25	44.23	52.07	25.14	37.61	51.95	56.18
MON	1996	27.27	37.97	29.48	42.04	26.61	35.63	30.40	38.74	32.29	44.57	24.11	28.65	22.18	26.56	34.71	46.76	25.21	33.64	47.88	50.89
MON	1997	39.34	35.88	31.28	39.26	29.03	33.71	33.27	35.64	30.82	41.43	23.92	27.63	25.59	25.46	30.79	43.03	27.10	30.92	43.09	47.11
MON	1998	22.05	34.13	25.90	36.97	25.77	32.15	30.63	33.17	30.36	38.84	21.58	26.82	23.21	24.68	33.61	39.96	25.22	28.77	34.59	43.94
PET	1992	69.85	74.80	66.20	71.74	52.61	57.60	67.67	70.96	70.86	74.31	61.55	67.84	38.83	40.07	82.54	87.43	66.67	70.62	77.50	83.44
PET	1993	51.02	47.18	56.02	54.42	47.47	44.38	55.39	53.23	60.44	58.58	34.46	33.35	32.04	32.02	69.42	63.62	40.17	46.40	79.81	67.50
PET	1994	48.67	41.19	37.96	46.33	43.18	38.63	43.20	43.67	45.09	49.42	35.82	30.25	27.29	28.39	62.26	52.57	23.16	37.98	76.30	56.68
PET	1995	29.59	36.98	41.87	40.72	39.78	34.71	38.30	37.24	44.02	43.08	25.44	28.15	25.79	25.99	48.72	44.99	28.91	32.31	62.18	49.11
PET	1996	28.28	33.99	29.55	36.79	23.22	32.02	32.36	32.96	30.50	38.64	20.65	26.75	21.42	24.57	38.95	39.72	23.38	28.58	48.56	43.71
PET	1997	25.86	31.93	28.10	34.13	28.84	30.26	28.57	30.29	28.69	35.63	21.02	25.86	26.98	23.94	38.87	36.21	23.41	26.31	42.24	39.97
PET	1998	26.07	30.30	29.76	32.05	22.42	28.95	28.21	28.42	28.36	33.27	22.28	25.22	24.01	23.78	32.00	33.50	23.26	24.82	45.69	36.97

Note: Aspen-Trembling aspen; Cedar-Western red cedar; Fescu-Plains rough fescue; Beech-American beech
Birch-White birch; Bfern-Bracken fern; Dfir-Douglas fir; Jpine-Jack pine; Spruce-Black spruce; Tam-Tamarack

a--is actual data
p--is simulated data

VITA

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