APPENDIX 1. Model Description and Logic

1.0 Overview and State Variables

The functions in TEM have been well documented in previous work (Raich et al., 1991; McGuire et al., 2001; Zhuang et al., 2001, 2002, 2003). Here, we review the descriptions of TEM that are relevant to this current study, and describe the logic and mathematical expressions in the model that are unique to the TEM-DVM with multiple vegetation pools. Table A1 lists the state variables, fluxes, and parameters, with their respective units, which are described in the text below. Tables A2, A3, and A4 contain the variables specific to the ecosystems in this study and plant functional types within these ecosystems that are used in model calibrations and parameterizations.

As in previous versions of TEM, TEM-DVM contains basic state variables for carbon in living vegetation (C_V), nitrogen in living vegetation (N_{VS} and N_{VL}), organic carbon in detritus and soils (C_s), organic nitrogen in detritus and soils (N_s), and available inorganic soil nitrogen (N_{AV}). However, while previous versions of TEM simulated the dynamics of these aggregated carbon and nitrogen pools for an ecosystem type, the new version disaggregates the vegetation carbon and nitrogen pools by plant functional type (PFT) found in a given ecosystem. Furthermore, vegetation carbon and nitrogen pools of each PFT have been disaggregated into leaf (L), wood (W), and root (R) components. These disaggregations add nine new state variables in addition to C_V, N_{VS} and N_{VL} for every PFT assumed to comprise an ecosystem. These state variables change from month to month according to the differential inputs and losses driven by seasonal changes in climate.

As in previous versions of TEM, we use a variable time step 5th-6th order Runga-Kutta integration procedure (Runge - Kutta – Fehlberg, Cheney and Kincaid, 1985) to assure stability in the integration over time. For each leaf, wood, and root component of each PFT, we calculate the change in carbon in the living vegetation:

$$dC_{VL} / dt = GPP_{Lt} - R_{At} - LITTER_{CLt} \tag{A1a}$$

$$dC_{VW} / dt = GPP_{Wt} - R_{At} - LITTER_{CWt} \tag{A1b}$$

$$dC_{VR} / dt = GPP_{Rt} - R_{At} - LITTER_{CRt}, \tag{A1c}$$

where R_A is autotrophic respiration, and $LITTER_{CL,}$ $LITTER_{CW,}$ $LITTER_{CR}$ are the litter carbon fluxes of the L, W, and R tissues. Total combined leaf, wood, and root C_V for each PFT is then:

$$dC_V / dt = GPP_t - R_{At} - L_{Ct}, \tag{A2}$$

Nitrogen in the living vegetation for each leaf, wood, and root tissue for each PFT is:

$$dN_{VL} / dt = NUPTAKE - LITTER_{NLt} \tag{A3a}$$

$$dN_{VW} / dt = NUPTAKE - LITTER_{NWt} \tag{A3b}$$

$$dN_{VR} / dt = NUPTAKE - LITTER_{NRt}, \tag{A3c}$$

where NUPTAKE is the uptake of N by the vegetation, and $\mathrm{LITTER}_{\mathrm{NL},}$ $\mathrm{LITTER}_{\mathrm{NW},}$ $\mathrm{LITTER}_{\mathrm{NR}}$ are the litter nitrogen of the L, W, and R tissues. Total combined leaf, wood, and root N_V for each PFT is then:

$$dN_V / dt = \mathrm{NUPTAKE} - \mathrm{LITTER}_{Nt} \qquad \textbf{(A4)}$$

The change in organic carbon and detritus in the soils (C_S) is the difference between LITTER_C and heterotrophic respiration:

$$dC_S / dt = \mathrm{LITTER}_{Cst} - R_{Ht} \qquad \textbf{(A5)}$$

The change in organic N in the detritus and soils is the difference between LITTER_N and net N mineralization:

$$dN_S / dt = \mathrm{LITTER}_{Nt} - \mathrm{NETNMIN}_t \qquad \textbf{(A6)}$$

The change in available inorganic soil N (N_{AV}) is the sum of N inputs to the ecosystem and net nitrogen mineralization (NETNMIN) minus total N lost from the soils (NLOST) and NUPTAKE:

$$dN_{AV} / dt = \mathrm{NINPUT}_t + \mathrm{NETNMIN}_t - \mathrm{NLOST}_t - \mathrm{NUPTAKE}_t \qquad \textbf{(A7)}$$

In TEM-DVM, interactions between the carbon and nitrogen cycles are a fundamental component of the model. The relative allocation of effort by the vegetation to C versus N uptake is based on the comparison of N demand with N supply in which N feedback on C assimilation is implemented if N demand exceeds N supply. Therefore, we divide the model logic and its description below into three sections: (i) the calculations that occur before N feedback on C assimilation, (ii) those that occur during N feedback on C assimilation, and (iii) those that occur after N feedback on C assimilation. All the model calculations described below occur at the monthly time step that employs an adaptive step size integrator.

2. Before N Feedback

2.1 Water Balance and Leaf Phenology

Before N feedback occurs, the model performs calculations assuming that the C assimilation by each PFT is not limited by N availability. This includes computation of initial estimates of GPP, N uptake, and NPP for each PFT without N limitations. To compute these initial estimates, the model must first calculate water balance. First, potential evapotranspiration (PET) and evapotranspiration (EET) are calculated in the Water Balance Model in TEM (Vörösmarty et al., 1989) using input precipitation data. These estimates of PET and EET influence the phenology of plant leaf tissue as the ratio of EET/PET is smaller in months in which transpiration is compromised by water supply during drought or soil freezing. Therefore, once EET and PET have been estimated, the leaf phenology model in the TEM-DVM is implemented for each PFT. The monthly unnormalized leaf phenology (UNNORMLEAF) for each PFT depends on the current month's EET and the maximum EET of the previous year (PRVEETMX), and regression derived leaf phenology parameters (A_{LEAF}, B_{LEAF}, and C_{LEAF} ; Raich et al., 1991):

$$\mathrm{UNNORMLEAF} = (A_{LEAF} * (\mathrm{EET} / \mathrm{PRVEETMX})) + (B_{LEAF} * \mathrm{PRVLEAF}) + C_{LEAF} \quad \textbf{(A8)}$$

Each of these calculations includes the following check:

$$\text{If } (\mathrm{UNNORMLEAF} < (0.5 * \mathrm{MINLEAF}), \text{ then } \mathrm{UNNORMLEAF} = 0.5 * \mathrm{MINLEAF}, \quad \textbf{(A9)}$$

where MINLEAF is a pre-established value below which the normalized leaf phenology (LEAF) is not allowed to go. The normalized leaf component (LEAF) is then calculated for each PFT as the ratio of UNNORMLEAF and PRVLEAFMX, which is the highest UNNORMLEAF in the previous year:

$$\mathrm{LEAF} = \mathrm{UNNORMLEAF}/\mathrm{PRVLEAFMX} \quad \textbf{(A10a)}$$

$$\text{If } \mathrm{PRVLEAFMX} \leq 0.0, \text{ then } \mathrm{LEAF} = 0.0 \quad \textbf{(A10b)}$$

If the current leaf value for a given PFT is calculated to be less than that minimum leaf value then the current leaf value is set to that of the minimum leaf:

$$\text{If } \mathrm{LEAF} < \mathrm{MINLEAF}, \text{ then } \mathrm{LEAF} = \mathrm{MINLEAF} \quad \textbf{(A10c)}$$

The model includes a check such that the leaf variable can not be greater than 1.0 for each PFT:

$$\text{If LEAF} > 1.0, \text{then LEAF} = 1.0 \qquad \textbf{(A10d)}$$

2.2 Foliage and Leaf Area Index

Following the calculations of leaf phenology, the model calculates foliage and leaf area index (LAI). The foliage calculation, which was implemented in the version of TEM used in McGuire et al. (2001), and also described in detail in Zhuang et al. (2003), is a scalar function that ranges from 0.0 to 1.0. It represents the allocation of canopy leaf biomass (C_{VL}) during the month of maximum C_{VL} relative to a theoretical maximum possible leaf biomass (C_{VLmax}), which is a parameter that is determined based on GPP and maximum monthly C_{VL} at the calibration site. For each PFT, the foliage is a logistic function of $f(C_V)$:

$$f(\text{Foliage}) = 1.0 / (1.0 + m_1)\, e^{m2 \text{ x } \sqrt{f(Cv)}} \qquad \textbf{(A11)}$$

where m_1 and m_2 are parameters, and $f(C_V)$ is a hyperbolic function of the state variable for vegetation carbon for each PFT and two parameters (m_3 and m_4):

$$f(C_V) = (m_3 \text{ x } C_V) / (1.0 + m_4 \text{ x } C_V) \qquad \textbf{(A12)}$$

The calculation of monthly leaf area index (LAI) depends on specific leaf area (SLA; McGuire et al., 2001) and monthly canopy leaf biomass (C_{VL}) for each PFT:

$$LAI = SLA * C_{VL}, \tag{A13}$$

where monthly C_{VL} is estimated as f(FOLIAGE) x C_{VLmax} x f(LEAF).
The foliar percent cover is then calculated for each PFT, and is a function of Beer's Law.

$$FPC = 1 - e^{-extincoeff * LAI}, \tag{A14}$$

where the extinction coefficients (extincoeff) are pre-defined values, with plants higher in the canopy assigned greater extinction coefficients than those PFTs lower in the canopy. That is, even if the LAI of a PFT lower in the canopy is the same as that of a PFT higher in the canopy, it will have a lower FPC since the extinction coefficient is lower. If total FPC is less than 1, no light competition occurs. If FPC is greater than 1, then it is adjusted downward by dividing the original FPC of a given PFT by the total FPC across all PFTs (FPC_{TOTAL}) :

$$\text{If } FPC_{TOTAL} > 1, \text{ then } FPC_{PFT} / FPC_{TOTAL} \tag{A15}$$

2.3 Initial GPP and Initial N Uptake for all PFTs

Once the phenology, LAI, and FPC have been computed, an initial GPP and intial N uptake are calculated for each PFT. The initial GPP (InGPP) is a function of the maximum rate of CO_2 assimilation, which is moderated by several scalars, including the atmospheric CO_2 concentration, the irradiance of photosynthetically active radiation at canopy level (PAR; Raich et al., 1991), air temperature (T; Raich et al., 1991), nitrogen availability (N_{AV}; Raich et al., 1991), a multiplier accounting for changes in leaf conductivity of CO_2 resulting from changes in moisture availability (G_v), normalized leaf phenology (PHENOLOGY; described above), the ratio of canopy leaf biomass relative to maximum leaf biomass (FOLIAGE; described above), percent ground thaw at 10 cm depth (THAWPCT; Euskirchen et al., 2006), and foliar percent cover (FPC; described above). For each PFT:

$$\mathrm{InGPP} = C_{max}\ f(CO_2)\ f(\mathrm{PAR})\ f(\mathrm{T})\ f(G_v)\ f(N_{AV})\ f(\mathrm{PHENOLOGY})\ f(\mathrm{FOLIAGE})\ f(\mathrm{THAWPCT})\ f(\mathrm{FPC}) \qquad \textbf{(A16)}$$

Initial N uptake (INUPTAKE) is calculated as a function of soil moisture (MOIST; Raich et al., 1991), air temperature (T), available soil N (N_{av}; Raich et al., 1991), maximum rate of N uptake by the vegetation (N_{max}; Raich et al., 1991), a parameter accounting for relative differences in the conductance of the soil N diffusion (K_S; Raich et al, 1991), the concentration of N_{av} at which N uptake proceeds at one-half its maximum rate, normalized leaf phenology (PHENOLOGY; described above), and the Q_{10} value of root respiration ($\mathrm{RESPQ10}_R$), which is assumed equal to 2.0. For each PFT:

$$\mathrm{INUPTAKE} = f(\mathrm{MOIST})\ f(\mathrm{T})\ f(N_{av})\ f(N_{max})\ f(K_S)\ f(k_n)\ f(\mathrm{LEAF})\ f(\mathrm{RESPQ10}_R) \qquad \textbf{(A17)}$$

2.4 Heterotrophic Respiration

Heterotrophic respiration (R_H) represents decomposition of all soil organic matter in an ecosystem and is calculated at a monthly time step:

$$R_H = K_d C_S\, f(M_V) e^{0.069 H_T}, \quad \textbf{(A18)}$$

where K_d is a rate-limiting parameter that defines the rate of decomposition at 0°C, C_S is the soil carbon state variable, M_V is the mean volumetric monthly soil moisture (see Tian et al., 1999), and H_T is the mean monthly soil temperature (humic soil layer) derived in the soil thermal model (STM; Zhuang et al., 2001, 2002).

2.5 Litterfall C and N by Tissue Type for all PFTs

The C litterfall ($LITTER_C$) for the leaf, wood and root component for each PFT is calculated according to the rate of litterfall (CFALL) for each leaf, wood and root component ($CFALL_L$, $CFALL_W$, $CFALL_R$) and the amount of carbon in the vegetation for each leaf, wood, and root component. CFALL is modeled as a direct function of mean annual vegetation carbon and annual NPP for each PFT:

$$CFALL_L = (\text{annual } NPP_L) / 12 (\text{mean annual } C_{VL}) \quad \textbf{(A19a)}$$

$$CFALL_W = (\text{annual } NPP_W) / 12 (\text{mean annual } C_{VW}) \quad \textbf{(A19b)}$$

$$CFALL_R = (\text{annual } NPP_R) / 12 (\text{mean annual } C_{VR}) \quad \textbf{(A19c)}$$

Carbon in the litterfall is then a percentage of the amount of carbon in the vegetation of each PFT:

$$\mathrm{LITTER}_{CL} = \mathrm{CFALL}_{L} * C_{VL} \quad \textbf{(A20a)}$$

$$\mathrm{LITTER}_{CW} = \mathrm{CFALL}_{W} * C_{VW} \quad \textbf{(A20b)}$$

$$\mathrm{LITTER}_{CR} = \mathrm{CFALL}_{R} * C_{VR} \quad \textbf{(A20c)}$$

Following the calculation of litterfall carbon for each tissue type, the total litter carbon pool is set to the sum of the leaf, wood, and root carbon pools created above:

$$\mathrm{LITTER}_{C} = \mathrm{LITTER}_{CL} + \mathrm{LITTER}_{CW} + \mathrm{LITTER}_{CR} \quad \textbf{(A21)}$$

The N litterfall (LITTER_{N}) for the leaf, wood and root component all PFTs is calculated according to the rate of litterfall (NFALL) for each leaf, wood and root component of each PFT (NFALL_{L}, NFALL_{W}, NFALL_{R}) and the amount of carbon in the vegetation for each leaf, wood, and root component of each PFT. NFALL is modeled as a direct function of mean annual vegetation nitrogen and annual NUPTAKE for each PFT:

$$\mathrm{NFALL}_{L} = (\text{annual } \mathrm{NUPTAKE}_{L}) / 12 \ (\text{mean annual } N_{VL}) \quad \textbf{(A22a)}$$

$$\mathrm{NFALL}_{W} = (\text{annual } \mathrm{NUPTAKE}_{W}) / 12 \ (\text{mean annual } N_{VW}) \quad \textbf{(A22b)}$$

$$\mathrm{NFALL}_{R} = (\text{annual } \mathrm{NUPTAKE}_{R}) / 12 \ (\text{mean annual } N_{VR}) \quad \textbf{(A22c)}$$

N in the litterfall is then a percentage of the amount of carbon in the vegetation of each PFT:

$$LITTER_{NL} = NFALL_{L} * N_{VL} \qquad \textbf{(A23a)}$$

$$LITTER_{NW} = NFALL_{W} * N_{VW} \qquad \textbf{(A23b)}$$

$$LITTER_{NR} = NFALL_{R} * N_{VR} \qquad \textbf{(A23c)}$$

Following the calculation of litterfall N for each tissue type, the total litter N pool is set to the sum of the leaf, wood, and root carbon pools created above:

$$LITTER_{N} = LITTER_{NL} + LITTER_{NW} + LITTER_{NR} \qquad \textbf{(A24)}$$

2.6 Maintenance Respiration byTissue Type for all PFTs

Maintenance respiration (R_M) is the amount of carbon lost to the atmosphere from the plant tissues, and is a direct function of plant biomass in each leaf (C_{VL}), wood (C_{VW}), and root component (C_{VR}). We assume that increasing temperatures increase maintenance respiration rates logarithmically with a Q_{10} of 2.0 over all temperatures.

$$R_{ML} = K_{rL}(C_{VL})e^{0.0693T} \qquad \textbf{(A25a)}$$

$$R_{MW} = K_{rW}(C_{VW})e^{0.0693T} \qquad \textbf{(A25b)}$$

$$R_{MR} = K_{rR}(C_{VR})e^{0.0693T} \qquad \textbf{(A25c)}$$

where maintenance respiration is calculated for each leaf (R_{ML}), wood (R_{MW}), and root

(R_{MR}) component of each PFT. K_{rL}, K_{rW}, K_{Rr} are coefficients describing the respiration (carbon loss) rate of the vegetation per unit of biomass carbon at 0°C in grams per gram per month, and T is the mean monthly air temperature in degrees Celsius. Since there is little information available that describes whole and tissue plant respiration for most of the plant functional types considered in this study, we calibrated the values of K_{rL}, K_{rW}, K_{Rr} in TEM-DVM by constraining NPP of a tissue in a PFT based on the allocation of GPP to that tissue at the calibration site.

The model includes checks so that maintenance respiration can only send carbon from vegetation to the atmosphere. Total maintenance respiration is the sum of the maintenance respiration of the tissue components for each PFT:

$$R_M = R_{ML} + R_{MW} + R_{MR} \qquad \textbf{(A26)}$$

2.7 Partition InGPP Among Tissue Types and then Calculate InGPP by Tissue Type, Including Estimates from Growth Respiration for all PFTs

The initial values of GPP are allocated based on the assigned biomass partition for each leaf ($part_L = C_{VL}/C_V$), wood ($part_W = C_{Vw}/C_V$), and root ($part_R = C_{VR}/C_V$) component.

$$InGPP_L = InGPP * part_L \qquad \textbf{(A27a)}$$

$$InGPP_W = InGPP * part_W \qquad \textbf{(A27b)}$$

$$InGPP_R = InGPP * part_R \qquad \textbf{(A27c)}$$

The initial GPP is then recalculated based on the partitioned GPP:

$$InGPP = GPP_L + GPP_W + GPP_R \quad \textbf{(A28)}$$

A rough estimate of initial NPP(InNPP) is then calculated. NPP should equal the difference between GPP and combined maintenance respiration (R_M) and growth respiration (R_G). First, the initial NPP estimate is used to calculated R_G. These calculations are performed for each tissue and each PFT.

$$InNPP_L = InGPP - R_{ML} \quad \textbf{(A29a)}$$

$$InNPP_W = InGPP - R_{MW} \quad \textbf{(A29b)}$$

$$InNPP_R = InGPP - R_{MR} \quad \textbf{(A29c)}$$

The initial NPP is then calculated based on the partitioned NPP for each PFT:

$$InNPP = InNPP_L + InNPP_W + InNPP_R \quad \textbf{(A30)}$$

Growth respiration is initially set equal to zero for each tissue type for each PFT. If there is no plant growth, then R_G remains zero (e.g, no growth respiration occurs). If there is plant growth, then the leaf, wood, and root R_G ($R_{GL,}$ R_{GW}, R_{GR}) is assumed to be 20% of the Initial NPP (Raich et al., 1991) for each PFT.

$$R_{GL} = InNPP_L * 0.20 \quad \textbf{(A31a)}$$

$$R_{GW} = InNPP_W * 0.20$$ **(A31b)**

$$R_{GR} = InNPP_R * 0.20$$ **(A31c)**

Total growth respiration is the sum of the growth respiration of the tissue components:

$$R_G = R_{GL} + R_{GW} + R_{GR}$$ **(A32)**

NPP is then adjusted downward by the amount of growth respiration. That is, the initial value of NPP is then set equal to 80% of the original value for each leaf, wood, and root component for each PFT, and the InNPP for each PFT is recalculated as in (**A30**) above.

2.8 Initial N Uptake of Each PFT Based on Available N, Total N Input to the Soils, and Net N Mineralization

Initial N uptake by the plants (InUPTAKE) is adjusted for each PFT based on the total available N (N_{AV}), the total N input to the soils (NINPUT), and net N mineralization (NETNMIN). In this calculation, nitrogen uptake is limited by three factors: (i) the amount of available N, (ii) the amount of N input from outside the system, and (iii) the amount of N mineralization from the soil for each PFT:

If InUPTAKE > (N_{AV} + NINPUT + NETNMIN), then

$$InUPTAKE = N_{AV} + NINPUT + NETNMIN$$ **(A33)**

2.9 Set Structural Nuptake and Nuptake Equal to Inuptake for all PFTs and Set

Lnuptake to 0.

To start the model, all nitrogen uptake (NUPTAKE) is assumed to be structural nitrogen uptake (SUPTAKE) for each PFT, leaving none for labile nitrogen uptake (LUPTAKE):

$$\mathrm{SUPTAKE} = \mathrm{NUPTAKE} = \mathrm{INUPTAKE} \qquad \textbf{(A34a)}$$

$$\mathrm{LUPTAKE} = 0.0 \qquad \textbf{(A34b)}$$

2.10 Set GPP = InGPP, NPP = InNPP, Nmobl = 0, and Nresorb = 0 for each Tissue Type for all PFTs, Partition SUPTAKE

For each tissue type (leaf, wood, root) and all tissue types combined, GPP is set to the initial values.

$$\mathrm{GPP}_L = \mathrm{InGPP}_L \qquad \textbf{(A35a)}$$

$$\mathrm{GPP}_W = \mathrm{InGPP}_W \qquad \textbf{(A35b)}$$

$$\mathrm{GPP}_R = \mathrm{InGPP}_R \qquad \textbf{(A35c)}$$

The GPP is then calculated as the sum of the leaf, wood, and root components:

$$\mathrm{GPP} = \mathrm{GPP}_L + \mathrm{GPP}_W + \mathrm{GPP}_R \qquad \textbf{(A36)}$$

NPP is also set to the initial values for each tissue type, with the total NPP calculated as the sum of the leaf, wood and root components for each PFT:

$$\mathrm{NPP}_L = \mathrm{InNPP}_L \quad \textbf{(A37a)}$$

$$\mathrm{NPP}_W = \mathrm{InNPP}_W \quad \textbf{(A37b)}$$

$$\mathrm{NPP}_R = \mathrm{InNPP}_R \quad \textbf{(A37c)}$$

$$\mathrm{NPP} = \mathrm{NPP}_L + \mathrm{NPP}_W + \mathrm{NPP}_R \quad \textbf{(A38)}$$

For each tissue type, and all tissue types combined, nitrogen mobilization and nitrogen resorbtion are then set to zero. The total structural N uptake (SUPTAKE) is then partitioned among the leaf ($\mathrm{SUPTAKE}_L$), wood ($\mathrm{SUPTAKE}_W$) and root ($\mathrm{SUPTAKE}_R$) tissues for each PFT based on the nitrogen partition for each leaf ($\mathrm{npart}_L = N_{VL}/N_V$), wood ($\mathrm{npart}_W= N_{VW}/N_V$), and root ($\mathrm{npart}_R= N_{VR}/N_V$) component:

$$\mathrm{SUPTAKE}_L = \mathrm{SUPTAKE} * \mathrm{npart}_L \quad \textbf{(A39a)}$$

$$\mathrm{SUPTAKE}_W = \mathrm{SUPTAKE} * \mathrm{npart}_R \quad \textbf{(A39b)}$$

$$\mathrm{SUPTAKE}_R= \mathrm{SUPTAKE} * \mathrm{npart}_W \quad \textbf{(A39c)}$$

3. Nitrogen Feedback to NPP

3.1 Nitrogen Litterfall and Nitrogen Resorbtion for all Tissue Types and PFTs

In the calculations of N feedback to NPP, the model first examines the N in the litterfall (LITTER_N) for each leaf (LITTER_{NL}), wood (LITTER_{NW}), and root (LITTER_{NR}) component. If the N in the litterfall is less than the N in the C:N ratio of new production (CNEVEN) for a given leaf (CNEVEN_L), wood (CNEVEN_W), or root (CNEVEN_R) component, then the difference is resorbed ($\mathrm{NRESORB}_L$, $\mathrm{NRESORB}_W$,

$\mathrm{NRESORB}_R$), going from labile N to structural N. If the N in litterfall is more than the N calculated by CNEVEN of a given tissue type, then the LITTER_N is adjusted, and $\mathrm{NRESORB}_L$ is set to zero. For each PFT:

If $\mathrm{LITTER}_{NL} \leq (\mathrm{LITTER}_{CL} / \mathrm{CNEVEN}_L)$ then

$$\mathrm{NRESORB}_L = (\mathrm{LITTER}_{CL} / \mathrm{CNEVEN}_L) - \mathrm{LITTER}_{NL} \qquad \textbf{(A40a)}$$

If $\mathrm{LITTER}_{NL} > (\mathrm{LITTER}_{CL} / \mathrm{CNEVEN}_L)$ then

$\mathrm{LITTER}_{NL} = (\mathrm{LITTER}_{CL} / \mathrm{CNEVEN}_L)$, and

$$\mathrm{NRESORB}_L = 0 \qquad \textbf{(A40b)}$$

If $\mathrm{LITTER}_{NW} \leq (\mathrm{LITTER}_{CW} / \mathrm{CNEVEN}_W)$ then

$$\mathrm{NRESORB}_W = (\mathrm{LITTER}_{CW} / \mathrm{CNEVEN}_W) - \mathrm{LITTER}_{NW} \qquad \textbf{(A41a)}$$

If $\mathrm{LITTER}_{NW} > (\mathrm{LITTER}_{CW} / \mathrm{CNEVEN}_W)$ then

$\mathrm{LITTER}_{NW} = (\mathrm{LITTER}_{CW} / \mathrm{CNEVEN}_W)$, and

$$\mathrm{NRESORB}_W = 0 \qquad \textbf{(A41b)}$$

If $\mathrm{LITTER}_{NR} \leq (\mathrm{LITTER}_{CR} / V_{CNR})$ then

$$\mathrm{NRESORB}_R = (\mathrm{LITTER}_{CR} / V_{CNR}) - \mathrm{LITTER}_{NR} \qquad \textbf{(A42a)}$$

If $\mathrm{LITTER}_{NR} > (\mathrm{LITTER}_{CR} / V_{CNR})$ then

$\mathrm{LITTER}_{NR} = (\mathrm{LITTER}_{CR} / \mathrm{CNEVEN}_R)$, and

$$NRESORB_R = 0 \quad \textbf{(A42b)}$$

The total N in the litterfall and N resorbtion across all tissues is then calculated for each PFT:

$$LITTER_N = LITTER_{NL} + LITTER_{NW} + LITTER_{NR} \quad \textbf{(A43)}$$

$$NRESORB = NRESORB_L + NRESORB_W + NRESORB_R \quad \textbf{(A44)}$$

Next, N resorbtion is then adjusted based on the NRESORB calculated above, and the vegetation N (V_N) for each leaf (V_{NL}), wood (V_{NW}), and root (V_{NR}) component, the vegetation C (V_C) for each leaf (V_{CL}), wood (V_{CW}), and root (V_{CR}) component, and the C:N ratio (V_{CN}) for each leaf (V_{CNL}), wood (V_{CNW}), and root (V_{CNR})component. For each PFT:

$$\text{If } V_{CL} > 0 \text{ then } NRESORB_L = (V_{NL} / V_{CL}) \text{ x } V_{CNL} \quad \textbf{(A45a)}$$

$$\text{If } V_{CW} > 0 \text{ then } NRESORB_W = (V_{NW} / V_{CW}) \text{ x } V_{CNW} \quad \textbf{(A45b)}$$

$$\text{If } V_{CR} > 0 \text{ then } NRESORB_R = (V_{NR} / V_{CR}) \text{ x } V_{CNR} \quad \textbf{(A45c)}$$

The total N resorbtion is then recalculated for each PFT as above in **(A44).**

3.2. Calculate N Required by each Tissue Based on the Current Value of NPP for that Tissue

The N requirements (NREQUIRE) for each leaf ($NREQUIRE_L$), wood ($NREQUIRE_W$), and root ($NREQUIRE_R$) tissue and each PFT are determined based on NPP:

$$NREQUIRE_L = NPP_L / CNEVEN_L \quad \textbf{(A46a)}$$

$$NREQUIRE_W = NPP_W / CNEVEN_W \quad \textbf{(A46b)}$$

$$NREQUIRE_R = NPP_R / CNEVEN_R \quad \textbf{(A46c)}$$

The total N required across all tissues is then recalculated for each PFT:

$$NREQUIRE = NREQUIRE_L + NREQUIRE_W + NREQUIRE_R \quad \textbf{(A47)}$$

3.3 If NREQUIRE > NUPTAKE + LABILEN, then Down- Regulate NPP, Recalculate Growth Respiration and GPP

NPP is down-regulated as needed based on the comparison of N demand, i.e., NREQUIRE, and possible N supply, i.e., the sum of NUPTAKE and LABILEN for each PFT:

If NREQUIRE > (NUPTAKE + LABILEN), then

$$NPP = NPP * (NUPTAKE + LABILEN) / NREQUIRE \quad \textbf{(A48)}$$

The NPP of leaf, wood, and root components for each PFT are then calculated based on the NPP calculated just above, and the initial NPP:

$$NPP_L = InNPP_L * NPP/InNPP \quad \textbf{(A49a)}$$

$$NPP_W = InNPP_W * NPP/InNPP \quad \textbf{(A49b)}$$

$$NPP_R = InNPP_R * NPP/InNPP \quad \textbf{(A49c)}$$

Total NPP is then recalculated for each PFT, as in **(A38)**.

Growth respiration for each leaf, wood, and root component is set to one-fourth of NPP for a given tissue component for each PFT:

$$R_{GL} = NPP_L * 0.25 \quad \textbf{(A50a)}$$

$$R_{GW} = NPP_W * 0.25 \quad \textbf{(A50b)}$$

$$R_{GR} = NPP_R * 0.25 \quad \textbf{(A50c)}$$

The total R_G is then computed based on the values of each leaf, wood, and root R_G for each PFT, as in **(A32)** above.

GPP is recalculated for each leaf, wood, and root component for each PFT:

$$GPP_L = NPP_L + R_{GL} + R_{ML} \quad \textbf{(A51a)}$$

$$GPP_W = NPP_W + R_{GW} + R_{MW} \quad \textbf{(A51b)}$$

$$GPP_R = NPP_R + R_{GR} + R_{MR} \quad \textbf{(A51c)}$$

Total GPP is then computed, summing over the leaf, wood and root GPP for each PFT, as in **(A36)** above.

Nitrogen mobilization by the PFTs (NMOBIL) is partitioned among tissues for each PFT so that it empties the labile N pool:

$$\mathrm{NMOBIL_L = (NREQUIRE_L / NREQUIRE) * LABILEN} \quad \textbf{(A52a)}$$

$$\mathrm{NMOBIL_W = (NREQUIRE_W / NREQUIRE) * LABILEN} \quad \textbf{(A52b)}$$

$$\mathrm{NMOBIL_R = (NREQUIRE_R / NREQUIRE) * LABILEN} \quad \textbf{(A52c)}$$

Total NMOBIL is computed by summing over all tissues for each PFT:

$$\mathrm{NMOBIL = NMOBIL_L + NMOBIL_W + NMOBIL_R} \quad \textbf{(A53)}$$

3.4 If NREQUIRE < LABILEN, then Down-Regulate NUPTAKE, and Calculate NMOBIL, SUPTAKE, and LUPTAKE

The model then checks for the alternative, if the N requirement is less than the N supply, and down regulates N uptake accordingly:

If NREQUIRE < (NUPTAKE + LABILEN), then

NUPTAKE = INUPTAKE * INPRODCN * (INPRODCN – 2 * NPP/NREQUIRE), **(A54)** where INPRODCN is the initial C:N ratio of biomass production. If labile N is larger than the N requirement, the structural leaf, wood, and root components for each PFT receive all of the N they need from the labile pool:

If $\mathrm{LABILEN} \geq \mathrm{NREQUIRE}_L + \mathrm{NREQUIRE}_W + \mathrm{NREQUIRE}_R$, then

$$\mathrm{NMOBIL}_L = \mathrm{NREQUIRE}_L$$
$$\mathrm{NMOBIL}_W = \mathrm{NREQUIRE}_W$$
$$\mathrm{NMOBIL}_R = \mathrm{NREQUIRE}_R \qquad \textbf{(A55)}$$

The model then checks if tissue-specific NMOBIL is less than zero when C_V of the tissue is greater than zero, in which case it and adjusts NMOBIL accordingly for each leaf, wood, and root component and PFT. The check for carbon content of the tissue greater than zero is to accommodate plant functional types that do not have a particular tissue type (e.g., forbs without wood tissue). The adjustment of NMOBIL through the multiplication of the current N:C ratio of the tissue with the target C:N ration the tissue (V_{CN}) is the key constraint in the model that controls the vegetation C:N ratio:

If $\mathrm{NMOBIL}_L < 0$ and $C_{VL} > 0$, then

$$\mathrm{NMOBIL}_L = \mathrm{NMOBIL}_L * (N_{VL}) / (C_{VL}) * (V_{CNL}) \qquad \textbf{(A56a)}$$

If $\mathrm{NMOBIL}_W < 0$ and $C_{VW} > 0$, then

$$\mathrm{NMOBIL}_W = \mathrm{NMOBIL}_W * (N_{VW}) / (C_{VW}) * (V_{CNW}) \qquad \textbf{(A56b)}$$

If $NMOBIL_R < 0$ and $V_{CR} > 0$, then

$$NMOBIL_R = NMOBIL_L * (N_{VW}) / (C_{VW}) * (V_{CNW}) \quad \textbf{(A56c)}$$

The total NMOBIL is then recalculated as in **(A53)** above.

The model checks if NMOBIL is greater than LABILEN, and adjusts NMOBIL accordingly for each leaf, wood, and root component and each PFT:

If NMOBIL > LABILEN, then

$$NMOBIL = NMOBIL * (LABILEN / NMOBIL)$$
$$NMOBIL_L = NMOBIL_L * (LABILEN / NMOBIL)$$
$$NMOBIL_W = NMOBIL_W * (LABILEN / NMOBIL)$$
$$NMOBIL_R = NMOBIL_R * (LABILEN / NMOBIL) \quad \textbf{(A57)}$$

If there is not enough labile N to satisfy N requirements, the model drains the labile pool into the three leaf, wood, and root structural pools based on the N requirement of each component for each PFT:

If NREQUIRE > NMOBIL and NREQUIRE < (NMOBIL + NUPTAKE), then

$$NMOBIL_L = NREQUIRE_L / (NREQUIRE * LABILEN)$$
$$NMOBIL_W = NREQUIRE_W / (NREQUIRE * LABILEN)$$
$$NMOBIL_R = NREQUIRE_R / (NREQUIRE * LABILEN) \quad \textbf{(A58)}$$

The total NMOBIL is then recalculated as in **(A53)** above.

Structural uptake to the leaves is then set for each leaf, wood, and root component for each PFT:

$$\mathrm{SUPTAKE_L} = \mathrm{NPP_L} / \mathrm{CNEVEN_L} - \mathrm{NMOBIL_L} \qquad \textbf{(A59a)}$$

$$\mathrm{SUPTAKE_W} = \mathrm{NPP_W} / \mathrm{CNEVEN_W} - \mathrm{NMOBIL_W} \qquad \textbf{(A59b)}$$

$$\mathrm{SUPTAKE_R} = \mathrm{NPP_R} / \mathrm{CNEVEN_R} - \mathrm{NMOBIL_R} \qquad \textbf{(A59c)}$$

If SUPTAKE is less than zero for any tissue, then SUPTAKE is set to zero for that tissue. Structural uptake is calculated as the sum of the leaf, wood, and root components for each PFT:

$$\mathrm{SUPTAKE} = \mathrm{SUPTAKE_L} + \mathrm{SUPTAKE_W} + \mathrm{SUPTAKE_R} \qquad \textbf{(A60)}$$

The model does not permit SUPTAKE to be greater than total N uptake, and when necessary will adjust SUPTAKE downward for each leaf, wood, and root component for each PFT since there would not be adequate N to uptake:

$$\begin{aligned} &\text{If SUPTAKE} > \text{NUPTAKE, then} \\ &\qquad \mathrm{SUPTAKE_L} = (\mathrm{SUPTAKE_L} / \mathrm{SUPTAKE}) * \mathrm{NUPTAKE} \\ &\qquad \mathrm{SUPTAKE_W} = (\mathrm{SUPTAKE_W} / \mathrm{SUPTAKE}) * \mathrm{NUPTAKE} \\ &\qquad \mathrm{SUPTAKE_R} = (\mathrm{SUPTAKE_R} / \mathrm{SUPTAKE}) * \mathrm{NUPTAKE} \qquad \textbf{(A61)} \end{aligned}$$

Total SUPTAKE is then recalculated as in **(A60)** above.

The model compares the final value of labile N to the final value of structural N (V_N) multiplied by LABILNCON (the maximum proportion of V_N allowed in the LABILE N pool; the parameter is generally set to 0.20), and adjusts LUPTAKE accordingly for each PFT.

If (LABILEN + NUPTAKE – SUPTAKE + NRESORB + NMOBIL) < LANBILNCON * (V_N + SUPTAKE – LITTER_N – NRESORB – NMOBIL), then LUPTAKE = NUPTAKE – SUPTAKE **(A62)**

If (LABILEN + NUPTAKE – SUPTAKE + NRESORB + NMOBIL) ≥ LANBILNCON * (V_N + SUPTAKE – LITTER_N – NRESORB – NMOBIL), then

LUPTAKE = (LABILNCON (V_N + SUPTAKE – LITTER_N – NRESORB – NMOBIL) – STON + NRESORB – NOMOBIL **(A63)**

Finally, NUPTAKE is calculated for each PFT:

NUPTAKE = SUPTAKE_L + SUPTAKE_W + SUPTALE_R + LUPTAKE **(A64)**

4.0 After N Feedback

4.1 Calculate GPP and NPP by Tissue Type for all PFTs, Calculate Ecosystem NEP

and NLOST

Following the calculations of N feedback, final monthly values of GPP **(A36)** and NPP (**A38**) are recalculated by ecosystem type and for all PFTs. Net ecosystem productivity (NEP) is then calculated for the ecosystem as the difference between the ecosystem NPP_{ALLPFT} (i.e., NPP summed over all PFTs) and R_H:

$$NEP = NPP_{ALLPFTS} - R_H \quad \textbf{(A65)}$$

Total N lost from the soils (NLOST) is then calculated as a function of available N and soil moisture (SM), rainfall, snowmelt infiltration (SNOWINF) and EET. Soil moisture, rainfall, and snowmelt infiltration are calculated in the water balance model (Vörösmarty et al., 1989):

$$NLOST = (N_{AV} / SM) * (RAIN + SNOWINF) - EET \quad \textbf{(A66)}$$

NLOST is then reduced if necessary to prevent N_{av} going to zero.

5.0 Simulated Monthly Changes in State Variables

Finally, the changes in the state variables (equations A1 – A7 above) are calculated, and the model advances to the next month.

LITERATURE CITED

Cheney, W., and D. Kincaid. 1985. Numerical mathematics and computing. Second edition. Brooks/ Col Publishing Co. Monterey, CA. pp. 325-328.

Euskirchen, S.E., A.D. McGuire, D.W. Kicklighter, Q. Zhuang, J.S. Clein, R.J. Dargaville, D.G. Dye, J.S. Kimball, K.C. McDonald, J.M. Melillo, V.E. Romanovsky, and N.V. Smith. 2006. Importance of recent shifts in soil thermal dynamics on growing season length, productivity, and carbon sequestration in terrestrial high-latitude ecosystems. Global Change Biology 12:731-750.

McGuire, A.D., S. Sitch, J.S. Clein, R. Dargaville, G. Esser, J. Foley, M. Heimann, F. Joos, J. Kaplan, D.W. Kicklighter, R.A. Meier, J.M. Melillo, B. Moore III, I.C. Prentice, N. Ramankutty, T. Reichenau, A. Schloss, H. Tian, L.J. Williams, and U. Wittenberg. 2001. Carbon balance of the terrestrial biosphere in the twentieth century: Analyses of CO2, climate and land-use effects with four process-based ecosystem models. Global Biogeochemical Cycles 15:183-206.

Raich J.W., E.B. Rastetter, J.M. Melillo, D.W. Kicklighter, P.A. Steudler, B.J. Peterson, A.L. Grace, B. Moore III, C.J. Vörösmarty. 1991. Potential net primary productivity in South America: Application of a global model. Ecological Applications 1:399-429.

Tian H., J.M. Melillo, D.W. Kickligher, A.D. McGuire, and J. Helfrich. 1999. The sensitivity of terrestrial carbon storage to historical climate variability and atmospheric CO_2 in the United States. Tellus, 51B: 414-452.

Vörösmarty, C.J.,B.M. Moore III, A.L. Grace, M.P. Gildea, J.M. Melillo, B.J. Peterson, E.B. Rastetter, and P.A. Steudler. 1989. Continental scale models of water balance and fluvial transport: an application to South America. Global Biogeochemical Cycles 3:241-265.

Zhuang, Q., V.E. Romanovsky, and A.D. McGuire. 2001. Incorporation of a permafrost model into a large-scale ecosystem model: Evaluation of temporal and spatial issues in simulating soil thermal dynamics. Journal of Geophysical Research 106:33649-33670.

Zhuang, Q., A.D. McGuire, J. Harden, K.P. O'Neill, and J. Yarie. 2002. Modeling the soil thermal and carbon dynamics of a fire chronosequence in interior Alaska. Journal of Geophysical Research 107: 10.1029/2001JD001244.

Zhuang, Q., A.D. McGuire, J.M. Melillo, J.S. Clein, R.J. Dargaville, D.W. Kicklighter, R.B. Myneni, J. Dong, V.E. Romanovky, J. Harden, and J.E. Hobbie. 2003. Carbon cycling in the extratropical terrestrial ecosystems of the Northern Hemisphere: a modeling analysis of the influences of soil thermal dynamics. Tellus 55B:751-776.

Table A1. State variables, fluxes, and parameters described in Appendix 1 and defined in the TEM-DVM with multiple vegetation pools. L, W, R = leaf, wood, root

Acronym	Definition	Units
State Variables		
C_S	C in soil and detritus	$g\ m^{-2}$
C_{VL}, C_{VW}, C_{VR}	C in L,W, R of vegetation	$g\ m^{-2}$
C_V	Total C in vegetation (sum of the L, W, R)	$g\ m^{-2}$
N_{AV}	Available inorganic N in soil and detritus	$g\ m^{-2}$
N_{VL}, N_{VW}, N_{VR}	N in L,W, R of vegetation	$g\ m^{-2}$
N_V	Total N in vegetation	$g\ m^{-2}$
Carbon Fluxes		
GPP_L, GPP_W, GPP_R	L, W, R GPP limited by nutrient availability	$g\ m^{-2}\ mo^{-1}$
GPP	Total GPP limited by nutrient availability	$g\ m^{-2}\ mo^{-1}$
$InGPP_L$, $InGPP_W$, $InGPP_R$	L, W, R Gross primary productivity not limited by nutrient availability	$g\ m^{-2}\ mo^{-1}$
InGPP	Total GPP not limited by nutrient availability	$g\ m^{-2}\ mo^{-1}$
$InNPP_L$, $InNPP_W$, $InNPP_R$	L, W, R Net primary productivity not limited by nutrient availability	$g\ m^{-2}\ mo^{-1}$
InNPP	Total NPP not limited by nutrient availability	$g\ m^{-2}\ mo^{-1}$
$LITTER_{CL,}$ $LITTER_{CW,}$ $LITTER_{CR,}$	L, W, R litter C	$g\ m^{-2}\ mo^{-1}$
$LITTER_C$	Total litter C	$g\ m^{-2}\ mo^{-1}$
NEP	Net ecosystem productivity	$g\ m^{-2}\ mo^{-1}$
NPP_L, NPP_W, NPP_R	L, W, R NPP limited by nutrient availability	$g\ m^{-2}\ mo^{-1}$
NPP	Total NPP limited by nutrient availability	$g\ m^{-2}\ mo^{-1}$
R_H	Heterotrophic respiration	$g\ m^{-2}\ mo^{-1}$
$R_{ML,}$ $R_{MW,}$ $R_{MR,}$	L, W, R maintenance respiration	$g\ m^{-2}\ mo^{-1}$
R_M	Total maintenance respiration	$g\ m^{-2}\ mo^{-1}$
$R_{GL,}$ $R_{GW,}$ $R_{GR,}$	L, W, R growth respiration	$g\ m^{-2}\ mo^{-1}$
R_G	Total growth respiration	$g\ m^{-2}\ mo^{-1}$
Nitrogen Fluxes		
INUPTAKE	Initial N uptake by vegetation (not N limited)	$g\ m^{-2}\ mo^{-1}$
$LITTER_{NL,}$ $LITTER_{NW,}$ $LITTER_{NR,}$	L, W, R litter N	$g\ m^{-2}\ mo^{-1}$
$LITTER_N$	Total litter N	$g\ m^{-2}\ mo^{-1}$
LUPTAKE	Labile N uptake	$g\ m^{-2}\ mo^{-1}$
NETNMIN	Net rate of mineralization of N_S	$g\ m^{-2}\ mo^{-1}$
NINPUT	N inputs from outside the ecosystem	$g\ m^{-2}\ mo^{-1}$
NLOST	Total N lost from the soils	$g\ m^{-2}\ mo^{-1}$
$NMOBIL_{L,}$	L, W, R N mobilization	$g\ m^{-2}\ mo^{-1}$

NMOBIL$_{W}$, NMOBIL$_{R}$,		
NMOBIL	Total N mobilization	g m^{-2} mo^{-1}
NRESORB$_{L}$, NRESORB$_{W}$, NRESORB$_{R}$,	L, W, R N resorbtion by the plants	g m^{-2} mo^{-1}
NRESORB	Total N resorbtion by the plants	g m^{-2} mo^{-1}
NUPTAKE	N uptake by the vegetation (N limited)	g m^{-2} mo^{-1}
SUPTAKE$_{L}$, SUPTAKE$_{W}$, SUPTAKE$_{R}$,	L, W, R N uptake by the vegetation for structural N	g m^{-2} mo^{-1}
SUPTAKE	N uptake by the vegetation for structural N	g m^{-2} mo^{-1}
Parameters		
ALEAF, BLEAF, CLEAF	Regression derived leaf phenology parameters	
CFALL$_{L}$, CFALL$_{W}$, CFALL$_{R}$	Proportion of C_{VL}, C_{VW}, C_{VR} lost as L_{CL}, L_{CW}, L_{CR}	g g^{-1} mo^{-1}
CNEVEN$_{L}$, CNEVEN$_{W}$, CNEVEN$_{R}$,	C:N ratio of new production in the L, W, R	
CNEVEN	C:N ratio of new production	
K_{d}	Heterotrophic respiration rate at 0°C	g g^{-1} mo^{-1}
K_{RL}, K_{RW}, K_{RR},	L, W, R respiration rate at 0°C	g g^{-1} mo^{-1}
LABILENCON	the maximum proportion of V_{N} allowed in the labile N pool	g m^{-2}
MINLEAF		
NFALL$_{L}$, NFALL$_{W}$, NFALL$_{R}$	Proportion of N_{VL}, N_{VW}, N_{VR} lost as L_{NL}, L_{NW}, L_{NR}	g g^{-1} mo^{-1}
N_{max}	Maximum rate of N uptake by the vegetation	g g^{-1} mo^{-1}
npart$_{L}$, npart$_{W}$, npart$_{R}$,	L, W,R N partition	
part$_{L}$, part$_{W}$, part$_{R}$,	L, W,R biomass partition	
SLA	Specific leaf area	
V_{CNL}, V_{CNW}, V_{CNR}	L, W, R C:N ratio	g g^{-1}
Selected Intermediate Variables		
FPC	Foliar projected cover	
INPRODCN	Initial C:N ratio of biomass production	
LEAF	Normalized leaf phenology	
NREQUIRE	Total N required by the vegetation	g g^{-1} mo^{-1}
NREQUIRE$_{L}$, NREQUIRE$_{W}$, NREQUIRE$_{R}$	L, W, R N required by the vegetation	g g^{-1} mo^{-1}
PRVLEAFMX	the highest UNNORMLEAF in the previous year	
UNNORMLEAF	Unnormalized leaf phenology	

Table A2. Parameterizations of the plant functional types used in the model calibrations and parameters obtained following calibration for the boreal forest, partitioned between the leaf, wood, and root components. Available N = 1.69 g N m^{-2}, SOIL C = 22500 g C m^{-2}; SOIL N = 1500 g N m^{-2}. GPP = gross primary productivity (g C m^{-2} yr^{-1}); NPP_{sat} = NPP at nitrogen saturation; NPP_n = Nitrogen content in NPP; N_{up} = Nitrogen uptake; Veg C = vegetation carbon (g C m^{-2}); Veg N = vegetation nitrogen (g N m^{-2}), Veg. C:N = carbon to nitrogen ratio in the vegetation. Salix = *Salix* spp.; Decid. = deciduous shrubs; E. green = evergreen shrubs; Feather = feather moss; n/a = not applicable

Variable	Plant Functional Type									Total Boreal Forest
	Spruce	Salix	Decid.	E.green	Sedges	Forbs	Grasses	Lichens	Feather.	
Pools, Fluxes, and Parameters Used in Calibrations										
GPP	468.74	81.73	27.51	22.23	29.85	28.44	11.29	7.75	42.18	719.72
NPP_{SAT}	200.39	61.30	25.73	20.79	27.91	26.59	10.56	7.25	39.44	419.93
NPP										
Leaf	25.55	13.17	8.85	7.99	5.60	5.33	2.12	3.87	21.09	93.57
Wood	44.76	26.61	3.81	1.34	n/a	n/a	n/a	n/a	n/a	76.51
Root	63.28	1.09	1.09	1.79	9.33	8.89	3.53	n/a	n/a	89.00
Total	133.59	40.87	13.76	11.12	14.92	14.22	5.65	3.87	21.09	259.08
NPP_n										
Leaf	0.36	0.53	0.38	0.27	0.26	0.25	0.09	0.01	0.49	2.64
Wood	0.08	0.69	0.11	0.04	0.00	n/a	n/a	n/a	n/a	0.92
Root	0.90	0.02	0.02	0.03	0.19	0.17	0.07	n/a	n/a	1.38
Total	1.34	1.23	0.50	0.34	0.45	0.42	0.16	0.01	0.49	4.94
N_{up}										
Leaf	0.18	0.18	0.13	0.13	0.13	0.13	0.05	0.01	0.24	1.32
Wood	0.04	0.23	0.04	0.02	n/a	n/a	n/a	n/a	n/a	0.46
Root	0.45	0.01	0.01	0.01	0.09	0.09	0.03	n/a	n/a	0.69
Total	0.67	0.41	0.17	0.17	0.22	0.21	0.08	0.01	0.24	2.47
Veg. C										
Leaf	121.92	13.17	8.85	6.03	5.60	5.33	2.12	35.22	100.35	298.60
Wood	1519.45	129.81	76.07	13.10	n/a	n/a	n/a	n/a	n/a	1738.43
Root	410.34	4.00	4.20	1.17	9.33	8.89	3.53	n/a	n/a	441.46
Total	2051.72	146.98	89.12	20.30	14.92	14.22	5.65	35.22	100.35	2478.49
% of total Veg. C	82.8	5.9	3.6	0.8	0.6	0.6	0.2	1.4	4.0	100.0
Veg. N										
Leaf	1.05	0.53	0.38	0.15	0.26	0.25	0.09	0.99	2.31	6.01
Wood	2.74	3.05	3.10	0.23	n/a	n/a	n/a	n/a	n/a	9.12
Root	3.52	0.06	0.06	0.01	0.19	0.17	0.07	n/a	n/a	4.07
Total	7.30	3.64	3.54	0.39	0.45	0.42	0.16	0.99	2.31	19.21
Veg C:N										
Leaf	116.67	24.98	23.53	40.56	21.31	21.04	22.44	35.57	43.38	49.67
Wood	554.76	42.53	24.53	56.83	n/a	n/a	n/a	n/a	n/a	190.58
Root	116.67	67.11	68.03	96.15	50.00	52.08	54.05	n/a	n/a	108.38
CNEVEN										
Leaf	70.57	24.98	23.53	29.88	21.31	21.04	22.44	264.66	43.38	35.29
Wood	554.76	38.53	35.76	33.35	0.00	0.00	0.00	0.00	0.00	82.66
Root	70.57	63.49	61.35	64.72	50.00	52.08	54.05	0.00	0.00	64.39
C_{fall}										
Leaf	0.018	0.083	0.083	0.110	0.083	0.083	0.083	0.001	0.018	0.026
Wood	0.003	0.017	0.004	0.009	n/a	n/a	n/a	n/a	n/a	0.004
Root	0.013	0.023	0.022	0.128	0.083	0.083	0.083	n/a	n/a	0.01
N_{fall}										
Leaf	0.014	0.028	0.028	0.075	0.042	0.042	0.042	0.001	0.009	0.018
Wood	0.001	0.006	0.001	0.007	n/a	n/a	n/a	n/a	n/a	0.004
Root	0.011	0.008	0.008	0.095	0.042	0.042	0.042	n/a	n/a	0.014
Extin. coeff	0.55	0.45	0.35	0.35	0.15	0.15	0.15	0.10	0.10	n/a
Calibrated Values										
C_{max}	939.0	255.0	50.0	83.0	50.0	27.0	28.0	26.0	25.0	n/a

N_{max}	3.1	2.5	2.5	0.80	1.4	1.5	2.2	1.1	2.1	n/a
K_d	0.00544	0.00571	0.00556	0.00541	0.00577	0.00544	0.00541	0.00544	0.00542	n/a
K_r										
Leaf	-3.5	-2.35	-2.35	-7.50	-2.4	-2.12	-2.35	-2.35	-2.15	n/a
Wood	-8.2	-4.65	-4.65	-3.9	n/a	n/a	n/a	n/a	n/a	n/a
Root	-10.2	-0.20	-0.20	-1.0	-0.20	-0.20	-0.20	n/a	n/a	n/a

Table A3. Parameterizations of the plant functional types used in the model calibrations for the shrub tundra, partitioned between the leaf, wood, and root components. . Available N = 3.93 g N m^{-2}, SOIL C = 12800 g C m^{-2}; SOIL N = 800 g N m^{-2}. GPP = gross primary productivity (g C m^{-2} yr^{-1}); NPP$_{sat}$ = NPP at nitrogen saturation; NPP$_n$ = Nitrogen content in NPP; N$_{up}$ = Nitrogen uptake; Veg C = vegetation carbon (g C m^{-2}); Veg N = vegetation nitrogen (g N m^{-2}), Veg. C:N = carbon to nitrogen ratio in the vegetation. Salix = *Salix* spp.; Betula = *Betula* spp.; Decid. = deciduous shrubs; E. green = evergreen shrubs; Feather = feather moss; n/a = not applicable

Variable		Plant Functional Type									Total Shrub Tundra
		Salix	**Betula**	**Decid.**	**E.green**	**Sedges**	**Forbs**	**Grasses**	**Lichens**	**Feather.**	
GPP		143.89	288.65	42.33	9.03	19.39	28.39	11.35	16.45	37.38	596.86
NPP_{SAT}		107.92	216.49	39.57	8.44	18.13	26.54	10.61	15.38	34.95	478.04
NPP											
	Leaf	23.85	38.10	14.85	2.94	3.64	5.32	2.13	8.23	18.69	117.75
	Wood	46.12	96.93	4.48	0.91	n/a	n/a	n/a	n/a	n/a	148.45
	Root	1.97	9.29	1.83	0.66	6.06	8.87	3.55	n/a	n/a	32.23
Total		71.95	144.33	21.16	4.51	9.69	14.19	5.67	8.23	18.69	298.43
NPP_n											
	Leaf	1.16	1.84	0.73	0.09	0.17	0.26	0.09	0.01	0.54	4.89
	Wood	1.23	2.64	0.12	0.03	n/a	n/a	n/a	n/a	n/a	4.02
	Root	0.03	0.18	0.02	0.01	0.12	0.17	0.07	n/a	n/a	0.60
Total		2.42	4.66	0.87	0.13	0.28	0.43	0.16	0.01	0.54	9.51
N_{up}											
	Leaf	0.39	0.61	0.24	0.05	0.08	0.13	0.05	0.01	0.27	1.82
	Wood	0.41	0.88	0.04	0.01	n/a	n/a	n/a	n/a	n/a	1.34
	Root	0.01	0.06	0.01	0.00	0.06	0.09	0.03	n/a	n/a	0.26
Total		0.81	1.55	0.29	0.06	0.14	0.21	0.08	0.01	0.27	3.43
Veg. C											
	Leaf	23.85	38.10	14.85	1.30	3.64	5.32	2.13	18.70	89.00	196.89
	Wood	194.07	502.07	30.67	9.47	n/a	n/a	n/a	n/a	n/a	736.29
	Root	6.10	38.35	2.25	0.66	6.06	8.87	3.55	n/a	n/a	65.84
Total		224.03	578.52	47.77	11.43	9.69	14.19	5.67	18.70	89.00	999.02
% of total Veg. C		22.4	57.9	4.8	1.1	1.0	1.4	0.6	1.9	8.9	100.0
Veg. N											
	Leaf	1.16	1.84	0.73	0.03	0.17	0.26	0.09	0.67	2.59	7.54
	Wood	1.94	5.73	0.66	0.18	n/a	n/a	n/a	n/a	n/a	8.52
	Root	0.08	0.56	0.04	0.01	0.12	0.17	0.07	n/a	n/a	1.04
Total		3.18	8.14	1.43	0.22	0.28	0.43	0.16	0.67	2.59	17.10
Veg C:N											
	Leaf	20.63	20.68	20.36	37.69	21.90	20.78	22.67	27.89	34.39	26.12
	Wood	100.00	87.55	46.44	52.27	n/a	n/a	n/a	n/a	n/a	86.45
	Root	72.99	68.26	60.42	90.09	51.81	51.55	54.35	n/a	n/a	63.05
CNEVEN											
	Leaf	20.63	20.68	20.36	32.07	21.90	20.78	22.67	818.80	34.39	24.08
	Wood	37.49	36.72	36.04	34.69	0.00	0.00	0.00	0.00	0.00	36.92
	Root	56.66	52.22	86.21	68.73	51.81	51.55	54.35	0.00	0.00	53.91
C_{fall}											
	Leaf	0.083	0.083	0.083	0.188	0.083	0.083	0.083	0.037	0.018	0.050
	Wood	0.020	0.016	0.012	0.008	n/a	n/a	n/a	n/a	n/a	0.017
	Root	0.027	0.020	0.068	0.084	0.083	0.083	0.083	n/a	n/a	0.041
N_{fall}											
	Leaf	0.028	0.028	0.028	0.110	0.042	0.042	0.042	0.001	0.00875	0.020
	Wood	0.018	0.013	0.005	0.006	n/a	n/a	n/a	n/a	n/a	0.013
	Root	0.012	0.009	0.016	0.055	0.042	0.042	0.042	n/a	n/a	0.021
Extin. coeff.		0.45	0.45	0.35	0.35	0.15	0.15	0.10	0.10	0.10	n/a
		Calibrated parameters									
C_{max}		255.0	625.0	83.0	23.9	45.0	66.8	27.8	38.8	86.1	n/a
N_{max}		2.5	8.5	0.81	0.19	0.23	0.76	0.29	0.02	0.10	n/a
K_d		0.00544	0.00503	0.00541	0.00552	0.00304	0.00531	0.00538	0.00539	0.00538	n/a
K_r											
	Leaf	-2.3	-3.9	-7.5	-3.3	-1.2	-3.6	-4.1	-3.1	-3.9	n/a
	Wood	-4.6	-6.2	-3.9	-5.8	n/a	n/a	n/a	n/a	n/a	n/a
	Root	-0.20	-0.05	-1.0	-0.5	-3.3	-1.8	-1.6	n/a	n/a	n/a

Table A4. Parameterizations of the plant functional types used in the model calibrations for the sedge tundra, partitioned between the leaf, wood, and root components. Available N = 1.71 g N m^{-2}, SOIL C = 12600 g C m^{-2}; SOIL N = 400 g N m^{-2}. GPP = gross primary productivity (g C m^{-2} yr^{-1}); NPP_{sat} = NPP at nitrogen saturation; NPP_n = Nitrogen content in NPP; N_{up} = Nitrogen uptake; Veg C = vegetation carbon (g C m^{-2}); Veg N = vegetation nitrogen (g N m^{-2}), Veg. C:N = carbon to nitrogen ratio in the vegetation. Betula = *Betula* spp.; Decid. = deciduous shrubs; E. green = evergreen shrubs; Feather = feather moss; Sphag. = *Sphagnum* spp.; n/a = not applicable

Variable	**Plant Functional Type**								**Total Sedge Tundra**
	Betula	**Decid.**	**E. green**	**Sedges**	**Forbs**	**Lichen**	**Feather**	**Sphag.**	
GPP	1.08	20.19	17.37	56.71	15.82	18.52	13.21	11.88	154.79
NPP_{SAT}	1.01	18.88	16.25	53.02	14.79	17.32	12.35	11.11	144.73
NPP									
Leaf	0.33	6.19	5.30	10.63	2.97	9.26	6.61	5.94	47.23
Wood	0.13	3.14	2.20	n/a	n/a	n/a	n/a	n/a	5.47
Root	0.08	0.76	1.19	17.72	4.94	n/a	n/a	n/a	24.70
Total	0.54	10.09	8.69	28.36	7.91	9.26	6.61	5.94	77.40
NPP_n									
Leaf	0.02	0.19	0.16	0.48	0.12	0.02	0.13	0.10	1.22
Wood	0.00	0.06	0.04	n/a	n/a	n/a	n/a	n/a	0.10
Root	0.00	0.02	0.03	0.80	0.19	n/a	n/a	n/a	1.04
Total	0.02	0.27	0.23	1.27	0.31	0.02	0.13	0.10	2.35
N_{up}									
Leaf	0.01	0.06	0.08	0.24	0.06	0.01	0.07	0.05	0.57
Wood	0.00	0.02	0.02	n/a	n/a	n/a	n/a	n/a	0.04
Root	0.00	0.01	0.02	0.40	0.10	n/a	n/a	n/a	0.52
Total	0.01	0.09	0.12	0.64	0.16	0.01	0.07	0.05	1.13
Veg. C									
Leaf	0.33	6.19	7.61	10.63	2.97	80.45	31.45	74.26	213.89
Wood	1.52	12.54	13.04	n/a	n/a	n/a	n/a	n/a	27.10
Root	0.13	0.93	1.26	17.72	1.25	n/a	n/a	n/a	21.29
Total	1.99	19.66	21.91	28.36	4.21	80.45	31.45	74.26	262.28
% of total Veg. C	0.8	7.5	8.4	10.8	1.6	30.7	12.0	28.3	100.0
Veg. N									
Leaf	0.02	0.19	0.16	0.48	0.12	1.30	0.47	1.27	4.01
Wood	0.02	0.21	0.21	n/a	n/a	n/a	n/a	n/a	0.44
Root	0.02	0.22	0.19	0.80	0.19	n/a	n/a	n/a	1.41
Total	0.06	0.61	0.56	1.27	0.31	1.30	0.47	1.27	5.86
Veg C:N									
Leaf	21.98	32.44	47.25	22.28	25.55	61.67	66.65	58.28	53.33
Wood	77.24	60.45	62.20	n/a	n/a	n/a	n/a	n/a	62.05
Root	6.15	4.29	6.70	22.28	6.44	n/a	n/a	n/a	15.05
CNEVEN									
Leaf	21.98	32.44	32.49	22.28	25.55	483.92	49.95	58.31	38.85
Wood	56.15	55.06	55.61	0.00	0.00	0.00	0.00	0.00	55.30
Root	87.78	41.32	37.38	22.28	25.56	0.00	0.00	0.00	23.75
C_{fall}									
Leaf	0.083	0.083	0.058	0.083	0.083	0.010	0.018	0.007	0.018
Wood	0.007	0.021	0.014	n/a	n/a	n/a	n/a	n/a	0.017

Root	0.051	0.069	0.079	0.083	0.331	n/a	n/a	n/a	0.097
N_{fall}									
Leaf	0.028	0.028	0.042	0.042	0.042	0.001	0.012	0.003	0.012
Wood	0.003	0.008	0.008	n/a	n/a	n/a	n/a	n/a	0.008
Root	0.001	0.002	0.007	0.042	0.042	n/a	n/a	n/a	0.030
Extin. coeff	0.45	0.35	0.35	0.15	0.15	0.15	0.15	0.15	n/a
Calibrated Values									
C_{max}	2.5	46.4	39.7	128.6	35.4	42.1	29.7	26.3	n/a
N_{max}	0.02	0.55	0.72	4.01	0.97	0.12	0.41	0.32	n/a
K_d	0.001609	0.001548	0.001557	0.001429	0.001561	0.001552	0.001569	0.001572	n/a
K_r									
Leaf	-3.1	-3.5	-2.2	-6.3	-3.2	-4.4	-3.9	-4.9	n/a
Wood	-4.6	-3.5	-4.8	n/a	n/a	n/a	n/a	n/a	n/a
Root	-0.05	-0.05	-0.05	-1.6	-0.1	n/a	n/a	n/a	n/a