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A State-Dependent Model of Forest Floor Development

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Abstract: A state-dependent, dynamic forest floor development model is presented. The model considers litterfall as input. The decomposition of the litter was modelled as influenced by the quality of litter and miccroclimatic conditions (temperature and moisture). Microclimatic conditions were determined based on weather data and stand structure. The predictions of the model compared with an independent data set suggested that the model functions realistically under a range of weather and stand conditions. The resulting model should be valuable in the prediction of fire behavior.

Dinamik Bir Orman Ölü Ürtü Gelişim Modeli

Özet:Duruma bağlı, dinamik bir orman ölü örtü gelişim modeli sunulmuştur. Model dökülen yaprak miktarını girdi olarak alır. Ölü örtünün ayrışması, ölü örtü kalitesi ve mikroklimatik şartlara (sıcaklık ve nem) bağlı olarak modellenmiştir. Mikroklimatik şartlar hava durumuna ve meşçere yapısına göre belirlenmiştir. Bağımsız bir veri grubu ile karşılaştırılan model sonuçları, modelin belirli hava durumu ve meşçere yapısı durumlarında gerçeğe uygun olarak işlediğini ortaya koymuştur. Oluşturulan model, yangın davranışlarının tahmininde değerli katkılar sağlayabilir.

Introduction

Forest floor dynamics have been of great interest to several forestry disciplines. Silviculturists are interested in it as a medium that can be manipulated to affect seed bed quality. Hydrologists are interested in knowing how it relates to the reception and flux of moisture with the subsurface environment of stand. Fire scientist are interested in it in relation to the potential fire hazard reflected in different magnitudes over the stages of stand development. Therefore forest floor dynamics and development has received an overall research effort of enormous proportions. Much of the work has dealt with nutrient dynamics associated with the decomposition of material deposided to the forest floor.

Several studies indicate that the rate of decomposition on the forest floor material is influenced by the physical and chemical nature of the litter it contains; aeration, soil temperature (1, 2, 3, 4, 5, 6, 7, 8, 9, 10), moisture conditions (1,6,7,5), chemical composition of the litter, particularly the intial N and lignin concentrations (11, 12, 13, 14), and the kinds and numbers of microflora and fauna present (15,16,17). The relative effect of these factors vary depending on the time and the conditions. The chemical porperties of litter have a more pronounced effect on the decomposition process in the eary stages (18) than those of temperature and mousture. However, the combined effect of forest floor temperature and moisture on microbes and soil animals is the diriven force in different decomposition rates of organic matter low in nutrients (i.e., of later stages of decompositon) (4,19). Thus a model should incorporate the timely effects of factors contributing to the decomposition of forest floor.

Here, an attempt was made to develop a model which combines the most important factors that play a major role in the decomposition process, and to describe functional relationships quantitatively. The model simulates forest floor development over time and under silvicultural interventions (i.e., thinnings). The resulting model should be valuable in the prediction of fire behavior.

Description of the Model

The model simulates forest floor development of a managed stand over time and under silvicultural practices such as thinnings. Litter from the canopy is added to and depleted from the forest floor annually. Decomposition of organic matter is controlled by soil tempereture and moisture. The model was constructed such that it describes functional relationships quantitatively that would be common to a wide range of situations rather than fitting a trace of growth repponses from a small set of measured situations (20). The model requires above ground stand structure parameters (crown fuel loading and crown closure) to simulate litterfall and soil temperature. The model developed by Bilgili and Methven (1995)(21) was used for this purpose. Their model simulates the growth responce of a crown from year to year. The growth of a crown is achieved through growing the crown layer whorl by whorl. The capacity to produce new foliage is dependent on the current amount of foliage in the crown and the amount of light the crown receives. When a change in stand density and/or site index is inflicted on the model as (a) driving variable(s), the growing area per tree increases and canopy growth and structure changes.

The model is generic in nature i.e., it can simulate forest floor dynamics in any plantation or managed natural stand for which sepecies specific model parameters are provided. In this study, red pine *(Pinus resinosa* Ait.), white spruce (*Picela glauca* (Moench) Voss) and black spruce (*Picea mariana* [Mill.] B.S.P.) were considered.

The bounding of the model considers both temporal and spatial aspects; the time span of the model is 100 years, with forward steps of one year. All calculations were done on a per hectare basis. There is no chronological time sequence in the model; all state variables were determined from internal calculations developed from the driving variable(s) (e.g., crown closure), or from functional relationships with other variables. The results of the simulations do not depend on stand age. That is, the model is state dependent rather than time-dependent.

A number of parametres were specified for model construction in that the sensitivity of the model to parameter change was monitored, and the pattern and scale of output were examined as to the extent they were valid, either by virtue of reasoning, or in comparison with data available (22,20)(Table 1). Prediction of the parameter values and the calibration of the model were done using literature data (e.g., 23,3,4,19,24). For validation purposes, the model was tested against independent data (25).

Table 1. Parameter values used in the model.

Parameters	red pine	black spruce	white spruce
k_1	0.3	0.3	0.3
k_2	0.2	0.2	0.2
k_3	0.025	0.02	0.02
k_4	0.018	0.02	0.02

The Model Structure and Overview

Figure 1 shows the decomposition process as a flow chart. Litter deposited for the current year was divided into two classes: leaves (LL) and branches (BL), fast and slow decomposing parts of the organic matter, respectively. The litter deposited in the current year was called fresh (≤1-year-old) litter. The rest of the forest floor was called non-fresh litter (LLO for non-fresh leaf and BLO for non-fresh branch litter). Fresh and non-fresh litter differ in their decomposability characteristics.

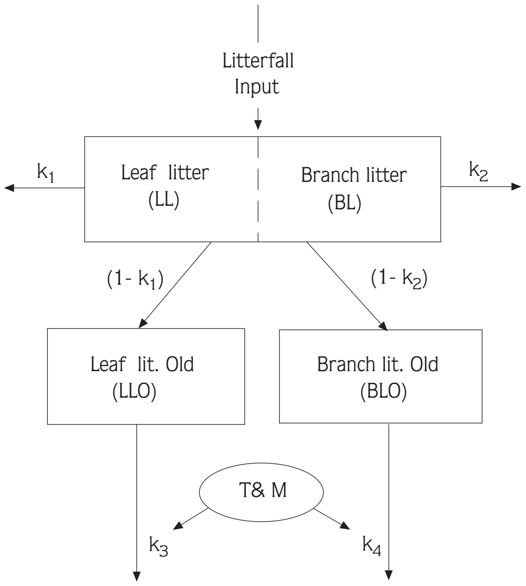

Figure 1. Model used for predicting forest floor over time. The state equations are given in the text and their associated coefficients in Table 1. T and M are temperature and moisture, respectively.

To predict forest floor fractions of leaf and branch litter for the current year, Equations 1 and 2 were used.

$$\Delta LL=LL(1-k_1) \qquad (1)$$

$$\Delta BL=BL(1-k_2) \qquad (2)$$

Equations 1 and 2 determine the remaining fresh litter that will be deposited into the non-fresh litter class for the next year's simulation. Remaining forest floor was determined from Equations 3 and 4.

$$\Delta LLO=LLO(1-k_3f(TM)) \qquad (3)$$

$$\Delta BLO=BLO(1-k_4f(TM)) \qquad (4)$$

Where

f(TM)=relative decomposition rate which adjusts k_3 and k_4 for microclimatic conditions (i.e., temperature and moisture regimes) (Figure 2).

Then the total forest floor (FF) was calculated as:

$$\Delta FF=\Delta LL+\Delta BL+\Delta LLO+\Delta BLO \qquad (5)$$

Finally, the state variables were updated for use in the next year's simulation.

$$LLO=\Delta LL+\Delta LLO \qquad (6)$$

$$BLO=\Delta BL+\Delta BLO \qquad (7)$$

To include the effect of temperature and moisture content of the forest floor on decomposition, various studies on litter decomposition were consulted (e.g., 23, 3, 4, 5, 19, 24) to generate a relationship between decomposition rates and temperature and moisture regimes (Figure 2). Decomposition rates in Figure 2 are percentages of maximum potential decomposition rates for a species.

The decomposition calculations were done on a monthly basis. Thus, monthly average values of ambient temperature and moisture were used in the calculations. Moisture content of the duff (F) layer of the forest floor is determined from the Duff Moisture code (DMC) of the Fire Weather Index (FWI) system. The DMC is a numerical rating of the average moisture content of partially decomposed, loosely compacted organic layer of moderate depth (26).

Temperature at the forest floor level was calculated from air temperature in the open, which can be obtained daily or hourly from fire weather stations.

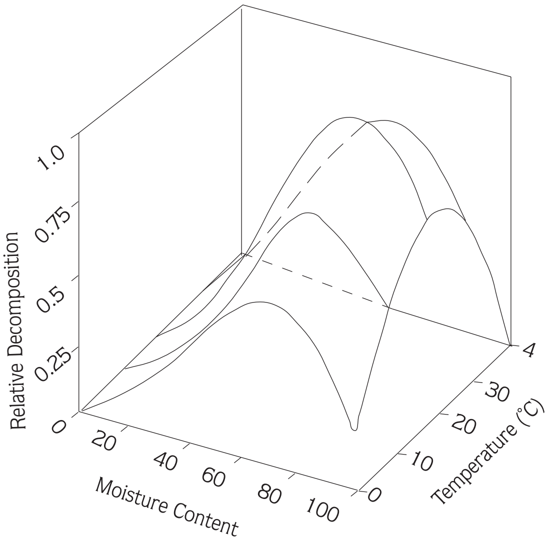

Figure 2. Relative decomposition rates as a function of temperature and moisture contents.

Air temperatures in the open are converted to ambient air temperatures for stands of high density (after 27):

$$T_c=-0.11+0.96T_a-0.00008\ T_a^3 \qquad (8)$$

where

T_c=air temperature (°C) under closed canopy;

T_a=air temperature (°C) in the open.

In the case of interventions when the stand structure is altered, this simple conversion is not enough. The effect of any alteration should be accounted for to show variations in temperature. For this, Equation 9 (27) was used with the difference that vegetative surface area index was replaced with crown closure (CC).

$$T_v=T_a+(T_c-T_a)\mathrm{In}(I+CC_s)/\mathrm{In}(I+CC_m) \qquad (9)$$

where

Table 2. The summary of measured height, crown base height (CBH), crown fuel loading (foliage weight) (CFL), and duff and surfcace fuel loading of the stands sampled. SD is standard deviation

Stand ID	Stand Type[1]	Year Planted	Initial Spacing (m)	Site Index (m)	Treatment[2]	Treat. Date	Density #/ha	Height (m)		CBH		Foliage Weight (kg/tree)		Forest Floor			
														Duff[3]		Surface[4]	
								Mean	SD[5]	Mean	SD	Mean	SD	Weight	SD	Weight	SD
3747	bS	1975	1.80	13	-	-	2819	5.22	0.51	0.00	0.00	5.45	0.79	0.83	0.37	-	-
BRON	bS	1968	1.80	13	-	-	3095	7.30	1.03	1.01	0.37	6.31	1.85	0.95	0.45	-	-
BURN	bS	1968	1.85	12	-	-	2880	6.89	0.66	0.00	0.00	7.14	1.07	1.20	0.53	-	-
3656	rP	1970	2.00	24	-	-	2587	11.39	1.03	5.96	0.52	7.86	1.80	3.19	2.04	0.90	0.49
4464	rP	1934	1.40	20	-	-	1050	21.35	1.09	14.82	0.82	11.72	3.63	4.98	1.71	0.45	0.24
4562	rP	1939	1.80	21	T	1976	655	22.32	0.98	13.94	1.59	21.24	6.50	2.79	1.16	0.69	0.29
4764	rP	1939	1.80	21	T	1976	434	21.31	0.90	11.88	1.20	25.29	5.87	4.32	3.23	0.60	0.14
4888	rP	1934	1.50	20	R	-	1070	22.29	0.73	15.54	0.80	12.41	3.81	2.73	1.47	0.69	0.15
5256	rP	1939	1.80	21	TP	1963	601	21.96	0.91	13.85	0.89	18.47	5.09	3.95	2.33	0.77	0.19
8238	rP	1944	1.80	18	T	1976	1522	17.18	0.91	11.23	0.72	9.84	2.93	3.78	0.94	0.71	0.71
3138	wS	1962	1.80	14	P	-	2677	8.97	1.94	3.80	0.76	6.96	3.09	4.21	1.83	-	-
3361	wS	1965	1.80	14	P	-	2740	7.58	1.13	2.85	0.33	6.04	1.84	2.64	0.93	-	-
3558	wS	1965	1.80	14	P	-	1440	14.36	2.39	8.14	1.16	6.48	2.37	1.44	0.53	-	-
3831	wS	1944	1.60	15	R	-	1440	14.36	2.39	8.14	1.16	10.37	6.49	5.91	2.19	-	-
3850	wS	1944	1.65	14	R	-	1227	13.67	2.82	7.47	0.91	11.48	5.52	7.56	2.03	-	-
3852	wS	1944	1.60	12	R	-	1669	11.77	2.49	6.79	1.03	7.30	3.98	8.45	2.40	-	-
8841	wS	1943	1.80	15	-	-	1634	14.72	1.90	9.52	1.15	7.54	4.12	4.76	2.30		

[1] bS: black spruce; rP:red pine; wS: white spruce.

[2] T: thinned; P: pruned; R: reserve.

[3] Duff represents loosely compacted decomposing upper organic layer excluding newly fallen litter.

[4] Surface fuels represent newly fallen leaves and other fine litter including fine branches.

[5] SD: standard deviation

T_v=ambient air temperature (°C) on the forest floor;

CC_s=crown closure of the stand simulated;

CC_m=the maximum crown closure of closed stands (=1.5).

Model Performance

To test the validity of the model under varying situations, data were collected in red pine, black spruce and white spruce plantations in the Acadia Experimental Station forest in 1991. The field data included forest floor loadings, tree height, crown weight, crown base height (CBH), initial spacing, and the history of the interventions (Table 2).

Table 3 contains forest floor data in the stands sampled along with the model outputs. although the overall predictions were reasonable, the duff was underpredicted in all but a few white spruce stands. This can be ascribed to the fact that the model functions using only the litter deposited by the initial tress. However, most of the spruce stands had a moss layer to differing degrees with a fine root component. Relatively open stands also had understorey vegetation to differing degrees.

The prediction of the surface fuel loads was favorable. However, since the duff for spruce stands contained all of the forest floor material (the size of the needles and the compactness of the forest floor pre-

Table 3. Measured and calculated duff and surface fuel loadings of the stans sampled. SD is standard deviation

Stand ID	Stand Type	Forest Floor					
		Duff-Weight (kg/m^2) F-Layer			Surface (L-Layer) Kg/m^2)		
		Measured	SD	Calculated (Model)	Measured	SD	Calculated (Model)
3747	bS	0.83	0.37	0.65	-[1]	-	0.18
BRON	bS	0.95	0.45	0.53	-	-	0.49
BURN	bS	1.20	0.53	1.30	-	-	0.41
3656	rP	3.19	2.04	2.76	0.90	0.49	0.94
4464	rP	4.98	1.71	4.08	0.45	0.24	0.58
4562	rP	2.79	1.16	2.62	0.69	0.29	0.61
4764	rP	4.32	3.23	2.24	0.60	0.14	0.54
4888	rP	2.73	1.47	4.07	0.69	0.15	0.58
5256	rP	3.95	2.33	2.29	0.77	0.19	0.56
8238	rP	3.78	0.94	3.56	0.71	0.17	0.65
3138	wS	4.21	1.83	3.00	-	-	0.54
3361	wS	2.64	0.93	2.71	-	-	0.50
3558	wS	1.44	0.53	2.71	-	-	0.50
3831	wS	5.91	2.19	3.95	-	-	0.39
3850	wS	7.56	2.03	3.69	-	-	0.54
3850	wS	8.45	2.40	3.20	-	-	0.38
8841	wS	4.76	2.30	3.75	-	-	0.35

[1] Surface fuels were included with the duff portion.

cluded separating the two), a comparison could not be made for these stands.

Discussion and Conclusions

The simulations made with the model have given some insight into forest floor dynamics by incorporating the most important factors affecting decomposition. Although many assumptions and simplifications were made in the process of constructing the model, the predictions of the model reveal that it is capable of functioning under a range of situations. To examine fully the extent to which the model can be used with no major problems, a rigorous test of the model should be carried out using different site with different thinning regimes. The lack of data precluded such a test.

With proper parameter determination, the model can be adapted easily for species other than those included in this study. The parameters required for new species can be obtained from the literature (e.g., maximum crown width and height growth parameters) or determined by running the model and varying the values of parameters each time to approximate measured data.

The fact that the model utilizes stand structure parameters in predicting decomposition rates has some advantages: it is well documented that fuel characteristics affect fire behavior, and that any changes in stand structure will influence fuel characteristics (i.e., fuel load, fuel moisture). Thus models which fail to take this into account are highly limited in application. This can only be incorporated into fire behavior analyses by such dynamic state-dependent models as the one presented in this paper. The ability to predict the characteristics of crown fuels over space and time can provide a dynamic component to the fuel models used in such systems as the Fire Behavior Prediction system developed by the Canadian Forest Service. Not only will this assist in actual fire behavior prediction, but will also provide a tool for incorporating fire management concerns into management planning.

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