AN APPROACH TO MODELING THE CONSEQUENCES OF BEECH MORTALITY FROM BEECH BARK DISEASE

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Abstract.—Changes to an extant model of forest growth and transition that allow an evaluation of the consequences of beech bark disease are outlined. Required are a function to scale beech growth for the effects of beech bark disease, a function to predict beech mortality from beech bark disease, and a function that predicts root-sprout regeneration of beech.

The introduction of Cryptococcus fagisuga to North America and the ensuing occurrence of beech bark disease has caused noticeable, but largely unquantified, changes in the relative species composition and productivity of northern hardwood forests. One way to quantify the effects of beech bark disease is to use a model of forest growth and transition that can project changes in a stand over time with, and then without, the influence of beech bark disease. No model that is currently available can do this with any degree of validity, but a model has been developed that yields quantitative descriptions of northern hardwood growth, transition, and nitrogen dynamics in the absence of beech bark disease. This is the FORTNITE model as documented by Aber and Melillo (1982). This model has as its underpinnings the JABOWA model, which was first documented by Botkin, Janak, and Wallis (1970). This paper discusses modifications to JABOWA or FORTNITE that would be needed to simulate the effects of beech bark disease on forest growth and transition.

Both JABOWA and FORTNITE project the growth of individual trees on 10- by 10-m plots on a yearly time-step. The fundamental tree growth function as the form:

\[ \frac{d[D^2H]}{dt} = R'LA'(1-DH/D_{max})H_{max} \]  

where

- \( R \) is a growth rate parameter,
- \( LA \) is the estimated leaf area of the tree,
- \( D \) is tree diameter measured at breast height (137 cm),
- \( H \) is tree height, and
- \( D^2H \) is proportional to tree volume.

The value of \( R \) depends on intertree crowding, yearly evapotranspiration, and growing degree days. The crowding factors vary among trees on a plot; the environmental effects vary among species. In FORTNITE, \( R \) also is scaled for available nitrogen, which is a dynamic variable. To simulate beech bark disease, an additional scaling factor is needed to slow the growth of diseased beeches. Mize and Lea (1979) reported that the 10-year diameter growth of beech during a disease episode in the central Adirondacks of New York was 74% of the predisease rate. How much of this diameter-growth reduction was due to beech bark disease is unknown as diameter growth may decrease over time in the absence of disease.

To scale diameter growth, we note that

\[ d[D^2H]/dt = (d[D^2H]/dD)dD/dt \]  


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so that
\[
\frac{dH}{dt} = R'LA' \left(1 - \frac{H}{H_{\text{max}}} \right) \left(2H + D^2 \frac{dH}{ddt} \right) \tag{3}
\]
In JABOWA and FORTNITE, \( H \) and \( dH/ddt \) are removed from the right hand side of (3) using the assumed relation

\[
H = 137 + b_1D^2 - b_2D^2 \tag{4}
\]
for which

\[
\frac{dH}{dD} = b_1 - 2b_2D \tag{5}
\]
The values of \( b_1 \) and \( b_2 \) are constrained to yield \( H = H_{\text{max}} \) and \( \frac{dH}{dD} = 0 \), i.e.,
\[
b_1 = 2 \left( \frac{H_{\text{max}} - 137}{D_{\text{max}}} \right) \quad b_2 = \left( \frac{H_{\text{max}} - 137}{D_{\text{max}}} \right) \tag{6}
\]
where 137 is breast height (cm), thus, the parametrization is based on \( H_{\text{max}} \) and \( D_{\text{max}} \), i.e., the heights and diameters of record trees for each species.

Stout and Shumway (1982) have shown that the \( H \) vs \( D \) relation in hardwoods varies with site quality, and have proposed the relation

\[
\frac{dH}{dD} = b(S - H) \tag{7}
\]
\( S \) is site dependent, and \( b \) varies among species, but is constant within species. This function can be solved in closed-form to yield

\[
H = 137 + S(1 - \exp(-bD)) \tag{8}
\]
where 137 (cm) is a correction for \( D \) measured at breast height. Utilization of (6) and (7) would require a function that predicts \( S \) with the environmental variables in JABOWA or FORTNITE. Whether (4) and (5) or (6) and (7) are used on the right-hand side of (3), a scaling function is needed to account for the effects of beech bark disease. Undoubtedly, the growth reduction will vary in time and place.

Perhaps the greatest impact of beech bark disease is the mortality of beech in regions that are newly infested by beech bark disease. In JABOWA and FORTNITE, tree death is a random event. Each species (i) is assumed to have a maximum age (AGEMXi) to which it can live. Each tree of the \( i^{th} \) species has a yearly probability of death equal to 0.0/AGEMXi. In addition, if \( dD/ddt \) is less than a minimum increment, a tree's probability of death is increased by .368.

To determine whether a tree should be removed, a uniform random deviate from \( U(0,1) \) is generated. If the random number is less than the probability of mortality, the tree is removed. Although we can scale \( dD/ddt \) to account for beech bark disease and may thereby increase the probability of death, this will not cause enough trees to die to simulate a disease episode.

One way to proceed is to use the logistic function to predict the probability \( P \) that a tree will die within a year as:

\[
P = \frac{1}{1 + \exp(b_0 + b_1X_1 + b_2X_2 + \ldots + b_nX_n)} \tag{9}
\]
where
\[
X_i \quad \text{are variables describing the tree and its disease, if any}
\]
\( b_i \) are coefficients estimated by logistic discrimination

The probability of tree death will change as one or more of the \( X_i \) change.

An obvious disease variable is disease presence (1) or absence (0) in the location of interest. Figure 1 shows the estimated beech mortality rate at the generally infested Huntington Wildlife Forest, Newcomb, NY, between 1976 and 1981, by diameter class. Mortality rate was extreme in the largest diameter classes, but quite low in the smallest classes. On the basis of this relation we can speculate that after the initial onslaught of the disease has removed the largest trees, overall rate of mortality due to beech bark disease should decrease because growth is slowed and trees remain longer in the lower diameter classes. This appears to be the case in the so-called aftermath zone. Also included in Figure 1 for comparative purposes are the estimated 5-year mortality rates for sugar maple and yellow birch by diameter class. In the absence of beech bark disease we should expect beech mortality to be similar.

Another major component of forest transition models is a procedure to simulate ingrowth. In FORTNITE, the number of trees of each species that is added to a plot each year depends on available light, soil moisture, nitrogen, and degree-day variables. The diameter at breast height (1.37 m) of a new stem ranges between 0.5 and 0.7 cm according to a uniform random deviate. The procedure makes no distinction between new stems of seed or sprout origin and may
underestimate the ingrowth of small beeches of root-sprout origin which are released when the parent stems die from beech bark disease. This deficiency can be overcome by adding to FORTNITE a sprout regeneration procedure patterned after the one described by Shugart and West (1976).

Before a model is used to draw conclusions about the consequences of beech bark disease, trials should be undertaken to see if solutions of the model bear some correspondence to reality. With such assurance obtained, ameliorative silvicultural treatments can be simulated and their respective expected marginal benefits computed and ranked. It is then wise to determine whether the best (most profitable or least costly) treatment changes when small changes in the values of the parameters and initial values of the state variables are imposed. If the suggested silvicultural alternative is sensitive to a small change in the model, it may be necessary to obtain a more precise estimate of a parameter or an initial value. There is also the possibility that two or more treatments will yield virtually equivalent returns, but this should be obvious before the sensitivity analysis is undertaken.

**Figure 1.**--Estimated five-year mortality rates for beech, yellow birch, and sugar maple at the Huntington Wildlife Forest, Newcomb, New York, by diameter class.

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**SUMMARY**

The FORTNITE model (Aber, Melillo, and Federer, 1982) simulates the growth, transition, and nitrogen dynamics of the northern hardwood forest type in eastern North America. A major species of this forest is beech, which recently has become infected by beech bark disease. As structured presently, the model does not simulate the influence of beech bark disease. This paper outlines the changes and additions to FORTNITE that are needed before such simulations are possible. Required are a function to scale beech growth for the effects of beech bark disease, a function to predict beech mortality from beech bark disease, and a function that predicts root-sprout regeneration of beech. After these changes are incorporated into FORTNITE it should be possible to do simulations with and without the influence of beech bark disease in order to assess some of its ecological consequences.

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**RÉSUMÉ**

Le modèle FORTNITE (Aber, Melillo et Federer, 1982) simule la croissance, la transition et la dynamique de l'azote dans le type forestier de la forêt feuillue du nord-est américain. Une essence très importante de ce type forestier est le hêtre à grandes feuilles, qui est récemment devenu infecté par la maladie de l'écorce du hêtre. Tel qu'organisé présentement, le modèle ne simule pas l'influence de cette maladie. Le présent article donne un aperçu des changements et additions nécessaires à FORTNITE afin de rendre ces simulations possibles. Les paramètres requis sont: une fonction qui estime la croissance du hêtre pour connaître les effets de la maladie de l'écorce du hêtre; une fonction pour prédire la mortalité due à la maladie; et une fonction qui prédit la régénération par rejets de racines chez le hêtre. Après l'insertion de ces changements dans FORTNITE, il devrait être possible de faire des simulations, avec ou sans influence de la maladie de l'écorce du hêtre, afin d'en évaluer quelques-unes de ses conséquences écologiques.

LITERATURE CITED


