Using a Traditional Growth and Yield Model (STEMS) to Drive a Management Simulator (FORCYTE-11)

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Abstract. FORCYTE-11 is a large forest ecosystem simulation model whose main purpose is yield trend evaluation. It can be used to predict and to compare forest biomass growth and yield for alternative resource management strategies for which there may be little or no empirical data. The underlying approach of the model is to complement a user-supplied description of the state and dynamics of the existing ecosystem with a phenomenological process simulation of those processes that are affected by the management actions. The required input data may not be easily available or may be expensive to collect. An alternative approach is described in which a traditional growth and yield model (STEMS) has been modified to provide the needed ecosystem description for FORCYTE-11. Input variables needed by the method are the conventional stand parameters such as stand age, average stand Dbh, stand density, and site index. The method is being used to calibrate FORCYTE-11 for trembling aspen (*Populus tremuloides* Michx.) over a range of site classes in Alberta, Canada, and has potential application to other species in the boreal mixed-wood forest.

Introduction

FORCYTE-11 (Kimmins and Scoullar 1989) is an ecologically based forest stand management model whose intended application is the examination of the long-term consequences of different management scenarios for site fertility, nutrient cycling, and biomass yield. It models the changes in growth conditions induced by various silvicultural practices and includes an assessment of economic and energy efficiency aspects. It is therefore a potentially useful resource management tool for the evaluation of alternative forest management strategies, even

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over the shorter term if the growth conditions change markedly from those of the past. As rising demands on the forest necessitate progressively more intensive management, such decision-making aids become increasingly necessary.

FORCYTE-11 calibration data requirements

The model uses what Kimmins (1986) describes as the "hybrid simulation" approach, combining traditional stand yield data (historical bioassay) with simulation process modelling of those processes affected by management actions. It must be calibrated for a given biogeoclimatic ecoregion. FORCYTE-11 requires soil and nutrient data from several sites along a nutrient gradient. In addition, at each site, detailed growth data for the trees and major plant species are needed. Such historical bioassay data that describe the past growth of today's forest are used in the setup programs (the _GROW programs, Kimmins and Scoullar 1989) to provide quantitative descriptions (the TREND files) of the ecosystem state dynamics for the different site qualities. Having the same structure, these descriptions can be regarded as different parameterizations of a phenomenological growth submodel; each calibration site is represented by a different set of parameter values.

In predicting the growth of the future forest, the model (program MANAFOR) uses process simulation to monitor the nutritional status of the ecosystem components and to compute a dynamic estimate of nutritional site quality. Using this as an index, it employs a time-dependent interpolation (look-up) process to determine the appropriate growth submodel parameterization. Thus, if the growth conditions are similar to one of the calibration sites, the predicted yield will essentially echo the past growth records for that site, rather like a conventional empirical stand yield table. However, if the nutrient conditions should change, FORCYTE-11 has the powerful ability to adjust the growth parameters dynamically to reflect the changes, something traditional stand yield models cannot do.

One of the practical difficulties in applying FORCYTE-11 is the need for detailed chronosequence data to calibrate the growth submodels over a range of nutrient conditions. Often, such data are not readily available or are expensive to obtain. The solution thus far has been to collect site-specific field data and to rely on published literature to fill in the inevitable gaps, an approach not without considerable difficulties (Peterson et al. 1988).

An alternative approach is to use one of the established, empirically based yield models to provide the bioassay calibration data for FORCYTE-11. Although site-specific nutrient and soil data are still required, this approach has much to recommend it, including the potential for integration with geographic information systems. We are investigating the use of STEMS (Belcher et al. 1982) for this purpose.

STEMS as an input to FORCYTE-11

STEMS can be classified as an individual tree distance-independent model. It was developed at the North Central Forest Experiment Station in Minnesota for many species, including most that are found in the boreal forests of western Canada. The model simulates annual Dbh increment and mortality of either individual trees or Dbh classes of trees.

The growth and mortality functions developed in STEMS were incorporated in a variant of the model (STEMS*) to produce the growth data for calibration of the FORCYTE-11 setup programs. These functions are potential Dbh growth, crown ratio function, Dbh growth modifier function, and mortality function (Belcher et al. 1982; Buchman et al. 1983; Holdaway 1984, 1986). Because FORCYTE-11 is based on biomass rather than volume, STEMS* also includes biomass regression equations for stemwood, stem bark, branches, and foliage.

User-supplied input parameters for STEMS* include site index, stand initial conditions, and the time period over which to project stand growth. The initial conditions include tree list Dbhs (or average tree Dbh), an initial stand age, and the corresponding stand density. The model then predicts stand density and various biomass components at 5-year intervals over the specified prediction period.

By estimating site index and measuring a representative sample of Dbhs for a series of even-aged stands on sites of different nutrient quality, the user can thus generate the site-specific chronosequence data required for FORCYTE-11 calibration. Because STEMS* only projects forward in time, independent estimates of early stand development may also be required.

Application to aspen

FORCYTE-11 employs a user-defined measure of site quality over a nutrient gradient (other conditions, notably climate and moisture which are not modelled explicitly, are assumed constant). Although the user is required to rank the site quality (Q = 1 to 100), the index that the MANAFOR program uses for its look-up process is internally calculated according to the observed growth records during the setup calibration. For Alberta, a medium-quality site (arbitrarily set at Q = 50) would correspond to a site index (SI, height in meters at reference age 50) of about 17m. Good (Q = 75) and poor (Q = 25) sites would be associated with SI values of 22m and 12m, respectively.

MacLeod (1952) described a dense medium site with an SI of 17m, stand density of 12,350 stems per hectare at age 20, and average Dbh of 4.5 cm. Using these parameters, STEMS* produced biomass chronosequence data from ages 20 to 110 years. It is interesting to compare the STEMS* results with the data used by Peterson et al. (1988) in their quasi-empirical calibration of FORCYTE-11 for

Alberta aspen. Figure 1 indicates excellent agreement for stand density, but individual biomass components show varying degrees of discrepancy. As an example, the STEMS* stemwood biomass accumulation peaks both higher and later (fig. 2). Other woody components (branches and bark) are in much better agreement. Foliage biomass, an important component of the driving function of FORCYTE-11, reaches comparable maximum values, but at a later age (about 100 years) in the STEMS* projection than in the Peterson data (about 30 years).

There is no a priori reason to regard Peterson's data as a more accurate representation of "reality" than the STEMS* projection; indeed, Peterson's data is a highly edited combination of raw field data and literature values from a wide geographic range (Peterson et al. 1988; Peterson, personal communication). However, several comments can be made about the uncertainties in the STEMS* approach. One significant area of imprecision that can be resolved by further research is that of the Dbh-biomass regression equations. Several sets of equations for aspen were tried (Peterson et al. 1970; Singh 1982; Ribe 1973), but, although all for the same species, the resulting curves were very different from one another. Those in best agreement with the Peterson calibration data were those produced by the Peterson et al. (1970) regressions, but even they were based on observations of a particular aspen clone of possible atypical growth form in the foothills of Alberta (Peterson, personal communication).

A more fundamental limitation shared by all empirically based dynamic models is the expected reduction in accuracy with increasing prediction period. As noted by the developers of STEMS, the 90-year projection used above verges on the extreme. For maximum accuracy, STEMS* should be used to augment other, more direct data where available. In this context, it is worthwhile to remember that FORCYTE-11 is intended as a yield trend evaluator rather than an absolute yield predictor.

To test how well the STEMS*-generated data behave within the FORCYTE-11 model, the aboveground bioassay data in the Peterson calibration were replaced by the STEMS* values. All other data, including belowground, soils, and nutrient information were left intact. The diagnostic output from the submodel (program TREEGROW) very closely echoes the input calibration data from STEMS*; figures 3 and 4 demonstrate this for stemwood and foliage biomass respectively. This agreement indicates that the parameterized growth submodel behaves in an acceptable manner as a simple yield table.

To test the predictive part of FORCYTE-11 with STEMS*, calibration bioassay data for two different site qualities (SI = 17m and SI = 12m) were prepared and used to overlay the values in Peterson's calibration set (Q = 50 and Q = 25, respectively). Conditions for the unmanaged stand were emulated as closely as possible. Also shown in figures 3 and 4 are the results of a run of the management predictor (MANAFOR 1) for the unmanaged stand with adequate nutrients available. The close tracking of the predicted results with the calibration data is

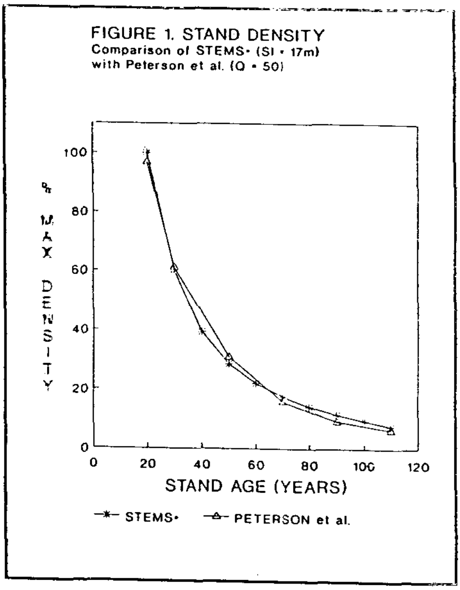

Fig. 1. Stand density: Comparison of STEMS (SI = 17m) (*) with Peterson et al. (Q = 50) (△).*

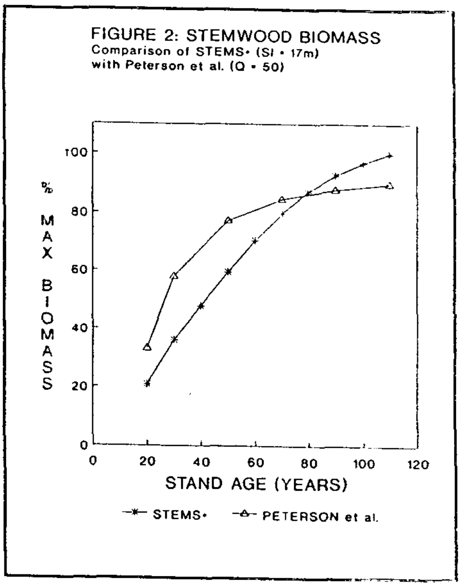

Fig. 2. Stemwood biomass: Comparison of STEMS (SI = 17m) (*) with Peterson et al. (Q = 50) (△).*

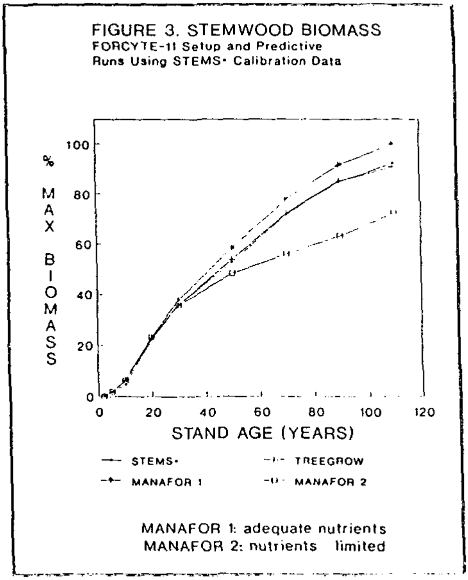

Fig. 3. Stemwood biomass: FORCYTE-11 setup and predictive runs using STEMS calibration data (• = STEMS*, + = TREEGROW, * = MANAFOR 1, □ = MANAFOR 2).*

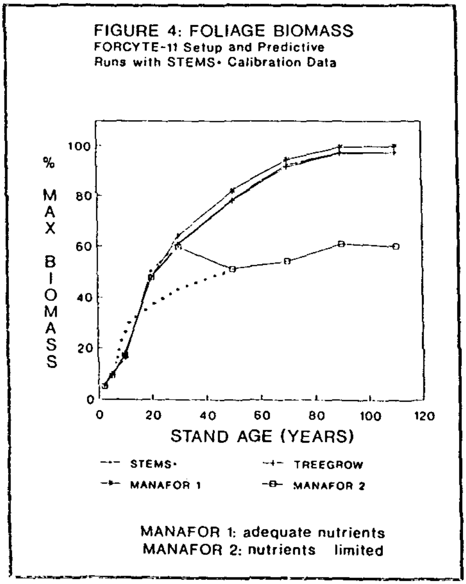

Fig. 4. Foliage biomass: FORCYTE-11 setup and predictive runs with STEMS calibration data (• = STEMS*, + = TREEGROW, * = MANAFOR 1, □ = MANAFOR 2).*

very encouraging when we realize that considerable process simulation has gone into these predicted results. We must comment, however, that not all predictions track as well as those shown; in particular, stand density shows disturbing differences, indicating that self-thinning in the management predictions is being underestimated. (This may be related to the incomplete calibration referred to below).

Finally, to prove that changes in the nutrient status do indeed affect the predicted growth, a managed stand scenario was emulated by artificially reducing the nitrogen nutrient pool in the initial system ecostate. As can be seen in the MANAFOR 2 curves of figures 3 and 4, when the excess labile pool of nitrogen becomes exhausted between years 20 and 30, both foliage and stemwood become stunted as nutrient availability limits subsequent growth. In fact, the expected response is not as sharp as shown, and it is believed that the sudden break at year 30 is an artifact of an incomplete calibration. The dotted curve indicates the expected response when the complete calibration set is assembled.

Conclusions

An empirically based stand yield model (STEMS) has been modified (STEMS*) to provide the biomass chronosequence data for calibration of the FORCYTE-11 model. The advantages of this approach over the empirical calibration method are several: (1) FORCYTE-11's growth submodels can be calibrated over a range of site qualities by using appropriate site indices; (2) site-specific information is used both for initial condition definition for STEMS* and, where available, to complement STEMS* projections; (3) because STEMS integrates data from an extensive data base, the projections provide optimally smoothed growth bioassay curves required by FORCYTE-11; and (4) the method can be used to guide calibration of FORCYTE-11 for other species of interest, such as white spruce and jack pine. In addition, because STEMS* requires input of only a few commonly available stand parameters, this approach may provide a practical link of FORCYTE-11 to regional, multi-stand management support through geographic information systems.

One area needing further research lies with the Dbh-biomass regression relationships. Surprisingly, although the published regression curves were at considerable variance with each other and with quasi-empirical data assembled by Peterson et al., the resulting FORCYTE-11 runs were encouragingly similar, self-consistent, and plausible. This fact, however, underscores the other main research need: sensitivity analysis of the FORCYTE-11 model. In a future paper, the implications of imprecisions in STEMS*-generated data on FORCYTE-11–predicted trends will be presented, along with a more general systems analysis of the FORCYTE-11 model.

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