ECOLOGICAL PROCESSES IN FOREST GAP MODELS — ANALYSIS AND IMPROVEMENT

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1. INTRODUCTION

In the last two decades, forest succession models of the JABOWA/FORET type ("gap models") have grown to rather complex models. This makes simulation studies tedious, not the least because of the long simulation times and the inflexibility in experimenting with model modifications. Thus, only little could be learned about the relative importance of the numerous ecological processes built into the models and about their mathematical properties from a systems theoretical viewpoint.

Focusing on the FORECE model [2], we first analyze how many simulation runs have to be performed to allow for meaningful calculations of statistical properties of the model output. We then examine the state variable update in the model as a first step toward model simplification. Based on these experiences, we evaluate the relative importance of the ecological processes in the model, and we present a simplified forest gap model encapsulating a minimal set of essential ecological processes to allow for efficient interactive as well as large-scale simulations.

2. MODEL CONVERGENCE

In forest gap models, species biomasses and numbers from several simulation runs are not normally distributed at a given point in time. Hence, model convergence can not be estimated through convergence of averages or standard deviations, nor by confidence intervals. As a more robust statistical measure, we took the interval between the 10% and the 90% percentile (p_{10}, p_{90}) divided by the median of the samples. Theoretically, this quotient should converge toward some non-zero value as the sample size approaches infinity.

We arbitrarily chose the site Bern(Switzerland, 540 m.a.s.l.) to perform the analysis for three species, each having a typical ecological role. The years 400, 800 and 1200 were selected for the analysis to minimize autocorrelation.

Model convergence is very slow, reflecting the highly stochastic nature of gap models (Fig. 1). We conclude that in general a minimum of 100–150 samples (runs) are needed if meaningful statistics are to be calculated. If possible, 200 or more runs should be performed. Simplified forest gap models facilitate such large simulation studies.

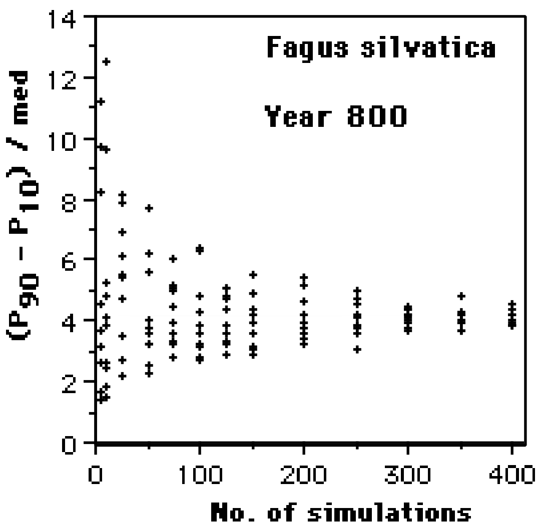

Fig. 1: Convergence of the FORECE model. The variability coefficient as a function of the number of simulated variates (Each point is the mean from 10 simulation experiments). The horizontal line is the best estimate of a conjectured boundary value and was computed from 4000 simulations.

3. STATE VECTOR UPDATE

Our analysis showed that the updating of the state vector in most forest gap models [1, 2, 3] is inconsistent with the model assumption of a time step of one year. Given state $\underline{x}$ and input vector $\underline{u}$ at time t, the following computational sequence results in a more consistent updating of the new state vector at time $t+\Delta t$: (1) determining which trees will die, (2) calculating the growth increment of the trees which will survive, and (3) recruitment of young trees within Δt. The resulting model structure conforms to the discrete-time formalism $\underline{x}(t+\Delta t) = \underline{f}(\underline{x}(t), \underline{u}(t))$ and renders models easier to understand and hence to modify. Since our new update mechanism avoids repeated calculations of some variables within the same Δt, e.g. leaf area index, simulations are faster.

Comparing results from 200 simulation runs between the original FORECE model by Kienast [2] and the new model adopting the corrected updating mechanism shows, only slight changes occur if updating is changed, but the new model version is 25% faster (Fig. 2).

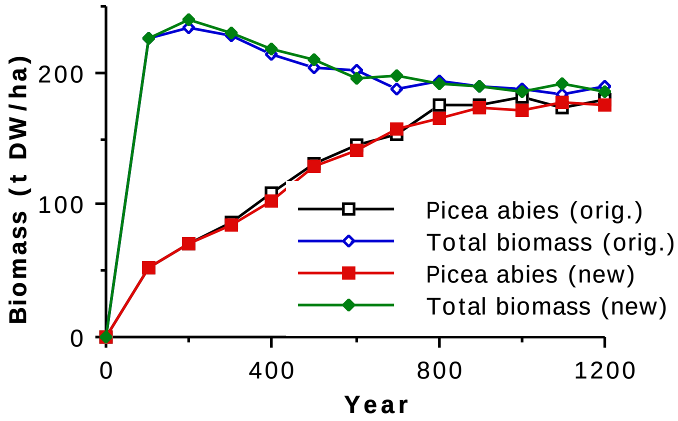

Fig. 2: Comparison between the original FORECE and the new model with the consistent updating. Data from 200 runs for the site Zermatt, Switzerland.

4. MODEL SIMPLIFICATION

Our model analysis indicates that in central Europe the following processes and factors are of minor importance:

- Temperature indicator values according to Ellenberg
- Influence of degree-days and frost occurrence on seedling establishment
- Scoring system used to determine the weighting of species in the seed pool
- Sprouting from tree stumps

A completely new model was built from FORECE to remove above processes and to simulate cohorts of trees of identical size instead of single trees of similar size.

Simulation results of the new model are shown in Fig. 3. The successional properties of the new model are very similar to the ones from the original version. The main feature of the new model is that it runs four times faster than the original FORECE model. This allows for interactive simulation studies and structural model analysis on personal computers (e.g. IBM PC or Macintosh).

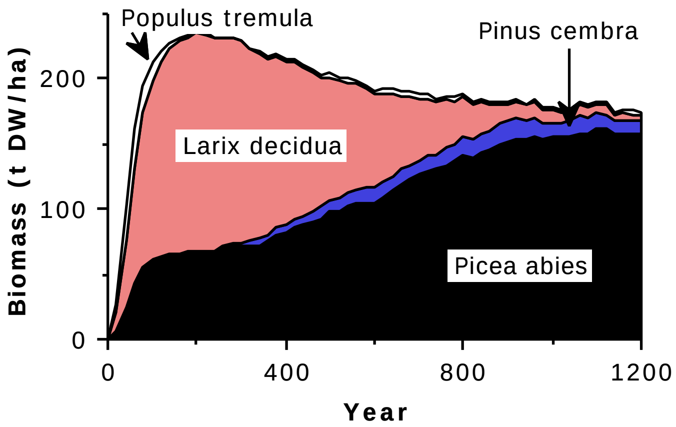

Fig. 3: Simulation results from 200 runs with the simplified, new forest gap model for the site Zermatt, Switzerland.

5. CONCLUSIONS

In the context of the influence of climatic change on forest ecosystems, we are confronted with the problem whether two stochastic simulation samples are significantly different from each other or not. Our study showed how crucial a sufficiently large sample size is, if one wishes to assess significant impacts of global change on forests by simulation studies.

Correcting the update mechanism and simplyfing the structure reduces the overhead present in many other gap models, which makes sensitivity and stability analysis as well as interactive exploration of model behaviour feasible on modern workstations. We hope that hrough these improvements, it will become possible to further a "Theory of Forest Dynamics" in order to advance our understanding of the human impact on the involved processes and systems.

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