

21 Landscape-Scale Model Relating the Nordic Mountain Birch Forest Spatio-Temporal Dynamics to Various Anthropogenic Influences, Herbivory and Climate Change

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B The HIBECO Model: Details About Structure and Design

The component interactions of the HIBECO model has been included as simplistically and generalized as far as possible while still maintaining a realistic representation of the processes and interactions under study with respect to the management problems in focus. In this way we are able to produce model outputs that more clearly emphasize the principal consequences from various management regimes and perturbations on the birch forest structure and dynamics on a landscape scale.

Representation of intra-cell mountain birch demography

Local birch demography is modelled in two alternative modes in the HIBECO model. The first mode, stochastic growth, simulates a simplified system which is optimized for simulation speed and structural simplicity when it comes to phenomenological illustrations of multi-scaled perturbation effects at various landscape scales. An alternative and structurally more detailed mode, *deterministic growth*, is optimized for management scenario studies where more details are necessary to produce sufficiently realistic results.

Stochastic growth

According to the first and simplest mode of local birch demography intra-cell mountain birch stands are “coarse-grained” to an average stem size class variable with size range 1 to 10. Size class 1 means that young stems dominate the stands in a specific cell by means of stem area at ground level (AGL), and size class 10 means that old-aged stands dominate. In the “stochastic growth” mode we do not specify size more explicitly than these ten classes (age classes and their relation to size will be specified in the next mode; see below). For each given number of time increments -- normally ten steps -- the cells' age class variable is incremented by 1, except for treeless cells (defined as size class 0), which may be forested as class 1 in accordance to specific rules during a simulation, and class 10 which stay in this class unless a perturbation event resets the cell to class 1 (followed by new regrowth from seedlings or saplings).

Tree density is not explicitly defined in this growth mode. It is simply assumed that a cell with the tree size variable set to 1 has sufficiently extensive density of young-aged trees of this size class to dominate the presence of birch trees, considering all age classes in this cell. In other words, older trees are rare enough not to influence the overall classification of dominant tree size with respect to AGL. Further, since the cell has a size classification >0 it means that birch trees cover a “significant” part of the cell. A more specific real-world applicable definition of “dominance” and “significance” is not crucial for the current simulation studies that are based on virtual landscape conditions, but a

stringent rule should be defined in cases where virtual landscapes are replaced by data from real landscapes.

By default the increments from one size class to the next takes place every tenth time step, meaning that it takes 100 years to cycle from the smallest size class 1 to the largest size class 10. However, a stochastic function may replace the deterministic 10-year size class increments, so that the size increments take place in accordance with a probability function with a given mean and standard deviation. For example, one function may express that most cells upgrade their birch size class variable every tenth time step, while some cells (say, 10 or 20 %, chosen randomly from step to step) upgrade somewhat faster or slower. This effect incorporates a degree of local environmental stochasticity in the local forest growth dynamics.

Under homogeneous landscape conditions the abovementioned stochastic element of the stepwise size increment is by definition homogeneously distributed if the same probability function for class increment is applied all over the arena with the same parameters in its functional expression. In other words, the stronger the stochastic effect, the more non-correlated will two neighbouring cells become after (say) 100 model years of growth, even when they start at size index 1 at the same time. However, a more spatially autocorrelated kind of local growth variability is also included in the model, in order to achieve better coherence with realistic growth conditions across a more realistic, heterogeneous landscape. A GIS layer of specific “growth rate stochastic functions” for individual cells can be activated for a given simulation, so that local growth for example can be defined to be a function of altitude-dependent summer climate and local variations in nutrient levels. In the HIBECO model a local (cell-scale) “growth coefficient” is included in the size increment algorithm. This coefficient equals 1 by default (i.e., “normal”, or standard growth rate multiplied by 1), while it falls towards zero close to the current local altitudinal limit for birch growth (i.e., relatively smaller experienced growth rate). A simple statistical Monte Carlo algorithm is incorporated in the HIBECO model to produce both homogeneously and heterogeneously distributed stochasticity in the size class increments in this respect.

Due to the larger or lesser degree of stochasticity related to size class increments, and the fact that intra-cell tree size variability is averaged out to be represented by a single cell-specific size class variable, we call this mode “*stochastic growth*” dynamics.

Deterministic growth

According to the more detailed alternative mode of intra-cell forest demography the population of mountain birch trees in any cell is split into 105 age classes from 0 (seedlings and saplings) to 104 (old trees), and the number of trees in each age class is specified and recalculated dynamically. Thus, contrary to the stochastic growth mode described above, the birch forest is here modelled with age structure as well as explicit density variables for each of the 105 age classes in each of the 1 Ha cells. At each time increment of one year all trees of a given age class are re-classified as belonging to the next higher age class. Trees of age class 104 stay at this class, meaning that this class includes all trees of age 104 years and older.

A life table database feeds the model with age-specific growth and survival parameters, like stem diameter increments, stem death rate, and

frequency of replacement of dead stems by regrowth (multiple of saplings) from the root. A simplified form for intraspecific competition, a rudimentary form for self-thinning rule, is activated for the deterministic mode. This rule defines age class-specific upper limits on stem density, meaning that “surplus” stems are removed during transitions from one year class to the next.

A separate life table for monocormic and polycormic growth is defined, since life table parameters vary considerably between these two growth forms. The actual table used for any given cell is defined to depend on local summer temperature conditions, which is assumed to be a suitable proxy variable also for local soil- and wind conditions facilitating dominance of mono- or polycormy at the spatial scale of 1 Ha and larger. In practice this means that close to the treeline the model’s forest dynamics follows the polycormic growth conditions, while a mixture of monocormic and polycormic growth is applied for the lower-altitude forest. Depending on the purpose of specific simulations this detail of growth form may be simplified to applying a mixture of mono-and polycormic growth conditions over the entire landscape with strongest weight to polycormic parameter conditions.

This simplification is not as unrealistic as it looks at first sight, since -- in the current context -- we are primarily investigating management scenarios where new growth is initiated at logged sites, and the end result from this regrowth is a new stand of old growth after a given period of time. Whether this “next-generation” stand was initiated by seedlings or saplings or a mixture of both may be of little relevance for the outcome in this context, as long as the expected end result after (say) 60 or 100 years after logging is similar in respect to birch cover, age-class distribution, and expected quantities in each age class under the given growth conditions. The picture is more complex, though, in areas with intense grazing by ungulates, since seedling and sapling regrowth dynamics may show different susceptibility to grazing effects in particular the first years after clear-cutting. The preceeding chapter of this book (Chap. 20) illustrates this challenge, with an example from complex habitat facilitation under influence of positive feedback mechanisms. Further, spatial expansion of birch into new territory (for example, from improved climate) will also be dependent on seed dispersal and seedlings, and not dependent on saplings from existing roots.

A transition table defines the relationship between current age class cover from these deterministic growth conditions and the 10 size classes that were defined earlier for stochastic growth conditions. The degree of dominance of the oldest age classes (with respect to AGL) have largest statistical weight when the normally heterogeneous mixture of age class cover in a cell is translated into a size class value.

This more detailed mode of spatio-temporal forest growth dynamics with age-specific forest dynamics and demography is called “deterministic growth” in our model framework.

Forest line definition

The default forest line in both areas is defined to lie in the zone for a 3-month maximum summer temperature range of 13.4--13.8 °C. In comparison, the average maximum temperature isotherm 13.2 °C for the four warmest months (i.e., somewhat lower than the 3-month variable) was found to match the the mountain birch forest line with the highest degree of statistical significance (Odland 1996). The birch forest ecotone in a region of the Usa Basin in Sibir was found to be

increasingly patchy in the 15.5-13.5 °C zone for the mean one-month summer (July) temperature, where forest cover decreased from ca 10% at the 15.0 °C isotherm to near zero at the 13.5 °C isotherm (Virtanen et al. 2002). However, local and regional variations are substantial within the mountain birch distributional range, and the definitions of forest line, timber line and treeline is difficult to apply in practice on a typically very fragmented ecotone between the forest at lower elevations and the treeless areas at higher elevations (see also Chap. 1, this Vol.). In addition we have the uncertainty related to what extent a local borderline is the direct result of climate, historic influences from tree felling, chronic overgrazing effects from ungulates, and severe insect outbreaks. Thus, for the current study the most important aspect of the forest line is not whether it is defined to be best correlated with isotherm X or Y or somewhere in between, but to what extent it is changing in relative terms in the landscape as a result of climate change and local grazing pressure. It is also important for the spatial explicit modelling to maintain the general pattern of a typically fragmented border zone, which in the model is simplified as a 50% cover of forested grid cells in the forest transition zone defined by the given temperature range of 0.4 °C between 13.4 and 13.8 °C.

Simulation Rules and Spatio-Temporal Boundary Conditions

To begin with the basic model dynamics, the local intra-cell state of birch tree size class (stochastic growth mode) or age class distribution (deterministic growth mode) is at the start of each simulation drawn from a predefined statistical distribution using a simple Monte Carlo algorithm to define the initial conditions for each cell at time step 1. The algorithm initiates most cells with medium-aged trees, but with sufficient variability at the cell scale of 1 ha to give a size distribution covering a larger range of classes at this “unit” scale.

In addition to characterizing size class for the trees in each cell it is also important to have a variable for local density of trees. Further, one must define a variable for how large a part of the cell is actually or potentially covered by birch trees. Most 1-ha pixel areas in real birch forested landscapes can be expected to have some treeless patches due to unsuitable growth conditions. These two variables, pixel-level density and cover, will in practice be quite strongly correlated, but it is also a fact of natural birch forests that the cover may vary quite substantially even between cells with relatively high and similar tree densities at the pixel scale. In some cells, the trees can be relatively uniformly dispersed, while in other cells the trees are grouped into various stands in a local matrix of non-forested areas (Fig. 21C).

This degree of intra-cell openness will be crucial for the level of potential or experienced grazing pressure in this cell, and how easily grazers may penetrate this cell while commuting between other grazing patches in the area outside any specific cell. This aspect will be described in more detail in the next chapter (Chap. 22).

The openness in combination with other factors is also important for calculating actual “experienced” density of birch stems in the birch stands, so that a proper function for mortality due to intraspecific competition at high densities can be processed successively during the simulation. The age-specific stem mortality will be strongly dependent on whether the given number of stems in a given cell are strongly clumped (i.e., higher “experienced” density for the trees) or

more uniformly dispersed. The actual distribution of trees in each age class will also play a crucial role in this respect.

Consequently, in the HIBECO model the birch stem cover within each cell is described by a cover index from 0--5, where each increment in the index defines 20% increase in potential total tree crown cover. A Monte Carlo simulation is applied to generate an approximately normal distribution of intra-cell cover indices, with mean cover index 2.5. The actual cover indices are defined as being mutually independent from cell to cell (i.e., spatially uncorrelated at a spatial scale of 1 ha), and they retain their value through an entire simulation run.

During the initial computation of cell- and age-specific number of birch stems the values for each cell are adjusted for cover. For example, if the cover index for a given cell is 3 (40--60% cover), each of its initial age-class abundances, produced from a Monte Carlo algorithm, are in this example multiplied with $(\text{cover index})/(\text{maximum cover}) = 3/5$, so that the local abundance initially expresses a similar actual "experienced" density where non-birch patches are removed from the 1 Ha gross area at pixel scale. Thus, after this "trimming" each cell will have a more variable cell density of stems, but this inter-cell variance is positively correlated with cover index.

A similar adjustment is made in the algorithm for yearly intra-cell self-thinning effects and in the transition calculation from intra-cell age class distribution to size class dominance index. A cell with relatively small birch cover index value (i.e., a "clumped" intra-cell dispersion of stems) can be expected to experience a stronger intrinsic competition between stems than a cell with larger cover index, given a similar overall density of stems in the two cells.

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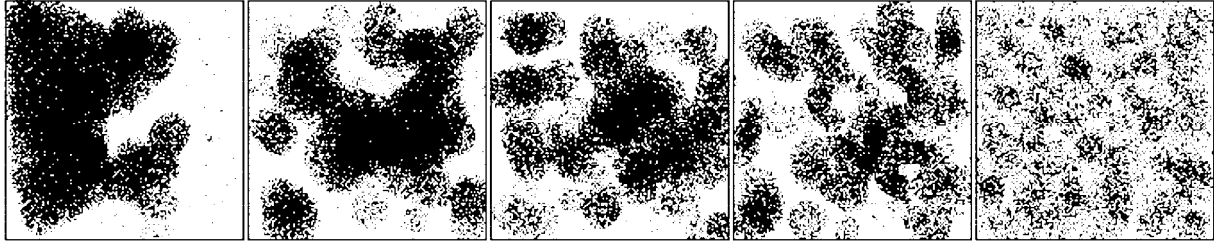


Fig. 21C. In the HIBECO model the birch stem cover within each cell is described by a cover index from 0-5, where each increment in the index defines 20% increase in actual or potential total tree crown cover. In this example, an index of 3 (40--60% cover) to the left is gradually changed to an index of 5 (80--100% cover) to the right, while the total cell density of trees is kept constant. The latter trees may experience a lower level of intraspecific competition, and the site may also be more or less penetrable for grazing animals. Both aspects will strongly depend on other factors as well, like the age distribution of the trees