Balancing Ecology and Economy in Forestry: A Theoretical Investigation

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Findings
- The size-structure and productivity of uneven-aged forests are strongly controlled by asymmetric competition for light between large and small trees.
- Ignoring the asymmetric competition effect leads to large overestimations of the potential to increase ecological value by increasing the diameter at which trees are harvested.
- Both for ecological and economic values it is optimal to harvest all trees at a certain diameter rather than harvesting many size-classes simultaneously.
- The Pareto-optimal harvesting strategies are confined to harvesting diameters above 50 cm corresponding to relatively low ecological impacts.
- The model provides a transparent and computationally efficient tool for evaluating the trade-off between ecological and economic values in uneven-aged forest management.

Background
While forests have traditionally been managed for wood production, there are good reasons to account also for other objectives, such as biodiversity conservation and other ecological values. In contrast to clear-cut based “normal” forestry, uneven-aged forest management can preserve a more natural structure and associated ecological values. However, due to the complex interactions among trees in such forests, optimal management modeling quickly becomes an insurmountable obstacle. A promising recent development to overcome this impasse is the perfect plasticity approximation (PPA, see below), which has opened a new avenue of ecologically realistic and analytically tractable forest models. Here we use a PPA based model to investigate the potential for combining economic and ecological values under uneven-aged forest management.

Model

General model equations

\[ \text{ND}, D \] is the density (number per m²) of trees of diameter \( D \) at time \( t \). The dynamics of the forest is defined by:

\[
\begin{align*}
\frac{d \text{ND}}{dt} &= -\frac{\alpha D}{\mu D} - \left( \mu + c(D) \right) N(D,t) \frac{D}{D'} \\
\frac{d \alpha}{dt} &= \left( \mu + c(D) \right) N(D,t) \frac{D}{D'}
\end{align*}
\]

In eq. 1, \( D \) and \( \mu \) are growth and mortality rates, respectively, where the indices \( u \) and \( d \) denote below and above the critical height \( h^* \) (fig. 3). \( c(D) \) is the cutting rate. \( D' \) is the critical diameter, i.e. \( D \) for trees with \( h > h^* \), defined by:

\[
\int_0^{h^*} A(D)(1-D')dD = 1
\]

Equation 2 reflects the size-structured competition for light which occurs implicitly in the model: once the tallest individuals have filled the canopy, the remaining individuals are assumed to be in the understory where light availability is reduced. Recruitment of new trees (reproduction) is

\[
N(D,t = 1) = \int_0^{h^*} A(D) \frac{N(D,t)}{N(D,t)} \frac{D}{D'} dD
\]

In eq. 3, \( F(D) \) is fecundity per crown area and \( A(D) \) is the crown area.

Equation 4 conserves mass across the growth-rate discontinuity at \( D' \):

\[
\lim_{D \to D'} G(D,t) = \lim_{D \to D'} A(D,t)
\]

The model is based on a standard representation of the dynamics of a size-structured population. To add the effect of size-asymmetric competition for light (that strongly controls the dynamics of most forests) in a tractable way, we used the perfect plasticity approximation (PPA, see below). To represent uneven-aged forest management the forest was assumed to be in steady state, i.e. approximating continuous harvesting causing no drastic fluctuations in forest structure.

The perfect plasticity approximation (PPA)