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A simulation of the development and restoration of old-growth structural features in northern hardwoods

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Abstract

Thinning treatments in second-growth forest may be a practical means of accelerating the development of certain old-growth structural features in regions where old stands are presently uncommon. We used CANOPY, an individual-tree model calibrated with data from thinned and unthinned stands, to simulate effects of thinning on growth rates and development of old-growth structural features in second-growth northern hardwoods. Three simulated, moderately heavy thinnings over a period of 45 years nearly doubled the predicted mean radial increment of canopy trees, percent of stand basal area in large trees, and area of canopy gaps. Compared to untreated stands, thinned stands had fewer dead trees per ha, but the dead trees were larger in size and the overall volume of snags and logs was little affected. In a 77-year old even-aged stand, moderately heavy thinning was predicted to reduce the time needed to attain the minimum structural features of an old-growth forest from 79 to 36 years. Simulated treatments in an older, uneven-aged stand gave mixed results; the moderately heavy treatment stimulated individual tree growth, but the removal of some medium-sized canopy trees in conjunction with natural mortality delayed the development of old-growth structure. Total volume of dead wood may still be deficient under the thinning regimes investigated in this study, but predicted live-tree structure 45 years after moderately heavy thinning was typical of stands in the advanced transition and steady-state stages of old-growth development. Results suggest that thinning can substantially accelerate the development of old-growth structure in pole and mature northern hardwoods, but response in older, uneven-aged stands is more modest, and treatments in these stands may need to be more conservative to achieve restoration goals.

Keywords: Forest models; Gap dynamics; Individual tree growth model; Northern hardwood forest; Old-growth forest; Old-growth restoration; Restoration ecology; Uneven-aged management; Thinning treatments

1. Introduction

The inclusion of old-growth forest on a landscape appears to contribute significantly to regional biodiversity. Some forest types, such as deciduous forests in eastern North America, may have few, if any, obligate old-growth species; nevertheless, a number of species in these regions may have higher populations in old growth than in younger stands (Howe and Mossman, 1996; Werner and Raffa, 2000; Lindner et al., 2006). Old growth has been defined in various ways (Hunter, 1989; Oliver and Larson, 1996), but a conceptual definition with broad applicability is ''ecosystems distinguished by old trees and related structural attributes . . . encompassing the later stages of stand development'' (Tyrrell et al., 1998). Specific structural features of old-growth forest known to influence species diversity include cavity trees and dead snags of various sizes, large fallen logs, tip-up mounds, canopy gaps in various stages of recovery, and a forest canopy with multiple layers of foliage (Willson, 1974; DeGraaf and Shigo, 1985; Spies and Franklin, 1988; Hunter, 1990). While much of the evidence on species diversity in old growth is based on observational studies, comparative studies and experiments appear to confirm that management practices resulting in reduced structural heterogeneity can have a negative effect on diversity of flora and fauna (Scott, 1979; Stribling et al., 1990).

Because old-growth stands are currently rare in most parts of the world, strategies for increasing the relative proportion of stands with old-growth structural features may involve various combinations of active and passive restoration techniques. In most parks and some other public lands, mature forests are typically set aside in reserves and allowed gradually to develop old-growth features over time with only minimal human

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intervention (e.g., removal of exotic species). On other public lands such as state or national forests, silvicultural treatments in second-growth stands already being managed for timber production may be altered to accelerate the naturally slow development of old-growth structural features, while continuing a certain level of timber extraction (e.g., USDA Forest Service, 2004; Keeton, 2006). These treatments can introduce canopy gaps and coarse woody debris into dense, uniform second-growth stands lacking such features, which can improve habitat for some species of concern (e.g., certain regionally declining neotropical migrant songbirds; Robinson and Robinson, 1999; Gram et al., 2003; Jobes et al., 2004). Thinning can also help accelerate the development of large trees, increasing long-term growth rates in some species by more than 90%, even among canopy trees 80–125 years old (Ellis, 1979; Singer and Lorimer, 1997). Intermediate levels of human intervention are also possible, such as the use of a limited series of thinnings to hasten the development of old-growth features, after which felling of trees is discontinued once the desired condition is reached.

The long-term consequences of these alternative approaches to old-growth restoration are not well known because of limited data on long-term forest development. 'Transitional' old growth stands (i.e., stands 100–200 years old), which could potentially offer some insight into developmental trends by means of chronosequence analysis or long-term permanent plots, are uncommon in most parts of the world. Because of the relative newness of the old-growth restoration concept, long-term results from experimental trials are also presently unavailable.

Given these circumstances, investigation of old-growth development over an extended period of time can benefit from a computer simulation approach. Bormann and Likens (1979) have been among the few investigators to simulate forest development well into the old-growth stages, using the JABOWA model. They proposed that stand development after clearcutting progresses through several stages, which they labeled the reorganization, aggradation, transition, and steady state phases. More recently, the SORTIE model has been used to simulate long-term succession in northern hardwood forests (Pacala et al., 1996). However, with the exception of work by Busing and Garman (2002) in forests of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), most long-term simulations have focused on successional trends and biomass accumulation rather than stand structural characteristics or specific features of old-growth forest.

In a previous study in northern hardwoods, individual-tree, crown-based growth equations were calibrated with data from a wide range of tree ages and stocking levels to predict the effects of thinning treatments on time needed to promote the development of large trees (Singer and Lorimer, 1997). Trees 30 cm in diameter were predicted to reach 50 cm (the mean size of canopy trees in mesic old-growth stands in upper Michigan) in 46–49 years, compared to 92 years with no treatment. Because an integrated, spatially explicit stand model was unavailable at that time, it was not possible to investigate the effects of restoration treatments on overall stand structure, including features such as size distributions, canopy gaps, and coarse woody debris.

In the present paper, we use CANOPY, a new individual-tree model of stand development (Choi et al., 2001) to simulate the development of unmanaged, second-growth northern hardwood stands on good sites and to investigate the effects of alternative restoration treatments on overall stand structure and old-growth structural features. Principal questions included: (1) How long would it take for untreated and treated stands to attain minimum structural criteria of old-growth stands?; (2) What effect does treatment intensity have on the tree size distribution, volume of coarse woody debris, and density of large living trees and snags?; (3) Can later stages of old-growth structural development (i.e. transition or steady-state phases) be attained within a moderate span of time following the initiation of treatments? The CANOPY model was selected over other available models (e.g., STEMS or SORTIE; Belcher et al., 1982; Pacala et al., 1996) because the calibration data set includes plots from old-growth reserves and older, managed second-growth northern hardwood stands, and because the spatially explicit crown-growth routine permits a more detailed analysis of gap dynamics.

In simulating these management regimes, we recognize that restoration treatments cannot necessarily restore all of the attributes of old-growth forests. Restored old-growth forests may still be lacking some of the ecosystem processes and species that might be present in true old-growth stands because they have not had sufficient time to develop certain key attributes (e.g., advanced decay in living trees) or because conditions have not been conducive to the recolonization of missing species (Busing and Garman, 2002).

2. Methods

2.1. Study areas

The CANOPY model used in this paper (Choi et al., 2001) was developed to simulate long-term forest dynamics and was calibrated with data from northern hardwood stands on mesic, nutrient-rich sites in the upper Great Lakes region. The field data used in calibrating the model were collected between 1987 and 1991 in 15 northern hardwood stands in northeastern Wisconsin and western Upper Michigan (Cole and Lorimer, 1994; Dahir, 1994; Singer and Lorimer, 1997; Choi et al., 2001).

The calibration study sites lie within sub-subsections IX.3.1–3.3 (Upper Wisconsin-Michigan moraines) of the ecological landscape classification of Albert (1995), or in ecoregion subsections 212 Jc, Jl, and Jj of the National Hierarchical Framework of Ecological Units (Wisconsin Department of Natural Resources, 1999). Mean monthly temperature ranges from −12 °C in January to about 20 °C in July. Annual precipitation averages 820 mm and is fairly well distributed throughout the year. Elevations range from 500 to 550 m. Soils are classified as well- or moderately well-drained loamy Spodosols, originating from aeolian deposits on glacial till or glacial outwash. Two of the more productive habitat types (Kotar et al., 2002) were selected for study (*Acer-Osmorhiza-Caulophyllum and Acer-Tsuga-Dryopteris*), in order to reduce