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Predicted effects of prescribed burning and harvesting on forest recovery and sustainability in southwest Georgia, USA

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Abstract

A model-based analysis of the effect of prescribed burning and forest thinning or clear-cutting on stand recovery and sustainability was conducted at Fort Benning, GA, in the southeastern USA. Two experiments were performed with the model. In the first experiment, forest recovery from degraded soils was predicted for 100 years with or without prescribed burning. In the second experiment simulations began with 100 years of predicted stand growth, then forest sustainability was predicted for an additional 100 years under different combinations of prescribed burning and forest harvesting. Three levels of fire intensity (low, medium, and high), that corresponded to 17%, 33%, and 50% consumption of the forest floor C stock by fire, were evaluated at 1-, 2-, and 3-year fire return intervals. Relative to the control (no fire), prescribed burning with a 2- or 3-year return interval caused only a small reduction in predicted steady state soil C stocks ($\leqslant$25%) and had no effect on steady state tree wood biomass, regardless of fire intensity. Annual high intensity burns did adversely impact forest recovery and sustainability (after harvesting) on less sandy soils, but not on more sandy soils that had greater N availability. Higher intensity and frequency of ground fires increased the chance that tree biomass would not return to pre-harvest levels. Soil N limitation was indicated as the cause of unsustainable forests when prescribed burns were too frequent or too intense to permit stand recovery.

Keywords: Soil carbon; Soil nitrogen; Forest recovery; Forest sustainability; Ecosystem modeling; Fire; Thinning; Clear-cutting; Degraded soils; Military land management

1. Introduction

Land managers at military installations are faced with the challenge of managing a given amount of land for troop training in a manner that promotes the sustainability of ecosystems. One aspect of ecosystem sustainability is preserving natural resources on the landscape. A second aspect involves restoring terrestrial ecosystems on soils that have been degraded by continuous military use. Military activities that can potentially result in degraded soils include the use of heavy weapons, and off-road wheeled and tracked vehicle training.

Disturbance of soil physical properties, especially soil structure, are commonly reported effects associated with use of heavy machinery in forestry (Hatchell et al., 1970) and military training (Iverson et al., 1981; Prose, 1985; Braunack, 1986; Thurow et al., 1993). At Fort Benning, GA, field training with tracked vehicles has resulted in an overall loss of soil quality at some training sites (Garten et al., 2003). Barren, heavily disturbed soils have negligible O-horizons, lower soil N availability, and lower C and N stocks than soils subject to minimal military use (Garten and Ashwood, 2004). In some environments, the effects of soil disturbance by military vehicles can persist for decades (e.g., Iverson et al., 1981). This leads to questions about how land management practices affect ecosystem recovery after soil disturbance.

Land management at Fort Benning, GA, includes the use of prescribed ground fires and tree thinning or clear-cutting to promote healthy forests. Prescribed fire is a common land management practice to clear herbaceous and woody shrubs from beneath forest stands because it improves access for military training and timber management and reduces the

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fuel load that might otherwise contribute to wildfires. Burning also helps to restore and maintain fire-dependent plant communities that are important habitat for threatened and endangered species.

The challenge of military land use in the southeastern US is further complicated by the potential effects of prescribed fire and tree harvesting on highly weathered, coarse-textured Ultisols. The complexity of land management on such nutrient poor soils raises questions about how possible interactions between N availability, prescribed burning, and forest harvesting may limit ecosystem recovery on degraded land or prevent ecosystem sustainability after forest recovery. These questions are difficult to answer with field experiments because: (1) the study of ecosystem recovery requires a prolonged period of measurements, and (2) replication of such long-term experiments can be problematic.

The objective of this research was to use a simple compartment model to predict forest recovery on degraded soils and forest sustainability, after recovery, under different regimes of prescribed fire and tree harvesting at Fort Benning. This report describes the model and a model-based analysis for two different soil categories that differ in N availability. The model was parameterized for a generic, temperate forest ecosystem and has potential applications in environmental management for predicting both the recovery of forest biomass and soil quality on degraded lands.

2. Materials and methods

2.1. Study site

Fort Benning was established by the US military for infantry training near Columbus, GA, in 1918. The current size of the installation is ≈73,600 ha and the number of troops onsite ranges between ≈18,000 and 23,000 annually. Land use at this site prior to acquisition by the US Government was primarily a mixture of agriculture and forestry. Current land cover at Fort Benning is ≈49% mixed forest, 25% deciduous forest, 10% barren or developed land, 7% evergreen forest, 6% herbaceous grassland, 2% shrub land, and 1% water (Jones and Davo, 1997). Mean annual temperature in the Columbus area is 18.3 °C and mean annual precipitation is 130 cm.

Soils at the site are highly weathered Ultisols, mostly of Coastal Plain origin but with some minor inclusion of alluviums derived from the Piedmont ecological unit to the north. The two dominant Coastal Plain ecological units that cover most of the installation are Sand Hills and Upper Loam Hills. Sands and loamy sands are common on upland sites while sandy loams and sandy clay loams are commonly found in valleys and riparian areas. Further details on the biology, geology, physical setting, and history of Fort Benning are available elsewhere (Jones and Davo, 1997).

One of Fort Benning's forest management goals is to restore fire-dependent longleaf pine (*Pinus palustris* P. Mill.) communities, and to meet this goal ≈10,000 ha are subject to prescribed burning each year. Training compartments are burned, on average, once every 3 years (the range is annually to once every 5 years). The red-cockaded woodpecker (*Picoides borealis* Vieillot) recovery plan at Fort Benning requires controlled burns approximately every 3 years in habitat used by this endangered species. In addition to restoration of longleaf pine, timber management at Fort Benning generally involves thinning pine and pine/hardwood forests (≈2800 ha yr^{-1}) and clear-cutting of diseased or insect-damaged stands. Current forest management guidelines include maintenance of a 100-year harvest rotation for healthy loblolly (*P. taeda* L.) and shortleaf pine (*P. echinata* P. Mill.) if threatened or endangered wildlife species are not adversely impacted by forest removal (Swiderek et al., 2002).

2.2. Model structure

2.2.1. Software platform

The model was developed using Stella® Research Software (isee™ Systems, Inc., Lebanon, NH) Version 7.0.2 for Power Macintosh computers. First-order differential equations of the general form:

$$\mathrm{d}x/\mathrm{d}t = \text{fluxes into a compartment} - \text{fluxes from a compartment}$$

were solved on an annual time step with Euler's integration method. Although the latter method is less precise than Runge-Kutta methods, certain "if-then" type statements in the model mandated Euler's method. Throughout the text, variable names are identified by abbreviations with italicized, capital letters. In this report, equations are presented in Stella® language format (Appendix A) which will facilitate replication of the model by other researchers using isee™ software.

2.2.2. Model parameterization

The model was parameterized using information from field studies (Garten and Ashwood, 2004; Garten and Ashwood, 2005), literature sources, and parameter fitting. Prior research on Fort Benning (Garten and Ashwood, 2005) indicated that soils with varying sand content had different predicted thresholds to ecosystem recovery. Thresholds to recovery were less on soils with more than 70% sand content, apparently due to higher relative rates of net soil N mineralization in more sandy soils. Consequently, the model was parameterized for soils with >70% sand (identified as more sandy) and soils with <70% sand (identified as less sandy). For the reader's convenience, the various submodels and their parameter values are briefly described in the following paragraphs.