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Overstory cohort survival in an Appalachian hardwood deferment cutting: 35-year results[☆]

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ABSTRACT

Deferment cutting is a two-aged regeneration method in which the majority of the stand is harvested and a dispersed component of overstory trees—approximately 15–20% of the basal area – is retained for at least one-half rotation and up one full rotation for reasons other than regeneration. Careful consideration of residual trees, in both characteristics and harvesting, is necessary to improve the chances that individual trees will survive until the next planned harvest. A long-term experimental deferment cutting study was established on the Fernow Experimental Forest and Monongahela National Forest in West Virginia, USA in the early 1980s. Repeated tree measurements spanning the approximately 35-year study period permitted a survival analysis of the overstory cohort. The effects on survival were tested for three endogenous factors (dbh, species, crown class) and one exogenous factor (logging damage) using a Cox Proportional Hazards model, with stand effects (multiple trees measured within a stand) accounted for by using as frailty model. Survival rates were high, with 92% of trees surviving (910 of 985 trees). The mortality rate was low at six percent, (60 of 985 trees), and the number of trees cut or destroyed during logging was two percent (15 of 985 trees). Trees injured in the deferment harvest did not show increased risk of mortality, $p = 0.91$. Crown class also did not contribute to increased mortality, $p = 0.35$, as the majority of overstory trees retained were in the dominant and codominant classes. Six species, *Liriodendron tulipifera* L., *Prunus serotina* Ehrh., *Quercus alba* L., *Quercus montana* Willd., *Quercus rubra* L., *Quercus velutina* Lam., had sufficient sample sizes to test for species differences. However, species was not significant for survival, $p = 0.10$. The only significant factor in survival was dbh, $p < 0.01$, with larger trees having increased probability of survival. These results demonstrate that overstory trees in a deferment cutting can be acceptably maintained midway through the next rotation and likely until the next regeneration harvest.

1. Introduction

Deferment cutting is a two-age regeneration method imported to the central Appalachian region from Europe in the early 1980s (Smith and Miller, 1991). The practice was applied to *Larix*, *Pinus*, and *Quercus-Fagus* stands in Germany (Kostler, 1956; Troup, 1966) to improve the visual appeal of clearcuts, which served as the motivation for implementation in the Appalachian region as well. Deferment cutting results in a stand with two cohorts, an older cohort of larger and taller trees scattered throughout the stand and a younger developing cohort in a separate canopy stratum underneath. This stratification may persist through the length of the cutting cycle, depending on the species present and site quality. Deferment cutting has parallels with seed tree cuts however differs in that the overstory of a seed tree cut is removed after regeneration is established; in a deferment cutting, the overstory is retained for at least one-half rotation and up to a full rotation (Miller et al., 1997). In current terminology a deferment cutting could be classified as either of two regeneration methods: clearcut with reserves or seed tree with reserves. Reserves refer to the retention of residuals for objectives other than regeneration. In this respect, deferment cutting therefore is an early application of the concept of variable retention (Franklin et al., 1997), where it could be considered an example of a low retention prescription. The deferred (retained) trees may either by dispersed or aggregated in clumps.

In a deferment cutting, objectives other than regeneration vary. Benefits to the system beyond improving aesthetics include: production of large-diameter sawtimber or veneer trees, increased structural diversity, seed source for reproduction or mast, retention of scarcely

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represented species, maintenance of species composition, soil protection, and retention of wildlife habitat (Smith et al., 1989; Miller and Kochenderfer, 1998; Stringer et al., 2006).

Concerns about the negative perception of clearcutting were the primary motivation for establishment of deferment cuts on the Fernow Experimental Forest (FEF) and the Monongahela National Forest (MNF) starting with an experimental study in the 1980s and continuing with operational harvests during the next decade (Miller et al., 1997). Since then, a variety of research questions have been examined on these study sites. Miller and Schuler (1995) investigated both the quality and development of the new cohort as did Miller et al. (1995, 1997) and Thomas-Van Gundy and Schuler (2008). The latter study also examined the vigor and quality of the deferment (residual) trees. Smith et al. (1994) focused on logging damage to residual overstory trees during the deferment cuts and estimated wound closure times. Miller et al. (1995) also studied songbird density and nest survival of songbirds and this was expanded and followed up by McDermott and Wood (2009). Outside of this region, Carter et al. (2006) studied the impact that deferment cutting and two other treatments had on soil properties.

One of the questions asked by Smith et al. (1989) in regard to deferment cutting was whether the deferred overstory trees would be able to withstand mortality risks such as wind and ice events and insect attacks with results reported for stands 5 years post-harvest. Several studies conducted under the auspices of variable retention address this question. Five variable retention treatments, one of which is similar to deferment cutting, plus a control were tested for their effect on overstory mortality in the Demonstration of Ecosystem Management Options (DEMO) study in Oregon and Washington (Maguire et al., 2006; Urgenson et al., 2013). A difference between patterns was observed within the 15% retention level, where the dispersed pattern exhibiting significantly higher mortality of overstory trees than the aggregated. In Alberta, mortality of residual trees was examined in dispersed structural retention harvests conducted in boreal mixed woods (Bladon et al., 2008). Bole damage, slenderness, and crown class were significant factors for mortality dependent on species. Expanding-gap silviculture may utilize a low retention dispersed prescription in the treated gaps, such as in the Acadian Forest Ecosystem Research Program (AFERP) in central Maine (USA). Reserve tree mortality in that long term experiment was found to differ for by species and tree vigor (Carter et al., 2017). Single-tree selection studies at low residual stocking levels are also similar to low retention dispersed treatments. Kiernan et al. (2012) found increasing dbh and decreasing residual density lowered the mortality rate of sugar maple (*Acer saccharum* Marsh.) located in New York, USA Northern hardwood stands. In the central Appalachian region, Smith et al. (1989) and Miller et al. (1997) reported preliminary mortality percentages 5 and 10 years, respectively, after deferment cuts. However, long-term survival data from the central Appalachian region has not been analyzed in depth.

Clearcutting continues to be a concern for the public today as it was forty years ago. The removal of forest as part of the mountaintop removal of coal is often included as a factor by opponents of the practice. Clearcuts in public viewsheds continue to prompt inquiries from concerned citizens (Boothe, 2017). Visual alternatives to clearcutting provide forest managers opportunities to positively influence public perceptions of forestry practices. With 35 years of repeated measures data now available, the viability of leaving these deferred overstory trees can be assessed. The objective of this study therefore is to examine several factors potentially affecting mortality of the overstory residual trees within the experimental deferment study on the FEF and MNF in order to provide guidance to forest managers seeking to implement deferment cutting as an alternative to clearcutting.

2. Methods

2.1. Site description

Study compartments were established as part of a long-term study of the individual tree deferment cutting practice. Study sites are located on the MNF and the FEF in north-central West Virginia within the Allegheny Mountains Section (M221B). Rainfall averages 1500 mm annually and is well distributed throughout the year. Soil parent material is primarily sandstone and shale with an occasional limestone contribution. Soils are medium-textured and well-drained with the average soil depth exceeding one meter (Miller and Schuler, 1995). The selected stands were unmanaged second-growth mixed hardwoods at the time of the initial deferment cutting, with ages between 75 and 80 years. Site indices span 18–24 m (northern red oak (*Quercus rubra* L.) base age 50) on all sites and compartment sizes ranged from 3 to 6 ha.

2.2. Experimental design

Six study sites (compartments) were established between 1980 and 1985. One of the original six compartments (Olson Tower-83) experienced a localized extreme weather event that skewed its mortality results, and thus, it was dropped from the study reducing the number of compartments to five. One compartment has a natural rhododendron division that splits the compartment into two subcompartments (Compartments 80A and 80B-Fish Trough). Due to this subdivision and because the two differed in aspect, each subcompartment was considered as an independent compartment in this analysis.

All trees with dbh greater than 2.54 cm were cut within each compartment at the time of study establishment except for approximately 30–35 deferment trees per hectare. The goal of this deferment cutting was a residual basal area of slightly less than 5 m^2/ha. Retention of basal area in each compartment ranged between 14 and 20% of preharvest levels after the deferments cuts, with mean dbh by compartment ranging from 20 to 45 cm. In nearly all cases, deferment trees were selected from the dominant and codominant crown classes. On five out of six compartments, deferment trees were chosen with timber management as an objective. Trees were selected based on quality of the butt log, lack of epicormic branching, and no evidence of decay (Smith et al., 1989) with consideration also given to keeping trees relatively evenly spaced—about 15–18 m apart. Species were chosen that were considered economically important. Compartment 84 (Lucy Draft) had deferment trees selected with a wildlife objective in mind—mast production. This resulted in favoring oak species. A secondary objective was to reduce the proportion of a significant white pine (*Pinus strobus* L.) component present in the stand, with the deferment trees serving as a seed source.

Compartments have been measured asynchronously at irregular intervals (1–10 years) with the latest compartment inventory conducted in 2016. Permanent regeneration and growth plots were established on the compartments for which results have been previously reported (Smith et al., 1989; Miller and Schuler, 1995; Thomas-Van Gundy and Schuler, 2008). All deferment trees were individually and permanently tagged. As this study focuses on deferment tree survival, deferment tree variables of interest include: crown class, dbh, logging damage, and species. A post-deferment harvest inventory was conducted and any logging damage to deferment trees was recorded. There were 985 deferment trees present in the initial inventory that preceded the deferment cut

2.3. Statistical analysis

Overstory survival was analyzed on an individual tree basis using a frailty model developed by McGilchrist (1993), which is an extension of the Cox Proportional Hazards (CPH) model (Cox, 1972). This frailty model incorporates a random subject-specific effect which in our case