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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 will be used to account for the clustering of trees within stands (compartments). CPH models the time to an event – here death through natural morality, which is coded as a 1. Survival time is measured as the time from the pre-deferment harvest inventory until death, the last periodic inventory for the compartment, or time of removal from the study, here cut or destroyed during the deferment harvest. Fifteen deferment trees across the six compartments were recorded as cut/destroyed during the deferment cutting operation, thus they did not experience the modeled event. The conditions of a tree surviving to the final inventory and being cut or destroyed in the deferment harvest are considered right censored events, which means the subject did not experience the event (natural mortality) during the study period or the subject left the study—tree was cut/destroyed during the harvest. These right censored observations are coded as a 0.

Frailty model for clustered data

$$\lambda(t;\mathbf{z}) = e^{\gamma_i} e^{\boldsymbol{\beta} \mathbf{z}_{ij}(t)} \lambda_0(t) \qquad (1)$$

where i is the compartment number, γ_i is the random component for the ith compartment, t is the tree survival time, $\boldsymbol{\beta}$ is a px1 vector of unknown parameters, $\mathbf{z}$ is a 1xp vector of covariates, j is the index for the observations in the ith cluster, and $\lambda_0(t)$ is the baseline hazard function, an unspecified but non-negative function. The term $e^{\gamma i}$ models the frailties, where each represents a cluster-specific effect on deferment tree survival attributable to the compartment.

The full model using compartment as the random component (Eq. (1)) included four independent variables: crown class, dbh (cm), logging damage, and species. All overstory trees in this study were either dominant or codominant trees. Five species, yellow-poplar (*Liriodendron tulipifera* L.), black cherry (*Prunus serotina* Ehrh.), white oak (*Quercus alba* L.), chestnut oak (*Quercus montana* Willd.), and northern red oak, had sufficient sample sizes to test for species differences (Fig. 1). Other species were grouped together into an “all other species” category. Logging damage was considered as a categorical (dichotomous) variable defined by presence/absence of post-harvest exposed sapwood. Backward elimination was used to remove non-significant model terms with $\alpha = 0.05$ as the significance level. Significance testing was performed using Proc PHREG (note PH stands for “Proportional Hazards”) in SAS® software Version 9.4 (SAS Institute Inc., 2012). Customized hazard ratios were obtained using the hazard ratio option of Proc PHREG.

3. Results

Survival rates were high, with 92% of trees surviving to the most recent periodic inventory (Fig. 2). Six percent of the deferment trees experienced natural mortality and less than two percent were cut or destroyed (and thus censored) during logging. While 33% of the trees had logging damage i.e. exposed sapwood, trees injured in the deferment harvest did not show increased risk of mortality. Crown class and species did not affect overall survival. DBH was the only significant factor in the survival model (Table 1) with larger trees having increased probability of survival. A customized hazard ratio for a 5 cm increase in dbh was calculated with 95% confidence limits – a dbh increase of 5 cm reduced the hazard of dying by 20–40%.

There was a significant cluster-specific effect, i.e. differing frailties among compartments. However, only the Lucy Draft-84 compartment had a significant frailty confidence interval. Frailty confidence intervals for the other compartments included the value of one and thus were not significant (Table 2).

4. Discussion

A limited number of studies exist for mortality of residual trees in deferment cuts, even when considering the alternative nomenclature of clearcutting with reserves, shelterwood with reserves, and variable retention harvesting. There is also some overlap of factors examined in this study and other assessments of mortality of retention trees. Bladon et al. (2008) included crown class as a potential factor influencing mortality five years after a variable retention harvest with 10% dispersed retention (TPH), which is slightly lower than that of this study. They found that crown class was a significant factor in mortality for three species: trembling aspen (*Populus baslamifera* L.), paper birch (*Betula papyrifera* Marsh.), and white spruce (*Picea glauca* Moench). There was no pattern in differences in mortality rates between crown classes that was consistent for the three species related to change in crown class, meaning the results were species dependent.

Our deferment cutting prescription most closely resembles the 15% dispersed retention treatment (15%D) in the DEMO study conducted in Douglas-Fir forests in Oregon and Washington, USA (Maguire et al., 2006; Urgenson et al., 2013). In coniferous forests of the the Pacific Northwest, USA Urgenson et al. (2013) found the highest rate of mortality was for intermediate stems in the 15%D treatment approximately 11.5 years after harvest. Our analysis did not find an effect due to crown class, likely due to the selection criteria for deferment trees.

The majority of deferment trees selected in this study were in the codominant and dominant crown classes. Only seven trees transitioned to the intermediate class during the study period and all of those were initially dominant and codominant. Individual spacing of deferment trees was given consideration when selecting leave trees with spacing on the order of 15–18 m. Each tree dominated its surrounding growing space for some time after the deferment cut with effects to the height and species composition of the regenerating stands seen 20 years post-harvest (Miller et al., 2004). It was more than a decade before any deferment tree was crowded to the point of classification as an intermediate tree, and this only happened to only seven trees, less than one percent of the total number. There are some steeper slopes on some sites where in-growth on the uphill side may have led to this situation. Given the 75–80 year competitive advantage of the deferment trees, the minor disadvantage of being a codominant vs. dominant tree played no role in

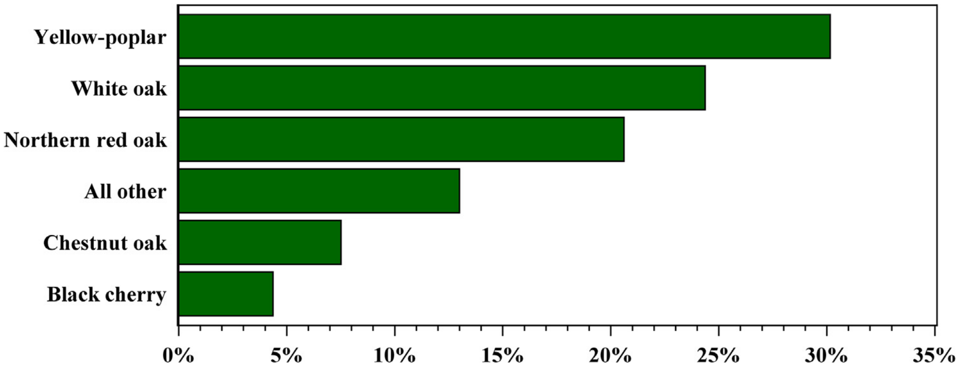

Fig. 1. Overall species composition of the overstory immediately post-cutting across all stands in order of percent occurrence at the start of the study (n = 985 trees).

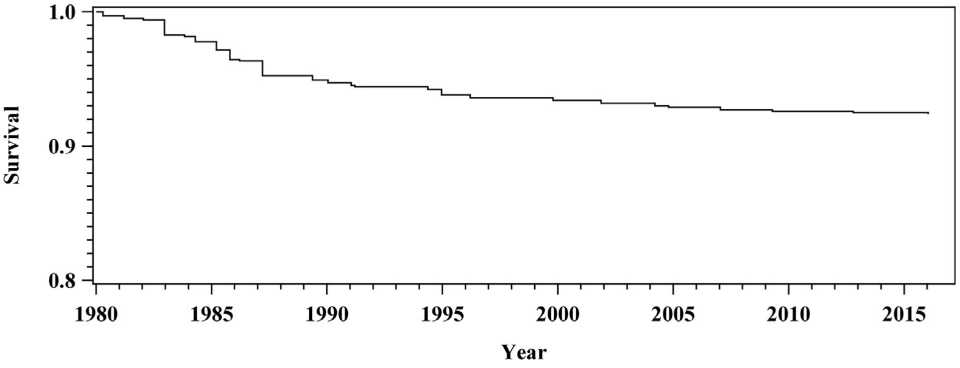

Fig. 2. Proportion of deferment trees surviving.

Table 1
Significance tests for overstory tree factors affecting survival.

Effect	df	Wald χ^2	p-Value
Crown class	1	0.36	0.3529
DBH	1	22.38	< 0.0001
Logging damage	1	0.01	0.9079
Species	4	6.48	0.0996
Compartment	–	20.23	0.0006

Table 2
Examination of cluster-specific effect of compartment on the deferment tree survival. Significance is indicated where the confidence interval for exp(γ_i) (the frailty) does not contain 1, or alternatively, where the confidence interval for γ_i contains 0.

		95% Confidence limit $\hat{\gamma}_i$			95% Confidence limit exp($\hat{\gamma}_i$)	
Compartment	$\hat{\gamma}_i$	Lower	Upper	exp($\hat{\gamma}_i$)	Lower	Upper
Fish Trough-80A	−0.31	−1.32	0.70	0.74	0.27	2.02
Fish Trough-80B	0.51	−0.27	1.29	1.66	0.76	3.62
Riffle Creek-81	0.05	−0.70	0.80	1.05	0.50	2.22
Shavers Fork-82	0.42	−0.31	1.15	1.52	0.73	3.17
Lucy Draught-84	−1.99	−3.16	−0.81	0.14	0.04	0.44
Red House-85	−0.12	−0.94	0.70	0.89	0.39	2.02

survival. This could change if at some point the second cohort was able to overtop the first but that is highly unlikely as stand conditions after deferment cut favored shade intolerant species. At age 20 and 25, the second age class in four of the sites assessed here were found to be mainly pole-sized yellow poplar, with northern red oak sharing dominance with yellow-poplar on the Riffle Creek site (Thomas-Van Gundy and Schuler, 2008).

Bladon et al. (2008) found a difference in mortality rates for paper birch, trembling aspen, balsam poplar (*Populus balsamifera Michx.*), and white spruce after a structural retention harvest of boreal mixedwoods in Alberta, CA. The species differences found sometimes interacted with other factors, such as crown class. In central Maine, Carter et al. (2006) found a difference in mortality attributable to species. Northern white cedar (*Thuja occidentalis* L.) had the greatest mortality (19% and eastern hemlock (*Tsuga canadensis* L.) the lowest (2.1%) over the 20-year period among species considered for analysis (scarce species ($n < 50$) were excluded). In our study, consideration of species' lifespan led to speculation that some species selected might experience greater rates of mortality. With initial stand age approximately 75–80 years and given the length of time since study establishment, the first cohort's age is at least 110 years. Of the species examined, black cherry has the shortest average lifespan at 100 years with diameter growth slowing after 80–100 years of age (Burns and Honkala, 1990). The average lifespan of black cherry is exceeded by northern red oak, 200 years; yellow-poplar, 250 years; and both white and chestnut oak, 300 years (Loehle, 1988). However, there were no significant species differences in mortality – black cherry deferment trees survived as well as the other species.

Logging damage was also a concern at the time of study initiation. Logging damage was carefully tracked with both presence and size of damage measured post-harvest and in subsequent inventories. However, mortality was unaffected by the presence of logging wounds. Urgenson et al. (2013) also reported no significant effect due to felling or yarding for dispersed treatments in the DEMO study. Only white spruce experienced a significant increase in mortality due to logging damage in the Bladon et al. (2008) study conducted in Alberta, CA. On the FEF and MNF, Smith et al. (1994) reported that small logging wounds (approximately 325 cm^2 or less) would close in 5–10 years. They estimated that larger wounds, (325–1300 cm^2) would close in 15–20 years after logging. As mentioned, fifteen trees in this study were destroyed in the deferment harvest, so logging appears to present an immediate mortality risk but no significant long-term effect as the trees in the region appear capable of encapsulating logging wounds without an observable increase in mortality.

DBH was considered as a possible mortality factor by Bladon et al. (2008) but only reported as significant in regard to their slenderness coefficient (height/dbh), and only for understory paper birch and co-dominant and understory balsam poplar. For each species, increasing slenderness increased mortality, so for a given height, an increase in dbh would decrease the slenderness coefficient, therefore resulting in lower mortality. Increasing dbh in sugar maple reduced mortality in single-tree selection plots in NY as did decreasing residual density (Kiernan et al., 2012). Saud et al. (2016) reported a protective effect for dbh (increasing dbh reduces mortality) when examining shortleaf pine (Pinus echinata Mill.) mortality over a 25 year period. In this study, DBH is the only factor significantly related to mortality with increasing diameter associated with higher levels of tree survival. Mortality agent was not recorded over time in this study but larger trees tend to be more windfirm and are more competitive for resources in general prior to senescence.

5. Conclusions

The low rate of mortality in this study demonstrates that overstory trees in a deferment cutting can be acceptably maintained midway through the next rotation and likely until the next regeneration harvest. The two-age structure of these stands provides an improvement visually over time versus a clearcut, particularly in later decades where very large and older trees are scattered throughout the stand. This addresses the visual concerns expressed by the public. Forest managers are free to choose any of the studied species, which is helpful in regard to desired objectives and spacing considerations. The lack of significance in regard to mortality by species provides forest managers the opportunity to maintain species diversity in the overstory, with size being the sole factor of importance out of those considered. Changes in quality due to logging damage were unexplored in this study, but concerns about increased mortality over time due to logging injury are not supported. With mortality being so low, concerns expressed about the viability of deferment cutting can be put to rest and forest managers can be confident that the practice can be implemented successfully in the Appalachian region.

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