

Article

Tree Girdling for Potential Bat Roost Creation in Northwestern West Virginia

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Abstract: Cavity/crevice tree-roosting bats in North America face an uncertain future with many factors impacting their populations. To benefit crevice/cavity roosting bat species, forests are often enhanced with the use of tree girdling. In October 2015, 20 maples, 22 oaks, and 18 hickories were girdled using a method with fell cut and herbicide (frilling) or double-girdling with a chainsaw. From 2016–2021, targeted trees were observed and the tree's decay state was collected. The average time for trees to display suitable roosting characteristics for frilling trees was 3.23 years while it was 4.46 years for double girdling. The average time frilling trees contained suitable roosting characteristics was 3.20 years while it was 1.63 years for double girdling. The frilling method resulted in a quicker kill of trees than double girdling and frilling trees had suitable roosting characteristics for a longer duration. Frilling was effective killing all three types of trees, while the double girdling was less effective, especially on oaks. When grouping species and treatment in analysis, only average decay states between maple frill and oak double girdling and hickory frill and oak double girdling were significantly different. This evaluation demonstrates that roost tree creation relating to tree species and girdling methodology has a temporal component that should be considered when managing for crevice/cavity bat roosts and multiple habitat creation methods should be used in conjunction with snag creation to provide sustainable bat habitat over longer time periods.

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1. Introduction

Crevice/cavity roosting bats rely on trees for roosting, either under loose bark or within cavities [1–7]. Many tree-roosting bats in eastern North America (including the Indiana (*Myotis sodalis* Miller and Allen) and northern long-eared bat (*Myotis septentrionalis* Trouessart) only use caves during hibernation (approximately October–April) with the rest of the year being spent in forests. These same bat species rely on crevice/cavity tree roosts to rear their young during the summer. The maternity roosts provide a thermal advantage to allow their young to grow at faster rates [8] which gives them advantages such as reduced competition and early access to foraging resources. Roosts also provide other advantages such as protection from adverse weather conditions and predators [7].

Although Indiana bats and northern long-eared bats are both cavity/crevice roosters, they differ somewhat in their roost use and selection. Indiana bats prefer roosting underneath exfoliating bark while northern long-eared bats prefer cavities [9,10]. Indiana bats prefer roosts that are larger in diameter and taller than the surrounding stand with greater solar exposure [9,11,12]. Northern bats prefer more heavily shaded roosts in interior forest [13].

Most crevice/cavity roosting bats rely on trees that have progressed to a snag [2,5,6] for desirable roost characteristics to form with live hickory species being an exception

[2,7,14]. Once a tree has died, the tree may start to have its bark fall off and/or the tree may start to decay and produce cavities as roosting opportunities. Only a select subset of trees in a particular forest contain these desirable characteristics for bat roosts and these resources are ephemeral [15]. At times, a forest may fall below the desired “optimal” roost density of 14 roosts/acre [16]. Snag creation can aid in keeping desired roost densities.

Snag creation methodology began in the 1970s [17] and was tested mostly in the northwestern United States (Oregon, Washington, Idaho, Montana) with a few studies in the Midwest and Southeast (Michigan, Wisconsin, Florida, Texas, Kentucky) [17–28]. Various snag creation techniques have been used including: girdling [19,20,25], fungal inoculation [25,29,30], explosives [25,29], and saw topping [25,31,32].

Girdling is an effective snag creation method. It can create a dead tree having an intact top (in comparison to saw-topping) [17]. Girdling can be used in tandem with other techniques (fungal inoculation and limbing). The safest and most cost effective snag-creation method is girdling [17].

A major gap in snag creation research, especially girdling, concerning cavity/crevice roosting bats is how quickly these targeted trees develop desirable roost characteristics (sloughing bark, cavities) and how long they retain these desirable bat roost characteristics. Very little published research exists on snag creation in West Virginia or in the Northeastern United States in general. Gathering additional data on tree decay states over many years on trees targeted for snag creation would help inform land managers on proper treatment options to aid cavity/crevice tree roosting bat populations in the Northeastern United States.

As populations of cavity/crevice tree roosting bat species in North America continue to decline due to disease and habitat destruction, forest managers and natural resource agencies will be considering these bats in development and management plans moving forward [1]. Decision making entities will need bat conservation measures at their disposal in order to balance economic and wildlife resources. Therefore, documenting and studying potential bat conservation measures should be a priority as information regarding longevity and effectiveness is lacking [7]. Using roost tree decay state data collected at an established bat conservation site in West Virginia, we assessed the effectiveness of two tree girdling methods on three different genera of trees. Our study objectives were: (1) To determine the temporal loss associated with tree girdling methodologies as they relate to replacing bat cavity/crevice roosts; (2) to determine the length of time the girdled trees display desirable cavity/crevice roosting characteristics; and (3) to identify how tree species and treatment methods affect potential roost tree creation.

2. Materials and Methods

2.1. Study Site

The North Fork Hughes River (NFHR) Bat Conservation Site is a 23.6 hectares (20.0 hectares forested) property on a predominately west facing hillside located in Ritchie County, West Virginia (Figure 1). The bats in the state have been hit hard with White Nose Syndrome with dramatic declines in little brown (*Myotis lucifugus* Le Conte), Indiana, northern long-eared, and tri-colored bats (*Perimyotis subflavus* Cuvier) and the area provides much needed permanent habitat for the species [33]. The site along with the adjoining acreage is mostly forested with hay fields present in large bottomlands adjacent to the property. NFHR and a perennial tributary Goose Run runs within and adjacent to the property that places it upon a connecting corridor to other landscape features. The site is composed of moderately xeric, deciduous forest (*Quercus* spp. Linnaeus, *Carya* spp. Nutt., *Pinus* spp. Linnaeus, and *Liriodendron tulipifera* Linnaeus) with elevations ranging from 220–299 m. Bottomlands contained boxelder (*Acer negundo* Linnaeus) and American sycamore (*Platanus occidentalis* Linnaeus). NFHR is of moderate slope with approximately 60% of the site’s hillsides ranging from 0–35°. Resident bats species include: northern long-eared bat, silver-haired bat (*Lasionycteris noctivagans* Le Conte), Indiana bat, little brown

bat, big brown bat (*Eptesicus fuscus* Palisot de Beauvois), eastern red bat (*Lasiurus borealis* Müller), eastern small-footed bat (*Myotis leibii* Audubon and Bachman), hoary bat (*Lasiurus cinereus* Palisot de Beauvois), and tricolored bat. The study area on average receives 113.7 cm of rain and averages 11°C Celsius (C) [34].

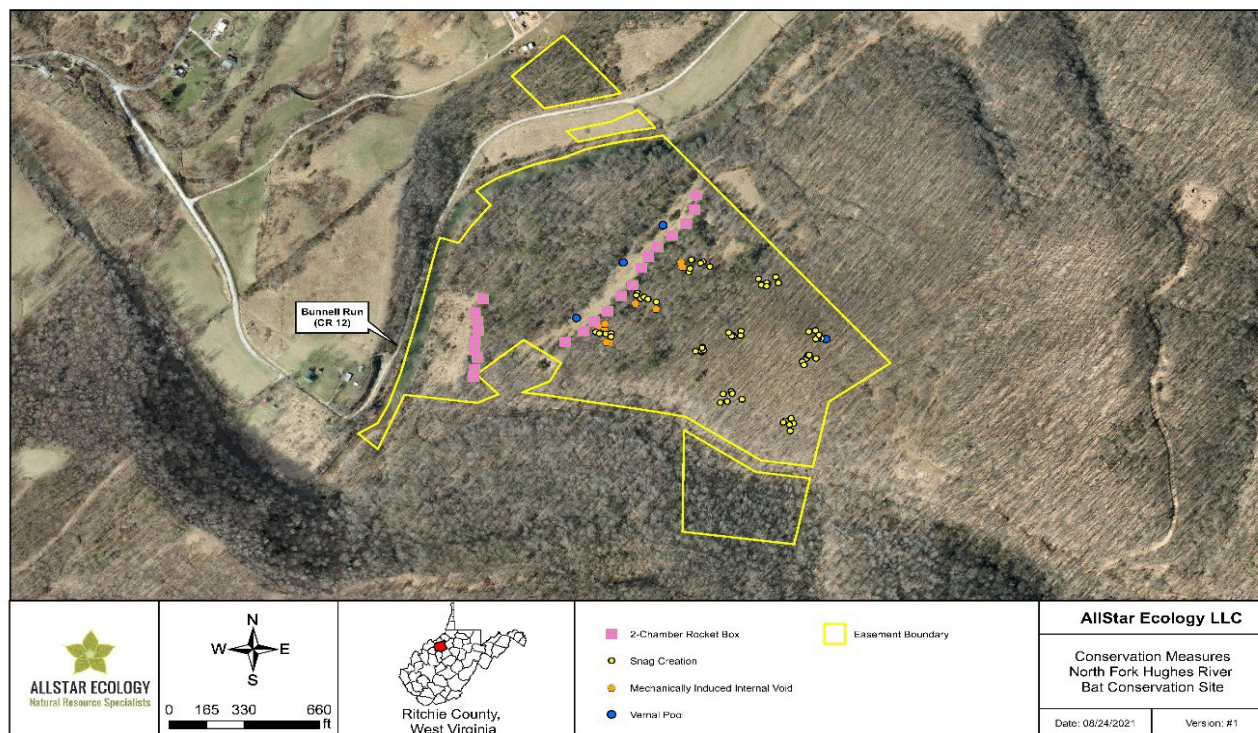


Figure 1. A view of North Fork Hughes River Bat Conservation Site.

2.2. Tree Girdling

Trees selected for girdling were based on two factors: (1) species and (2) diameter at breast height (DBH). Targeted trees were ≥ 20.32 cm DBH [35]. Black oak (*Quercus velutina* Lam.), red oak (*Quercus rubra* Linnaeus), white oak (*Quercus alba* Linnaeus), chestnut oak (*Quercus prinus* Willd.), pignut hickory (*Carya glabra* Mill.), mockernut hickory (*Carya tomentosa* Lam. Ex Prior.), shagbark hickory (*Carya ovata* Mill.), and red maple (*Acer rubrum* Linnaeus) trees were species chosen to be girdled. Ten groups of six trees (sixty trees total) were selected for girdling (Table 1). Half of the trees of each genus chosen were randomly selected for one of two girdling treatments: frilling or double chainsaw (Figure 2).

2.2.1. Frilling

This girdling technique involves applying herbicide after a single line of hatchet cuts has been made around the trunk of the tree [36,37] (Figure 2). A 50:50 mix of 41% glyphosate was used as the herbicide.

2.2.2. Double Chainsaw Girdling

To create a snag using double chainsaw (DC) girdling, one uses a chainsaw to cut parallel, horizontal grooves through the bark several inches apart [37] (Figure 2).



Figure 2. A view of tree girdling techniques after application: (a) Frilling (b) DC.

Table 1. Treatment types and tree species.

Genus/Treatment Type	Number of Trees
Maple DC	10
Maple Frill	10
Hickory DC	9
Hickory Frill	9
Oak DC	11
Oak Frill	11

After treatment in October 2015, we visited trees once in fall of the following years (2016–2021) and we categorized trees into a roost decay state [35] that ranged from 1–9 (Figure 3).

2.3. Decay States

Trees were considered to have roosting potential if they contained cavities or sloughing bark (roost decay states 4–6). The United States Fish and Wildlife Service’s Indiana Bat Survey Guidelines contains roost decay states and are utilized for classifying Indiana bat roost trees that are found via radio telemetry and for identifying potential Indiana bat habitat [35].

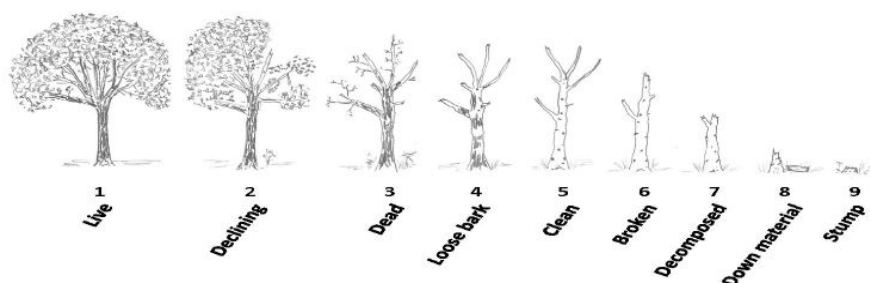


Figure 3. Roost decay states and their corresponding numbers and representative condition [35].

2.4. Data Analysis

Trees were categorized into their respective genus in data analysis due to sample size. Categories in data analysis included: maples treated via DC, maples treated via frilling, hickories treated via DC, hickories treated via frilling, oaks treated via DC, and oaks

treated via frilling. We assessed differences between years, species, and treatments relating to decay states with Kruskal–Wallis test and then followed with a post-hoc Games–Howell test for evaluation of treatments and species groups. Descriptive statistics were run on decay state. Statistical significance was accepted at $\alpha = 0.05$.

3. Results

Decay states declined during the years ($H = 183.993$, d.f. = 5, p value < 0.001; Table 2; Table S1). Mean decay states started at 2.5 in 2016 and ended at 5.9 in 2021. No trees reached the sloughing bark state (4) until 2017 with a maximum number of trees (42) reaching this state in 2019.

Decay states differed between treatments from 2016–2021 ($H = 17.457$, d.f. = 1, p value < 0.001). The mean decay state of double chainsaw trees was 3.71 compared to frilled trees with a mean decay state of 4.01. All frilled trees were in at least the declining state by 2017 while some double chainsaw trees were still in the live stage.

Between the six groups of treatments/species from 2016–2021, decay states differed ($H = 19.738$, d.f. = 5, p value = 0.001). However, only average decay state between two treatments/genera groups (1-maple frill and oak DC 2-hickory frill and oak DC) had close to one average decay stage of difference (Tables 3 and 4). These were only treatments/species groups (1. maple frill and oak DC 2. hickory frill and oak DC) that had significant differences in average decay stages.

Tree species decay states varied between treatments within maples and oaks (maple: $H = 5.624$, d.f. = 1, p value = 0.018; oak: $H = 9.643$, d.f. = 1, p = 0.002). There was no significant difference in treatment types and roost decay state in hickories (hickory: $H = 2.264$, d.f. = 1, p value = 0.132). Across all species, decay state was greater in frilled trees than DC trees from 2016–2019. However, in 2020–2021 DC treatment trees exceeded frilled trees in average decay state (Figure 4).

The average length of time both treatments contained suitable bat roost characteristics (sloughing bark, cavities, decay state 4–6) was 3.2 years for frilling and 1.63 years for DC.

Table 2. Percent kill* of each treatment/species group.

Treatments	*2016	*2017	*2018	*2019	*2020	*2021
Maple DC	0%	0%	0%	63%	100%	100%
Maple Frill	80%	90%	90%	90%	100%	100%
Hickory DC	11%	56%	67%	89%	100%	100%
Hickory Frill	89%	89%	100%	100%	100%	100%
Oak DC	27%	45%	91%	91%	91%	91%
Oak Frill	91%	91%	100%	100%	100%	100%

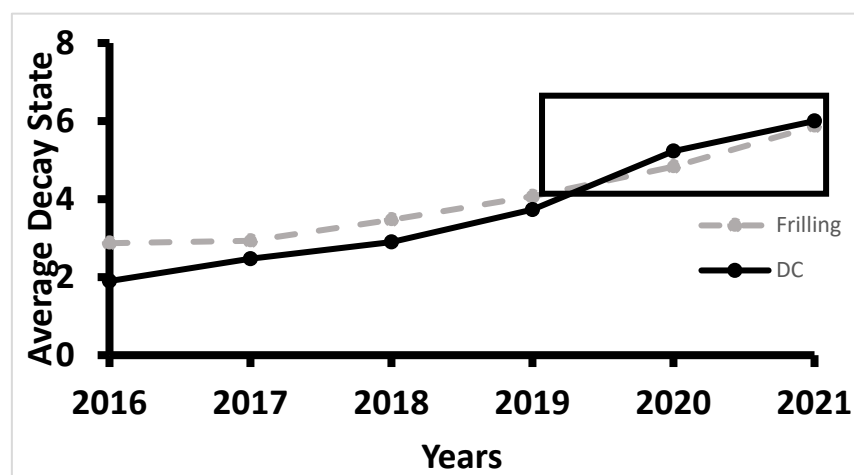
* kill is indicated by decay state 3 or greater.

Table 3. Games Howell Test output on species/treatment.

Group 1	Group 2	Mean	Standard Error	q-Stat	df	q-Crit	Lower	Upper	p-Value	Mean-Crit
Maple frill	Oak frill	0.55	0.18	3.09	84.3	4.12	−0.18	1.27	0.25	0.73
Maple frill	Hickory frill	0.02	0.23	0.09	111.5	4.10	−0.91	0.95	1	0.93
Maple frill	Maple DC	0.11	0.29	0.39	101.11	4.10	−1.09	1.32	0.99	1.21
Maple frill	Oak DC	0.94	0.20	4.72	111.10	4.10	0.12	1.75	0.01	0.81
Maple frill	Hickory DC	0.37	0.28	1.29	95.83	4.11	−0.79	1.52	0.94	1.16
Oak frill	Hickory frill	0.57	0.18	3.20	75.78	4.13	−0.16	1.30	0.22	0.73
Oak frill	Maple DC	0.43	0.26	1.67	69.99	4.14	−0.63	1.50	0.84	1.07
Oak frill	Oak DC	0.39	0.14	2.80	110.32	4.10	−0.18	0.97	0.35	0.57
Oak frill	Hickory DC	0.18	0.24	0.74	64.20	4.15	−0.83	1.19	0.99	1.01
Hickory frill	Maple DC	0.14	0.30	0.47	99.87	4.10	−1.07	1.35	0.99	1.21
Hickory frill	Oak DC	0.96	0.20	4.81	101.48	4.10	0.14	1.78	0.01	0.82
Hickory frill	Hickory DC	0.39	0.28	1.37	94.49	4.11	−0.77	1.55	0.92	1.16
Maple DC	Oak DC	0.83	0.27	3.01	85.18	4.12	−0.30	1.95	0.28	1.13
Maple DC	Hickory DC	0.25	0.34	0.73	111.99	4.10	−1.14	1.64	0.99	1.39
Oak DC	Hickory DC	0.58	0.26	2.20	79.75	4.12	−0.50	1.65	0.62	1.07

Table 4. Descriptive statistics per treatment/genera from 2016–2021.

Group	Mean	Size	Variance
Maple Frill	4.20	60	3.08
Oak Frill	3.65	66	0.75
Hickory Frill	4.22	54	2.82
Maple DC	4.08	60	7.33
Oak DC	3.26	66	1.86
Hickory DC	3.83	54	5.84

**Figure 4.** Average decay state of both treatment types over time. The rectangle encompasses the time period where trees are in a decay state that could produce potential bat roosts.

4. Discussion

Based on our results, frilled trees decayed at a faster rate initially than DC trees (Table 2). This is in agreement with previous studies on snag decay methods [25,26,38]. Most frilled trees died within the first year after treatment while it took some DC trees almost five years to reach the same decay state. However, the mean decay state in DC trees in 2020–2021 exceeded that of frilled trees due mostly to these trees falling over and rapidly increasing their decay state.

When data collection took place in October 2021, 43% of the trees had already fallen or had significant pieces fall off (decay states 7–9) and desirable roosting characteristics only lasted on average 1.63–3.2 years between both treatments. This is in contrast to a study on Douglas-fir snags that can remain standing for ≥ 25 years [18]. It appears these species of hardwoods in West Virginia do not remain standing long once killed and are much more ephemeral in nature than Douglas-fir snags. Perhaps selection of larger diameter trees would help the longevity of the snag [27]. Snag retention was similar to a study done in California conifers where most snags fell after 8 years [39]. Based on our current average decay state over time for experimental trees, forest managers in the Northeastern United States may need to continue supplementation of forests with newly created snags to keep roost trees at appropriate availability levels.

It took approximately four years after treatment for most trees to become potential bat roosts (decay states 4–6, sloughing bark, cavities). This should be considered by forest managers and agency regulators especially if trees are being girdled as a conservation measure for bats to offset tree clearing activities are needed immediately. Artificial roosts can serve as immediate replacements for lost natural roosts and have been proven to be an effective conservation tool and can be used as a temporal stop-gap until girdled trees become suitable habitat [40–45]. However, care needs to be taken in order for the artificial roosts to be appropriately chosen and deployed [46].

Oaks were the most resilient species when girdled (Average Decay State: Oak = 4.5; Maple = 6.55; Hickory = 7). Other studies [22,47] found decay states over time were species specific. Oaks took the longest to progress through decay stages. This should be considered by forest managers in the region as oaks are a common tree species. A mixture of faster decaying tree species (*Acer* spp.) and slower decaying trees species (*Quercus* spp.) will help cover a larger temporal space where roosts will be available.

Our study is in line with previous research that cites 84% [22] of girdled trees within 4.5 years in Wisconsin died and 31 out of 75 snags (43%) being downed after 4 years in Texas [48]. Our study found 97% of DC trees to die within 5 years (in line with the Wisconsin study) and 33% of total treated trees to be down within 5 years (similar to the Texas study). Both Wisconsin and Texas studies used similar DBH selection criteria as ours (≥ 25.4 cm).

Knowing that DC treated trees took longer to decay and that oaks were the slowest to decay can help increase snag retention in oak-maple-hickory dominated forests which can be found in the Northeast and Midwest United States.

All treated trees produced desirable bat roost tree characteristics such as sloughing bark and/or cavities which are necessary for eastern United States cavity/crevice tree roosting bats (such as the Indiana and northern long-eared bat) during the summer reproductive period [1,2,6,7,11,13–16,49]. These girdling methods can be used across the range of any cavity/crevice tree roosting bats to increase roosting availability. Using these techniques can help provide much needed roosting habitat for cavity/crevice tree roosting species as development continues to decrease available forested habitat.

5. Conclusions

When creating snags as potential bat roosts, it would be advisable for land managers to use both girdling treatments and various tree species as it will leave more snags on the

landscape for a longer period of time. It appears snags will need to be replenished in deciduous Northeastern United States forests approximately every eight years, as it takes on average four years for native trees to display desirable roosting characteristics for cavity/crevice roosting bats, and then they only last in this state for 1–4 years.

Supplementary Materials: The following are available online at www.mdpi.com/article/10.3390/f13020274/s1, Table S1: NFHR PRT Creation Evaluation Results_20211122_ForSubmission.xlsx.

Author Contributions: E.S.S. drafted the first version of the manuscript. R.L.W. conceptualized the study and created the methodology; data analysis, E.S.S.; data collection, R.L.W. and E.S.S.; writing—review and editing, E.S.S. and R.L.W.; supervision, R.L.W.; project administration, R.L.W. All authors have read and agreed to the published version of the manuscript.

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