Research Article

Protecting Red-Cockaded Woodpecker Cavity Trees Predisposed to Fire-Induced Mortality

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Abstract

*Reducing fire-induced mortality of cavity trees used by red-cockaded woodpeckers (*Picoides borealis*) is a challenge and concern in managing this federally endangered species. Prior to the 2001 burning season, 814 active and inactive longleaf pine (*Pinus palustris*) cavity trees on Eglin Air Force Base (AFB) in northwest Florida, USA, were prepared via 6 protection methods (combinations of mechanical, hand, and backfiring preparation) and monitored for postburn survival after 1 year. We collected data on a suite of variables that may be useful in determining cavity tree predisposition to fire-induced mortality. Mortality of protected trees (2.62%) was significantly lower than that of unprotected trees (6.18%), and protection methods did not differ in their effectiveness at preventing mortality. Bark char was significantly more prevalent on unprepared control trees than protected trees, but no differences were apparent among protection treatments. Mechanical clearing alone took the least amount of time and resources; therefore, we determined mechanical clearing to be the most efficient preparation method. Stem char, needle scorch, percent sap cover, and whether the cavity burned were the characteristics most closely related to mortality 1 year postfire. We recommend that the percent of the bole covered in sap and cavity height be considered when preparing to reduce stem char, needle scorch, and the incidence of burned-out cavities. Managers of red-cockaded woodpecker populations can use these results and recommendations to adjust their burn program, improve the efficiency of their cavity tree protection methods, and better target cavity provisioning for maintaining a viable pool of cavity trees.* (JOURNAL OF WILDLIFE MANAGEMENT 70(3):702–707; 2006)

Key words

bark char, cavity tree, fire, longleaf pine, mortality, needle scorch, preparation, prescribed burning, protection, red-cockaded woodpecker.

Eglin AFB is currently the largest single location of longleaf pine, contains 70% of the remaining old-growth longleaf pine acreage (3,642 ha), and harbors the fourth-largest population of red-cockaded woodpeckers in the world (Varner and Kush 2001, U.S. Fish and Wildlife Service 2003). The concurrent decline of the red-cockaded woodpecker (RCW) and the once-extensive longleaf pine ecosystem is well-documented (U.S. Fish and Wildlife Service 2003) and resulted in its listing as a federally endangered species in 1970 (35 Federal Register 16047, 13 Oct 1970). Red-cockaded woodpeckers require older living pines—often with decayed heartwood—for excavating nest and roost cavities (Jackson 1977, Rudolph and Conner 1991), and a shortage of potential cavity trees is severely limiting current growth of RCW populations and overall species recovery (Costa and Escano 1989). The construction of drilled artificial cavities, inserts, and starts has been successful in short-term population expansion, but these methods should not completely replace efforts to restore and conserve potential natural-cavity trees.

Frequent fires (every 2–3 years) are vital in controlling hardwood encroachment and stimulating understory vegetation and arthropod communities that characterize optimal RCW foraging habitat (Conner and Rudolph 1991, Hardesty et al. 1997, Walters et al. 2000, Provencher et al. 2001, U.S. Fish and Wildlife Service 2003). Prescribed fire, as a tool in restoring longleaf ecosystems and recovering RCW populations, must be implemented in a manner that provides for the maintenance of suitable habitat without compromising the continued survival of active and potential cavity trees. Red-cockaded woodpecker cavity trees are especially susceptible to fire because cavity trees produce profuse amounts of resin that cover the bole (Conner et al. 1991, 1998), and generally accepted guidelines suggest protecting these trees to a minimum of 3 m from the bole prior to prescribed fire application in RCW clusters (Conner and Locke 1979, U.S. Fish and Wildlife Service 2003).

In the past decade, construction of artificial cavities and translocation have been largely successful in expanding the population on Eglin AFB, but approximately 28% (1,723) of all natural cavity trees (6,226) surveyed since 1995 are confirmed dead. Direct mortality from fire has claimed 26% of these trees, 56% were lost to hurricanes, and an additional 15% died from unknown causes most likely related to delayed postfire-related stresses such as beetles and other pathogens. The Natural Resources Branch at Eglin AFB, Jackson Guard, has had an active fire management program for more than 15 years. Approximately 900 RCW cavity trees, within planned burn areas, are annually prepared prior to prescribed burning via a combination of mowing, raking, backfiring, and light bark scraping depending on the fire risk potential of each individual tree. In addition, an RCW biologist is present on every burn to check protection treatments before and monitor cavity trees during the burn. The loss of RCW cavity trees to fire coupled with the enormous amounts of staff resources and time consumed by

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cavity tree protection to mitigate this loss created a need to assess both the efforts required and effectiveness of various fire-protection methods in reducing RCW cavity tree mortality.

Our objectives included 1) documenting the rates and causes of cavity tree mortality for the 2001 fire season on Eglin AFB, 2) identifying key preburn fire risk and postburn fire effects variables that can aid managers in identifying cavity trees predisposed to mortality from fire, and 3) assessing the effectiveness and efficiency of several fire protection methods in reducing cavity tree mortality after 1 season.

Study Area

In 2001, Eglin AFB occupied approximately 187,774 ha (464,000 acres) within the Eastern Gulf Coastal Plain in northwest Florida, USA. The climate was humid, subtropical, and characterized by warm, humid summers (average maximum temperature was 32.3°C [90°F]) and mild winters (average minimum temperature was 5.6°C [42°F]). Annual rainfall averaged approximately 152 cm, predominantly in the summer and late winter/early spring (U.S. Air Force 2002). Deep, well-drained, fine sandy soils of the Lakeland association were the most common soil type occurring across approximately 78% of the base. The most extensive natural community type found on Eglin AFB was the sandhills matrix that was characterized, when fire-maintained, by a canopy of longleaf pine, an open midstory of oaks and other hardwoods, and a diverse understory of grasses, forbs, and smaller shrubs. Where fire has been excluded for more than 5 years, encroachment by Choctawhatchee sand pine (*Pinus clausa* var. *immuginata*) and/or a variety of oak species has begun to alter the historically open, savannah-like structure of these communities.

Methods

Preburn

Prior to the 2001 burning season (Jan–Jun), we collected data for 27 variables related to cavity tree characteristics, surrounding vegetation structure and potential fire-risk (sap flow, catface scars, etc.) from 616 red-cockaded woodpecker cavity trees within 38 planned burn areas. We included cavity trees with active, inactive, enlarged/long-inactive, and artificial cavities. Within these burn areas, we subjected 800 cavity trees to one of six cavity tree protection preparation treatments: 1) clearing with hand tools and light raking, 2) mechanical clearing only (performed with a DR® mower), 3) mechanical clearing and light raking, 4) mechanical clearing and raking to mineral soil, 5) burning out from the tree base prior to the actual burn, and 6) control (no treatment). We defined light raking as removal of all vegetation and the litter layer with fire rakes while leaving the organic duff layer intact. Deep raking removed all vegetation, litter, and the duff layer down to mineral soil. Protection treatments were applied to drip-line distance, or an average of 3 m, from the base of each tree as was generally recommended (U.S. Fish and Wildlife Service 2003). We assigned treatments randomly to all cavity trees; however, due to recommendations by the U.S. Fish and Wildlife Service, active trees received only treatments 1, 3, and 5, and treatment 2 was assigned only to trees with enlarged long-inactive cavities. Additionally, we collected data on the effort required (no. people × minutes /cavity tree) for a crew of 2–5 workers to prepare each of a random sample of 411 trees for comparison among preparation treatments. Because wildfires are unplanned events, we did not collect preburn data on cavity trees, or their environs, prior to wildfire passing through these areas.

Postburn

During spring and summer 2002, we collected data on the temperature of fire reaching the bole (as measured by Omega® 5 dot, nonreversible temperature labels placed 2 m from the base of the tree on the leeward side of the bole), fuel consumption, fresh bark char, needle scorch, re-leafing, and first year postburn mortality for 1,030 cavity trees, 814 of which fell in areas burned under prescription, and 216 of which were subjected to wildfire. Of these 1,030 cavity trees, 370 were active, 359 possessed an enlarged long-inactive cavity, 227 were currently inactive, and 74 had artificial cavities.

Data Analysis

Traditional hypothesis testing did not seem appropriate in analysis of cavity tree characteristic and mortality data. Instead, we performed an exploratory hypothesis generation approach, through a variety of analyses, in an attempt to identify mortality correlates in the data. The intent of this data-mining technique was to form a better understanding of what factors were contributing to fire-induced cavity tree mortality by exploiting as much of the data as possible, and to then identify the most efficient protection methods to mitigate potential mortality.

We initially analyzed preburn and postburn data according to four subgroupings of all cavity trees measured: 1) all trees, 2) trees only within prescribed burn areas (prepped and control), 3) wildfire trees only, and 4) prepped trees only. The patterns of missing data differed greatly among these subgroupings and among the various variables measured, thus, we constructed several analyses to use as much of the data as possible when examining variables. Recognizing that only selected treatments were applied to active cavity trees, we constructed contingency tables to test for differences in mortality for untreated (control) cavity trees among the current status classes (active, inactive, enlarged, artificial) of trees that experienced both prescribed fire and wildfire as well as those subjected to wildfire alone.

We used univariate permutation *t*-tests (PROC MULTTEST of the SAS system) to compare the means of all continuous fire risk variables between dead and alive trees. Univariate permutation t-tests adjust for multiplicity in univariate tests (Westfall and Young 1993). We log transformed variables for which data was collected in cover classes for data analysis. We constructed contingency tables for the categorical variables, and we compared the proportions of dead to alive trees across the levels of these categorical variables. Due to the small cell sizes (few number of dead trees), we used exact tests to calculate P-values (PROC FREQ of the SAS System).

We fit logistic regression models (PROC LOGISTIC of the SAS system) using a stepwise model selection approach to identify candidate predictor models of tree mortality. Due to patterns of missing data, we used more than one run with different subsets of variables, in several instances, so as to increase sample sizes as much as possible. The model set included those constructed from only continuous variables, those constructed from only categorical variables, and models containing both continuous and categorical variables.

Because bark char and needle scorch were the postburn variables most closely associated with mortality, we employed univariate permutation t-tests to compare mean bark char and needle scorch among protection treatments, and we used chi-square analysis to compare the proportion of trees exhibiting bark char and needle scorch between control and protection treatments. Finally, we used orthogonal comparisons of univariate permutation t-tests to compare log-transformed effort requirement means by preparation treatment.

Results

We did not detect significant difference in mortality among untreated (control) active, inactive, enlarged, and artificial cavity trees subjected to either wildfire or prescribed burning ($P \geq \chi^2 = 0.4829$, $N = 563$) or for those subjected to wildfire alone ($P \geq \chi^2 = 0.7896$, $N = 207$). Our results suggested that unprotected active trees are no more susceptible to fire-induced mortality than those that are inactive, enlarged, or artificial, thus our results validated the ability to detect potential differences in mortality among the various protection treatments (including a control) regardless of cavity status. Within areas where we conducted prescribed burns in 2001, the mortality rate of cavity trees was 4.25% (34 of 800 trees dead) after 1 year including 8 active trees (2.6% of active trees). The mortality rate was similar for cavity trees located within areas that experienced wildfire (3.24%) and for all trees combined (4.04%). Of the 41 cavity trees that died 1 year after the 2001 fire season, 63% of the mortality could be attributed directly to fire damage while 37% succumbed due to unknown or a combination of causes (fire, disease, insects, drought, etc.). Within prescribed burn areas, protected trees (those prepped prior to a burn) experienced a significantly lower rate of mortality (2.70%) than those left unprotected (6.18%, $P \geq \chi^2 = 0.021$). Hand clearing and light raking exhibited the lowest mortality at 0.86%, and mechanical clearing and light raking experienced the highest mortality at 4.46%. However, we found no statistical differences in cavity tree mortality among the various protection methods ($P \geq \chi^2 = 0.162$, Fig. 1).

All Trees Combined

When we combined all cavity trees for analyses, dead trees exhibited significantly greater mean diameter at breast height (dbh), lower mean % forb cover, higher mean % woody litter, and higher mean % woody >15 m in their immediate surroundings prior to burn, and they also exhibited greater mean fresh bark char height and % needle scorch postburn (Table 1). Trees exhibiting burned out cavities experienced significantly greater 1-year mortality ($P \geq \chi^2 < 0.001$). Logistic regression identified % forb cover ($P = 0.021$), fresh bark char ($P < 0.001$), and % woody litter ($P = 0.042$) as significantly related to tree mortality under the continuous-variables-only model. Logistic regression also identified both cavity burned ($P < 0.001$) and fresh bark char ($P = 0.028$) under the combined continuous and categorical model. A significantly higher proportion of trees in the control (unprotected) displayed fresh bark char than protected trees ($\chi^2 = 4.2695$, $\Pr \geq \chi^2 = 0.039$, $N = 1016$). There was no difference between control and protected trees in the proportion of trees with needle scorch ($\chi^2 = 0.3564$, $\Pr \geq \chi^2 = 0.551$, $N = 1016$). We found no significant differences in mortality among protection treatments when we combined all trees for analysis ($P \geq \chi^2 = 0.290$; Fig. 1)

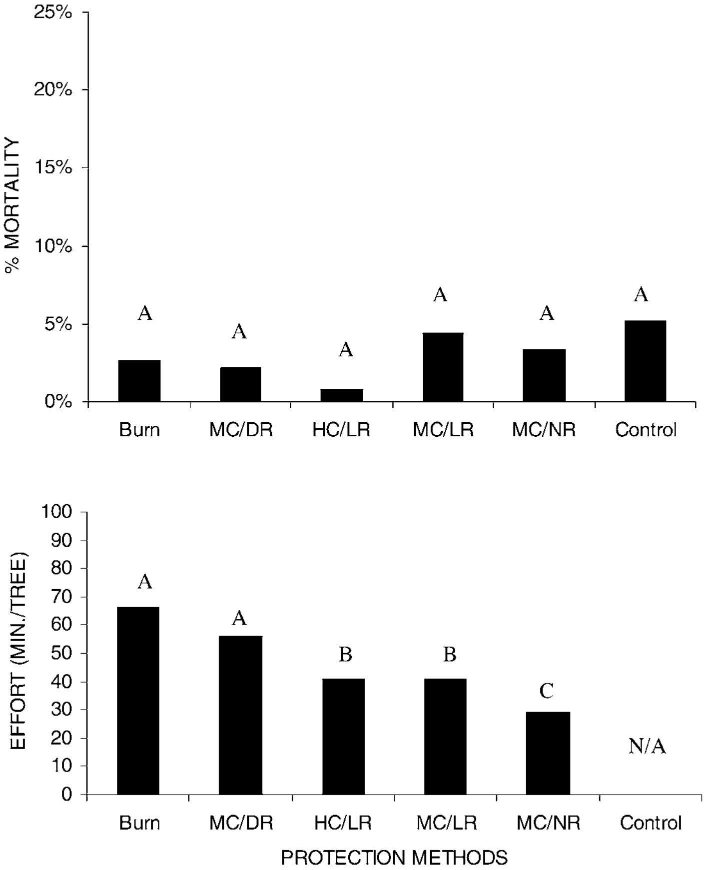

Figure 1. Comparison of protection effort requirement and % mortality (for all trees) among 5 red-cockaded woodpecker cavity tree fire protection methods on Eglin Air Force Base, Fla., USA, 2001. MC / DR = mechanical clearing / deep raking, HC / LR = hand clearing / light raking, MC / LR = mechanical clearing light raking, MC / NR = mechanical clearing / no raking. Treatments followed by different letters differ significantly at the alpha ≤ 0.05 level.

Rx Fire Only

For cavity trees subjected to prescribed burning (both protected and control), dead trees had greater mean dbh, lower mean % forb cover, greater mean % woody litter, and higher mean % woody >15m in their immediate surroundings prior to burn, and they also had greater mean fresh bark char height and % needle scorch postburn (Table 1). Trees with burned out cavities displayed significantly greater first year mortality ($P \geq \chi^2 < 0.001$), while as noted previously, protected trees experienced significantly lower mortality than those left unprotected ($P \geq \chi^2 = 0.021$). These results were similar to those found for all cavity trees combined. Logistic regression similarly identified % forb cover ($P = 0.021$), fresh bark char ($P < 0.001$), and % woody litter ($P = 0.041$) as significantly related to tree mortality under the continuous-variables-only model and fresh bark char ($P < 0.001$) alone was related to tree mortality when categorical predictors were combined with continuous predictor variables.

Table 1. Differences in preburn and postburn fire risk variable means between live and dead cavity trees on Eglin Air Force Base, Fla., USA, 2001.

		Prepped only[a]			Rx only			Wildfire only			All Trees		
Variable	**Status**	**N**	**Mean**	***P* value**	**N**	**Mean**	***P* value**	**N**	**Mean**	***P* value**	**N**	**Mean**	***P* value**
Preburn													
Tree d.b.h. (cm)	Alive	376	37.19	0.245	587	37.58A	0.044				596	37.56A	0.043
	Dead	10	39.62		29	40.16B					29	40.31B	
Sap flow (%)	Alive	372	15.36A[b]	0.033	581	11.33	0.794				590	11.49	0.761
	Dead	9	29.44B		28	10.36					28	10.36	
Forb cover class[c]	Alive	373	3.12A	0.036	582	3.09A	0.005				591	3.05A	0.007
	Dead	9	1.56B		28	1.86B					28	1.86B	
Woody litter class	Alive	371	2.28	0.210	580	2.30A	0. 011				589	2.31A	0.012
	Dead	9	2.89		28	3.04B					28	3.04B	
Woody >15m class	Alive	373	3.48	0.739	582	3.67A	0. 002				591	3.65A	0.002
	Dead	9	3.77		28	5.21B					28	5.21B	
Postburn													
Fresh bark char (m)	Alive	411	0.46	0.592	708	1.11A	<0.001	209	2.02A	0.0023	917	1.32A	<0.001
	Dead	8	0.73		22	3.46B		7	5.01B		29	3.84B	
Needle scorch (%)	Alive	411	22.74	0.921	708	23.19A	0.009	204	11.86A	0.0042	912	20.65A	0.001
	Dead	8	21.25		22	42.05B		7	42.14B		29	42.07B	

[a] Column data represent mortality comparisons within four datasets: trees prepped, trees burned in prescribed fire, trees burned in wildfire, and all trees combined.

[b] Means followed by different letters differ significantly at the alpha $\leq$ 0. 05 level

[c] Class values are presented as log transformed means.

Wildfire Only

Our analysis of postburn data identified greater mean fresh bark char height and greater % needle scorch for dead trees (Table 1). Once again, a significantly greater percentage of trees experienced mortality if the cavity was burned out ($P \geq \chi^2 = 0.003$). Logistic regression identified fresh bark char ($P < 0.001$) and % needle scorch ($P = 0.026$) as predictors of cavity tree mortality under the continuous variables only model, while a model containing both continuous and categorical predictor variables identified cavity burned ($P < 0.001$) and % needle scorch ($P = 0.032$) as predictors.

Prepped Only

For those trees subjected to 1 of the 6 protection preparation methods, dead trees possessed a significantly lower mean % forb cover and higher mean % sap flow on the bole (Table 1). In contrast to the other 3 data sets, prepped trees that died displayed no significant differences in fresh bark char height, % needle scorch, or whether the cavity burned out. Fresh bark char was much lower in general for prepped trees (Table 1), but we did not make statistical comparisons among datasets. We found no differences in the rate of mortality among the protection methods ($P \geq \chi^2 = 0.600$). Cavity height ($P = 0.022$) was the only variable we identified as predictive of cavity tree mortality in a model produced through logistic regression of prepped trees, with cavity trees with lower cavities more susceptible to mortality. There were no differences among protection methods in mean fresh bark char and needle scorch or in the proportion of trees with the presence of fresh bark char ($\chi^2 = 4.2171$, $P \geq \chi^2 = 0.519$, $N = 458$) or needle scorch ($\chi^2 = 3.4981$, $P \geq \chi^2 = 0.624$, $N = 458$).

Effort Requirement

Effort requirement differences were significant among protection treatments (Fig. 1). Of the various preparation treatments, mechanical clearing alone was the fastest, most efficient method for protecting cavity trees followed by both hand and mechanical clearing with light raking. Lighting small backfires and mechanical clearing with deep raking were the most intensive, time-consuming methods for cavity tree protection.

Discussion

Managers of red-cockaded woodpecker populations accept some risk of fire-induced mortality in cavity trees. If the cavity tree mortality rate on Eglin AFB for 2001 (4.25%) is projected into the future, a 50% loss of cavity trees will occur within 16 years without new cavity tree recruitment. However, protecting cavity trees, whether active or inactive, reduced first-year mortality by half. Low mortality rates, in general across the protection treatments, may limit the resolution of differences among these treatments, thus warranting additional collection of mortality data on these trees over time to further validate present findings. In addition to mortality, we compared control and protection treatments in preventing char and scorch, as these factors were most closely associated with cavity tree mortality. When compared to unprotected control trees, preparation of cavity trees significantly reduced the likelihood of bark char but did not reduce scorch. This result is not surprising given that scorch in the canopy is more a function of fire line intensity within the burn block, while bark char is an indicator of fire line intensity at an individual tree bole.

We demonstrated the effectiveness and efficiency of protecting cavity trees in advance of prescribed fire operations through mechanical vegetation clearing. Although not statistically significant in this experiment, hand clear/light rake had the lowest absolute mortality at 0.86% and mechanical clear/light rake had the highest mortality at 4.46%. This is perhaps due to a more thorough removal of vegetation and attention to detail through intensive hand clearing. It may also be a result of damage to trees due to contact with the mower head or fine root disturbance.

Identifying the risk factors that predispose individual cavity trees to fire-induced mortality should aid managers in focusing their protection efforts on mitigating for specific tree and stand characteristics. In our study, cavity trees exhibiting high amounts of preburn sap flow, extensive postburn bark char, needle scorch and/or burned out cavities were more susceptible to mortality from fire. The significance of these factors suggest that RCW cavity trees, active and inactive, are vulnerable to excessive fireline intensity. Extreme heating of the bole, especially over a prolonged period, can cause significant mortality in many different species of pine due to partial or entire cambial damage (Fahnestock and Hare 1964, Ryan 2000, Menges and Deyrup 2001). Hare (1965) found that cambial temperature in a suite of species continues to rise even after the heat source was removed. This effect would be exacerbated in RCW cavity trees if resin wells and old or new sap flow was ignited.

The degree and height of stem char, following fire, has been shown to be a reliable predictor of pine mortality, including longleaf pine (Storey and Merkel 1960, Dixon et al. 1984, Varner et al. 2005). Bud damage associated with needle scorch and consumption has also been correlated with pine mortality in the South (Storey and Merkel 1960, Wade and Johansen 1987). In contrast to observations made by Connor et al. (1991) on the Angelina National Forest in East Texas, cavity height was only a reliable predictor of mortality for prepped trees, and height to lowest sap flow was not a significant factor in mortality on Eglin AFB. It may be that % sap flow is of more use as a fire-risk variable than height to lowest sap flow because sap often flows downward at unequal rates and with varying coverage along the bole. Differences in our study may also be due to the unique conditions associated with the droughty sandhills of Eglin AFB on which longleaf typically exhibits a poor growth form of shorter stature and smaller diameter than on the more productive soils of the Angelina National Forest. We did not measure fine root consumption in duff, so its relative influence on cavity tree mortality remains unquantified but has been identified as an additional stressor for old-growth pines (Yoder et al. 1994, Kush and Varner 1999, Varner et al. 2005). Because fire intensity on the bole, bud damage, and sap and cavity ignition drive mortality in longleaf pine, the degree of stem char, needle scorch, % sap flow and whether the cavity burned may be useful risk variables for mortality on an individual cavity tree basis in longleaf sandhills. The application of fire and protection methods may be tailored by managers to mitigate these factors, particularly via lower intensity fires on days of high duff moisture and simple, effective methods of cavity tree preparation such as mowing.

Our study also pointed to a number of stand-level characteristics that influenced cavity tree mortality. When left unprotected, cavity trees surrounded by less forb cover, greater woody fuel loading, and a higher midstory density were more susceptible to mortality. Increased mortality in cavity trees surrounded by a midstory of taller oaks and other broad-leaf trees (>15 m) may be due to the tendency of fire managers to conduct higher intensity burns in these thicker stands and the concomitant risk of fire damage to cavity tree boles when taller midstory trees torch. Higher intensity fires, of longer duration, carry greater mortality risks just by their nature, especially when coupled with heavy amounts of woody fuel loading. Lower % forb cover in a cavity tree's surroundings was consistently related to cavity tree mortality as well. Lower forb cover density may be an indicator of a closed canopy stand condition characterized by a denser hardwood midstory component that could potentially produce greater flame lengths. A number of studies have found that hardwood midstory encroachment has a negative effect on both understory diversity and/or forb productivity, and that midstory reduction can improve forb cover in the understory (Brockway and Lewis 1997, Provencher et al. 2001). Over time, frequent, low-intensity fires are effective in reducing woody cover in the midstory and may concomitantly mitigate the risk of cavity tree mortality by reducing fireline intensity on the boles of trees.

Management Implications

Because we found no statistical differences among protection treatments in their effectiveness at preventing mortality, we recommend that the preparation method that requires the least amount of effort may be used to accomplish the task of protecting cavity trees. Mechanical preparation—whether by a mower or tree-cutter—requires fewer personnel, is cost-effective, and allows crews to protect many more trees in a shorter period. Increased efficiency may ultimately offset the resources required for additional preparation of inactive or future cavity trees. From recent observations, mowing performed in late autumn appears to remain effective for up to 6 months and can provide protection in advance of wildfires. Mechanical methods also serve to temporarily reduce hardwood encroachment around cavity trees, a condition that has been associated not only with abandonment of the cavity itself but also of the entire cluster (Van Balen and Doerr 1978, Hovis and Labisky 1985, Conner and Rudolph 1991). In preparing cavity trees, equipment operators must be careful to avoid damaging trees with the mower head or by disturbing fine roots if the mower blade is set too low. In addition, mechanical methods should not be used in wetland areas and should be used with caution in flatwoods habitat to avoid damage to flatwoods salamander (*Ambystoma cingulatum*) habitat. We recommend long-term monitoring of cavity trees protected using different preparation treatments to help further distinguish differences in effectiveness, if any, among those methods. The individual tree and stand fire risk variables we identified may be useful in anticipating cavity tree mortality for at least one year following fire. Attention to these risk variables will allow managers to target cavity provisioning in clusters where mortality may affect cavity availability in the near future. The combination of frequent, low-intensity prescribed fires and more extensive cavity tree preparation will ensure the long-term survival of active and potential cavity trees.

Acknowledgments

We would like to express our appreciation to Eglin Air Force Base Jackson Guard Natural Resources staff for their expert guidance and for the hours of hard work invested in implementing treatments and data collection for this project. We would also like to thank Science Applications International Corporation for technical assistance, Louisiana State University Department of Experimental Statistics for statistical analyses, and the United States Fish and Wildlife Service for recommendations made in designing a study with the least impact to the species. In memory of E. Barry Moser, with our greatest respect.

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Associate Editor: Greenberg.