RED-HEADED WOODPECKER DENSITY AND PRODUCTIVITY IN RELATION TO TIME SINCE FIRE IN BURNED PINE FORESTS

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ABSTRACT

Red-headed woodpecker (*Melanerpes erythrocephalus*) populations are declining range wide, and fire is an important process necessary for creating their habitat throughout their range. In order to evaluate the effect of fire on the density and reproduction of this species, we examined nesting activities of red-headed woodpeckers from 2001 to 2005 in landscapes dominated by fires of different ages. We established six 300 ha to 400 ha sites in recently burned sites (i.e., burned in 2000) and two similarly sized old burn sites (i.e., burned in 1988 and 1991). Reproductive success and productivity (number of fledglings per nest) were higher in old burn sites compared to recent burn sites due to low predation rates in the old burn sites. Nest densities of red-headed woodpeckers were higher in the old burn habitats as compared to the recent burn sites. Based upon this productivity and density information, we developed a conceptual model that describes the potential effects of fire severity upon this species. Because our study sites in the Black Hills, South Dakota, are at the western edge of the red-headed woodpecker's range, it is unknown whether patterns detected in our study will be representative of patterns found throughout its range in other burned habitats. Long term studies conducted in multiple burns will broaden our understanding of how fire severity might influence the density and reproduction of birds nesting within burned pine forests.

Keywords: Black Hills, burns, density, *Melanerpes erythrocephalus*, ponderosa pine, productivity, red-headed woodpecker

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INTRODUCTION

Red-headed woodpeckers (*Melanerpes erythrocephalus*) range from eastern North America into the midwest and are experiencing population declines across their range (Smith *et al.* 2000, Rich *et al*. 2004, Sauer *et al.* 2006). The causes of the decline are not well understood, but reductions in decadent trees (i.e., snags or live trees with dead limbs) due to logging, firewood harvesting, and urban forestry practices may be contributing factors (Smith *et al*. 2000, King *et al.* 2007). Red-headed woodpeckers are aerial flycatchers that generally nest in large decadent trees located in relatively open woodlands (Vierling and Lentile 2006). King *et al*. (2007) suggested that fire is an important process in maintaining suitable habitat within portions of this species' range. Red-headed woodpeckers nest in a variety of forested environments, including college campuses (Ingold 1989), golf courses (Rodewald *et al*. 2005), anthropogenic woodlots (Gentry *et al.* 2006), and pine savannas created and maintained by fire (King *et al.* 2007).

Pine savannas were once common in the Black Hills, South Dakota, but changes in fire regimes over the past decades have caused these forests to become denser than they were historically (Shinneman and Baker 1997). Ponderosa pine (*Pinus ponderosa*) is the dominant forest type in the Black Hills, and the southern portion of the Black Hills historically experienced frequent, low severity surface fires that created open woodlands (Shinneman and Baker 1997). The woodlands maintained by this fire regime contained a productive herbaceous layer with few trees due to the amount of sunlight that was able to penetrate to the forest floor. However, open woodlands have been replaced by denser forests in recent decades due to fire exclusion (Brown and Sieg 1996). Currently, higher tree densities and subsequent increased fuel loading has led to an increase in the prevalence of stand-replacing (i.e., high severity) fires (Covington and Moore 1994). Once considered to be the most abundant woodpecker in the Black Hills (Cary 1901), red-headed woodpeckers are now experiencing high rates of decline in this region (Sauer *et al*. 2006). We hypothesized that woodpecker declines in the southern Black Hills might be related to changes in forest structure caused by current fire regimes.

An evaluation of the effects of fire on red-headed woodpecker reproduction is important as the occurrence of stand-replacing fires increases throughout western North America, and as managers use fire as a tool to create nesting habitat (e.g., King *et al*. 2007). Vierling and Lentile (2006) recently reported that red-headed woodpeckers nesting in a recent burn (1 yr to 4 yr post-burn) in the Black Hills had a reproductive success of approximately 47 %. Fires can create a favorable environment for red-headed woodpeckers through two mechanisms: fires create snags that are necessary for nesting, and fires often create suitable flycatching habitat through the creation of openings in the forest (Wilson *et al*. 1995, Vierling and Lentile 2006). However, habitat quality may decline as post-fire succession occurs for multiple reasons. First, nest site availability may decline as snags fall down. Second, forest regeneration creates a higher density of young trees, which will likely restrict the ability of these woodpeckers to flycatch (King *et al.* 2007). Finally, reproductive success may decline as post-fire succession occurs due to recolonization of nest predators such as squirrels and chipmunks that are missing in early post-fire forests due to a lack of plant cover (Saab and Vierling 2001).

The predator community within the Black Hills is unique when compared to similar habitats in the Rocky Mountains. Pine martens (*Martes americana*), a known cavity nest predator (Korpimaki, 1987, Sonerud, 1989, Nilsson et al. 1991), are present only in the portions of the Black Hills dominated by white spruce (*Picea glauca*) (G. Brundige, Custer State Park, personal communication). Other possible mammalian predators of nest cavity dwellers include the least chipmunk (*Tamias minimus;* Higgins *et al.* 2004), red squirrel (*Tamiasciurus hudsonicus;* Fisher and Wiebe 2006), northern flying squirrel (*Glaucomys sabrinus;* Higgins *et al.* 2004), common raccoon (*Procyon lotor*; Fisher and Wiebe 2006), deer mouse (*Peromyscus maniculatus;* Purcell and Verner 1999, Walters and Miller 2001), and white-footed mouse (*P. leucopus*; Guillory 1987).

Post-fire environments are important for a variety of species, but species-specific information is necessary for a better understanding of fire effects on wildlife (Saab and Powell 2005). Our objectives were to: (1) report on reproductive success and productivity for red-headed woodpeckers in burns of different ages in the Black Hills, (2) compare densities of red-headed woodpeckers between different aged burn sites, and (3) propose a conceptual model that examines the influence of fire severity and post-fire succession upon red-headed woodpeckers.

METHODS

Study Area

The Black Hills, located in western South Dakota and northeastern Wyoming, are an isolated, forested mountain range rising over 1000 m above the Great Plains (Shepperd and Battaglia 2002). Ponderosa pine is the dominant tree species in the Black Hills, but patches of aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), bur oak (*Quercus macrocarpa*), and white spruce also occur in the region (Shinneman and Baker 1997). Lentile (2004) suggested that the current Black Hills fire regime was best described as mixed-severity. Mixed severity regimes are complex and are comprised of a combination of unburned patches and patches that are affected by low severity (surface fire), moderate severity (a combination of surface fire and torching) and high severity (represented by stand-replacing fire; Agee 2005).

We examined red-headed woodpecker reproduction within three major study areas: the Jasper Fire site, Wind Cave National Park, and Custer State Park. The Jasper Fire site was our recent burn site, having burned in late August and early September, 2000. This fire was a mixed severity fire and burned 33 795 ha of ponderosa pine and aspen in the southern Black Hills. The Jasper Fire occurred between latitudes 43° 41’ 35” N to 43° 55’ 48” N, longitudes 103° 46’ 1” W to 104° 0’ 47” W, and elevations ~1500 m to 2100 m. The Jasper Fire burned in an area that had not burned in the previous century (Brown and Sieg 1996), although dendrochronological studies indicate that the region historically experienced more frequent, low severity fires (~10 yr to 15 yr between fires; Brown and Sieg 1996). Ponderosa pine dominated the tree species (~88 %) at the study sites with aspen stands comprising ~2 % of the landscape. Burn severities differed within these forest types: 18 % of ponderosa pine forests burned at low severity, 53 % burned at moderate severity, and 29 % burned at high severity (Vierling and Lentile 2006). For the aspen dominated stands, 21 % burned at high severity, 24 % burned at moderate severity, and 55 % burned at low severity (Vierling and Lentile 2006). We generated these severity levels via an unsupervised classification whereby we classified remotely sensed data into low, moderate, and high severities following application of the ISODATA algorithm (Ball and Hall 1965) and refined with field data (Lentile *et al.* 2006). Low severity landscapes had low tree mortality (<1 %), predominately green tree canopies (<25 % canopy scorch), and >70 % vegetative or needle cover on the ground (Lentile 2004). Conversely, landscapes that burned under high severity had complete tree mortality (100 % blackened canopies) and <30 % vegetative ground cover (Lentile 2004). Areas that burned at moderate severity showed approximately 23 % tree mortality, >25 % canopy scorch, and 30 % to 70 % vegetative ground cover (Lentile 2004). The mean patch size burned at low severity was 10.4 ha (± 2.7 ha), the mean patch size burned at moderate severity was 24.1 ha (± 7.1 ha) and the mean patch size burned at high severity was 7.5 ha (± 1.0 ha) (Lentile *et al.* 2006). In general, areas burned under low and moderate severity had a lower stand density and occurred on less steep slopes compared to areas that burned under high severity (Lentile *et al.* 2006). Post-fire logging of dead trees occurred at the edge of one of the study sites within the Jasper Fire, and this area was excluded from the analysis.

Our old burn sites consisted of two major stand-replacing fires that burned in 1988 and 1991 in the southern Black Hills. The Galena Fire site (43° 47' 57" N, 103° 21' 47" W) occurred in Custer State Park, and the second site, the Shirttail Fire site (43° 34' 20" N, 103° 29' 44" W), overlapped boundaries between Wind Cave National Park and adjacent Forest Service land. Both sites contained relatively homogeneous ponderosa pine forests burned by high severity wildfires 11 yr to 14 yr prior to the first study year. The Shirttail Fire burned approximately 1700 ha in 1991 and the Galena Fire burned approximately 6900 ha in 1988. Post-fire logging of dead trees >23 cm in diameter occurred within portions of both burns. The post-fire vegetation structure was similar in the two old burn study units; for instance, the density of trees and snags >23 cm in diameter did not differ significantly between the two old burn sites (Gentry and Vierling 2007). We do not have data regarding overall tree mortality in each fire or within the study sites, but we selectively placed study sites in areas that experienced predominantly high severity fire. The three burn sites are within approximately 35 km of each other.

Within the Jasper Fire region, we established six study sites of 300 ha to 400 ha. Saab *et al.* (2002) noted that pre-fire canopy cover might reflect post-fire woodpecker use and, therefore, we selected sites based on pre-fire canopy cover (Vierling *et al.* 2008). Two of the six study sites had a pre-fire canopy cover of >70 %, two study sites had a pre-fire canopy cover of 40 % to 70 %, and two study sites had a pre-fire canopy cover of <40 %. We used the Black Hills National Forest Resource Information System (RIS) database (Lentile *et al.* 2006) to identify our sites within the burned landscape and randomly selected the sites within each pre-fire canopy cover class. We established one study site within each of the two old burn sites that were of similar size to the recent burn study sites.

Nest Searching

For four years at each site, we employed nest searching to document woodpecker nesting activity. In the Jasper Fire, we searched for nests from 2001 to 2004, whereas nest searching activities in the old burns occurred between 2002 and 2005 for the Shirttail Fire and between 2003 and 2005 for the Galena Fire.

From late April through early July, we followed nest searching methods described by Dudley and Saab (2003) to find red-headed woodpecker cavities. Within each study site, we established transects every 200 m and searched for nests by walking each transect until we surveyed the entire unit (see Dudley and Saab 2003). Once we found a nest, we monitored it every 3 days to 4 days with a TreeTop Peeper™ cavity viewer (Sandpiper Technologies, Inc., Manteca, California, USA) until the nest failed or fledged young. We assumed predation was the major cause of nest failure when eggs disappeared from the nest cavity or when hatchlings disappeared from the nest cavity prior to their ability to fly. In order to calculate nest densities, we recorded all nest locations and study site perimeters using a global positioning system (GPS). We reported nest densities as the number of nests km^{-2}. We were unable to do a complete survey of the Jasper Fire sites for red-headed woodpeckers in 2004; therefore, we only report nest densities for red-headed woodpeckers for 2001-2003.

Data Analysis and Model Development

For each habitat, we used the Johnson (1979) version of the Mayfield (1975) nest success calculation to estimate reproductive success (i.e., the number of nests successful in fledging at least one young). We based the productivity estimates (i.e., the number of fledglings per nest) upon direct observations of nest contents. Although we did not statistically test reproductive or density measures between recent and old burns due to pseudoreplication issues (i.e., we had a single recent burn with several study sites), we do present the raw data.

We developed a conceptual model based upon our knowledge of fire effects on vegetation and the ecological requirements of this species. We used nest-site selection data from the Jasper Fire (Vierling and Lentile 2006) and the Galena and Shirttail sites (Vierling *et al*. 2009) in conjunction with our density data to formulate the conceptual model. While a suitable nest snag is important (Vierling *et al.* 2009), the habitat surrounding the nest tree is also important (Vierling *et al.* 2009), and King *et al.* (2007) suggest that the importance of the nest snag is outweighed by the importance of the habitat surrounding the nest snag. The habitats surrounding red-headed woodpecker nest sites in the recent and old burns had fewer trees and snag stems than random sites (Vierling and Lentile 2006, Vierling *et al.* 2009). Researchers attribute the selection of nest sites within the more open woodlands in these study sites (Vierling and Lentile 2006, Vierling *et al.* 2009) and in other sites to the flycatching requirements of this species (Bock *et al.* 1971, Smith *et al.* 2000, Vierling *et al.* 2009). Therefore, we assumed that the habitat surrounding the nest snag is likely to influence nest site selection, and thus abundance, within a particular burn.

RESULTS

We found 17 nests in the recent burn site and 38 nests in the old burn sites. Reproductive success in the recent burn site was lower (47 %) compared to reproductive success in the old burn sites (92 %), and productivity (pooled between years) was higher in the old burns compared to the recent burn (2.8 ± 0.25 fledglings $nest^{-1}$ vs. 1.6 ± 0.55 fledglings per nest). Predation was the primary cause of nest failure in both sites. In the recent burn sites, nest failures due to predation increased from 44 % in 2002 to 57 % in 2003. In contrast, only two (5 %) of the nests in the old burn sites failed due to predation; the only other nest failure in the old burn sites occurred due to the cavity tree falling over prior to fledging of the young.

The nesting density of red-headed woodpeckers was lower in the recent burn compared to the older burns. The average density in the recent burn was 0.25 nests km^{-2}, compared to an average density in the older burns of 2.0 nests km^{-2}. In the recent burn, nesting densities peaked in the second year of the study at 0.38 nests km^{-2} and declined in the third year of the study. In contrast, nest densities in the old burn sites averaged 3.0 nests km^{-2} at the onset of the study and decreased thereafter (Table 1).

Table 1. Density of red-headed woodpecker nests km[-2] in a recent burn compared to older burn sites in the Black Hills, South Dakota. Numbers in parentheses represent the number of nests. We monitored an additional nest in the Jasper Fire study sites in 2004, but were unable to conduct a full survey of the entire study site. Therefore, density information in the Jasper Fire is based only on years 2001-2003.

	Year of burn		
	1988	1991	2000
Survey year	Galena Fire	Shirttail Fire	Jasper Fire
2001			0.09 (2)
2002		1.8 (7)	0.38 (8)
2003	4.2 (8)	1.8 (7)	0.29 (6)
2004	2.1 (4)	1.3 (5)	
2005	2.1 (4)	0.8 (3)	

Based upon the patterns of reproduction and density within these burned sites, we developed a conceptual model that assumes an initial dense forested landscape that is subsequently burned by one of three different severities (low, mixed, and high) (Figure 1). When developing the model, we assumed that the resulting burned areas did not experience post-fire salvage logging activities. In our model, red-headed woodpecker densities would be affected by post-fire vegetation structure, which is influenced by time since fire and fire severity. Because we begin with an assumption of an initially dense forested landscape, red-headed woodpeckers would have the lowest densities under low severity conditions due to the lack of snag creation and the low number of forest openings created by the fire. In contrast, the high severity fire would create large numbers of snags and a relatively open environment for aerial flycatching. In the growing seasons following the high severity fire, a productive herbaceous understory capable of supporting their prey base (i.e., insects) is likely to develop. This type of burned environment would sustain relatively high densities of red-headed woodpeckers until snags begin to fall and tree densities increase. The reduction in snags would reduce the availability of nesting substrates, and the increased tree density would likely: 1) inhibit flycatching maneuverability, and 2) reduce understory productivity. Thus, as live tree density increased, red-headed woodpecker densities are hypothesized to decrease. The mixed fire severity would generate an intermediate response to the two extremes.

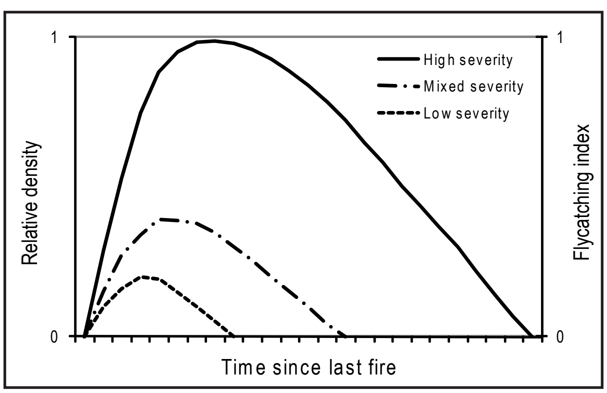

Figure 1. This conceptual model illustrates relative red-headed woodpecker densities in response to different severities of fire in initially dense forests. The flycatching index is a relative measure of forest structure that would affect flycatching activities.

DISCUSSION

Reproductive success and productivity appeared higher in the old burns as compared to the recent burn sites. These older burn sites functioned as demographic metapopulation sources for Lewis's woodpeckers (*Melanerpes lewis*; Gentry and Vierling 2007), and likely functioned similarly for red-headed woodpeckers. The lack of predation in these sites may be due to the relationship between potential nest predator habitat requirements and habitat availability. Avian predators were rare (Gentry and Vierling 2007), and noted nest predators of cavity nesting species, such as common ravens and pine marten, were absent from our study sites. Gentry and

Vierling (2007) sampled for potential mammalian nest predators such as weasels, sciurids, and mice in the old burned study sites. They found lower densities of squirrel and chipmunk densities within the burned sites as compared to the adjacent unburned site, and did not observe weasels within the surveyed plots (Gentry and Vierling 2007).

We predicted that red-headed woodpecker reproduction rates would be higher in the old burn sites compared to the recent burn site due to predator colonization, but predation rates were higher in the recent burn site. This pattern is in contrast to other studies examining nest survival as a function of time since fire. Saab *et al.* (2007) noted that nest survival was generally lower for cavity nesters in late (5 yr to 12 yr) post-fire periods as compared to early (1 yr to 4 yr) post-fire periods. Additionally, Saab and Vierling (2001) reported that recently burned forests (i.e., burns ≤5 yr old) in Idaho function as metapopulation sources for Lewis's woodpeckers, and attribute the mechanism of this function to low nest predation rates. They also noted that nest predation rates were low in two stand-replacing burns and hypothesized that the low predation rates were likely due to the fact that predators had not yet recolonized the large burned area. One of the main reasons the sites examined in our Black Hills study likely had higher nest predation rates (53 % overall) as compared to the Idaho study sites (16 % predation rates; Saab and Vierling 2001) might relate to the pattern of fire severity. The mixed severity nature of the Jasper Fire left a landscape mosaic of unburned patches adjacent to patches that burned under low severity, and interspersed with high severity patches (Lentile 2004). Sciurids and mustelids (two major potential groups of woodpecker nest predators) rely on live trees for forage and cover, and post-fire succession can affect recolonization rates (Fisher and Wilkinson 2005). Fisher and Wilkinson (2005) note that the use of burned habitats by sciurids and mustelids can occur within the first 10 years of the fire, but that the presence of unburned forest in the burn mosaic may cause colonization to occur sooner. Because low severity patches and unburned areas likely provide habitat for nest predators, variability in the spatial arrangement of these unburned and low severity patches likely influence nest predation in the first few years following fire. The interrelationships between fire severity, potential nest predator populations, avian reproduction, and post-fire succession require further study.

Nest densities were high in the old burns and relatively low in the recent burn. Red-headed woodpeckers are extremely conspicuous and it is unlikely that we missed nesting activities in our observations and subsequent nest density estimates. The higher nest density in the old burn combined with relatively high productivity suggests that red-headed woodpeckers nesting in old burns contribute more young to the overall population than those nesting within young burns. However, old burns are likely to decline in quality for nesting red-headed woodpeckers over time due to snag loss and increasing tree densities.

Fire severity influenced red-headed woodpecker nest-site selection in the recent burn site (Vierling and Lentile 2006). However, to our knowledge, no models incorporate mixed fire severity scenarios in their examination of the density of cavity nesting aerial flycatchers as post-fire succession occurs. We developed our conceptual model based on our knowledge of eight study sites within three distinct wildfires that burned within the Black Hills. Conceptually, our models can be extended to other cavity nesters (e.g., Lewis's woodpeckers and mountain bluebirds [*Sialia currucoides*]) that share a similar foraging guild. However, we do not know the threshold at which tree density becomes prohibitive to aerial flycatching or how long it takes after a fire to reach that threshold. Kotliar *et al.* (2002) suggested that post-burn forests lose their burn specialist species by 25 years post-burn. King *et al.* (2007) modeled red-headed woodpecker nest occurrence relative to limb tree density (which was the number of trees within 0.04 ha that possessed a decayed limb) and found that the probability of red-headed woodpecker occurrence increased with increasing limb tree density until limb tree density was approximately 200 limb trees ha^{-1}. At this threshold, the probability of red-headed occurrence was 100 %; however, the model did not address how the probability of occupancy would change if limb densities exceeded 250 limb trees ha^{-1}. Although they did not model occurrence at higher limb tree densities, King *et al.* (2007) noted that suitable nesting habitat is likely limited by factors that allow succession to increase live-tree stem density in a particular stand.

We would emphasize that our model is a conceptual one based on initially dense, unburned pine forest, and that the model's applicability might change depending on initial forest conditions. For instance, an open woodland undergoing frequent low severity fires would influence red-headed woodpecker densities differently than represented in our model. Saab *et al.* (2007) modeled densities of cavity nesters without the explicit incorporation of severity, but their models had several attributes that are not present in this study. First, they were able to monitor woodpecker responses to fire continuously for >10 yr following fires in Idaho. This represents a unique data set because most studies that examine avian responses to fire are typically 2 yr to 3 yr long (Smucker *et al.* 2005). Additionally, they were able to conduct their study across multiple burns, and were additionally able to experimentally evaluate the effects of post-fire logging on woodpecker populations. Validation of our proposed model of red-headed woodpecker response to fire severity would require a similar long-term view of post-fire succession in multiple burned sites.

Our study reports on reproductive activities of red-headed woodpecker at the edge of their range. Smith *et al.* (2000) noted a lack of data on red-headed woodpecker reproduction, and our data comprise some of the first reproductive data from burned areas in the Black Hills. Because fire may be used as a management tool to enhance habitat, it is important that we gain a better understanding of post-fire succession and its effects on the demographics of red-headed woodpeckers. We can gain essential insight into these issues through studies of longer duration within the same burned habitat type, incorporate larger sample sizes across multiple burns, and involve known (banded) individuals. Finally, because of the unexpected differences in the patterns of predation on redheaded woodpeckers between old and recent burns, we suggest that further studies examine the relationships between fire severity, nest predator communities, and avian reproductive activities over long time periods.

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