DIRECT EFFECTS OF FIRE ON ENDANGERED MOUNT GRAHAM RED SQUIRRELS

JOHN L. KOPROWSKI,* KATHERINE M. LEONARD, CLAIRE A. ZUGMEYER, AND JULIA L. JOLLEY

Wildlife Conservation and Management, School of Natural Resources, University of Arizona, Tucson, AZ 85721
**Correspondent: squirrel@ag.arizona.edu*

ABSTRACT—Direct mortality of forest wildlife due to fire is rarely documented. In June and July 2004, the Nuttall Complex Fire burned 11,898 ha in the Pinaleño Mountains, southeastern Arizona. Portions of these mountains serve as the only habitat of endangered Mount Graham red squirrels (*Tamiasciurus hudsonicus grahamensis*). Survival of radio-collared red squirrels over a period that included the fire was lower in areas that were burned than on unburned areas; however, the majority of squirrels on our study areas survived the fire. Distance of nests from middens did not differ between pre-fire and post-fire periods for animals in burned or unburned areas, indicating that squirrels did not abandon middens immediately after surviving the effects of fire.

RESUMEN—La mortandad directa de la fauna silvestre de los bosques a causa del fuego raramente se documenta. En junio y julio del 2004, el Nuttall Complex Fire quemó 11,898 ha en las Pinaleño Mountains, al sureste de Arizona. Porciones de estas montañas sirven como el único hábitat de las ardillas rojas en peligro de extinción, *Tamiasciurus hudsonicus grahamensis*. La supervivencia de las ardillas rojas con radiocollares en un período que incluyó al fuego fue más baja en áreas que fueron quemadas que en las no quemadas; sin embargo, la mayoría de las ardillas en nuestras áreas de estudio sobrevivieron al fuego. La distancia de los nidos desde los muladares no difirió entre los periodos de pre-fuego post-fuego para los animales en áreas quemadas o no quemadas, indicando que las ardillas no abandonaron los muladares inmediatamente después de haber sobrevivido a los efectos del fuego.

Fire is considered a major disturbance to forest communities and is under heavy anthropogenic influence (Pyne, 1982; Smith, 2000). Policies of fire suppression for nearly a century in the United States have resulted in significant changes in fire frequency, catastrophic fire frequency, and forest structure, prompting efforts to reintroduce fire into ecosystems through prescribed burns and wildfire containment (Pyne, 1982; Smith, 2000). Consequences of fire to long-term ecosystem health are often studied (Barlow and Peres, 2004); however, short-term, direct effects of fire on animals are not well known.

Wildlife mortality due to fire is rarely documented apart from anecdotal observations. Direct, fire-induced mortality is reported for insects (Gerson and Kelsey, 1997), fish (Rieman and Clayton, 1997), amphibians (Vogl, 1973), and reptiles (Vogl, 1973; Erwin and Stasiak, 1979; Simons, 1989; Smith et al., 2001). Due to high vagility, birds typically avoid fire; however, eggs, nestlings, and occasionally adults are reported to perish (Hakala et al., 1971; Erwin and Stasiak, 1979; Geluso et al., 1986; Peres, 1999; Lyon et al., 2000). Mortality of large mammals due to fire is known, especially among species with low mobility (Peres, 1999; Silveira et al., 1999; Lyon et al., 2000; Barlow and Peres, 2004). Among small mammals, burrowing mammals have the greatest likelihood of survival, and non-fossorial mammals have reduced survival (Erwin and Stasiak, 1979; Sutherland and Dickman, 1999; Vernes, 2000). Marsupial mice (*Antechinus*: Friend, 1993), possums (*Psuedocheirus peregrinus*: Friend, 1993), shrews (*Sorex*: Hakala et al., 1971), voles (*Microtus, Clethrionomys*: Hakala et al., 1971; Keith and Surrendi, 1971; Erwin and Stasiak, 1979; Ver Steeg et al., 1983; Geluso et al., 1986), woodrats (*Neotoma*: Tevis, 1956; Simons, 1989), harvest mice (*Reithrodontomys*: Erwin and Sta-

siak, 1979), eastern cottontails (*Sylvilagus floridanus*: Erwin and Stasiak, 1979), and hares (*Lepus americanus*: Hakala et al., 1971) have died reportedly due to fire.

The ability of arboreal-dwelling mammals to survive forest fires is not well understood due to difficulty in documenting loss of animals. Tree squirrels might be negatively impacted in the short-term by forest fire because fire reduces available foods, nests, and cavities (Kirkpatrick and Mosby, 1981). Tree squirrels flee wildfires (Bendell, 1974), although direct mortality of tree squirrels (e.g., red squirrel, *Tamiasciurus hudsonicus*) has been reported during intense fire (Hakala et al., 1971).

From 22 June to 25 July 2004, the lightning-caused Nuttall Complex Fire burned 11,898 ha in a mosaic of ground and crown fires within the Pinaleño Mountains of southeastern Arizona (United States Department of Agriculture, Forest Service, Southwest Area Wildland Fire Operations: www.fs.fed.us/r3/fire, Accessed October 2004). Endangered Mount Graham red squirrels (*T. h. grahamensis*) are restricted to high-elevation spruce-fir (*Picea-Abies*) and mixed-conifer forests of these mountains (Brown, 1984), and this population represents the southernmost extension of the species into arid regions of North America (Hoffmeister, 1986). The entire population of endemic Mount Graham red squirrels over 12,000 ha of marginal or occupied range was estimated at 284 ± 13 individuals in May 2004 (T. Snow, Arizona Game and Fish Department, in litt.). Herein, we examine direct effects of wildfire on endangered Mount Graham red squirrels.

METHODS—We studied Mount Graham red squirrels in approximately 440 ha of mixed-conifer and spruce-fir forest above 2,600 m in the Pinaleño Mountains, Graham County, Arizona. Our study areas were located near Merrill Peak, Columbine Visitor Center, and Mount Graham International Observatory. Forests were dominated by Engelmann spruce (*Picea engelmannii*) and corkbark fir (*Abies lasiocarpa* var. *arizonica*) at the highest elevations, with Douglas-fir (*Pseudotsuga menziesii*) and southwestern white pine (*Pinus strobiformis*) more common at low elevations (Hutton et al., 2003).

We trapped all resident adult red squirrels at middens (larderhoards: Finley, 1969) from April 2002 until June 2004 (Koprowski, 2005). Before the fire, endangered Mount Graham red squirrels were individually marked with uniquely numbered ear tags (Monel 1005-1, National Band and Tag, Newport, Kentucky), colored ear disks (1-cm Model 1842, National Band and Tag), and radio-collars (SOM 2190, Wildlife Materials International, Inc., Murphysboro, Illinois) weighing <5% of body mass.

Prior to the fire, locations of nocturnal nests were determined by locating radio-collared animals at dusk each week and obtaining coordinates with a GPS unit (GeoExplorer II, Trimble Navigation, Sunnyvale, California). For 2 nests not found, we used telemetry locations made as close to the time of fire as possible to estimate nest location. We calculated distance from nest tree to midden of residence using ArcView (Environmental Systems Research Institute, Redlands, California).

From 12 to 26 July 2004, after the fire had passed through our study areas, we visited middens of all marked residents on our study areas. Subsequently, we recorded severity of burn impacts at 2 scales: midden site (no evidence of fire, ground fire through midden, canopy and ground fire through midden) and burn impact area (outside perimeter of burn, within perimeter of burn). We used radio-telemetry to locate known individuals and assess survival. If we could not detect a signal, we visited middens repeatedly and observed the site from <50 m to assess occupancy status. In addition, we searched for radio signals in all forested habitat ≤5 km of middens and continued intensive searches for 60 d after the fire. This distance effectively included all contiguous habitat for animals in these locations. We conducted a complete census of all known middens in September 2004, but did not relocate any marked squirrels displaced by fire. Given our intensive searches and limited area of habitat, red squirrels not located were assumed to have perished. Fisher's exact tests were applied to frequency data to compare survivorship. We used Mann-Whitney *U*-tests to compare distances of nests from the midden of a resident between burned and unburned areas after the fire. We used Wilcoxon matched pairs tests to examine distance of nests from middens before and after the fire.

RESULTS—Fifty-seven adult squirrels (29 males, 28 females) with radio-collars resided on our study areas on 26 June 2004 prior to the rapid spread of the Nuttall Complex Fire. Twenty squirrels (9 males, 11 females) were impacted directly by fire, with 15 middens burned and 5 middens intact within the burn perimeter. Survival of resident squirrels differed between areas within the burn perimeter and unburned areas outside of the burn perimeter (Fisher's exact: $A = 4.54$, $df = 1$, $P < 0.0001$). All marked animals (37 individuals: 20 males, 17 females) in unburned regions out-

side of the burn perimeter survived; 35% of 20 resident squirrels at locations within the burn perimeter did not survive (4 of 9 males and 3 of 11 females not relocated). Each of the 3 females that were lost was lactating at the time of the fire, and all males possessed scrotal testes. We did not locate carcasses of any resident squirrels, likely due to the intensity of fire. For 5 of the 7 lost squirrels, the known nest tree was reduced entirely to ash. Intensity of fire also seemed to influence the likelihood of loss. Within the burn perimeter, 5 residents whose middens did not burn remained at their home sites, whereas 7 of 15 squirrels whose middens burned were not relocated.

For squirrels that survived the fire, nests were located at similar distances from midden centers in burned and unburned areas (burned median = 21.4 m, range = 3 to 640 m; unburned median = 38 m, range = 0 to 850 m; $U = 235.50$, $n = 37, 13$, $P = 0.92$). Neither squirrels within burned areas (pre-fire median = 16.1 m, 0 to 86.5 m; post-fire median = 21.4 m, range = 3 to 640 m; Wilcoxon: $n = 13$, $P = 0.44$) nor in unburned areas (pre-fire median = 23 m, range = 0 to 560 m; post-fire median = 38 m, range = 0 to 850 m; Wilcoxon: $n = 37$, $P = 0.09$) nested farther from their middens following fire. Of 13 squirrels that survived the fire, only 4 (31%) abandoned their middens during the 2 weeks following the fire, and each of these was in an area that experienced intensive crown fire.

Discussion—Mount Graham red squirrels were lost from the population during the Nuttall Complex Fire. Due to the limited habitat available (United States Fish and Wildlife Service, 1993) and intensive efforts to relocate squirrels, the 7 squirrels not relocated were likely direct mortalities of the fire. A loss rate of 35% over a 14-d period greatly exceeds many annual loss rates for red squirrel populations (Kemp and Keith, 1970; Rusch and Reeder, 1978). The impact of fire on Mount Graham red squirrels in burned areas seems to have been significant.

Although the wildfire resulted directly in mortality of squirrels, the majority of red squirrels survived. Scale and intensity of the fire are likely of great importance in determining likelihood of survival (Silveira et al., 1999). Small mammals often try to outrun fire and are successful (Geluso et al., 1986). If fires remain on the ground and do not burn at too high a temperature, then shelter of burrows (Yahner, 1980) or nests in the canopy (Fancy, 1980; Young et al., 2002) can serve as refuges. In contrast, fires that reach the canopy and crown likely lead to direct mortality of tree squirrels (Kirkpatrick and Mosby, 1981).

Many forest types inhabited by tree squirrels experience frequent ground fires (Brown and Smith, 2000) and squirrels probably have evolved under these conditions (Kiltie, 1989). Ground fires might pose little immediate problem for tree squirrels due to their ability to escape into the forest canopy (Kirkpatrick and Mosby, 1981). Crown fires, however, were not historically common in the forests of the southwestern United States (Brown and Smith, 2000); thus, squirrels might not have evolved effective ways of surviving such fires. Furthermore, fire in the canopy likely threatens the arboreal nests of tree squirrels (Kirkpatrick and Mosby, 1981).

Fire can have many positive impacts on restoration of forest health in the long-term (Pyne, 1982; Brown and Smith, 2000). The immediate consequences of fire, however, on Mount Graham red squirrels suggest a negative impact on the population through direct mortality of individuals. In addition, the Nuttall Complex Fire coincided with the peak period of lactation among females (Koprowski, 2005) when many juveniles were in natal nests. The mean litter size of 2 to 4 young (Steele, 1998) suggests that considerable losses of less mobile juveniles probably occurred. Furthermore, loss of larderhoarded foods stored within the midden might also decrease future survival and reproductive success (Price and Boutin, 1993; Larsen et al., 1997), as suggested for tree squirrels that scatterhoard and bury seeds (Kirkpatrick and Mosby, 1981). Avian and mammalian predators also might increase use of areas following fire and exacerbate direct losses associated with fire (Lawrence, 1966; Lyon et al., 2000). The low rate of initial abandonment of middens by residents is testament to the high site fidelity of red squirrels, probably due to investment in larderhoards and defense of space (Larsen et al., 1997). Survival of Mount Graham red squirrels during the Nuttall Complex Fire suggests tree squirrels have the potential to survive significant ground fires yet

remain vulnerable to crown fires that reach the canopy. Forest practices that reduce the risk of crown fire should minimize the likelihood of negative impact by wildfire on tree squirrels.

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