

PRE- AND POST-TREATMENT EFFECTS OF THE 2006 WARM FIRE ON NORTHERN
GOSHAWKS AND THEIR PREY POPULATIONS

Final Report:

JFSP Project Number 07-1-2-17
March 30, 2016

Principal Investigator:

Dr. Richard T. Reynolds, Research Wildlife Biologist, Rocky Mountain Research Station, 240 West Prospect Road, Fort Collins, Colorado 80526; Phone: 970/498-2585; e-mail: rreynolds@fs.fed.us

Co-Principal Investigator:

Dr. Curtis Flather, Research Ecologist, Rocky Mountain Research Station, 240 West Prospect Road, Fort Collins, Colorado 80526; Phone: 970/498-2569; e-mail: cflather@fs.fed.us

Associate:

Jeffrey Lambert, Biologist, Rocky Mountain Research Station, 240 West Prospect Road, Fort Collins, Colorado, 80526; Phone: 970/498-2586; email: jeffreylambert@fs.fed.us

This research was sponsored in part by the Joint Fire Science Program. For further information go to www.firescience.gov



I. ABSTRACT

Reductions in the frequency of fire in Southwestern ponderosa pine and mixed-conifer forests since initiation of forest management early in the 20th century changed the composition and structure of forest habitats of the northern goshawk (*Accipiter gentilis*), a food-limited species of conservation concern, and the birds and mammals it feeds on. A conservation strategy for the goshawk food web in frequent-fire forests (ponderosa pine, dry mixed-conifer) recommends restoring a historically-based mix of habitats created by tree groups with interlocking crowns, and scattered individual trees within an open (no tree cover) matrix of grass-forb-shrub communities, and well-distributed snags, logs, and woody debris. Such fine-scale mixes of habitats represented the evolutionary environment of the plants and animals in the hawk's food web in these forest types; environments that were sustained by frequent low-severity surface fire. Thus, fire played a key role in sustaining a fine-scale (≤ 4 ha) diversity of prey habitats from small grass-forb openings and closed-canopied tree groups and patches. Presence of these habitats and associated prey will influence the distribution, abundance, productivity, survival, and population viability of goshawks.

The 2006 Warm Fire burned 235 km² of ponderosa pine and mixed-conifer forests in a mix of no burn, low-severity, and high-severity levels on the North Kaibab Ranger District in northern Arizona in late June and early July 2006. Forest habitat metrics such as live tree and snag densities, cone production, and canopy and ground cover estimates were collected from 2007-2010 on 60 0.5km transects to compare the effects of low-, and high-severity fire, and no fire on goshawk prey species in ponderosa pine and mixed-conifer forests. We estimated abundances for 13 bird and mammal species in forests burned at different severities and tested predictive models for identifying the post-fire habitat characteristics that best predicted bird and mammal abundances. Red squirrel and golden-mantled ground squirrel abundances showed the most negative sensitivity to high-severity fire. Golden-mantled ground squirrels also showed sensitivity to low-severity fire. Chipmunk, American robin, and Steller's jay abundances were found to be evenly distributed across no burn and low-and high-severity fire. Hairy woodpeckers

and northern flicker abundances were higher following high-severity fire, likely due to increased numbers of snags, suitable substrates for cavity nests, and foraging opportunities on wood boring insects. Hairy woodpecker abundances were also higher in areas burned by low-severity fire. Only Golden-mantled ground squirrels were found to be negatively affected by low-severity fire relative to unburned forests. Compared to no burn and high-severity fire, low-severity fire had the least impact on the suite of prey, suggesting that using surface fire to restore and maintain a fine-scale habitat diversity will have the least impact on the full suite of prey. Restoring the species compositions (shade-intolerant, fire adapted) and structures (especially spatial pattern), including the grass-forb-shrub openings that are currently filled with trees, will benefit other important goshawk prey such as cotton-tail and jack rabbits, grouse, turkeys, and pigeons that occur in these forests but were detected too infrequently to estimate their abundances. Of course, an added value of a fine-scale mix of tree groups in a grass-forb-shrub matrix is a lowering of high-severity fire risk and consequent loss of habitats of most species in the goshawk food web.

II. BACKGROUND AND PURPOSE

Wildfire is a major disturbance in ecosystems across the United States (Agee 1993) and is an important driver of landscape change (Fulé et al. 1997). The historical fire regimes in the Southwest included frequent low-severity surface fires in ponderosa pine (*Pinus Ponderosa*) and lower elevation warm and dry mixed-conifer forests (White and Vankat 1993, Fulé et al 2000), less frequent mixed-severity fires in mid-elevation cool and mesic mixed-conifer forests, and infrequent, high-severity fires in higher elevation spruce-fir forests (White and Vankat 1993). In Arizona and New Mexico, pure ponderosa pine and mixed-conifer forests occupy nearly 2.5 and 1 million hectares of forest area, respectively (Brown 1994, Korb et al. 2013). As a dominant species in Southwestern forests, ponderosa pine can influence forest ecosystems and fire behavior (Moore et. al. 1999). As a consequence of frequent low-severity surface fire, ponderosa pine forests in Arizona have been described as low-density, open forests consisting of aggregations of old pine trees interspersed with aggregations of younger pine trees in a grass/shrub matrix (White 1985). Mixed-conifer forests have been classified into two sub-categories: warm/dry and cool/moist mixed-conifer (Romme et al. 2009). Dry mixed-conifer forests are typically located at lower elevations and are dominated by ponderosa pine and Douglas-fir, but can include white fir (*Abies concolor*) and aspen (*Populus tremuloides*) (Korb et al. 2013). Historically, these forests were characterized by large old trees, were relatively open with low trees densities, and had heterogeneous patches of uneven-aged trees (Binkley et al. 2008, Fule et al. 2009). Snag, log, and woody debris abundance was thought to be similar to ponderosa pine forests (Moore et al. 2004). Cool/moist mixed-conifer forests, in comparison, are found at higher elevations and include a greater abundance of Douglas-fir (*Pseudotsuga menziesii*) and other conifers adapted to these conditions (Romme et al. 2009). Cool/moist forests are more spatially heterogeneous regarding patch sizes that differ in tree ages and densities than ponderosa pine and dry mixed-conifer forest types due to a mixed-severity fire regime (Binkley et al. 2008, Fule et al. 2009).

Historically, the fire return interval in Southwestern ponderosa pine ranged from 2-25 years (Swetnam and Baisan 1996, Heyerdahl et al. 2001). Frequent fires in this ecosystem favored shade intolerant, fire resistant tree species, minimal fuel build up, and open forest conditions that promoted productive understory growth (Fule and Laughlin 2007). Pre-settlement mixed-conifer forests (both dry and moist mixed-conifer) were shaped by mixed-severity fire regimes consisting of areas burned by a mix of surface fire and stand-replacing fires occurring in the same event. These forest types contained trees of various ages and a species composition resulting from variation in fire intensity, frequency, and area burned (Fule et al 2003). Pre-settlement dry mixed-conifer forests were historically dominated by ponderosa pine, Douglas-fir, and white fir and had fire return intervals of 4-14 and 18-32 years (similar to ponderosa pine forests) (White and Vankat 1993, Brown et al. 2001, Korb et al. 2013). Historically, moist mixed-conifer forests had sub-decadal to century long fire return intervals upwards of 200 years (White and Vankat 1993, Romme et al. 2009). Moist mixed-conifer forests were characterized by cooler mesic conditions, increased tree density and canopy cover, infrequent intense fires, and fire intolerant overstory trees (White and Vankat 1993). Because of long fire return intervals in high elevation Engelmann spruce-sub-alpine fir landscapes, fire suppression has had little effect on these ecosystems (White and Vankat 1993). Due to more frequent surface fire, dry mixed-conifer forests were more open with groups of small trees similar to ponderosa pine forests (Fule et al. 2003, Romme et al. 2009). Moist higher elevation forests experienced less-frequent moderate- to high-severity fire, but when they burned these created patches (cohorts) of similar-aged trees (Fule et al. 2003, Romme et al. 2009). Alteration of the historic fire regimes, especially in ponderosa pine and dry mixed-conifer forests, resulted in conditions that increasingly favor more frequent and large high-severity wildfires.

How northern goshawks (*Accipiter gentilis*), a sensitive species in most Forest Service Regions, respond to habitat changes due to forest management and disturbances such as fire is of particular interest throughout its range. The goshawk is a large forest dwelling raptor that occupies mature temperate and boreal forests throughout the Holarctic (Squires and Reynolds 1997). Goshawk home ranges vary from

15-30 km² and are generally “fixed” in their locations, with minor yearly fluctuations due to their nesting and foraging requirements (Reynolds et. al. 1994). Goshawks occupy a variety of forest types that are composed of different vertical and horizontal structures. In the Southwest, goshawks typically nest in patches of large trees and hunt, primarily from tree perches, in open sub-canopy spaces, along forest edges, and into herbaceous and shrub openings for medium-sized birds and mammals (Reynolds et al. 1992, 2006, 2013). Nest sites are characterized by mature and old trees and relatively dense canopies that provide protection from predators and environmental extremes. Nest sites comprise < 1% (0.12 km²) of the total goshawk home range and have relatively low vegetative structural diversity compared to forest conditions in their large home ranges, which is used for foraging, roosting, and by juvenile hawks post-fledging (Reynolds et. al. 2006). On the Kaibab Plateau, mature and old forests with open understories are used more often than any other forest age and structural types by breeding goshawks (Bright-Smith and Mannan 1994, Reynolds et al. 2006). Adapted to foraging in the lower vegetation column of forests, a goshawk’s hunting ability is likely impaired when sub-canopy spaces are filled with small trees or tall dense brush (Reynolds and Meslow 1984). Loss of nesting and foraging habitat to high-severity fire lowers survival and nest productivity through loss of prey habitats and subsequent reduced prey abundance. There is a premium for understanding the effects of forest management, including the effects of different fire severities, on goshawk habitat and its population viability as is evidenced by numerous appeals and lawsuits against the Forest Service and multiple petitions to the Fish and Wildlife Service to list the hawk under the Endangered Species Act.

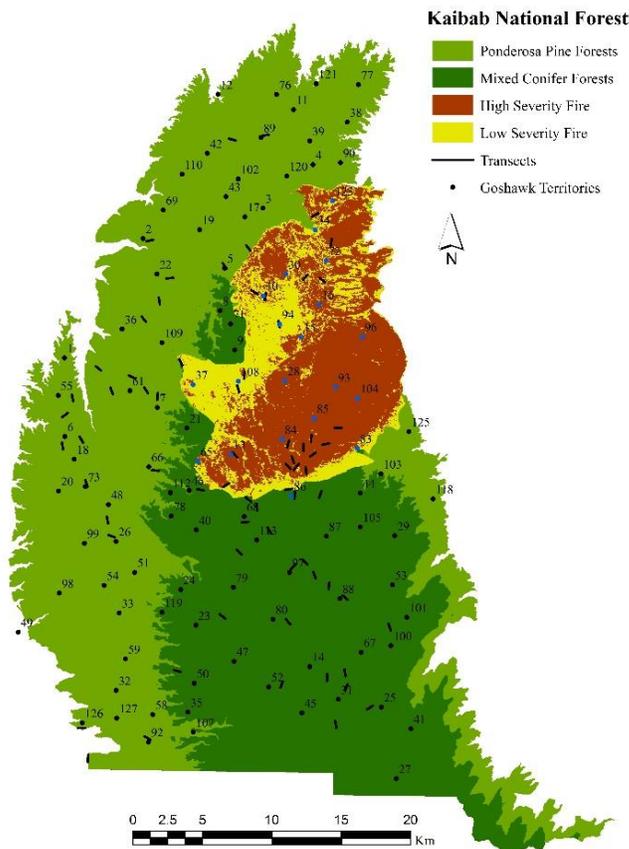
III. STUDY DESCRIPTION

We evaluated how fire severity affected the flora and fauna of the Kaibab Plateau. We conducted surveys of (1) the vegetation composition and structure of post-Warm Fire habitats and (2) estimated bird and mammal abundances in ponderosa pine and mixed-conifer forests on transects in areas unburned, burned at low-severity, and burned at high-severity fire.

Objectives

Assess the influence of low- and high-fire severity compared to no fire on nest survival and productivity of goshawks and the abundance of important goshawk prey in ponderosa pine and mixed-conifer forests.

1) Model the effects of forest structure and fire severity on select bird and mammal species; determine the best model for predicting bird and mammal responses in abundances to different fire severities.



2) Describe and compare the vegetation composition and structure in relation to fire severity in ponderosa pine and mixed-conifer forests.

3) Develop recommendations for using prescribed and fire-use fires for improving a fine-scale mix of prey habitats to support goshawk reproduction at the territorial level. The 1,285 km² study area includes the North Kaibab Ranger District of the Kaibab National Forest above 2,182 m elevation on the Kaibab Plateau in northern Arizona. The figure shows

105 northern goshawk breeding territories, 60 prey count transects and Warm Fire severity (affected territories are in blue). Almost all of the North Kaibab Ranger District had received tree harvests prior to the Warm Fire. Organized tree harvests on the NKRK began in the early 1900s and were primarily limited to cutting dead and dying trees (single-tree selection harvest) (Sesnie and Bailey 2003). In the 1960s, small patch cuts began in higher elevation mixed-conifer forests, but were discontinued in the early 1970s. In the 1980s intensive stand management using shelterwood/seed-tree cuts occurred to create even-aged forest patches in ponderosa and mixed-conifer forests, but by the early 1990s this protocol was discontinued (Sesnie and Bailey 2003). While pre-1960s selection harvests occurred over much of the NKRK, intensive stand management occurred in scattered patches of 0.12-0.16 ha on the Kaibab Plateau (Sesnie and Bailey 2003).

Sampling Design

To evaluate the effects of the 2006 Warm Fire on habitat composition and structure and associated prey species, we measured vegetation composition and structure and conducted bird and mammal counts on 60 transects placed in six strata (unburned, low-severity, and high-severity fire in ponderosa pine and mixed-conifer forests that had previously been treated with two different silvicultural prescription, single-tree harvested and shelter-wood/seed-tree harvest) over 4 post-fire years (2007-10). We sampled a total of 60 0.5km transects; 40 in unburned forest (23 in ponderosa pine, 17 in mixed-conifer), 8 burned by low-severity fire (4 in ponderosa pine, 4 in mixed-conifer), and 12 burned by high-severity fire (3 in ponderosa pine, 9 in mixed-conifer) (Table 1).

The 11 new transects we established were located and classified to fire severity level using Warm Fire vegetation burn severity maps (North Kaibab Ranger District 2007). Transect width varied by the detectability specific to each bird and mammal species and reflected the criteria used in the Salafsky (2004) study. Each transect consisted of 11 reference stakes marked at 50 meter intervals, four of which were randomly selected along each transect to serve as center points for vegetation plots. For the 20 goshawk territories impacted by the Warm fire (Figure 1, blue markings), the percentage of area burned at

high- and low-severity was determined for each territory using vegetation burn severity maps from the North Kaibab Ranger District (2007).

Vegetation Sampling

We determined the mean density of live trees and snags per km², tree canopy cover estimates (using a spherical densitometer), cone counts (to estimate cone productivity and index potential food for birds and mammals), understory ground cover measurements (from 20m radius plots on each transect), and the numbers of sapling (conifer and aspen ≥ 1.5 m in height and ≤ 10 cm dbh) for each plot.

Prey Sampling

From 2007-2010, we conducted distance sampling to estimate the abundance of bird and mammal species commonly found in goshawk diets on the Kaibab Plateau (Reynolds et al. 1994, Salafsky et al. 2005). We conducted counts on 0.5km line transects following assumptions and sampling protocols in Buckland et al. (2001) and procedures used by Salafsky (2004). We sampled each transect once in 2007 (late summer) then twice (early summer and late summer) annually from 2008-2010. Early summer counts occurred between 28 May and 24 June and late summer counts between 23 July and 14 August.

Goshawk Productivity

We used a within territory multi-step nest search protocol to assess goshawk territory activity on all 126 known goshawk territories (including the 20 affected by the Warm Fire) on the North Kaibab Ranger District (and in the Grand Canyon National Park). Territories received three classifications: “active” if females were observed in incubation posture or when eggs, egg fragments, nestlings, or fledglings were observed; “occupied only” when goshawks or their molted feathers were observed in a nest area on ≥ 2 occasions in a season but eggs were not laid; or of “unknown” status if none of the above criteria were met. Weekly visits were made to each “active” nest to monitor its status and follow the progression of nestling/ fledgling development. Final fledgling productivity for each territory was officially recorded as the number of young in or near the natal nest on the day the nest tree was climbed to band the young (typically >19 days post-hatching).

IV. KEY FINDINGS

Vegetation Composition and Structure

A. Tree density and canopy cover

Relative to no-burn and low-severity fire, total live tree density, large (>20cm dbh) live tree density, canopy cover, and conifer cone production were, as expected, lower in both ponderosa pine and mixed-conifer forests burned at high severity. The total and large (>20cm dbh) snag densities in high severity burns were higher in both ponderosa pine and in mixed-conifer forests than in low severity and unburned forests; however, these means were significantly different only for total snags in mixed-conifer and large snags in ponderosa pine. Although there were wider ranges of total live trees and canopy cover in unburned versus low-severity burn in both forest types, there were no significant differences in mean numbers of total and large live trees, and canopy cover from unburned forests. In ponderosa pine forests, densities of total and large snags were significantly higher in low severity versus unburned forests, but not in mixed-conifer.

B. Ground Cover

The percentage of live ground cover was greater on mixed-conifer transects burned by high-severity fire compared to low-severity fire and unburned transects. In contrast, there was no significant difference in the percentage of ground cover when ponderosa pine forests were compared across fire severities. The dominant flora (forbs and shrubs) found on transects were identified to species and reported by forest type and fire severity.

C. Sapling regeneration

There were more saplings in the 20m radius plots in mixed-conifer and ponderosa pine forest burned by high-severity fire than in low-severity. There were more saplings in mixed-conifer forests burned by high-severity fire than in unburned forests, but there were no significant difference between

pine forests burned by high-severity fire versus unburned. There were also fewer saplings in mixed-conifer and ponderosa pine transects burned by low-severity fire compared to unburned forest transects.

D. Cone Productivity

Mixed-conifer and ponderosa pine transects burned by high-severity fire had significantly fewer cones than low-severity fire and unburned transects. No significant difference in the number of cones were found along transects burned by low-severity fire versus unburned transects.

Effects of forest structure and fire severity on birds and mammals.

A. Prey Abundance

A total of 17 bird and mammal species were observed at least once during the four study years (Table 1). Of the seven species with ≥ 60 observations per year, the hairy woodpecker (high/low: not significant, high/unburned: $p < .01$) and northern flicker (high/low: $p = .02$, high/unburned: $p = .05$) were the only species that were more abundant in burned than unburned forests. In contrast, golden-mantled ground squirrels were less abundant in burned (high-severity: $p < .01$, low-severity: $p = .03$) than unburned forests. Similarly, red squirrels were less abundant in forests burned by high-severity fire than low-severity and unburned forests (low: $p < .01$, unburned: $p < .01$). Our models suggested that American robin, chipmunk, and Steller's jay abundances were similar in burned and unburned forests.

Table 1. Species count data and Warm Fire severity, North Kaibab Ranger District, Arizona.

<i>Species Common Name</i>	Species Counts by Fire Severity											
	High				Low				Unburned			
	2007	2008	2009	2010	2007	2008	2009	2010	2007	2008	2009	2010
American Robin	0	29	79	29	3	0	12	10	27	60	53	92
Black-tailed Jackrabbit	0	0	0	0	0	0	0	0	0	0	0	0
Blue Grouse	0	0	0	0	0	0	0	0	1	0	0	1
Chipmunk spp.	1	1	11	20	13	11	16	19	38	78	76	92
Clark's Nutcracker	1	23	7	3	4	0	2	2	21	17	7	3
Cottontail Rabbit	0	0	0	0	0	0	0	0	0	0	1	1
Downy Woodpecker	6	10	5	0	2	2	2	6	12	4	5	3
Golden-mantled Ground Sqr.	0	1	1	5	6	3	7	12	25	56	98	106
Hairy Woodpecker	37	51	39	21	19	22	33	13	41	38	39	20
Kaibab Squirrel	0	0	1	0	2	4	1	4	7	20	8	11
Mourning Dove	5	3	14	0	0	1	4	0	8	14	7	7
Northern Flicker	51	52	102	54	25	23	26	19	154	141	170	145
Red-naped Sapsucker	0	0	0	0	0	0	0	0	4	0	0	0
Red Squirrel	0	1	2	1	6	10	29	32	127	83	123	118
Rock Squirrel	0	0	0	0	0	0	0	0	0	0	0	2
Steller's Jay	5	8	18	2	8	6	10	9	46	45	50	45
Three-toed Woodpecker	0	4	2	1	0	0	1	2	5	0	4	4
Williamson's Sapsucker	0	0	0	0	0	1	2	0	6	12	7	7

Count data for 2007 only includes one late summer sample period while 2008-2010 included two sample periods.

Mammals - Red squirrel and golden-mantled ground squirrel abundances were lower in areas burned by high-severity fire, likely due to the loss of cone producing large live trees, nesting, and denning sites (woody debris, logs, stumps, live tree nests), food resources (e.g., conifer cone middens, herbaceous plants), and live tree canopy. Low-severity fire, that consumed ground fuels and reduced tree regeneration, can benefit many mammals by restoring the composition, structure, and fine-scale habitat patchiness, including snags, logs, and woody debris, that typified ponderosa pine and mixed-conifer forests before fire suppression (Carey and Harrington 2001, Covington and Moore 1994, Kennedy and Fontaine 2009, Kalies et al. 2012, Larson and Churchill 2012, Reynolds et al. 2013). These and other studies have shown wildlife respond favorably to habitat patchiness and diversity (tree, shrub, and grass/forb cover) created by low-severity ground fires (Allen et al. 1982, Schroeder 1984, Reynolds et al. 1992, Kalies et al. 2012). While golden-mantled ground squirrel abundances were lower in areas burned by low-severity fire, chipmunks and red squirrels were found in similar abundances compared to unburned forests. Restoration of vegetation composition and pattern driven by regular low-severity ground fire, therefore, could have both short and long-term benefits for mammal communities in mixed-conifer and ponderosa pine forests on the Kaibab Plateau, while causing minimal impact on some species.

Birds-We found that Hairy woodpeckers and Northern flickers responded favorably to high-severity fire during the four years of study. The abundance of northern flickers, a cavity nester, was associated with decreased canopy cover and increased ground cover; responses that were not unexpected because this woodpecker forages in openings associated with both burned and unburned open-canopied forests (Kotliar et al 2007). The effects of low-severity fire on avian abundances were mixed. Of the four bird species we were able to model; hairy woodpecker and northern flickers were the only species to show a positive relationship to high- (and low-: hairy woodpeckers) severity fire. American robins and Steller's jay's abundances were similar in burned and unburned forests in this study, probably due to their foraging and dietary preferences: grass, forb, and shrub openings that are found in unburned areas as well

as regenerated burned areas (Greene et al. 1998, Sackett and Haase 1998, Kotliar et al 2007, George and Zack 2008).

Effects of fire severity on goshawk breeding.

A. Goshawk breeding and productivity

The effects of high-severity, crown-killing fire on goshawk reproduction, depended on the proportion of territories burned (Table 2). Territories that lost more than 75% of forests to moderate- and high-severity fire were never re-occupied by breeders. Of territories that lost between 50-75% of their forests to moderate- and high-severity fires, only 43% had active nests in post-fire years. Post-fire re-occupancy of a burned territory appeared to depend on whether at least 1 alternate nest area within the territory escaped high-severity fire; some pairs reused unburned or partially-burned nest areas while others moved up to 1.7 km to unburned nest areas. Low-severity surface fire in nest areas as well as in all or large portions of surrounding territories had little or no effect on fire-year reproduction or future occupancy by breeders. The lack of low-severity fire effects in active nest areas on the production of fledglings was also observed in numerous prescribed low-severity surface fires in nest areas that were intended to reduce ladder-fuels on the NKRD (R.T Reynolds, Rocky Mountain Research Station, unpublished data).

Table 2. Breeding status of northern goshawk territories in the 2006 Warm Fire and the percentage of area burned by severity.

Territory	Fire Severity		2006 (Warm Fire)		2007		2008		2009		2010		2011	
	% High	% Low	Status	Fledged	Status	Fledged	Status	Fledged	Status	Fledged	Status	Fledged	Status	Fledged
93	100	0	Unk		Unk		Unk		Unk		Unk		Unk	
104	100	0	A	2	Unk		Unk		Unk		Unk		Unk	
85	99	1	Unk		Unk		Unk		Unk		Unk		Unk	
84	96	1	Unk		Unk		Unk		Unk		Unk		Unk	
96	94	3	A	1	Unk		Unk		Unk		Unk		Unk	
28	75	7	Unk		Unk		Unk		Unk		Unk		Unk	
72	64	5	Unk		Unk		Unk		Unk		Unk		Unk	
13	63	14	A	1 ^a	Unk		A(f)	0 ^b	Occ		Unk		Unk	
16	59	9	Unk		Occ		Unk		Unk		Unk		Unk	
30	58	4	A	2	A	3	A	1	Unk		Unk		Unk	
123	53	2	Unk		Unk		Unk		Unk		A	1	Unk	
34	52	5	Unk		Unk		Unk		Unk		Unk		Unk	
15	49	23	Unk		Unk		Unk		Unk		Unk		Unk	
83	49	0	A	3	Unk		A	1	A(f)	0	A	1	Unk	
10	39	16	A	1	Unk		A(f)	0	A	2	Occ		Unk	
65	19	6	A	1	A	2	A	1	A	1	A	2	Unk	
86	13	15	Unk		A(f)	0	Unk		Unk		A	2	Unk	
94	12	48	Unk		Unk		Unk		A	1	A	1	A	2
108	10	50	A	3	Occ		A(f)	0	Occ		A	1	A	2
37	0	51	A	3	Unk		Unk		Unk		Unk		Unk	

Active (A): Active and young fledged; (f): Territory failed, no young fledged

Occupied (Occ): Presence of goshawks on multiple occasions, no breeding took place.

Unknown (Unk): No breeding activities observed.

a: KG 13 2006: One young died in the fire before banding occurred

b: KG 13 2008: Dead female found under nest after being seen incubating

V. MANAGEMENT IMPLICATIONS

Fire and habitat management

Fire is the most important natural disturbance in southwestern pine and mixed-conifer forests. Frequent, low-severity surface fire was part of the evolutionary history of ponderosa pine and dry mixed-conifer plants and animals. Frequent low severity surface fire in these forest types maintained an open grass-forb-shrub matrix and a spatial pattern of trees aggregated into clumps, groups, and patches, with scattered individual trees. Both the tree species composition (fire-tolerant and shade-intolerant trees) and spatial pattern resulted from a feed-back between fire and vegetation. Frequent surface fire resulted in a characteristic composition and structure that in turn supported a low severity, surface fire regime. This historical composition and structure manifested in a fine-scale (<4ha), highly interspersed mix of habitats (grass-forb-shrub vegetation), dense groups of trees with interlocking crowns, snags, logs, and woody debris; that supported a variety of bird and mammal species (rabbits, ground squirrels, grouse, turkeys, and tree squirrels). A fine-scale diversity of habitats supports the full component of prey species at the goshawk territory level. Total prey abundances is an important covariate associated with goshawk fecundity. Having a full component of prey species at the territory level during La Niña droughts may ameliorate lows in prey abundance on goshawk fecundity because each prey species is likely to have different responses to drought—species' abundance losses may be buffered by others whose responses are not as extensive or are out of phase .

Each of the seven species (four birds, three mammals) with sufficient numbers of detections to model responded to fire or lack of fire in a variety of ways. Low-severity fire was significantly detrimental to only golden-mantled ground squirrels while chipmunks, robin, and Steller's jays showed no difference in abundance across the three burn strata. Furthermore, red squirrel and golden-mantled ground squirrel showed negative responses to high-severity fire while two other species (hairy woodpeckers, northern flickers) showed positive responses to high-severity fire: at least in the four years

studied. Our results suggested that high-severity fire on the North Kaibab Ranger District could be more detrimental to the larger suite of important goshawk prey than low-severity burns.

While knowledge of the effects of low-severity fire on birds and mammals in ponderosa pine and mixed-conifer is increasing, more information is needed to provide robust management recommendations. Nonetheless, during the last century vegetative species composition and structure in southwestern forests has changed to fire intolerant and shade tolerant tree species where forest openings are overgrown. Heavy accumulations of ground and ladder fuels, and increased frequencies and sizes of stand-replacement fires also characterize these forests (Cooper 1960, Covington and Moore 1994). Grass-forb-shrub vegetation productivity, biodiversity, and bird and mammal habitats have also declined due to tree shading and increased habitat homogeneity (Kalies et al. 2012, Reynolds et al. 2013). In response, there is a demand for restoring the historical species compositions, structures, and fine-scale spatial patterns, which facilitate the return of low-severity fire regimes and habitat heterogeneity that characterized the evolutionary environment of native plants and animals in these forests (Larson and Churchill 2012, Reynolds et al. 2013). While species detectability limited our ability to estimate abundances to a small sample of the suite of species in Kaibab goshawk diets, low-severity fire was found to benefit or have a neutral impact on many of species in this study. Restoration of a fine-scale mix of habitats (small tree groups interspersed within a grass-forb-shrub matrix, snags, and logs) are needed to support populations of the majority of bird and mammals important to many food webs.

VI. FUTURE WORK NEEDED

What we did not consider in this study was the effects of past forest management on the predictive models. During the past century, nearly the entire North Kaibab Ranger District received single tree harvests. In the 1960s through 1990 more intensive management was introduced including small < 4ha clearcuts and 12-16 ha shelterwood/seed tree harvests (Sesnie and Bailey 2003). We attempted to establish a sample of transects in the three burn/no burn categories in order to equally sample the most ubiquitous past tree harvesting prescriptions, single-tree and seed-tree, on the North Kaibab Ranger District. Unfortunately, due to the specific location of the Warm Fire, several burn severity areas did not contain equal areas of these management prescriptions suitable for situating transects; achieving a balance of management prescription by forest type was not possible. Given the differences in tree densities in single-tree harvested areas versus seed-tree harvested areas, one might expect some corresponding differences in bird and mammal abundances in the two treatments. The extent to which treating the two prescriptions as one on our final abundance estimates is unknown without further examination.

VII. DELIVERABLES CROSS-WALK

Proposed	Delivered	Status
Case study framework and plant and animal responses	Lambert and Reynolds (manuscript), Pre- and post-fire effects of the 2006 Warm Fire on goshawks and their prey	(1) In review
Lessons Learned	(1)Reynolds et al. Restoring composition and structure in Southwestern frequent-fire forests: a science-based framework for improving ecosystem resiliency (USDA Forest Service, Rocky Mountain Research Station, GTR-310) (2)Graham et al. Northern goshawk and its prey in the Black Hills: habitat assessment (USDA Forest Service, Rocky Mountain Research Station, GTR-339) (3)Reynolds et al. Long-term Demography of the Northern Goshawk in a Variable Environment. Wildlife Monographs.	(1) In print (2) In print (3) In Review
Regional <i>Lessons Learned</i> Workshops	(1)Multiple (2013-2015) knowledge transfer and tree marking workshops for restoring frequent-fire forests habitats and providing for the return of low-severity frequent return fire regime	(1)Completed
Refereed and tech transfer publications and guides documenting lessons learned	(1)One MS thesis	Completed document posted on JFSP website
Other miscellaneous presentation, workshops	(1)Multiple university lectures on Lessons learned. Numerous presentations to public organizations. (2)Knowledge transfer and training workshops to landowners in collaboration with NRCS	(1)Completed (2)In progress

VIII. LITERATURE CITED

- Agee, J.K., 1993. *Fire Ecology of Pacific Northwestern Forests*. Washington, DC: Island Press.
- Allen, S.A., Lancia, R.A., Betsill, C.W., 1982. Habitat preferences of cottontail rabbits in an intensive farm and a traditional farm. *Annual Conference Southeast Fish and Wildlife Agencies* 36, 614-626.
- Binkley, D., Romme, B., Cheng, T., 2008. Historical forest structure on the Uncompahgre Plateau: Informing restoration prescriptions for mountainside stewardship. Colorado State University, Colorado Forest Restoration Institute, Fort Collins, Colorado, USA.
- Bright-Smith, D.J., Mannan, R.W., 1994. Habitat use by breeding male Northern Goshawks in Northern Arizona. *Studies in Avian Biology* 16, 58-65.
- Brown, D.E., (editor). 1994. *Biotic communities: southwestern United States and northwestern Mexico*. University of Utah Press, Salt Lake City, Utah.
- Brown, P.M., Kaye, M.W., Huckaby, L., Baisan, C., 2001. Fire history along environmental gradients in the Sacramento Mountains, New Mexico: Influences of local patterns and regional processes. *Ecoscience* 8, 115-126.
- Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., Thomas, L., 2001. *Introduction to Distance Sampling*, Oxford: Oxford University Press.
- Carey, A.B., Harrington, C.A., 2001. Small mammals in young forests: implications for management for sustainability. *Forest Ecology and Management*. 65(4), 1014-1027.
- Cooper, C.F., 1960. Changes in vegetation, structure, and growth of southwest pine forests since white settlement. *Ecological Monographs* 30, 129-164.
- Covington, W.W., Moore, M.M., 1994. Southwestern ponderosa forest structure: Changes since Euro-American settlement. *Journal of Forestry* 92(1), 39-47.
- Fule, P.Z., Laughlin, D.C., 2007. Wildland fire effects on forest structure over an altitudinal gradient, Grand Canyon National Park, USA. *Journal of Applied Ecology* 44, 136-146.
- Fule, P.Z., Covington, W.W., Moore, M.M., 1997. Determining reference conditions for ecosystem management of southwestern ponderosa pine forests. *Ecological Applications* 7, 895-908.
- Fule, P.Z., Korb, J.E., Wu, R., 2009. Changes in forest structure of a mixed-conifer forest, southwestern Colorado, USA. *Forest Ecology and Management* 258(7), 1200-1210.
- Fule, P.Z., Heinlein, T.A., Covington, W.W., Moore, M.M., 2000. Continuing fire regimes in remote forests of Grand Canyon National Park. In 'Proceedings: Wilderness science in a time of change' (Eds. DN Cole and SF McCool) Pp 242-248. Report RMRS-P-15. In: USDA Forest Service Rocky Mountain Research Station, Ogden, Utah, USA.

- Fule, P.Z., Crouse, J.E., Heinlein, T.A., Moore, M.M., Covington, W.W., VanKamp, G., 2003. Mixed-severity fire regime in high-elevation forest of the Grand Canyon, Arizona, USA. *Landscape Ecology* 18, 465-486.
- George, T.L, Zack, S., 2008. Bird occupancy and richness in ponderosa forests with contrasting forest structure and fire history. *Canadian journal of Forest Research* 38(5), 936-942.
- Greene, E., Davison, W., Muehter, V.R., 1998. Steller's jay (*Cyanocitta stelleri*). In *The Birds of North America*, No. 343 (A. Poole, Ed). The Birds of North America Online, Ithaca, New York.
- Heyerdahl, E.K., Brubaker, L.B., Agee, J.K., 2001. Spatial controls of historical fire regimes: A multi-scale example from the interior west, USA. *Ecology* 82, 660-678.
- Kalies, E.L., Dickson, B.G., Chambers, C.L., Covington, W.W., 2012. Community occupancy responses of small mammals to restoration treatments in ponderosa pine forests, northern Arizona, USA. *Ecological Applications* 22(1), 204-217.
- Kennedy, P.L., Fontaine, J.B., 2009. Synthesis of knowledge of the effects of fire and fire surrogates on wildlife in U.S. dry forests. Special Report 1096. Oregon State University Extension Service, Corvallis, Oregon, USA.
- Korb, J.E., Fule, P.Z., Wu, R., 2013. Variability of warm/dry mixed conifer forests in southwestern Colorado, USA: Implications for ecological restoration. *Forest Ecology and Management* 304, 182-191.
- Kotliar, N.B., Kennedy, P.L., Ferree, K., 2007. Avifaunal responses to fire in southwestern montane forests along a burn severity gradient. *Ecological Applications* 17(2), 491-507.
- Larson, A.J., Churchill, D., 2012. Tree Spatial Patterns in fire-frequent forests of western North America, including mechanisms of pattern formation and implications for designing fuel reduction and restoration treatments. *Forest Ecology and Management* 267, 74-92.
- Moore, M.M., Covington, W.W., Fule, P.Z., 1999. Evolutionary environment, reference conditions, and ecological restoration: A southwestern ponderosa pine perspective. *Ecological Applications* 9, 1266-1277.
- North Kaibab Ranger District, 2007. Warm Fire Vegetation Burn Severity Maps. USDA Forest Service, North Kaibab Ranger District, Kaibab National Forest, Fredonia, AZ.
- Reynolds, R.T., Meslow, E.C., 1984. Partitioning of food and niche characteristics of coexisting Accipiter in Oregon. *Journal of Wildlife Management* 46, 124-138.
- Reynolds, R.T., Wiens, J.D., Salafsky, S.R., 2006. A review and evaluation of factors limiting Northern Goshawk populations. *Studies in Avian Biology* 31, 260-273.
- Reynolds, R.T., Joy, S.M., Leslie, D.G., 1994. Nest productivity, fidelity, and spacing of Northern Goshawks in Arizona. *Studies in Avian Biology* 16, 106-113.
- Reynolds, R.T., Sanchez Meador, A.J., Youtz, J.A., Nicolet, T., Matonis, M.S., Jackson, P.L., DeLorenzo, D.G., Graves, A.D., 2013. Restoring Composition and Structure in Southwestern Frequent-Fire

- Forests: A science-based framework for improving ecosystem resiliency. General Technical Report RMRS-GTR-310. In: USDA Forest Service Rocky Mountain Research Station, Fort Collins, Colorado, USA.
- Reynolds, R.T., Graham, R.T., Reiser, M.H., Bassett, R.L., Kennedy, P.L., Boyce Jr., D.A., Goodwin, G., Smith, R., Fisher, E.L., 1992. Management Recommendations for the Northern Goshawk in the Southwestern United States. General Technical Report RMRS-GTR-217. In: USDA Forest Service Rocky Mountain Research Station, Fort Collins, Colorado, USA.
- Romme, W.H., Floyd, M.L., Hanna, D., 2009. Historical range of variability and current landscape conditions analysis: South Central Highlands Section, Southwestern Colorado & Northwestern New Mexico. Colorado State University, Colorado Forest Restoration Institute, Fort Collins, CO, and USDA Forest Service, Rocky Mountain Region, Golden, CO.
- Sackett, S.S., Haase, S.M., 1998. Two case histories for using prescribed fire to restore ponderosa pine ecosystems in Northern Arizona. Pp 380-389 in T.L. Pruden and L.A. Brennan (eds.). Fire in Ecosystem Management: Shifting the Paradigm from Suppression to Prescription. Proceedings of the 20th Tall Timbers Fire Ecology Conference, 7-10 May 1996, Boise, ID. Tall Timbers Research Station. Tallahassee, Florida, USA.
- [Salafsky, S. R.](#), 2004. Covariation between prey abundance and northern goshawk fecundity on the Kaibab Plateau, Arizona. M.S. Thesis, Colorado State University, Fort Collins, Colorado, USA.
- [Salafsky, S. R.](#), [R. T. Reynolds](#), Noon, B.R., 2005. Patterns of temporal variation in goshawk reproduction and prey resources. *Journal of Raptor Research* 39(3), 237–246.
- Schroeder, R.L., 1984. Habitat suitability index models: blue grouse. Washington: U.S. Fish and Wildlife Service, U.S. Department of the Interior. FWS/OBS-82/10.81.
- Sesnie, S., Bailey, J., 2003. Using history to plan the future of old-growth ponderosa pine. *Journal of Forestry* 101, 40-47.
- Squires, J.R., Reynolds, R.T., 1997. Northern Goshawk (*Accipiter gentilis*). In A. Poole and F.Gill (EDS.). *The birds of North America*, No. 298. The Birds of North America Inc., Philadelphia, PA, USA.
- Swetnam, T.W., Baisan, C.H., 1996. Historical fire regime patterns in the southwestern United States since AD 1700. Pp. 11-32 in C.D. Allen (ed.). 2nd La Mesa Fire Symposium; Los Alamos, NM. General Technical Report RM-GTR-286. USDA Forest Service Rocky Mountain Research Station, Fort Collins, Colorado, USA.
- White, A.S., 1985. Pre-settlement regeneration patterns in a Southwestern ponderosa pine stand. *Ecology* 66, 589-594.
- White, M.A., VanKat, J.L., 1993. Middle and high elevation coniferous forest communities of the North Rim region of Grand Canyon National Park, Arizona, USA. *Vegetatio* 109, 161-174.

IX. ADDITIONAL REPORTINGS

Publications in Print

Graham, R.T., Bayard de Volo, S., Reynolds, R.T., 2015. Northern Goshawk and Its Prey in the Black Hills: Habitat Assessment. General Technical Report RMRS-GTR-339. In USDA Forest Service Rocky Mountain Research Station, Fort Collins, Colorado, USA.

Reynolds, R.T., Sanchez Meador, A.J., Youtz, J.A., Nicolet, T., Matonis, M.S., Jackson, P.L., DeLorenzo, D.G., Graves, A.D., 2013. Restoring Composition and Structure in Southwestern Frequent-Fire Forests: A science-based framework for improving ecosystem resiliency. General Technical Report RMRS-GTR-310. In: USDA Forest Service Rocky Mountain Research Station, Fort Collins, Colorado, USA.

Graduate Education

Lambert, J. 2015. The 2006 Warm Fire: Effects on Habitat and Prey Species of the Northern Goshawk. M.S. Thesis, Colorado State University, Fort Collins, CO.

Publications in review

Reynolds, R.T., Lambert, J.S., White, G.C., Lambert, C., Flather, C.H., Bayard de Volo, S., Battett, L.S., Bird, B.J., (in review). Long-term Demography of the Northern Goshawk in a Variable Environment. Wildlife Monographs.

Lambert, J.S., Reynolds, R.T., (in prep). Pre- and Post-fire effects of the 2006 Warm Fire on goshawks and their prey.