EFFECTS OF FIRE ON GOLDEN EAGLE TERRITORY OCCUPANCY AND REPRODUCTIVE SUCCESS

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Abstract: We examined effects of fire on golden eagle (*Aquila chrysaetos*) territory occupancy and reproductive success in southwestern Idaho because wildfires since 1980 have resulted in large-scale losses of shrub habitat in the Snake River Plain. Success (percentage of pairs that raised young) at burned territories declined after major fires ($P = 0.004$). Pairs in burned areas that could expand into adjacent vacant territories were as successful as pairs in unburned territories and more successful than pairs in burned territories that could not expand. Success at extensively burned territories was lowest 4–6 years after burning but increased 4–5 years later. The incidence and extent of fires did not help predict territories that would have low occupancy and success rates in postburn years. The presence of a vacant neighboring territory and the amount of agriculture and proportion of shrubs within 3 km of the nesting centroid best predicted probability of territory occupancy. Nesting success during preburn years best predicted the probability of a territory being successful in postburn years. Burned territories with high success rates during preburn years continued to have high success rates during postburn years, and those with low success in preburn years continued to be less successful after burning. In areas where much shrub habitat has been lost to fire, management for golden eagles should include active fire suppression and rehabilitation of burned areas.

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Most raptor studies have focused on immediate or short-term responses of wintering or foraging raptors to fire (Komarek 1969, Smallwood et al. 1982, Tewes 1984, Chavez-Ramirez and Prieto 1994); long-term effects of fire on nesting raptors are poorly understood. Watson et al. (1987) predicted that burning may reduce golden eagle prey by eliminating shrub habitat. Predictions about the effects of fire or other habitat alteration on breeding raptor populations are complicated by the interaction between habitat quality and attributes of the pair (Newton 1991, 1992). Nesting success depends not only on habitat but also on the individuals that live there.

Golden eagles typically use and defend a group of 1–13 nests and a surrounding hunting range collectively known as a "territory" (Watson 1997). Golden eagles occupy territories year-round in southwestern Idaho, and the same individuals tend to occupy the same territory year after year (Marzluff et al. 1997, Watson 1997). Golden eagles nesting in southwestern Idaho prey primarily on black-tailed jackrabbits (*Lepus californicus*; Steenhof and Kochert 1988), and golden eagle reproduction is closely tied to jackrabbit abundance (Steenhof et al. 1997). Black-tailed jackrabbits in southwestern Idaho are associated with shrub habitats, and jackrabbit densities are low in disturbed grassland habitats (Smith and Nydegger 1985, Knick and Dyer 1997). In the early 1980s, wildfires in southwestern Idaho burned vast areas of shrubs, resulting in large stands of exotic annual grasses (primarily cheatgrass [*Bromus tectorum*]) and forbs. The reduction in black-tailed jackrabbit habitat within the foraging areas of nesting golden eagles provided a unique opportunity to study long-term effects of fire on occupancy and nesting success of golden eagles.

In this paper, we examine 24 years of data on golden eagle territory occupancy and reproductive success in relation to the occurrence of wildfires. Because of the relation between black-tailed jackrabbits and shrub habitats, and the dependence of golden eagles on jackrabbits,

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we predicted that large-scale losses of shrub habitat due to fire would adversely affect nesting golden eagles. We hypothesized that burned territories would have lower occupancy and success rates than unburned territories, and success and occupancy would be related positively to abundance of remaining shrubs.

STUDY AREA

The study area consisted of the 196,225-ha Snake River Birds of Prey National Conservation Area (NCA) in southwestern Idaho (42°50′ N, 115°50′ W). The principal physiographic feature of the study area is the Snake River Canyon, with basalt cliffs ranging from 2 to 125 m in height. Topography above the canyon is generally flat or slightly rolling, with a few isolated buttes. Annual precipitation averages 20 cm and occurs mainly in winter; summers are hot and dry. Native vegetation in the area is characteristic of a shrub-steppe community, with big sagebrush (*Artemisia tridentata*), shadscale (*Atriplex confertifolia*), and winterfat (*Krascheninnikovia lanata*) vegetation associations (U.S. Department of the Interior 1979, 1996). Wildfire destroyed approximately 50% of the shrub cover in the NCA from 1981 to 1985 (Kochert and Pellant 1986). Thus, for this paper, we defined preburn years as 1971–81 and the postburn years as 1986–94.

METHODS

Nesting Population Surveys

Beecham (1970) and Kochert (1972) had identified nearly all of the 36 historical golden eagle nesting territories in the NCA when our study began. From 1971 to 1994, we searched all historical golden eagle territories within the NCA for nesting activity at least twice during each nesting season. We searched on foot and from boats, ground vehicles, fixed-winged aircraft, and helicopters, and we subsequently surveyed territories from the ground if reproductive outcome could not be determined from aircraft (Steenhof et al. 1997).

Occupancy and Reproductive Success

We monitored reproductive activity at all historical golden eagle nesting territories each year from 1971 to 1994 (Steenhof et al. 1997). We categorized territories that showed signs of territorial activity, courtship, brood-rearing activity, eggs, young, or any other conspicuous field sign (decorated nests, roosts, etc.) as "occupied." A "successful" territory produced ≥1 young that reached 51 days of age (80% of normal fledging age; Steenhof 1987). Unoccupied (vacant) territories were considered unsuccessful when we calculated success. Some golden eagle nests (<10) that contained known nesting attempts, but were inspected after young had fledged, were considered successful if (1) a nest platform decorated the same year was worn flat and contained fresh prey remains, (2) fresh fecal matter covered the back and extended over the nest's edge, and (3) no dead young birds were found within 50 m of the nest (Steenhof and Kochert 1982). Estimates of preburn nesting success excluded some nesting attempts where researchers may have influenced the outcome of a nesting attempt in a given year by treating diseased young, installing shade devices, or transplanting young in or out of nests (<15% of nesting attempts), or where investigators were known to have caused egg or chick mortality ($n = 6$).

Habitat Assessments

We assessed habitat and disturbance characteristics within 3 km of the nesting centroid of each historical territory ($n = 36$). Similar to the "range centre" reported by McGrady et al. (1997), the nesting centroid was the average of the Universal Transverse Mercator coordinates for all nests in which golden eagles from a particular territory laid eggs from 1971 to 1994. Coordinates of nests used more than once were entered into the calculations for each year the nest was used.

We defined the area within 3 km of the nesting centroid as a "proximity ring" (Steenhof 1982) and believe it provides a reasonable estimate of the exposure of golden eagle territories to burning. The proximity ring formed by this radius encompassed most of the distances traveled from the nest during the breeding season by radiotagged pairs and included mean distance traveled from nests during the nonbreeding (3 km) and breeding (1 km) seasons, as well as the average size of their 95% core use areas (Marzluff et al. 1997). The amount of burned area within the home ranges of 9 radiotagged golden eagle pairs studied by Marzluff et al. (1997) correlated positively with the amount of burned area within their proximity rings (Spearman rank $r = 0.93$, $P < 0.001$).

We overlaid the proximity rings for the 36 territories on habitat and disturbance layers in a Geographic Information System (GIS). The layers depicted burns, 1979 and 1994 vegetation types, and agriculture. The burn layer was digitized from 1:24,000-scale U.S. Geological Survey topographic maps depicting boundaries of fires that occurred from 1950 to 1994 (U.S. Department of the Interior 1996). The 1979 vegetation map was developed via visual interpretation of low-level aerial photographs and field verification of vegetation stands (U.S. Department of the Interior 1979), and the 1994 vegetation map was developed via supervised classification of Landsat thematic mapper satellite imagery (Knick et al. 1997). The agricultural layer depicted all agricultural lands, including fallow fields, and was a composite of the 1979 and 1994 vegetation layers and 1993 U.S. Bureau of Reclamation agricultural maps (U.S. Department of the Interior 1996).

We computed the area of each habitat and disturbance characteristic within each proximity ring. We calculated the proportion of area that burned each year and the total proportion burned since 1950, excluding areas that reburned. We used the 1994 NCA vegetation map to determine the percentage of area covered by shrubs in postburn years.

Statistical Analyses

Because specific pre- and postburn years varied by territory and annual success rates of golden eagles vary significantly with prey and weather conditions (Steenhof et al. 1997), we adjusted for "year effect" in pre- and postburn analyses. We evaluated occupancy and success of each burned territory during years before and after it burned, relative to the 9 unburned territories in the same corresponding years. We computed standardized scores for each territory during both the preburn and postburn periods. Standardized scores were the difference between mean occupancy or success for the burned territory during the particular time period and mean occupancy or success for the 9 unburned territories during the same years. For example, mean preburn nesting success for the Commeford territory from 1971 to 1983 was 75.0%, while mean success for all unburned territories during the same years was 50.5%. Thus the preburn score was 24.5 (75.0–50.5). Mean success for postburn years (1984–94) was 54.5% for the Commeford territory and 44.9% for all unburned territories, and the postburn score was 9.6 (54.5–44.9).

We used Wilcoxon signed rank tests (Z) to determine whether standardized occupancy or success scores decreased after the territory burned. We used stepwise logistic regression to identify variables important in predicting occupancy and success of golden eagle territories in postburn years. We included 3 habitat variables (percentage of the area in shrubs, in agriculture, and burned as of 1994) and 2 golden eagle variables (mean 1971–81 nesting success and whether the nearest adjacent territory was vacant during postburn years) in stepwise logistic regression models predicting occupancy and success from 1986 to 1994.

We used SYSTAT (Wilkinson et al. 1994, SPSS 1997) and StatXact (Cytel Software 1989) for statistical analyses and considered P-values ≤ 0.05 as significant. Because we predicted the direction of changes in occupancy and success in relation to the habitat and disturbance variables, we used 1-tailed tests unless otherwise stated.

RESULTS

Fire Occurrence

From 1950 to 1994, fires burned 0–100% ($\bar{x}$ = 35%, median = 29) of the area within the proximity rings of 36 historical golden eagle territories in the NCA. We used the mean proportion of area burned to distinguish between extensively and moderately burned territories and classified 17 as extensively burned ($\bar{x}$ = 61%, range = 36–100%), 10 as moderately burned ($\bar{x}$ = 22%, range = 11–29%), and 9 as unburned ($\bar{x}$ = 0.3%, range = 0–2%). The incidence of fires was relatively low prior to 1980. Only 14 territories burned between 1950 and 1979. These 14 territories and 13 new ones burned during the 1980s; all but 1 burned between 1981 and 1985. Fires in the 1980s were larger and more numerous than in the 1970s; a mean of 50% of the area within 3 km of nesting centroids burned in the 1980s compared to 7% during the 1970s. From 1990 to 1994, territories essentially remained unburned, with ≤3.3% of the area burned around only 5 nesting centroids.

Postfire Changes in Occupancy and Success

Mean standardized occupancy scores for all 27 burned territories did not change after burning (Table 1; Z = − 0.38, P = 0.36); however, effect of burning on occupancy scores was related to whether or not pairs could expand into

Table 1. Mean standardized occupancy and success scores for 27 burned golden eagle nesting territories pre- and postburning in southwestern Idaho, 1971–94. Standardized scores are presented as departures from mean occupancy or success for 9 unburned territories, which is set at zero (See text for details). Burned territories with positive scores performed better relative to the unburned territories, and those with negative scores did poorer.

Preburn		Preburn		Postburn	
Territory type	n	$\bar{x}$	95% CI	$\bar{x}$	95% CI
Occupancy					
All burned territories	27	−8.8[a]	−15.6 to −2.0	−21.2[a]	−37.1 to −5.4
With vacant neighbors[b]	9	−5.3	−11.8 to 1.2	1.9	−0.9 to 4.6
With occupied neighbors[c]	18	−10.6[a]	−20.5 to −0.6	−32.8[a]	−55.1 to −32.4
Success					
All burned territories	27	0.8	−7.4 to 9.2	−14.2[a]	−25.6 to −3.9
With vacant neighbors	9	1.0	−15.8 to 17.9	1.9	−15.6 to 19.1
With occupied neighbors	18	0.8	−9.8 to 11.3	−22.9[a]	−9.8 to −36.0

[a] Mean scores that do not include zero in their confidence intervals differ from unburned territories ($P < 0.05$).
[b] Territories where nearest neighboring territory is vacant or no territories occur within 9 km.
[c] Territories where all adjacent territories are occupied.

neighboring vacant territories. Pairs in 9 burned territories either expanded their territories or had the opportunity to do so: 3 used portions of a vacant neighboring territory (U.S. Geological Survey, Snake River Field Station, unpublished data), 5 were the nearest neighbor to a vacant territory, and 1 had no neighboring territory within 9 km. Occupancy scores at these 9 territories increased after burning ($Z = 2.07$, $P = 0.02$). When we eliminated these 9 from the dataset, the decline in occupancy scores for the remaining 18 burned territories approached significance (Table 1; $Z = -1.46$, $P = 0.07$).

In contrast to occupancy, mean standardized success scores for all 27 burned territories decreased after burning (Table 1; $Z = -2.62$, $P = 0.004$). Success scores at the 9 territories with the opportunity to expand did not change after burning ($Z = 0.06$, $P = 0.48$); based on 95% confidence intervals, postburn success of these territories did not differ from the unburned territories (Table 1). When we eliminated these 9 from the dataset, the decline in success scores at the 18 territories that could not expand was highly significant ($Z = -3.07$, $P = 0.001$).

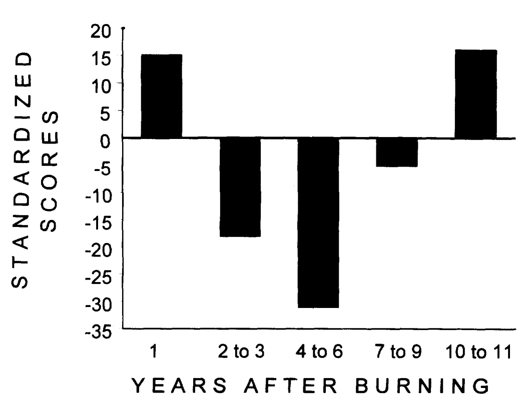

Fig. 1. Mean standardized success scores of 15 extensively burned golden eagle territories in relation to years postburn. Standardized scores are presented as departures from mean success of 9 unburned territories, which is set at zero in the graph (See text for details).

Postburn success rates were related to time since burning. Standardized success scores at 15 extensively burned territories remained relatively high for the first year after ≥30% of the area within 3 km of their nesting centroid had burned (Fig. 1). Success scores then steadily declined to a low 4–6 years after burning and then subsequently increased again. After 10–11 years, standardized scores were similar to those 1 year after major burns.

Factors Related to Postburn Occupancy and Success of Territories

From 1986 to 1994, 81–89% of 36 golden eagle territories in the NCA were occupied each year. Twenty-six territories (72%) were occupied in all 9 postburn years, and 5 were never occupied from 1986 to 1994. The probability of a golden eagle territory being occupied in all 9 postburn years was not related to whether the area within 3 km of the nesting centroid had burned or to how much of it had burned (Table 2). However, 3 other variables were significant in a stepwise logistic regression model predicting whether a territory would be occupied in all postburn years: (1) presence of a vacant neighboring territory, (2) percentage of agriculture within a 3-km radius of the nesting centroid, and (3) percentage of shrubs within the 3-km radius were all positively related with occupancy (Table 2).

Table 2. Results of 2 separate logistic regression procedures predicting occupancy and success at golden eagle territories in postburn years. The first model distinguishes territories occupied in all years ($n = 26$) from those vacant at least 1 year ($n = 10$), 1986–94. The second model distinguishes territories successful in >5 years ($n = 14$) from those successful <5 years ($n = 21$), 1986–94[a]. One territory was excluded from the success model due to incomplete data.

Variable	Parameter estimate[b]	SE	t-ratio	P-value	Odds ratio
Occupancy					
Intercept	−2.647	1.590	−1.665	0.096	
% shrub	0.081	0.032	2.540	0.011	1.085
% agriculture	0.107	0.050	2.154	0.031	1.113
Vacant neighbor	1.710	0.786	2.177	0.030	5.529[c]
Success					
Intercept	−2.933	1.165	−2.517	0.012	
1971–81 success	0.049	0.021	2.382	0.017	1.051

[a] Variables shown are those that contributed significantly to stepwise logistic regression models ($P < 0.05$; SYSTAT, logit procedure). Variables that did not contribute significantly to either model were percentage of area burned and whether or not burns occurred within 3 km of the nesting centroid. Overall significance was 0.04 for the occupancy model ($G_3 = 13.33$) and 0.07 for the success model ($G_1 = 7.15$).
[b] Positive values indicate that an increase in the independent variable is associated with a higher probability of a territory being occupied or successful.
[c] Territories were 5.5 times more likely to be occupied in postburn years if the neighboring territory was vacant.

Annual nesting success of golden eagles in the NCA ranged from 32 to 80% between 1986 and 1994. Twenty-one territories were successful in <50% of postburn years. Habitat measures failed to predict which territories would be successful in >50% of postburn years. The only variable that contributed significantly to a logistic regression model (Table 2) predicting success in postburn years was a territory's nesting success in preburn years (1971–81). Preburn nesting success was positively associated with nesting success in postburn years, and the model was significant ($P = 0.007$).

DISCUSSION

Overall, golden eagles in the NCA responded negatively to the loss of shrubs (black-tailed jackrabbit habitat) that resulted from fires. However, the incidence and extent of fires did not help us to predict which territories would have low occupancy and success rates in postburn years. Responses to fire were variable and influenced by at least 3 factors: (1) whether the nearest neighboring territory was vacant; (2) the ability to use alternative foraging habitat (i.e., farmland, cliff, talus, riparian); and (3) the underlying quality of the pair or territory.

Territories were more likely to be occupied during postburn years if the nearest neighboring territory was vacant, and success of pairs that had the opportunity to extend their range into a neighboring vacant territory did not change after burning. Golden eagle pairs responded to reduced shrub habitat from burning by ranging over larger areas and concentrating their use in the shrub patches within these larger ranges (Marzluff et al. 1997). Postburn success rates might have been even lower if neighboring territories had not become vacant after burning.

Golden eagles also may have compensated for loss of shrub habitat due to burning by using alternative habitats. Marzluff et al. (1997) observed that some golden eagles in areas with little shrub habitat as a result of burning in the NCA restricted their foraging to small areas of cliff and riparian habitat around their nests. They preyed less on black-tailed jackrabbits and took more alternate prey such as rock doves (*Columba livia*), waterfowl, yellow-bellied marmots (*Marmota flaviventris*), and desert cottontails (*Sylvilagus nuttalli*). Territory occupancy during the postburn years was predicted, in part, by the amount of agriculture within the proximity rings. The positive relation with agriculture could be explained by availability of alternate prey in farmlands. Golden eagles nesting in agricultural areas in southwestern Idaho took more ring-necked pheasants (*Phasianius colchicus*), yellow-bellied marmots, and other prey than golden eagles in the rangelands (Kochert 1972).

Postburn nesting success at individual territories was related primarily to nest success in preburn years. Territories with high success rates during preburn years continued to have high success rates in postburn years. Territory occupancy and breeding success for many bird species are related to quality of the territory (habitat) and of the pair occupying the territory

(Newton 1992, Marzluff et al. 1996) The situation is complicated by the tendency for better birds to occupy better habitats (Newton 1991, 1992). For example, low-quality sparrowhawk (*Accipiter nisus*) territories had the highest turnover, and high-quality territories were occupied by older and more successful birds who produced most young for the population (Newton 1991). High-quality golden eagle territories in the NCA (as measured by preburn success) had higher success rates after burning, even when the habitat was altered greatly. Because individuals tend to occupy the same territory year after year (Marzluff et al. 1997, Watson 1997), these territories may have been occupied by older, resident pairs with more familiarity and experience with the territory. Alternatively, if high turnover of pairs occurs in poorer golden eagle territories, the newer, less experienced birds may be less successful and more affected by habitat alteration. Additional research involving marked golden eagles would help to distinguish the influence of territory quality and individual bird quality on success rates.

We observed a slight lag in the negative response and a subsequent rebound of golden eagle nesting success to burning within extensively burned territories. During the first year after burning, resident golden eagle pairs may forage mainly in remnant shrub habitat containing prey that have concentrated after fires (Marzluff et al. 1997). In subsequent postburn years, prey declines associated with shrub loss may have caused decreased golden eagle nesting success. Golden eagles might then have adapted to alternative habitats and alternate prey, as observed with some radiotagged golden eagles (Marzluff et al. 1997), accounting for the rebound in success. Although golden eagles in the NCA specialize on black-tailed jackrabbits, they are able to use alternate prey during jackrabbit declines (Steenhof and Kochert 1988). The rebound in success may have resulted in part from reestablishment of shrubs and an ensuing response of black-tailed jackrabbits. We observed reestablishment of shrubs in some shadscale and greasewood (*Sarcobatus vermiculatus*) areas 10 years after burning, but reestablishment had not yet occurred in winterfat and big sagebrush areas (U.S. Department of the Interior 1996; U.S. Geological Survey, Snake River Field Station, unpublished data).

A decline in the number of nesting golden eagle pairs and the general decline in black-tailed jackrabbits (Steenhof et al. 1997) suggest a possible reduced carrying capacity for golden eagles in the NCA. Some abandoned territories may have been occupied only when jackrabbits were extremely abundant and were rendered less capable of supporting a pair of golden eagles after these territories burned. Three territories were vacant 4–8 years before they were extensively burned. These 3 territories were occupied in 1971, the highest peak of the black-tailed jackrabbit population, and were abandoned during the low years of the jackrabbit cycle in the 1970s (Steenhof et al. 1997). Once abandoned territories are occupied by neighboring golden eagle pairs, it may be difficult for new pairs to reoccupy historical territories. As long as prey resources are low, these territories may be occupied by only 1 pair.

MANAGEMENT IMPLICATIONS

The amount of shrub habitat was important to golden eagle territory occupancy in the NCA. Managers should strive to maintain native shrub communities. Stands of sagebrush–rabbitbrush interspersed with grasslands support sizable populations of black-tailed jackrabbits, important golden eagle prey (Knick and Dyer 1997). Although some territorial golden eagles traveled >10 km from nests (Marzluff et al. 1997), it may not be feasible to manage intensively for shrubs on such a large scale. We recommend managers maintain shrub stands within 3 km of golden eagle nests, which is the mean distance traveled by golden eagles during the nonbreeding season and includes 95% of the distances measured during the breeding season (Marzluff et al. 1997).

The goal of maintaining native shrub communities can be realized primarily through active fire suppression, and secondarily by reestablishing shrubs in burned areas. Fire suppression and reestablishment of shrubs are particularly important in areas like the NCA where a large proportion of the shrub habitat has been lost to fire, and the invasion of exotic annual plants has altered the fire ecology of the area (U.S. Department of the Interior 1996). Fire suppression should occur in both native shrub and grassland (burned) habitats because shrubs, particularly shadscale and greasewood, can reestablish naturally in burned grassland areas. If rehabilitation efforts fail or are not implemented, our results suggest some golden eagle pairs will adjust to burning and other habitat alterations, particularly if cliff, talus, riparian, and farmland habitats are available. However, overall losses to golden eagles will be significant.

Managers need to monitor long-term effects of habitat alteration and the relative values of different habitat patches. Monitoring must include more than a simple count of the number of occupied golden eagle territories because, as populations decline, productivity per pair may actually increase as marginal habitats are no longer used (Ferrer and Donazar 1996). Number of young golden eagles produced per pair did not decline in the NCA from 1971 to 1994, despite a decline in the number of occupied nesting territories and a possible reduced carrying capacity for golden eagles (Steenhof et al. 1997). Additional monitoring is needed to determine if the ability of golden eagles to withstand habitat alteration is a long-term response. Biologists will particularly need to know if some vacant territories will be reoccupied in future years or if more territories will become permanently vacant, and if remaining pairs compensate via increased productivity.

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