BLM Technical Note 434

Artificial Nest Structures as Mitigation for Natural-Gas Development Impacts to Ferruginous Hawks *(Buteo regalis)* in South-Central Wyoming

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BLM/WY/ST-10/009+1110

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Artificial Nest Structures as Mitigation for Natural-Gas Development Impacts to Ferruginous Hawks *(Buteo regalis)* in South-Central Wyoming

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Prepared for:
U.S. Department of Interior,
Bureau of Land Management
Utah State Office, Salt Lake City,
Wyoming State Office, Cheyenne, and
Colorado State Office, Lakewood

Table of Contents

List of Tables v

List of Figures vii

Abstract ix

Acknowledgements xi

Introduction 1

Study Area and Methodological Background 3

- Study Area. 3
- Survey Methods 4
- Analytical Methods. 5

Summary of Relevent Modeling and Statistical Results. 7

Discussion 11

Literature Cited. 15

List of Tables

Table 1. Ferruginous Hawk reproductive metrics by nest-accessibility categories (1976–2004) **8**

List of Figures

Figure 1. BLM Rawlins Field Office boundary (solid line) and general study area extent (dashed line) in south-central Wyoming.. . . . . **3**

Figure 2. Diagram of a typical artificial nest structure (ANS) used for Ferruginous Hawks in the BLM Rawlins Field Office in south-central Wyoming (originally represented in Tigner and Call 1996). **4**

Figure 3. Kernel density (within a 5-km radius) of active Ferruginous Hawk nests in the Rawlins study area relative to 105 artificial nest structure (ANS) locations before (1970–1987, upper panel) and after (1990–2006, lower panel) their installation. **7**

Abstract

The Ferruginous Hawk (*Buteo regalis*) may be particularly sensitive to human disturbance, but is also a highly versatile nester. South-central Wyoming supports one of the largest breeding populations of Ferruginous Hawks, as well as significant natural-gas development. Ferruginous Hawks were first documented nesting on natural-gas structures in the area during the 1980's. Because nests on natural-gas structures commonly failed due to human activities, the Rawlins Field Office of the Bureau of Land Management installed 105 artificial nest structures (ANSs) between 1987 and 2004 to provide area birds with viable nesting alternatives. Herein we draw on previous research to assess the efficacy of ANSs as a mitigation tool. Overall, Ferruginous Hawks used 85% of all available ANSs for nesting at some point. Nesting activity appeared to be positively associated with areas of natural-gas development and subsequent ANS installation. However, activity patterns at nest clusters (see definitions) with and without ANSs exhibited opposite relationships with development and drought. Productivity was significantly greater at ANSs relative to ground or rock-feature nests, and both nest success and productivity were greater at inaccessible (to mammalian predators) nests compared to accessible nests. Ferruginous Hawks utilizing ANSs maintained fewer alternate nests. Nest attendance and prey delivery were greater at ANSs and other inaccessible nests, likely contributing to their greater success and productivity. Our research suggests that birds in the study area responded rapidly to newly available manmade structures and fared well on ANSs. We suggest that the rapid shift to natural-gas structures and ANSs was likely due to their location within attractive foraging habitat lacking natural nest sites. Despite the apparent success of this ANS program, we caution that research on post-fledging survival associated with ANSs must be conducted before ANSs can be fully endorsed as a viable mitigation tool.

Acknowledgements

Funding for portions of the research summarized in this technical note was provided by the U.S. Department of Energy through the BLM Utah State Office (BLM Assistance Agreement JSA065003) as part of a larger undertaking called the "Raptor Radii Research Project." We wish to thank members of the Radii Project Steering Committee, which included Dave Mills (BLM Utah, Richfield Field Office), Steve Madsen (BLM Utah State Office), Dave Roberts (BLM Wyoming State Office), and Wes Anderson (BLM Colorado State Office) for their input and guidance. This manuscript also benefited from independent reviews provided by Heath Cline (BLM, Rawlins, Wyoming), Dr. Tom Thurow (University of Wyoming), and Dr. James Tigner (retired Wildlife Biologist, BLM, Wyoming).

Introduction

The Ferruginous Hawk (*Buteo regalis*) is commonly described as a species of raptor that is particularly sensitive to human disturbance (White and Thurow 1985, Bechard et al. 1990, Olendorff 1993), but also is one of the most versatile in use of nest substrates. Across its range, the Ferruginous Hawk is known as a consummate open-country specialist, and is known to nest on a diverse array of natural substrates, including the ground, piles of bison bones, small rock piles, larger rock outcroppings and cliffs, stout shrubs, low-growing trees, and a variety of erosional formations (Olendorff 1993, Bechard and Schmutz 1995, Neal 2007). Ferruginous Hawks have also nested on a variety of manmade substrates, including chimneys or roofs of abandoned buildings, windmills, haystacks, shelterbelts, and power-line towers (Gaines 1985, Olendorff 1993), and more recently natural gas infrastructure (Tigner and Call 1996, Neal 2007).

In the late 1970s, Bureau of Land Management (BLM) personnel in the Rawlins Field Office (RFO) in south-central Wyoming became concerned about the proximity of proposed natural-gas developments to historically active Ferruginous Hawk nests and prime foraging areas (J. Tigner personal communication). South-central Wyoming supports one of the largest known breeding populations of Ferruginous Hawks (Olendorff 1993). The species is currently listed as a state sensitive species in Wyoming and in most other states where it occurs, and garners similar recognition in several state-level and bird conservation region (BCR) plans developed by the overarching Partners in Flight avian conservation program (Rich et al. 2004). In 1980, at which point roughly 1,500 natural gas wells had been installed in the RFO, the first pair of Ferruginous Hawks nested on a 6-m tall, cylindrical, natural-gas condensation tank. Although these structures offer a flat, elevated substrate for nesting, they require regular maintenance visits by industry personnel. In the 1980s, when a further rapid expansion of natural-gas development occurred in the RFO, anecdotal evidence suggested that industry operators frequently destroyed nests or maintenance activities prompted nest abandonment by breeding adults.

In autumn 1987, the BLM and some of the natural-gas companies operating in the area cooperated in erecting 11 artificial nest structures (ANSs). The objective was to provide alternative substrates for birds nesting on natural-gas infrastructure, and thereby mitigate for apparent negative effects of natural-gas development on Ferruginous Hawk nesting success. Additional ANS installations continued to occur in subsequent years to mitigate for attempts by other hawks to nest on natural-gas structures. By 1991, 31 ANSs were available in the RFO, and by 2004 the number had increased to 105, with 100 of those specifically installed for Ferruginous Hawks and the rest for Golden Eagles (*Aquila chrysaetos*) and Red-tailed Hawks (*B. jamaicensis*).

Initial results for the 1988–1991 breeding seasons suggested that Ferruginous Hawks using ANSs produced an average of 2.7 fledglings per nest, compared to a range of "natural" nests that produced an average of 2.2 fledglings per nest (Tigner and Call 1996). While these results were informative, they were based on small sample sizes and largely haphazard sampling of natural nests. In 1995, inventory and monitoring efforts were increased to keep pace with natural-gas development, and in 2000 author Mike Neal began coordinating the project and further standardized the inventory and monitoring efforts throughout the RFO.

These factors culminated in an effort to determine if ANSs were more frequently active, successful, and productive than natural nests within the study area, and the resulting investigations ultimately formed the core of Neal's master's thesis at the University of Wyoming (Neal 2007), as well as a key component of the analyses presented in Smith et al. (2010). Here we summarize the analytical results presented in these two documents and synthesize resulting insight to formally evaluate the efficacy of ANSs as a mitigation tool for off-setting the effects of natural-gas development in the RFO. Together this report and Smith et al. (2010) comprise the primary products resulting from Phase I of the "Raptor Radii Research Project," for which HawkWatch International served as the Principal Investigator.

Study Area and Methodological Background

Study Area

The BLM – RFO administers an area encompassing approximately 1.72 million hectares of public land (Figure 1), largely associated with the northern sagebrush-steppe ecoregion (Kuchler 1964). The study area for analyses included all public land and any tracts of accessible private land within the RFO, encompassing 44,425 km^2. The BLM administers 223 Key Raptor Areas nationally. Individual field offices identified such areas based on biological and administrative characteristics. Key Raptor Areas have unusually high raptor nesting densities and habitat is a key activity-plan issue surrounding commodity production values (oil and gas, coal, gravel, etc.; Olendorff 1989). Throughout the shrubsteppe ecoregion, 78 such areas have been delineated, with 13 (17%) of these located within the RFO and specifically recognizing Ferruginous Hawks as a primary species of concern (Olendorff and Kochert 1992).

Within the RFO, a variety of natural substrates have provided traditional nesting locations for Ferruginous Hawks (Tigner and Call 1996), such as erosional formations, rock pillars and outcrops, hillsides, sagebrush (*Artemisia* spp.), juniper trees (*Juniperus* spp.), limber pines (*Pinus flexilis*), and aspen/cottonwood trees (*Populus* spp.). Documented use of manmade structures includes power poles, a pump house, an abandoned sheepherder's wagon, a windmill, and, more recently, natural-gas infrastructure and ANSs (Neal 2007). Most ANSs in the RFO were erected within 1 km of natural gas structures (e.g., condensation tanks) where Ferruginous Hawks had constructed nests during the same or previous nesting season. Any remaining nest material was moved from the natural-gas structure to the relevant ANS. ANSs were placed such that the spatial relationships to other nearby natural-gas infrastructure were similar to those associated with the natural-gas structure used for nesting. The rationale for such placements assumed that the Ferruginous Hawks would return to the area and use the newly available ANS containing their nest materials. A handful of other ANSs were erected to substitute for nests that had been built on other decrepit manmade structures unrelated to natural-gas development.

The ANSs used in the RFO consisted of a 3.5-m tall, pressure-treated post sunk 1 m into the ground, which

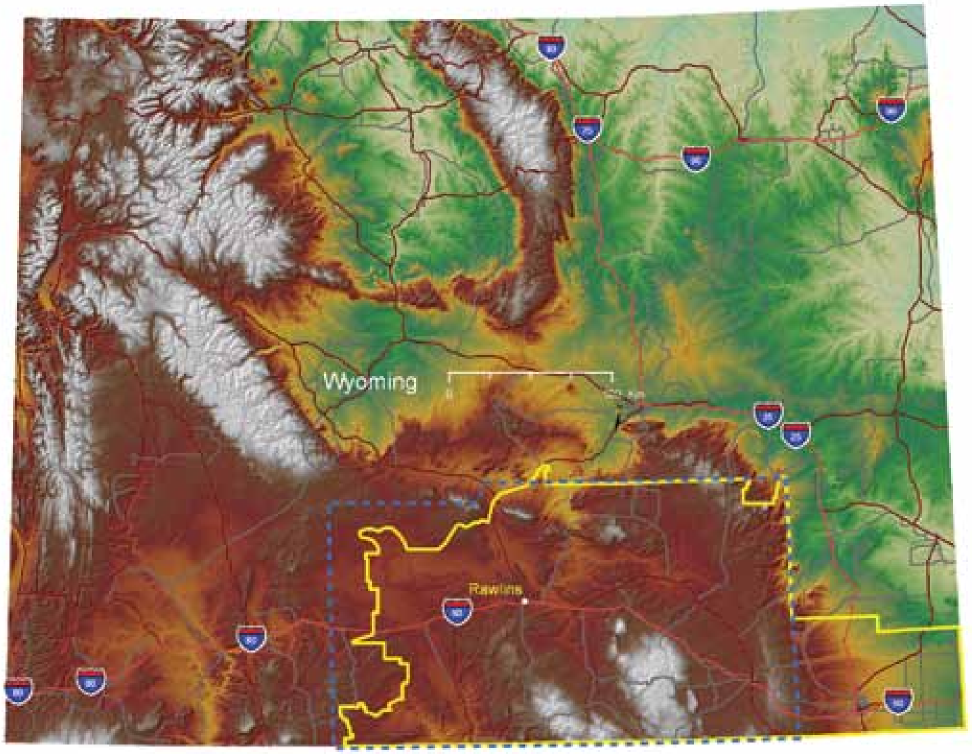

Figure 1. BLM Rawlins Field Office boundary (solid line) and general study area extent (dashed line) in south-central Wyoming.

supported a 1-m^2 nest platform (Figure 2; from Tigner and Call 1996). The nest platform was made of a 2” x 6” board frame, including one longer board to provide a perch to the side of the main nest area, and with hardware cloth stapled to the top of the frame to provide a base for the beginnings of a sagebrush “nest wreath.” The platform was then bolted to the top of the post. Many early prototypes were constructed with limber pine branches extending above the nest to help stabilize nest materials and nestlings, and to deter avian predators. While the addition of nest material or the sagebrush wreath helped attract breeding hawks to newly installed ANSs, the limber pine branches proved to be unnecessary. Due to the elevated platform created by ANSs, hawks augment nest construction 2.5 m above ground level.

Survey Methods

Detailed survey histories and methods are provided in Neal (2007) and Smith et al. (2010). Briefly, somewhat haphazard, annual nest monitoring, including gathering of limited productivity and mortality data, began in the RFO in 1976, although no data were collected for the 1977 nesting season. More consistent Ferruginous Hawk nest monitoring occurred from 1988 through 2004, while surveys in 2005 and 2006 were limited to priority nests (i.e., ANSs and other nests with documented activity in the previous 10 years; Heath Cline, Rawlins BLM, personal communication). The 1988–2004 efforts focused on documenting all active or occupied Ferruginous Hawk nests located on accessible public land (federal and state) within the RFO, with special emphasis on ANSs, high-density nesting areas, and development-related project areas. All raptor nest locations were hand-plotted on USGS 7.5’ quad maps, recorded in the BLM GIS database, and georeferenced in ArcMap 9.1 (Environmental Systems Research Institute [ESRI], Inc., Redlands, CA).

Surveys generally involved visits during April and May to document the initial activity status of nests, second

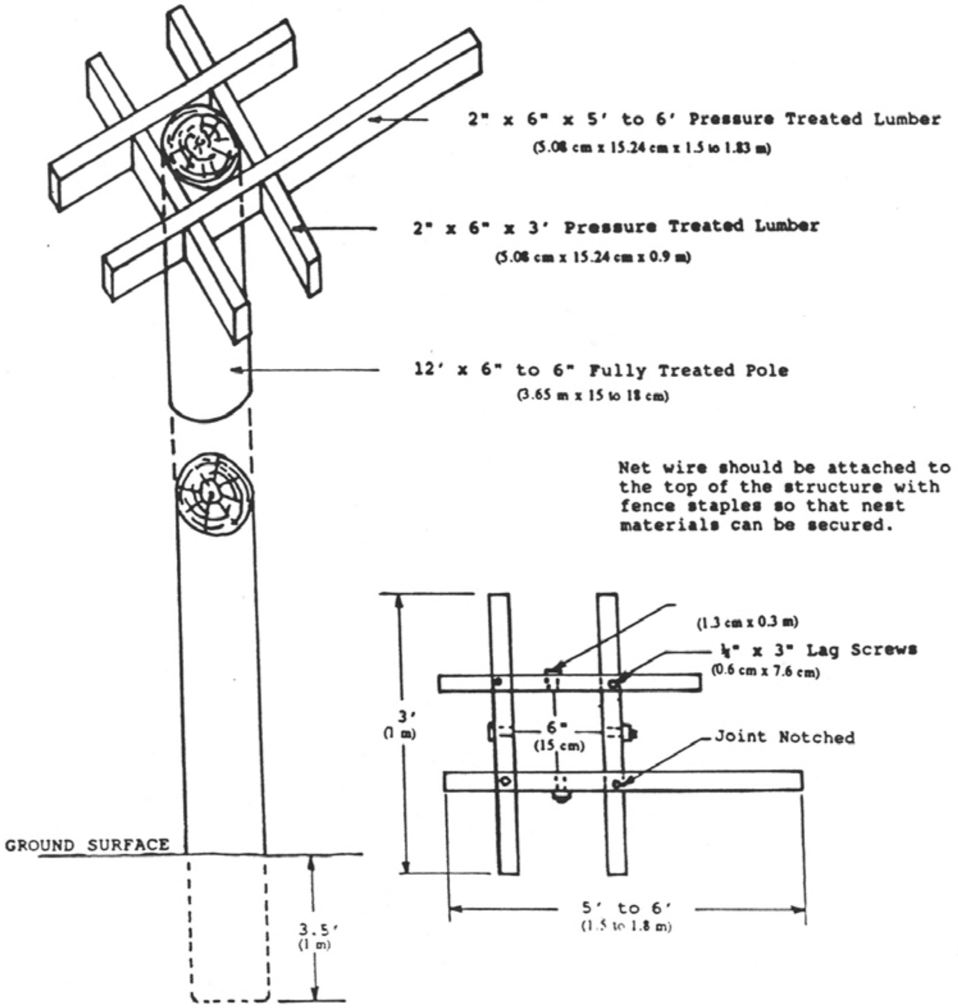

Figure 2. Diagram of a typical artificial nest structure (ANS) used for Ferruginous Hawks in the BLM Rawlins Field Office in south-central Wyoming (originally represented in Tigner and Call 1996).

visits in late May and early June to all "occupied" nests to reassess status and age any chicks present, and final visits in late June or early July to enumerate "near-fledglings" (i.e., chicks that reached at least 80% of the average fledging age for the species: 32–34 d). Most surveys occurred on the ground, but occasionally by way of aerial transects. "Active" nests were those where reproductive activities such as copulation, incubation, brooding, and nest attendance were observed. "Occupied" nests were those where one or more hawks were observed in the immediate vicinity of the nest or signs of presence (e.g., recent addition of nest materials, mute, pellets, or prey remains) were documented during the breeding season. Nests where no physical presence or signs of recent use were observed were classified as "inactive." "Alternate" nests were found within "nest clusters" (sensu Smith et al. [2010] and explained further below) in close proximity to well-established primary nests. In this context, designation of an "active alternate" nest implied that the nest was recently tended but another nest within the cluster was used for actual nesting, whereas designation of an "inactive alternate" nest implied a similar circumstance but that the nest had not been tended recently. "Used" nests received a final classification of active, active-failed (depredation specified as cause of failure when relevant), or occupied. Successful nests were defined as those in which at least one near-fledgling was produced, and "productivity" was estimated as the actual number of near-fledglings produced (Steenhof and Newton 2007). Nestling age was estimated using Moritsch (1985).

For purposes of the analyses summarized here, an "inaccessible" nest was defined as a nest that was >2.5 m above ground or otherwise could not be reached by most mammalian predators or an average human without the aid of specialized equipment (Neal 2007). The majority of nests classified as "accessible" were located on natural substrates and included no ANSs, whereas inaccessible nests typically were located on manmade substrates and especially ANSs. Accordingly, analyses comparing accessible and inaccessible nests largely reflected contrasts between natural and manmade nesting substrates and non-ANS versus ANS nests.

Among most raptor species, individual breeding pairs often maintain variable numbers of clustered, alternative nest sites, which they may tend each year and use in different years for actual nesting (Steenhof and Newton 2007). This means that in a given year no eggs will be laid in many nests in an area only because established breeding pairs laid their eggs in other nests within a given territory, which includes a cluster of nests. In turn, this means that the best definition of a sample unit for any multi-year assessments is for it to represent identifiable "nest clusters" used by individual breeding pairs (analogous to the "nesting territory" definition used by Steenhof and Newton [2007] but avoids potential confusion related to the ethologists' concept of territoriality). We used a combination of GIS-based nearest neighbor analyses, graphical consideration of topographic features, and inspection of individual nest histories to identify all distinct Ferruginous Hawk nest clusters within the RFO (Neal 2007, Smith et al. 2010).

Analytical Methods

We derived all analytical results discussed here from Neal (2007) and Smith et al. (2010), where detailed descriptions of data-preparation and analytical methods can be found. Here we provide a brief review of key methodological elements and introduce some important terminology, and then follow in the next section with a concise synthesis of results germane to evaluating the efficacy of ANSs as a mitigation tool for Ferruginous Hawks in the RFO. For several reasons, most of the analyses presented in Smith et al. (2010) evaluated patterns and relationships apparent from 1998 through 2006, whereas *most* of the analyses presented in Neal (2007) incorporated data from a longer period: 1976–2004.

In classifying the breeding status of nests and nest clusters for analytical purposes, we used three overlapping, binomial classification scenarios, and we conducted separate logistic regression analyses for each to evaluate differences and similarities in the results:

(1) "Used" = evidence of recent nest tending or actual breeding attempt (eggs laid) obtained

"Unused" = no such evidence obtained, despite nest check

(2) "Active" = breeding attempt confirmed

"Other" = all other cases, including some used (i.e., evidence of tending, but not actual breeding) and all unused classifications

(3) "Successful" = one or more chicks reared to at least 80% of the average fledging age for the species (32-34 d)

"Failed" = breeding attempt confirmed but no chicks reared to 80% of fledging age

We developed and evaluated multiple-regression and multiple-logistic-regression models that described relationships between Ferruginous Hawk nesting activity and potential predictor variables, which included:

1) Oil and Gas (OG) Development Factors derived from Principal Components Analysis (PCA) of original variables describing well and road densities and proximities at two spatial scales: within 0.8-km and 2.0-km radii of nest clusters.

2) Climate variables, including average current and prior-year Palmer Drought Severity Indexes and winter (Nov – Feb) precipitation totals (NOAA 2007).

3) Vegetation Factors derived from PCA of original variables describing proportional coverage of roughly 20 landcover/vegetation classifications represented in high-quality, 30-m-resolution maps derived from classified satellite imagery.

4) Selected two-way interaction terms; i.e., between development factors and vegetation/climate variables.

The dependent variables for these analyses included several "annual activity" metrics applied to ANS and non-ANS nest clusters, as well as a "proportional activity" metric applied to only non-ANS clusters. For the annual-activity analyses, the sample units were individual-year nest-status and productivity records. The dependent variables included three binomial response variables analyzed with multiple logistic regression: "used" versus "unused", "active" versus "other", and "successful" versus "failed." The response variable for the proportional activity models (analyzed with multiple regression) was the proportion of years between 1998 and 2006 in which a given nest cluster was either used or active, with analyzed nest clusters restricted to those for which at least five years of consecutive annual monitoring data were collected during the relevant period. We also analyzed two other suites of annual-activity models with multiple regression, where productivity was the continuous response variable. We independently considered all nest starts in one suite of models and only successful nests in the other suite of models. Modeling of annual-activity relationships with nesting success (successful or failed) and productivity as the dependent variables also involved independent analyses for accessible and inaccessible nests.

To provide some perspective on samples sizes, the original unfiltered 1976–2006 dataset available for analyses encompassed 3,745 individual Ferruginous Hawk nests, which we divided into 463 distinct nest clusters and among which 2,096 documented nest starts occurred. However, only 417 nest clusters and 1,234 nest starts were associated with adequate survey methods and histories to include in the analyses. Of the 1,234 nesting attempts, 750 (61%) occurred at 89 different ANSs, 88 (7%) at 13 other manmade-substrate nests, and 396 (32%) at 315 natural-substrate nests (mostly rocky-substrate, ground-hillside, and evergreen-tree nests).

Summary of Relevant Modeling and Statistical Results

Between 1987 and 2004, 89 of 105 (85%) available ANSs were used at some point by Ferruginous Hawks, with annual occupancy rates ranging from 52–70% (Neal 2007). The average time between installation and use of ANSs (*n* = 98) by nesting Ferruginous Hawks was 0.68 ± SE of 0.15 years (Neal 2007). Moreover, a comparison of pre-1988 and post-1990 kernel densities of active Ferruginous Hawk nests (Kernel Density Estimator, Spatial Analyst Extension, ArcGIS 9.2; ESRI, Inc. 2007) confirmed a distinct distributional shift related to the availability of ANSs. Although pockets of limited nesting activity remained in other scattered locations, the activity centers clearly shifted to ANS locations once they were available (Figure 3). We also examined the distributions of 54 well-monitored Ferruginous Hawk nest clusters in relation to three energy-development "hotspots" in the RFO between 1998 and 2006 (Neal 2007, Smith et al. 2010). Overall, active nest clusters averaged significantly closer to development-hotspot centers than inactive clusters. In combination, these data illustrate that human provisioning of new substrates (natural-gas infrastructure and ANSs) led to a rapid shift in Ferruginous Hawk nesting activity to areas favored for natural-gas development. In turn, this suggests that these core development areas provided prime foraging habitat for the species, but previously did not afford viable opportunities for nesting due to a lack of suitable substrates.

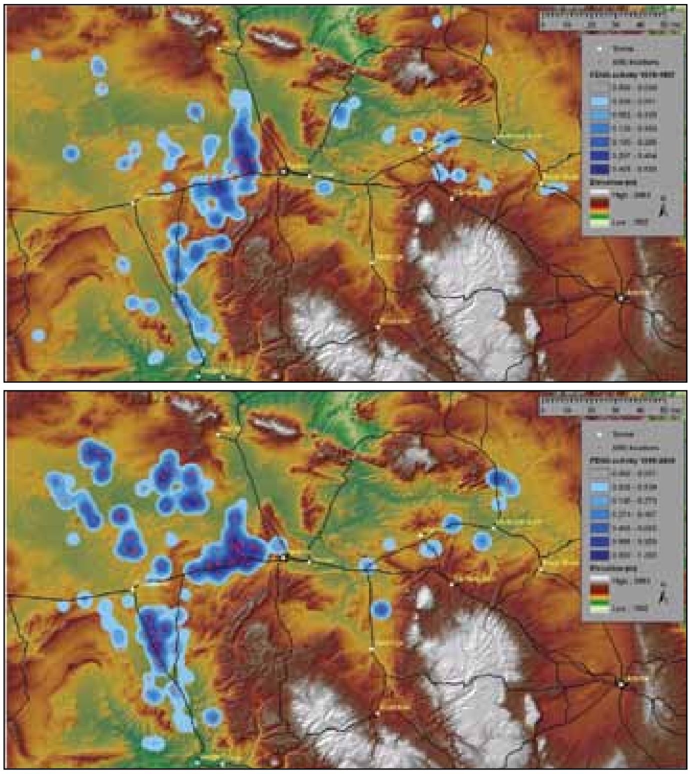

Figure 3. Kernel density (within a 5-km radius) of active Ferruginous Hawk nests in the Rawlins study area relative to 105 artificial nest structure (ANS) locations before (1970–1987, upper panel) and after (1990–2006, lower panel) their installation.

Multivariate modeling of apparent relationships between Ferruginous Hawk nesting activity and various OG development factors, climate variables, and vegetation factors revealed stark contrasts between results for non-ANS and ANS nest clusters. For example, both the annual-activity and proportional-activity models indicated that the probability of nesting at non-ANS clusters increased in areas of low overall OG development activity and where the relative prevalence and proximity of non-OG roads was high within 0.8 km but low at the 2.0 km scale. We detected exactly the opposite relationship between annual nest activity and development at ANS clusters, suggesting that nest accessibility serves to alter substantially the relationship between nesting Ferruginous Hawks and development. Similarly, we found that activity at non-ANS nest clusters tended to increase as annual drought severity decreased, whereas ANS clusters appeared to benefit from increasing current-year drought severity. We hypothesize that the latter relationship may derive from the fact that OG structures and water sources uniquely associated with development (e.g., evaporation ponds) may concentrate prey during drought periods by providing otherwise scarce water and shade (Smith et al. 2010). Again, these results suggest that the nesting ecology of ANS birds differed markedly from that of pairs using primarily accessible natural nests. Finally, we found that top models of annual nest activity generally performed poorly (i.e., failed relevant goodness-of-fit tests) for both ANS and non-ANS nest clusters. We suggest this was because nest accessibility was the primary driver of Ferruginous Hawk nesting success and productivity in this system. As a result, we believe additional development, climate, and vegetation variables added little to the explanatory ability of top models.

Neal (2007) also found that accessibility was a better predictor of nest success and productivity than substrate. In his study, all nests were classified into 10 nest-substrate classes and 4 "accessibility" categories (i.e., manmade accessible and inaccessible, and natural accessible and inaccessible). Statistical analyses (independent ANOVA and logistic regression analyses) revealed that nest substrate was a significant predictor of only productivity per nest start. Post-hoc comparisons further revealed that the productivity per nest start of inaccessible ANS nests was significantly greater than that of relatively accessible nests located on ground/hillside or rock features (e.g., rimrock and miscellaneous pillars and outcrops, but excluding high buttes and cliffs). In contrast, statistical analyses revealed that nest-accessibility was a significant predictor of all three modeled success and productivity metrics (i.e., nest success, productivity per nest, and productivity per nest start). Additionally, simultaneous evaluation of all three dependent variables against both nest substrate and accessibility as predictors with MANOVA (i.e., multivariate analysis of variance) further confirmed that accessibility was a much stronger predictor of Ferruginous Hawk nesting success and productivity. Overall, nest success was significantly lower at accessible nests (62.5 ± SE of 2.9%) compared to inaccessible nests (93.6 ± 0.8%; $t = -10.382$, df = 326, $P < 0.001$). Similarly, average productivity was significantly lower at accessible nests (1.61 ± SE of 0.08 large nestlings produced per nesting attempt) relative to inaccessible nests (2.74 ± 0.04 large nestlings per attempt; $t = -12.166$, df =397, $P < 0.001$). Comparison of summary success and productivity statistics for all four accessibility categories further revealed a consistent hierarchy, with natural-inaccessible nests being most successful and productive, followed by manmade-inaccessible, manmade-accessible, and finally natural-accessible nests (Table 1). Again, pronounced differences between success and productivity driven by nest accessibility may have swamped any potential influence of development, vegetation, or climate variables. We suggest success and productivity at accessible nests may have been more chance driven, due to the vulnerability of such nests to predators. In contrast, inaccessible nests were nearly always successful and at least minimally productive.

Neal's (2007) work evaluating comparative use of alternate nests and nest attendance and foraging relationships at accessible and inaccessible nests provided further insight about how ANSs and nest inaccessibility yielded greater success and productivity for Ferruginous Hawks using such nests. A significant reduction in the number of alternate nests used suggested that birds using ANSs were less dependent on maintaining large suites of alternate nests. Several factors may be involved in this dynamic. For example, increased long-term stability of ANS substrates may allow for greater perennial use of individual nests. Another possibility, though purely speculative at present, is that the wire bases of the ANSs may allow for greater annual "flushing" of the nest substrate by rains, thereby reducing the need to rotate nest use to help control build-up of nest-parasites (Philips and Dindal 1977). Perhaps most importantly, however, in light of Neal's findings, reduced sensitivity to disturbance from ground based activities and predators may be the most likely explanation for why reliance on multiple, alternative nests is reduced for breeding pairs that utilize ANSs. Mammalian predators such as coyotes (*Canus latrans*), badgers (*Taxidea taxus*), bobcats (*Lynx rufus*), and foxes (*Vulpes* or *Urocyon* spp.) are thought to be serious threats to ground nesting Ferruginous Hawks and recently fledged young (Bechard and Schmutz 1995). Human intrusions also likely function directly and indirectly as predation events, through direct persecution of hawks, nest destruction, and the provision of scent trails or roads for other ground predators (L. Apple and J. Tigner personal communication; M. Neal personal observation). The apparent significant benefit of nesting on inaccessible substrates makes perfect sense in light of this evidence. Lokemon and Duebbert (1976) also suggested that Ferruginous Hawks nesting on relatively secure nesting substrates (i.e., trees) might be less sensitive to human activity than ground nesters.

Neal's (2007) nest-attendance and prey-delivery results further clarified the fact that the apparent reduction in sensitivity to ground-based disturbance and depredation potential clearly translated to breeding adults at ANSs and other inaccessible nests being able to dedicate significantly more time to ensuring efficient provisioning and care of their young, which in turn translated to greater

Table 1. Ferruginous Hawk reproductive metrics by nest-accessibility categories (1976–2004).

Accessibility	Fledglings / Nest Start		Fledglings / Succ. Nest		Nesting Success	
Category[1]	*n*	Mean ± SE	*n*	Mean ± SE	*n*	Mean ± SE
MMAC	30	2.19 ± 0.23	25	2.76 ± 0.15	30	0.79 ± 0.07
MMIN	112	2.60 ± 0.07	111	2.82 ± 0.05	112	0.92 ± 0.09
NATAC	190	1.37 ± 0.10	112	2.51 ± 0.09	190	0.55 ± 0.04
NATIN	84	3.11 ± 0.10	83	3.19 ± 0.09	84	0.98 ± 0.01

[1] MMAC = manmade accessible; MMIN = manmade inaccessible; NATAC = natural accessible; and NATIN = natural inaccessible.

overall success and productivity for such nests compared to accessible nests. Schmutz et al. (1984) also found that ANSs were more successful than natural nests (95% vs. 67% of nests reaching near fledging age) for Ferruginous Hawks nesting in Alberta, and concluded that ANSs can be a useful tool for augmenting Ferruginous Hawk nesting in areas where prey are available but natural nest sites are sparse. Suter and Joness (1981) also suggested that nest security could be an important determinant of raptor responses to human disturbance.

A final bit of evidence that further testifies to the relative susceptibility of accessible natural nests to mammalian predation is that over the years a total of 13 adults and 8 nestlings were confirmed killed by mammalian predators at such nests, whereas only two other mammalian depredation events were ever documented and these involved adults killed away from their nests (Neal 2007).

Discussion

Analyses of reproductive metrics clearly demonstrated the importance of accessibility to the nesting ecology of Ferruginous Hawks. Significant differences in vital rates for accessible and inaccessible nests suggested that nest accessibility to mammalian predators and subsequent depredation might be the primary drivers of Ferruginous Hawk nest reoccupancy rates, success, and productivity in south-central Wyoming. Trade-offs between foraging and predator avoidance may affect survival and reproduction, especially if foraging profitability and predation risk differ among substrate choices (Sharp and Van Horne 1998). It appeared that natural-inaccessible substrates provided Ferruginous Hawks with the highest quality nesting sites, based on nest success and productivity. At accessible nests, success and productivity appeared to increase with long-term, consistent nest use. In contrast, success and productivity were higher on average at inaccessible nests, but did not vary markedly with consistency of nest use. Documentation of repeated nest site use may be one of the strongest indicators of overall habitat suitability, as elements in the environment such as prey abundance, availability of perch sites, and previous experience may be important in influencing yearly nest-site selection (Stalmaster 1982). In turn, prior nest success may influence whether a historical nesting site or territory is reoccupied (Dechant et al. 2003). Our research confirms that Ferruginous Hawks were more likely to reoccupy nest sites that were inaccessible to mammalian predators and that reproductive output was greater at such sites. Nesting Ferruginous Hawks may benefit from high nest reoccupancy rates, due to repeated exposure to localized resources (also see Gaines 1985, McDonald and Staats 1996).

The more obvious benefits of inaccessible nests are minimal destruction of nests or young by predators and reduced nest abandonment (Tigner and Call 1996). Many studies have reported significant losses of eggs or young to mammalian predators (Lokemoen and Duebbert 1976, White and Thurow 1985, Keough 2006), but RFO data also suggest that adult mortality may be significantly higher at accessible nest sites. Depredation of adults occurred throughout the breeding season, even during the fledging stage. The presence of extensive natural-gas road networks exacerbates adult depredation at accessible nests during incubation, because high traffic volume keeps these roads open in spring and they act as efficient travel corridors for mammalian predators. While enhancement of Ferruginous Hawk vital rates through inaccessibility to mammalian predators (Schmutz et al. 1984) is more readily quantified, increased survival of breeding adults may be more critical to the viability of the species.

Monitoring data from the RFO indicate that accessible nest clusters, comprised primarily of nests located on miscellaneous rock features, the ground or hillsides, and erosional features, were the norm prior to the period of intensive natural-gas development and availability of ANSs. Smith and Murphy (1978) reported that Ferruginous Hawk pairs constructed or renovated from 1–5 nests within their territories, with 86% of the nesting pairs constructing alternate nests. Other studies have noted that occupied nests often occurred in groups, with certain habitat areas containing multiple active nests and other seemingly identical habitat areas containing only old inactive nests (Weston and Ellis 1968), and that such distributions may represent significant portions of local populations (Bates and Norvick 1992). We suggest that historically and in natural settings, Ferruginous Hawks typically play a “shell game” centering on suites of accessible nests that are proximate to prey resources. The shell game is played when hawks variably tend and occupy several nests prior to incubation in an attempt to confuse roaming mammalian predators (Neal 2007).

There is little doubt that Ferruginous Hawks responded to the increased availability of manmade structures in the RFO by shifting their activity centers to the areas where such substrates were made available. While this shift may be indicative of a strategic response to an altered landscape, which includes greater mammalian depredation risks, it may come at the price of reducing nesting options or putting them in closer proximity to human disturbances. Many of the breeding territories currently exhibiting the highest reoccupancy rates in the RFO contain a single, primarily ANS, nest site. If this substrate is removed or destroyed, the territory could be rendered useless, as Ferruginous Hawks infrequently build new nests, apparently preferring to repair and reuse old nests instead (White and Thurow 1985, M. Neal and J. Smith personal observation). In other instances, hawks may return to their previous nesting territory even though their previously used nests have been removed or destroyed (Stalmaster 1982) and attempt to nest on less desirable substrates to take advantage of their experience with local prey resources. Considering these facts, it is critical that extensive use of ANSs as a mitigation tool is accompanied by a long-term commitment to their maintenance to avoid the potential scenario in which a significant portion of the nesting population is attracted to nests sites that are only temporary.

Presumably, Ferruginous Hawks began nesting on natural-gas infrastructure due to the elevated platform they afford and their proximity to primary prey resources (Neal 2007). The location and density of active Ferruginous Hawk nest sites may be positively correlated with spatial proximity to their prey (Rosamonde et al. 2003), with high nesting densities often corresponding to high abundance of ground squirrels (*Spermophilus* spp.; Schmutz and Hungle 1988). Although no data were available to evaluate it, we believe the rapid and almost wholesale shift of Ferruginous Hawk nesting in the RFO to use of natural-gas structures and ultimately ANSs was due to these new structures providing nesting substrates in the midst of attractive foraging areas previously devoid of suitable nesting sites (Smith and Murphy 1978). Additionally, one might expect burrowing mammals to increase in abundance in OG development areas due to increased soil disturbance. However, even if ground squirrels are less abundant in these broad desert flats, they may be more accessible. Ferruginous Hawks avoid foraging in dense vegetation due to reduced prey vulnerability (Sharp and Van Horne 1998, Dechant et al. 2003).

Clearly, under certain circumstances such as those that pertained in the RFO, ANSs can be very effective in directly mitigating for nests that may be destroyed or prone to disturbance from activities such as OG development. That said, we submit several caveats regarding their utilization:

1) Hawks previously habituated to disturbance or the use of manmade substrates are more likely to occupy ANSs.

2) Optimal occupancy occurs only when ANSs are placed proximate to areas with extensive prey bases (Call 1979, Howard 1980, and Olendorff et al. 1981).

3) Nestling and egg relocation to ANSs may be most effective when the new site is within 1 km and line-of-sight (Stalmaster 1982).

4) ANSs may not always prove acceptable to Ferruginous Hawks because they sometimes attract non-target species and they are typically more conspicuous than natural sites (Olendorff and Stoddard 1974).

5) Adequate resources should be allocated for the long-term monitoring, repair, and replacement of ANSs.

6) In dense development areas, installation of ANSs may create or aid in perpetuating an "ecological trap" (i.e., an inappropriate attraction to ultimately poor quality habitat [Gates and Gysel 1978]).

Very few data exist regarding survival of post-fledgling Ferruginous Hawks (Zelenak et al. 1997, Keough 2006). Survival of young at this stage may be very low, primarily due to inexperience in acquiring prey and avoiding predators and other agents of mortality (Mannan et al. 2004). If post-fledgling survival is low, estimates of the number of young fledged per nest typically reported in reproductive studies are poor estimates of actual reproductive success (Zelenak et al. 1997). Human activity near nests may raise the mortality rate by causing nestlings to fledge prematurely and render them more susceptible to predation (White and Thurow 1985). Fledglings from ANSs are thrust into a landscape containing a matrix of well-used roads that likely expand the distribution of mammalian predators by providing more efficient travel corridors for them. While a distributional shift to manmade-inaccessible nest sites that are more proximate to available prey resources may offer advantages in the short-term, in the long-term it may restrict nesting options, promote premature fledging, and decrease post-fledging survival. As such, a shift to nesting on ANSs may represent an ecological trap. It is currently unknown whether raptors possess the requisite feedback mechanisms to respond to decreased post-fledgling survival. Until future research more fully addresses issues of post-fledgling survival, overall foraging-range habitat use, and long-term population growth and recruitment dynamics in similar systems, it would be unwise to speculate whether ANS mitigation for large-scale natural-gas development actually introduces "source" or "sink" dynamics to existing Ferruginous Hawk populations (Neal 2007).

Another significant unknown and possible problem with regard to large-scale application of ANSs as a management tool for Ferruginous Hawks concerns the possibility that such could potentially result in a long-term change in the nesting behavior of the species. Clearly, at least in this south-central Wyoming ecological system, the shift to use of ANSs resulted in a significant change in the nest-use, nest-defense, and nestling-provisioning behaviors of the associated breeding birds compared to those nesting on natural substrates. Although we can only speculate on what any potential alteration in nesting ecology may mean for Ferruginous Hawks in the RFO in the future, we do believe the topic deserves consideration, given the scale at which ANSs are being used in the area. In the worst-case scenario, one might envision a population that, across several generations and through inter-generational transfer of learned behavior, can no longer function effectively in otherwise typical Ferruginous Hawk nesting situations. While this extreme may be unlikely, given the apparent adaptability of Ferruginous Hawks to a variety of both natural and manmade nesting substrates (Gaine 1985, Olendorff 1993, Tigner and Call 1996, Bechard and Schmutz 1995, Neal 2007), land managers should give thought to the potential dangers that may be associated with drastically altering the natural nesting ecology of a species. If there was a good reason to suspect that Ferruginous Hawk nesting use of ANSs would produce negative effects, it may be preferable to avoid immediate mitigation for use of OG structures and thereby "force" birds exposed to such developments to learn through repeated nest failures that nesting on OG infrastructure is not productive, with the hope that after a few failures they would return to nesting on natural substrates. However, given that a number of birds in the RFO successfully nested on OG structures and current legal protection of raptor nests under the Migratory Bird Treaty Act, this option may not be realistic.

Yet another facet of evaluating the overall merits of ANSs as a mitigation tool, which is worthy of attention but again impossible to evaluate in the current context, concerns possible impacts on the underlying ecosystem of changing the distribution and ecology of nesting Ferruginous Hawks. For example, significant concern has emerged recently over the possible influence that installation of power-lines and other manmade structures in habitats otherwise devoid of elevated hunting perches and nest substrates for raptors may be having on sensitive species such the Greater Sage-Grouse (*Centrocerus urophasianus*). Growing evidence suggests that the availability of manmade hunting perches may significantly increase depredation of sage-grouse by Golden Eagles and lead to the demise of historic breeding-display leks. Other sensitive species that may be similarly impacted in relevant habitats include for example, Burrowing Owls (*Athene cunicularia*), which typically occupy relatively open habitats compared to most other raptor species and are known to be susceptible to predation by other raptors (Klute et al. 2003), as well as species such as white-tailed prairie dogs (*Cynomys leucurus*). Ripple effects of shifts in the distribution of Ferruginous Hawks on populations of other key prey species, such as ground squirrels, cottontails (*Sylvilagus* spp.), and jackrabbits (*Lepus* spp.), also may occur with unknown consequences for overall ecosystem stability. Thus, while the evidence gathered in the RFO clearly suggests that ANSs served effectively to mitigate for use of natural-gas structures as substrates for nesting Ferruginous Hawks, at this point we cannot fully evaluate the long-term implications for the overall health of the population and the ecosystem as a whole.

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