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Commentary

Ponderosa Pine Forest Structure and Northern Goshawk Reproduction: Response to Beier et al. (2008)

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ABSTRACT Ecosystem-based forest management requires long planning horizons to incorporate forest dynamics — changes resulting from vegetation growth and succession and the periodic resetting of these by natural and anthropogenic disturbances such as fire, wind, insects, and timber harvests. Given these dynamics, ecosystem-based forest management plans should specify desired conditions such as tree species composition, age class, tree density and structure, size and density of snags and course woody debris, and the size, shape, and juxtaposition of trees, groups of trees, and stands in order to create and sustain habitats for wildlife. The management recommendations for the northern goshawk (*Accipiter gentilis*) in the southwestern United States (hereafter, recommendations; Reynolds et al. 1992) is a management plan designed to conserve this top predator by accounting for factors thought to limit their populations: vegetation structures, foods, predators, and competitors. The recommendations combined coarse- and fine-filter approaches to develop desired habitats for goshawks and their prey in landscapes whose compositions, structures, and patterns were conditioned on the aut- and synecologies of over- and understory plant species in forest ecosystems. Management plans that address all stages of a species' life history, the physical and biological factors limiting its populations, the habitats of other members of its ecological community, and the spatial and temporal dynamics of forests it occupies should be robust to failure (Reynolds et al. 2006*a*, *b*). The recommendations have been implemented in National Forests in the southwestern United States since 1996 (USDA Forest Service 1996), but their efficacy at conserving goshawk reproduction and survival has yet to be demonstrated. Recently, Beier et al. (2008) conducted a test of the recommendations and concluded that reproduction of goshawks declined as forest structures in their breeding areas became increasingly similar to those described in the recommendations. Here we show that methods they used to determine similarity to the structural conditions described in the recommendations resulted in inappropriate measures of similarity. We also show that their monitoring of goshawk reproduction on the 13 breeding areas used in their study was insufficient, and show how their insufficient monitoring introduced a systematic bias that reduced the precision of their test even if they had correctly measured similarity. We end by suggesting approaches for determining structural similarity to the goshawk recommendations in ponderosa pine and how to achieve adequate sampling for reproduction on breeding areas. © 2012 The Wildlife Society.

KEY WORDS *Accipiter gentilis*, desired conditions, food webs, forests, habitat, landscape, management, northern goshawk, ponderosa pine.

The habitat management recommendations for the northern goshawk (*Accipiter gentilis*) in the southwestern United States (Reynolds et al. 1992) is an ecosystem-based plan intended to conserve this top predator by accounting for factors that potentially limit its population growth: vegetation structure, food, predators, and competitors (for reviews *see* Reynolds et al. 2006*b*, Rutz et al. 2006). The recommendations identified separate management plans for southwestern ponderosa pine (*Pinus ponderosa*), mixed conifer, and spruce–fir forests because of different component plant and animal species in these 3 ecosystems. The recommendations specified multiple goshawk nest areas centrally located within territories and forest structures suited to their hunting behavior mixed with the habitats of their principal prey throughout goshawk home ranges. For ponderosa pine forests, the desired prey habitats occur in a mosaic of small groups of young to old trees in a matrix of grass–forb–shrub vegetation. Older forests with lifted tree crowns provided goshawks with subcanopy flight space and abundant hunting perches. Likewise, older forests with abundant snags, woody debris, and logs, and the grass–forb–shrub matrix provided critical prey habitats. To sustain these desired habitats, the recommendations specified the proportions of a landscape that occur at any point in time in 6 different tree-size classes

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(or vegetation structural stages, VSS). For the forested portion of the landscape (excludes the grass–forb–shrub openings between tree groups), about 10% of tree groups were in the seedling stage (VSS1), 10% in saplings (VSS2), and 20% each in young forest (VSS3), mid-aged forest (VSS4), mature forest (VSS5), and old forest (VSS6; Reynolds et al. 1992). The desired landscape would comprise a shifting mosaic of VSS groups as trees aged, moving groups from one VSS to the next. Fine-scale habitat diversity, achieved by maximizing the interspersion of different VSS groups within the grass–forb–shrub matrix, provides the adjacency of habitats needed by prey species. To assure that the desired habitats were within the biophysical capabilities of a site and, therefore, sustainable, the recommendations incorporated 1) local and regional variations in vegetation composition and structure, 2) tree development rates and longevity, 3) succession and natural disturbances, 4) the sizes, shapes, and juxtapositions of plant aggregations (trees and grass–forb–shrub vegetation), and 5) site potential.

The recommendations represented a desired condition landscape approach (as opposed to a reserve design) that encouraged active management to develop and maintain the desired conditions throughout managed landscapes (Reynolds et al. 1992, 2006*a*). They utilized a combination of coarse- and fine-filter approaches to conserving goshawks, and the resultant desired forest conditions approximated the composition, structure, and landscape pattern of southwestern ponderosa pine forests before Euro–American interruption of natural disturbance regimes, especially fire. Conservation strategies that address all stages of a species' life history, the physical and biological factors limiting its populations, the habitats of other members of its ecological community, and the spatial and temporal dynamics of ecosystems it occupies should be robust to failure (Reynolds et al. 2006*a*). The recommendations have been implemented on all National Forests in the Southwest since 1996, but their efficacy at creating and conserving goshawk and prey habitats has yet to be tested.

In a recent paper, Beier et al. (2008) described tests of the goshawk recommendations in which they evaluated empirical support for the hypothesis that goshawk reproduction is affected by different forest structures (tree density, diam distribution, and basal area; canopy closure [CC]; nos. of snags and logs) in 2 circular areas, the Central Zone (CZ) and the Foraging Band (FB), centered within 13 goshawk breeding areas in Arizona, USA. The CZ (243 ha, radius = 880 m) comprised about 10% of an estimated 2,430-ha goshawk home range, and the FB (972 ha, radius = 1,967 m, exclusive of the CZ), a band encircling the CZ that included about 40% of a home range (Beier et al. 2008:344). Their test used mean numbers of fledglings produced over years on the 13 goshawk breeding areas in ponderosa pine forests as a response variable and the percent similarity in the CZ and FB to forest structures described in 3 hypotheses as dependent variables. The hypotheses were 1) the goshawk recommendations (Reynolds et al. 1992), 2) preferred foraging habitat, a hypothesis described in Greenwald et al. (2005), and 3) presettlement (i.e., prior to Euro–American settlement) forest conditions (Fulé et al. 1997, 2002; Mast et al. 1999; Waltz et al. 2003). Beier et al. (2008:343–345) described the goshawk recommendations hypothesis as a mix of forest age and structural conditions intended to provide nest and foraging habitats for goshawks and habitats for 14 important goshawk prey species that included 6 tree-diameter classes, 2 minimum CC thresholds, and minimum thresholds for densities of snags and logs. They described goshawk preferred foraging habitat as a landscape of many large-diameter trees with dense CC, but with no special focus on prey habitats because "goshawks do not select stands with the greatest prey abundance" (here they cite Greenwald et al. 2005:120, but not the original source of the statement in Beier and Drennan 1997:569) and presettlement forests as having a lower basal area, stem density and CC with a larger fraction of the landscape dominated by large trees as documented in forest restoration studies (citations above). Beier et al. (2008) used percent similarity as an index of how each goshawk breeding area matched each structural hypothesis and used an information-theoretic approach to evaluate support for 8 candidate models (Beier et al. 2008:table 2). We limit our rebuttal of Beier et al. (2008) to their test of the goshawk recommendations.

Beier et al. (2008) evaluated 4 models based on the goshawk recommendations, 2 including the CZ only and 2 with the CZ and FB combined. They evaluated 2 models for each of these areas because their method for estimating CC, which they did not measure directly, "introduced unknown errors" and because "most goshawk breeding areas had far fewer snags and logs" than specified in the recommendations (Beier et al. 2008:345). Thus, they tested 2 models each for the CZ and CZ + FB: the distribution of tree diameter classes, CC, and number of snags and logs (hereafter, full models), and the distribution of tree diameter classes only (hereafter, diam distribution models) specified in the recommendations. Based on their 3 top models, Beier et al. (2008:342) concluded that goshawk reproduction decreased with increasing similarity to the goshawk recommendations and recommended that the U.S. Forest Service reconsider its decision to apply the recommendations to forest lands in Arizona and New Mexico, USA. Beier et al. (2008) found no support for models relating goshawk reproduction and percent similarity to preferred foraging habitat or presettlement forest conditions.

Our review of Beier et al. (2008) identified a number of items that suggested they misunderstood the desired forest structures described in the recommendations for ponderosa pine forests. These misunderstandings caused Beier et al. (2008) to measure forest structural characteristics unrelated to those in the recommendations, invalidating their measures of structural similarity to the recommendations. Evidence of their misunderstandings included, 1) no discussion or use of methods suited for detecting tree aggregations, 2) their inappropriate estimation of canopy cover (see below), and 3) their statement that the structures in the recommendations "differ markedly" from presettlement forest structures (Beier et al. 2008:348) when in fact the 2 structures are quite

similar (Reynolds et al. 1992, Long and Smith 2000, Reynolds et al. 2006*a*). Beyond nest areas, landscape mosaics of small groups of trees with interlocking crowns of different structural stages intermixed with grass–forb–shrub openings are 2 main structural characteristics described in the recommendations for ponderosa pine forests (Reynolds et al. 1992:23–29). Small groups of trees with interlocking crowns provide habitat and travel routes for tree squirrels, high canopy shading for several prey species, protected soil conditions for mycorrhizal fungi (foods of several prey), and open grass–forb–shrub habitats for rabbits, ground squirrels, and some avian prey. Openings also provide rooting space for the tightly grouped trees (Reynolds et al. 1992, 2006*a*; Youtz et al. 2008). To correctly measure similarity to the vegetation structures described in the recommendations, Beier et al. (2008) would first have had to determine whether trees were grouped and, if grouped, used follow-up methods for measuring the desired within-tree group structures (i.e., interlocking crowns, open understory, tree sizes, VSS). Instead, Beier et al. (2008:344) used variable-radius plots to collect forest stand data, a method poorly suited for detecting and measuring tree aggregations and their extent (see Stage and Rennie [1994] for discussion of the variable-radius plot). While tree aggregations might be detected in a series of variable-radius plots (i.e., some plots would contain many trees, others no trees), for the plots to provide accurate measures of similarity to the recommendations, Beier et al. (2008) would have had to determine whether any aggregated trees were close enough to have interlocking crowns. There is no evidence in Beier et al. (2008) that they did so.

The degree of CC in the recommendations was specified only for the VSS 4, 5, and 6 (mid-aged to old forest) tree groups and was to be measured only within these tree groups from a group's outer canopy drip-line to the opposite drip-line (Reynolds et al. 1992:23, 27, 87). Instead, Beier et al. (2008:344) estimated CC from a theoretical maximum stand-density index (SDI, see below) and used class boundaries (i.e., 30% SDI = 40% CC, 39% SDI = 50% CC, and 47% SDI = 60% CC) to relate a sampled stand's percentage of theoretical maximum SDI for ponderosa pine forests to obtain CC estimates. Stand density index is a metric of forest structure *at the stand scale* based on a stand's forest type, trees per area, average tree diameters, and basal area (McTague and Patton 1989, Shaw 2000). Beier's et al. (2008) stand-level CC estimates were inappropriate for measuring structural similarity to forests composed of small trees groups in which canopy cover is to be determined only within tree groups. A final indication that they misunderstood the recommendations is their statement that forest structures in the recommendations "differs markedly" from presettlement forest structures (Beier et al. 2008:348). A mosaic of tree structural stages in small groups within a grass–forb–shrub matrix, as described in the recommendations, is in fact quite similar to the groupy, multiaged forest within grass-dominated meadows encountered in the early 20th century (Pearson 1950, Cooper 1961, Covington et al. 1997).

As noted, variable-radius plots do not necessarily provide measures of tree aggregation. To determine an area's similarity to the vegetation structures described in goshawk recommendations, multiple spatially scaled measurements of tree distributions are needed at the stand level, the between-tree group level (spacing among groups), and the within-tree-group level (tree densities, sizes, basal areas, interlocking crowns, canopy cover, understory composition, and structure). Quantification of aggregation at these scales requires the mapping of trees on fixed-radius plots (Coomes et al. 1999, Sánchez-Meador et al. 2010). Mapping allows for point pattern analysis such as Ripley's $K(t)$ function (Ripley 1976, 1977). Ripley's $K(t)$ function can be transformed with a square-root, variance-stabilizing function to $L(t) - t$ (Besag 1977), where $L(t) - t$ values larger than, equal to, and smaller than 0 indicate aggregated, random, and uniform distributions, respectively. If trees are aggregated, then the density and spacing of tree groups, the sizes of groups, the numbers, sizes, and spacing of trees within groups, and other within-group structures such as interlocking crowns, can be determined for measures of similarity to the recommendations. If trees are not aggregated with interlocking crowns then similarity to the recommendations for ponderosa pine forests would be low. Although the recommendations did not specifically identify the sizes (area) of tree groups, numbers of trees per group, nor the proportion of an area that was grass–forb–shrub (only that openings should not exceed 61 m in width, Reynolds et al. 1992:28), they do state that groups be small to minimize within-group competition for space, light, and nutrients to optimize tree growth (big trees are a desired structure). In a follow-up paper, Reynolds et al. (2007) identified a range of 2–44 trees per group based on Cooper's (1961) and White's (1985) descriptions of old ponderosa pine tree groups in the Southwest. Beier et al. (2008) used fixed-radius plots for tallying snags and logs (0.405-ha circular plots) and seedlings and saplings (0.00405-ha circular plots), but they apparently did not sample the grass–forb–shrub vegetation, a critically important element for goshawk prey that require measurement to determine an area's vegetation structural similarity to the recommendations.

Because it remains uncertain whether the similarity measures reported by Beier et al. (2008) accurately represented the true similarities of the 13 breeding areas to the recommendations, we point to another flaw in their study: unequal and insufficient monitoring for reproduction among breeding areas. Beier et al. (2008) monitored only 5 (38%) of the 13 breeding areas in all 9 years of their 10-year study (because breeding areas could not have been unoccupied in their yr of discovery, they dropped the first yr of monitoring) and 2 breeding areas were monitored $\leq$4 years (Beier et al. 2008:table S1, supplemental material). We regressed the number of years during which each of their 13 breeding areas was monitored against the reproductive output of each. The regression showed a negative relationship between years monitored and reproduction; the numbers of fledglings produced on breeding areas declined with increasing years of monitoring (Fig. 1A). A similar regression of fledglings

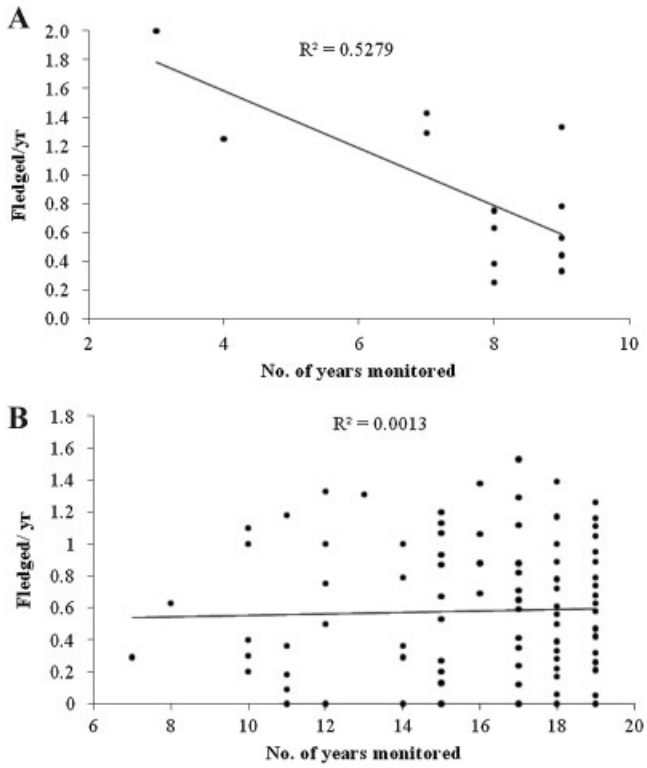

Figure 1. Effects of insufficient monitoring of fledgling production per year monitored in goshawk breeding areas. (A) The negative relationship between the number of years Beier et al. (2008) monitored 13 breeding areas (range = 3–9 yr, 1993–2002) and numbers of fledglings produced per year monitored; fledgling production declined with increasing years of monitoring. (B) The lack of a relationship between years monitored (range = 8–19 yr, 1991–2010) and fledglings produced per year monitored in 121 goshawk breeding areas on the Kaibab Plateau, Arizona, USA.

produced against years monitored on 121 goshawk breeding areas in our 20-year study of goshawks in northern Arizona, 200 km north of the Beier et al. (2008) study area, showed that with sufficient monitoring there was no relationship between years of monitoring and reproduction (Fig. 1B). Beier's et al. (2008) undersampling introduced a systematic bias by including higher reproductive outputs than was likely the case for 5 of the 8 (63%) undersampled breeding areas where similarities (in the CZ) to the recommendations were less than the average similarity of all 13 areas. The extent and direction of this bias is illustrated by the 2 least-sampled breeding areas, Hart Canyon and Aniceto Knoll. These areas produced a mean of 2.0 and 1.3 fledglings in the 3 and 4 years they were monitored; the highest and third-highest numbers of young produced on the 13 breeding areas, respectively ($\bar{x}$ fledglings produced per year monitored at the 5 fully monitored breeding areas was 0.7, Beier et al. 2008:table S1). If these 2 areas fledged young in the same irregular annual pattern as the 5 breeding areas with the full 9 years of monitoring (productive an average of 59% of the 9 years), then the actual number of fledglings produced could have been less by as much as half. Reproduction biased high on these 2 breeding areas; their low similarities to the recommendations (Hart, 28.8%, Aniceto, 30.9%; CZ mean similarity = 32%, , range = 21–56%, $n = 13$), combined with the overall effects of the systematic bias (5 of the 8 undersampled breeding areas had less than the mean CZ similarity, and 4 of the 5 had greater than the mean reproduction, of the 13 breeding areas; Beier et al. 2008:tables S1 and S2), undoubtedly had a significant influence on the negative relationship between fledglings produced and a breeding area's similarity to the goshawk recommendations in their top model (Beier et al. 2008:figure 2).

Undersampling is problematic because breeding by goshawks in the American Southwest is highly variable from year to year. In our 20-year (1991–2010) mark–recapture study of goshawks in northern Arizona, the annual proportion of 121 breeding areas on which egg laying occurred varied from 10% to 87% (Reynolds et al. 2005, R. T. Reynolds, unpublished data). Whereas this temporal variation was closely associated with inter-annual variation in prey abundance (Salafsky et al. 2005, 2007), a contributing factor was lack of egg laying for 1–5 years on every one of the territories following the disappearance of a breeder and the first breeding by its replacement (R. T. Reynolds, unpublished data). Given Beier's et al. (2008:343) own acknowledgment of large annual variation in egg laying by goshawks in western North America, we are puzzled by their inclusion of undersampled breeding areas.

Based on the assertion that home-range size has been evolutionarily adjusted to contain the requisite resource levels, an objective of the recommendations was to provide predator and prey habitats throughout goshawk home ranges. Therefore, we suggest that tests of the recommendations occur at the home range scale. Beier's et al. (2008:344) 2 top models included the CZ, about 10% of the inner core of a goshawk home range. Their justification for this narrow focus was that "areas close to the nest may have a different influence on goshawk reproduction than do more distant areas." We certainly agree with the supposition of a different influence in the inner portion of a home range, and the recommendations accounted for important differences by specifying different forest structures at nest areas and in the post-fledging family area surrounding nests (Reynolds et al. 1992). However, more distant areas from nests are used regularly by hunting adult males, the principal food providers at nests through the long breeding season (Eng and Guillion 1962, Ward and Kennedy 1994, Good 1998, Horie et al. 2008). While tests of the recommendations ought to occur at various spatial scales, those not including the outer portion of the home range are likely to miss important habitat relationships. Beier's et al. (2008) third-best model, which combined CZ and FB and included the inner 50% of a home range, also comes up short. In addition to including a larger portion of the home range, we also recommend that tests include some breeding areas with greater similarity to the vegetation structure in the recommendations than the maximum of 57% (range = 21–56% for the CZ, 26–57% for the FB, full models) in Beier et al. (2008:346–347). Recent work shows that some species decline more rapidly below a critical habitat abundance or quality threshold level; extinctions become more and more

frequent as habitat loss continues (Jansson and Angelstam 1999, Bascompte and Rodriquez 2001, Fahrig 2003, Swift and Hannon 2010). If the reverse is true—species abundances and richness increase in a nonlinear fashion as habitat abundance and quality increases—then a test of the recommendations ought to include some breeding areas with similarities much closer to the recommendations.

In our estimation, the approach used by Beier et al. (2008) to compare goshawk reproduction on a sample of breeding areas whose habitats have a range of similarity to the recommendations is sound. However, similarity measures must accurately reflect the structures described in the recommendations. For this we recommended using fixed-radius plots, tree stem mapping, and analyses capable of detecting tree aggregations (e.g., Ripley's $K(t)$ function). We also recommend sampling for similarity in the composition and structure of grass–forb–shrub vegetation in opening between tree groups. Of course, breeding areas should be selected randomly from a pool of breeding areas, and, to increase the test's precision, the sample should be stratified across a wide range of similarities (i.e., 0–100%) to the recommendations. Sampling for similarity is prohibitively expensive and time consuming; therefore, an initial stratification of the pool of available breeding areas could be achieved by classifying them into high, medium, and low similarities based aerial photographs. All sampled breeding areas must be monitored during the same period of years and with the same sampling effort, including searches for breeding goshawks that may have moved to alternate nests. The importance and extent of alternate nest searches is indicated by the frequency and distances of movements of goshawks among alternate nests; Reynolds et al. (2005) reported that annually a mean of 64% (range = 55–76%) of egg-laying pairs moved to alternate nests and movements were over a median inter-alternate nest distance of 402 m (max. = 2,400 m). Monitoring must also occur over sufficient years to include the temporal variation in goshawk reproduction stemming from good and poor prey years and turnovers of adults on breeding areas (Reynolds et al. 2005; Salafsky et al. 2005, 2007; R. T. Reynolds, unpublished data). A more appropriate measurement response to habitat structural conditions on breeding areas than Beier's et al. (2008) mean fledglings produced per year would be a total count of fledglings during the study years. Goshawks are large-area predators that hunt throughout their home range. Therefore, we recommend that tests of the recommendations should include the determination of similarity at the home range scale. Studies involving repeated measures of reproduction of the same goshawks on the same breeding areas result in correlated data; therefore, generalized linear mixed models could be used for modeling outcomes inherent within longitudinal and repeated-measures designs (Verbeke and Molenberghs 2000). Finally, because the desired habitats in the recommendations were, to a great extent, a synthesis of the habitats of 14 principal goshawk prey, we recommend testing the efficacy of the recommendations for increasing the diversity and the combined abundance of the suite of goshawk prey. Such a test could be conducted independently or in conjunction with a monitoring of goshawk breeding areas.

Beier et al. (2008) argued that many management prescriptions are based on ecological hypotheses and that evaluating support for such hypotheses can improve management. We were confident that a goshawk conservation strategy would be robust to failure if it addressed factors limiting their populations, included the habitats of plants and animals in the hawk's ecological community, and was informed by the spatial and temporal dynamics of the vegetation comprising forest ecosystems occupied by goshawks. Nonetheless, we agree with the Beier et al. (2008) call for an evaluation of the recommendations. However, because they appeared to miscalculate vegetation structural similarities to the recommendations and they introduced a systematic bias into their test by inadequately sampling breeding areas for reproduction, we find the Beier et al. (2008) test to be invalid and, therefore, reject their finding that goshawk productivity decreased with increasing similarity to the recommendations.

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