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WHEN ARE GOSHAWKS NOT THERE? IS A SINGLE VISIT ENOUGH TO INFER ABSENCE AT OCCUPIED NEST AREAS?

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Abstract.—We tested the efficacy of three methods (historical nest search, broadcast search, and tree transect search) for detecting presence of the Northern Goshawk (*Accipiter gentilis*) at occupied nest areas during the 1994 breeding season using only a single visit to a previously known nest area. We used detection rates in a probability model to determine how many visits are required to have confidence in reporting absence of goshawks. The purpose of this study is to understand if the three methods for detecting goshawks are robust enough for managers to rely on them for making land management decisions that may impact goshawk nest areas. Blind tests were conducted throughout the western United States. Results were similar among methods with goshawk presence going undetected at 36–42% of the occupied nest areas after a single visit. These results indicate that a single visit to a nest area is inadequate to provide reliable information on nest area occupation. Our probability of detection model showed that if each detection method is repeated three (historical or tree transect) or four (broadcast) times, goshawk absence can be inferred with a high level of confidence. Conclusions regarding nest area occupation using a single visit sampling method should be made with utmost caution. Classifying a nest area as vacant, when in fact goshawks are present, is a serious concern and leads to spurious conclusions. Land managers making habitat-altering decisions should not rely on a single visit to nest areas to establish the absence of goshawks. Possibilities for improving the detection of nesting goshawks include multiple independent visits using the same method, using a sequence of techniques in combination to yield an improved cumulative probability of detection, or developing a new method yielding a higher probability of detection. The historical nest search obtained the best results, followed by the tree transect and broadcast search.

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KEY WORDS: *Northern Goshawk; Accipiter gentilis; detection rates; forest management; nest area; occupancy; repeated sampling*

¿CUÁNDO ESTÁ AUSENTE ACCIPITER GENTILIS? ¿ES SUFICIENTE UNA SOLA VISITA PARA INFERIR AUSENCIA EN ÁREAS DE NIDIFICACIÓN OCUPADAS?

RESUMEN.—Probamos la eficiencia de tres métodos (búsqueda de nidos histórica, búsqueda por medio reproducción de grabaciones, búsqueda a lo largo de transectos de árboles) para detectar la presencia del halcón *Accipiter gentilis* en áreas de nidificación activas durante la época reproductiva de 1994, utilizando una sola visita a un área de nidificación previamente conocida. Utilizamos las tasas de detección en un modelo de probabilidad para determinar cuántas visitas se requieren para tener certeza al reportar una ausencia de esta especie de halcón. El propósito de este estudio es entender si los tres métodos para detectar a esta especie son suficientemente robustos para confiar en ellos al tomar decisiones de manejo de tierras que pueden afectar áreas de nidificación. Realizamos pruebas ciegas a través del oeste de los Estados Unidos. Los resultados fueron similares entre los métodos; la presencia de los halcones no fue detectada en el 36–42% de las áreas de nidificación activas luego de una sola visita. Estos resultados indican que una sola visita a un área de nidificación no es adecuada para obtener información confiable sobre la actividad de nidificación en el área. Nuestro modelo de probabilidad de detección mostró que si cada método es repetido tres (histórico o transecto de árboles) o cuatro (reproducción de grabaciones) veces, la ausencia de halcones puede ser inferida con un alto grado de confianza. Las conclusiones con respecto a la actividad de las áreas de nidificación utilizando el método de muestreo de una sola visita deben tomarse con gran precaución. La clasificación de un sitio de nidificación como vacío, cuando de hecho los halcones están presentes, es una preocupación seria y puede llevar a conclusiones falsas. Las personas encargadas de manejar las tierras y tomar decisiones con relación a la alteración de los hábitats no deberían confiar en una sola visita a los sitios de nidificación para determinar la ausencia de estos halcones. Algunas de las posibilidades para mejorar la detección de halcones que se encuentran nidificando incluyen realizar visitas múltiples e independientes utilizando la misma metodología, utilizar conjuntamente una secuencia de técnicas para producir mejores probabilidades de detección acumulativas o desarrollar un método nuevo que pueda proveer de una probabilidad de detección mayor. La metodología de búsqueda de nidos histórica obtuvo los mejores resultados, seguida por la de los transectos de árboles y la búsqueda por medio de reproducción de grabaciones.

[Traducción del equipo editorial]

The U.S. Department of Interior Fish and Wildlife Service (FWS) reviewed the status of the Northern Goshawk (*Accipiter gentilis atricapillus*) for Federal protection (i.e., listed as threatened or endangered under provisions of the Endangered Species Act) three times since 1991. In each case the FWS ruled that listing was unwarranted. Population trend is one of five factors used by the FWS for determining whether to list a species as threatened or endangered. The majority of nesting goshawks in the western United States are located on lands managed by the U.S. Department of Agriculture Forest Service (FS). Since the FS is required by the National Forest Management Act (NFMA) to maintain species population viability, monitoring the occupancy of goshawk nest areas is necessary to evaluate population trends.

Lacking a formal national goshawk monitoring program, the FS management approach to protecting goshawks in the southwestern United States is to locate goshawk nest trees and post-fledging family areas (Kennedy et al. 1994) prior to habitat alterations and then to apply goshawk management recommendations (varying from region to region) to conserve the nest area, manage the post-fledging family area, and manage the foraging area (Reynolds et al. 1992). After implementation of habitat management prescriptions, follow-up management practices should include monitoring the effect of habitat changes on species; however, this is rarely done. The untested assumption is that the management program will work as designed.

Finding and monitoring nesting goshawks is a critical component of successful adaptive land management practices if goshawks are to persist in managed landscapes. Goshawks exhibit strong fidelity to nest areas (Reynolds and Joy in press), but have fluctuating population numbers and nesting success year to year. Goshawks also frequently change nest locations within a nest area or between nest areas within a territory. Because a proportion of the local population of goshawks moves to alternate nest areas on an annual basis, sampling only the historical nest areas over time without finding the alternate nest areas will result in fewer and fewer occupied nest areas (i.e., the unwarranted appearance of a declining population).

Counting, sampling, and detecting birds are important concerns of avian researchers (Bart and Earnst 2002, Farnsworth et al. 2002, Rosenstock et al. 2002, Thompson 2002). Developing techniques to find goshawks efficiently has been an ongoing process (Kimmel and Yahner 1990, Kennedy and Stahlecker 1993, Joy et al. 1994, Watson et al. 1999, Penteriani 1999, Roberson et al. in press). Biologists have yet to develop an accurate, cost-effective method that will detect goshawks throughout the nesting period. This is because the species is secretive, difficult to find and study, and their behavior changes during the breeding season. Kennedy and Stahlecker (1993) tested a technique for broadcasting goshawk vocalizations from calling stations positioned on parallel transects that were placed tangential to the occupied nest. Their tests were conducted in the southwestern U.S. during the nestling to fledging stage. They found that the probability of detecting a goshawk, when within 100 m of a nest, averaged 70% throughout the season using multiple visits. The median detection distance was 141 m. On control transects, without broadcasting, detection rates dropped to between 30% (courtship) and 60% (fledgling).

In Washington, Watson et al. (1999) tested Kennedy and Stahlecker's (1993) broadcast method using three stations (400 m, 250 m, and 100 m) on a single transect that passed tangential to the nest at 100 m at its closest point. They found five visits at 100 m from the nest, eight visits at 250 m from the nest, and 10 visits at 400 m attained a 90% or higher detection rate. In another study using the broadcast technique from courtship to fledgling dependency, only 52% of goshawks were detected (McClaren et al. 2003); but, detections were lower during courtship (40%) and highest during fledgling dependency (75%). Kennedy and Stahlecker (1993), Watson et al. (1999), and McClaren et al. (2003) are examples of experienced goshawk biologists evaluating goshawk survey techniques. Their prior experience with goshawks and knowledge of nest locations may have positively influenced experimental results (i.e., their detection rates probably represent maximum rates under test conditions).

A problem with past goshawk inventory and monitoring efforts has been a reliance on methodologies whose bias, probability of detection, and magnitude of detection error were unknown. There has always been uncertainty associated with misclassifying a goshawk territory as unoccupied when it may be occupied (i.e., error of omission). In 1994, the FS identified the need to test the efficacy of techniques for finding goshawks. This was driven by the FS desire to implement specific habitat altering management actions designed to protect goshawk nest areas, post-fledging family areas, and the surrounding foraging area from harm (Reynolds et al. 1992), or to allow for flexible management options if goshawks were not present. Three commonly used detection methods available at that time were identified as needing testing (historical nest tree search, broadcast search, and tree search within potential nest areas). No investigators had compared the potential errors associated with the three typical inventory techniques.

Our objectives were to: (1) document the error associated with each of these three detection techniques and (2) use the error rates to estimate the number of nest area visits needed to infer absence of goshawks with different levels of confidence. We conducted a blind test of these methods for detecting breeding goshawks to reveal the magnitude of error associated with each technique. The reason we conducted blind tests was to control the variability introduced in previous tests conducted by experienced goshawk biologists that had prior knowledge of the nest area and its status (Kennedy and Stahlecker 1993, Joy et al. 1994); possibly influencing their results. We then input our results into a probability model to conceptually explore various combinations of detection rates, errors associated with these detection rates, and predict the number of sampling visits needed to have confidence in the information collected.

METHODS

We tested the efficacy of revisiting historical nest trees, broadcasting goshawk vocalizations in nest areas, and scanning all trees along transects established throughout nest areas within an 800 m diameter area centered on occupied (nest with eggs/young) nest areas. The size of our sampling unit was 1/35 the estimated size of the territory (2400 ha) (Reynolds et al. 1992) and was selected to account for alternate nest locations within a single nest area. Field tests were conducted from June to early mid-July 1994 during nestling and fledgling dependency periods (Squires and Reynolds 1997). Experienced field biologists determined that each nest area tested had nesting goshawks present prior to the test. During the testing period, occupancy was determined by observing goshawks incubating eggs, adults brooding young, or observing young at the nest. The same criteria were used at all study areas. Personnel naive to the presence and location of occupied nests were used to test the three methods. Only one method was tested, and only one visit was made, at each occupied nest area. The three methods were randomly assigned to active nest areas. To simulate normal field conditions, experience was allowed to vary among field members; no effort was made to randomize field crew experience among the three detection methods. Results from each state were pooled to improve sample size.

Study Areas. Tests were conducted in Arizona, California, New Mexico, and Wyoming. In Arizona ($N = 44$), tests were conducted in the Apache/Sitgreaves, Coconino and Kaibab National Forests. Forests in Arizona were dominated by ponderosa pine (*Pinus ponderosa*), white fir (*Abies concolor*), and Douglas-fir (*Pseudotsuga menziesii*). In California ($N = 10$), tests were conducted in the Klamath National Forest, where at higher elevations, forests were dominated by red fir (*Abies magnifica*), white fir, ponderosa pine, lodgepole pine (*Pinus contorta*), Douglas-fir, and incense cedar (*Calocedrus decurrens*), and lower elevation forests by ponderosa pine and white fir (Kuchler 1977). In New Mexico ($N = 11$) tests were conducted in the Santa Fe National Forest where forests contained ponderosa pine, Douglas-fir, white fir, and quaking aspen (*Populus tremuloides*) and at higher elevations subalpine fir (*Abies lasiocarpa*) and Englemann spruce (*Picea engelmannii*). In Wyoming ($N = 12$), tests were conducted in the Medicine Bow National Forest where lower elevation forests contained lodge pole pine with scattered quaking aspen, and higher elevation forests contained subalpine fir and Engelmann spruce (Alexander et al. 1986, Marston and Clarendon 1988).

Historical Nest Search. The most common goshawk search technique used prior to 1990 was to visit historical nest areas and relocate previously used nest trees to determine occupancy. Typically, little effort was spent in a broader search of a nest area if goshawks were not found. To simulate this method, biologists were given 1:24 000 scale maps marked with the approximate locations of nest trees within a nesting area where goshawks had previously nested. Biologists were instructed to relocate the nest trees and determine if goshawks were present and nesting. The strength of this method relies on goshawk fidelity to nest areas (Reynolds et al. 1994) and that field personnel often detect goshawk presence by observing the defensive behavior of goshawks near their nests. Other clues to goshawk nest area occupancy with this method included observing fecal material, prey remains, or molted goshawk feathers in the vicinity of nests. When these clues were found, the area was searched further to find the occupied nest.

Broadcast Surveys. This goshawk detection technique was developed in the early 1990s and involved broadcasting taped goshawk calls (alarm and juvenile food begging) to elicit a response. Field crews followed the procedure of Kennedy and Stahlecker (1993), as modified by Joy et al. (1994). Recorded calls of goshawks were broadcast from stations located at 300-m intervals, on parallel transects, in an 800 m radius area. A search was initiated to locate visually the nest once a goshawk responded. The broadcast method is a means of systematically searching the landscape for goshawks. This method is also useful for locating nesting pairs that move to alternate areas within their territory. A problem with the technique is that goshawks do not always respond to the broadcast call when they are present, may respond with a silent approach, or may respond to broadcast calls when they are far away from their nest areas and, thus, confound results. Additional confounding factors include seasonal effects and misidentification of calls such as Steller's Jay (*Cyanocitta stelleri*) mimicking goshawks (Kennedy and Stahlecker 1993).

Tree Transect. The tree transect technique is a systematic visual search of a forested area centered on the occupied nest. This method involved field crews walking along parallel transects spaced 50 m apart while examining individual trees along either side of and directly along the transect path for goshawk nests in tree crowns (Squires and Reynolds 1997). At 50 m, the probability of eliciting goshawk defensive behavior was assumed to be high because they could presumably hear or see the field crew. Crews also looked for prey plucking posts, fecal material or stains, and scattered prey remains that would provide evidence of a potential occupied nest nearby.

The Model. To address our second objective, we input the estimates of detection obtained from each search method above into a probability model (McArdle 1990). This allowed an estimation of the sample size needed to have confidence that goshawks were absent. In other words, how many revisits to the nest area are necessary to conclude goshawks are absent? Guynn et al. (1985) and Reed (1996) used probability models to retrospectively estimate confidence in detecting a species. Kery (2002) applied their model prospectively to infer how many visits were needed to be statistically confident that the species being sampled was absent.

McArdle's (1990) probability model includes: (1) the number of sampling visits (N) to an area, (2) the species probability of detection (ρ) during any visit, (3) and confidence (α) levels acceptable to the investigator (usually 95%, and therefore $\alpha = 0.05$). Assuming all visits to goshawk nest areas are similar and independent, the probability of not detecting nesting goshawks after N visits (Kery 2002) is:

$$\begin{array}{c}\text{Probability}\\(N\text{ unsuccessful visits})\end{array} = \alpha = (1 - \rho)^N \qquad (1)$$

We can solve for N and get:

$$\log(\alpha) = N \times \log(1 - \rho) \qquad (2)$$

$$N = \log(\alpha)/\log(1 - \rho) \qquad (3)$$

The minimum number of visits, N_{min}, needed to conclude that a 800-m radius circle containing a previously used nest area is unoccupied within a 95% confidence interval ($\alpha = 0.05$) can be estimated by substituting the probability of detection values (historical = 0.64, broadcast = 0.58, transect = 0.62; see Results for details) into Equation 4.

$$N_{min} = \log (0.05)/\log (1 - \rho) \qquad (4)$$

RESULTS

The results were similar for each method tested; between 58–64% of the occupied nest areas were found (historical nest search [16/25], tree transect [16/26], broadcast surveys [15/26]). Conversely, between 36–42% of the occupied goshawk nest areas were missed. The broadcast result for a single visit is identical to what Kennedy and Stahlecker (1993) reported. We did not test for temporal differences in the methods due to limited sample sizes. Despite the poor performance of each method for detecting goshawks using a single visit to a nest area, each method may be repeated several times to increase the probability of detection (Kennedy and Stahlecker 1993, Watson et al. 1999, McClaren et al. 2003). Using the detection results, we estimated the number of visits (N_{min}) needed to infer goshawk absence at nest areas at the 95% confidence level ($\alpha = 0.05$) as 2.9 for the historical nest search, 3.1 for the tree transect, and 3.5 for the broadcast survey. These detection results are only relevant to active nest areas.

Increasing the confidence level while maintaining a consistent detection rate quickly increases the number of visits needed to infer goshawk absence at nest areas and renders the sampling effort unrealistic (Table 1). For example, if we set the confidence level to 0.95, and want to limit the number of visits to two, then the probability of detection required for a method to be effective would have to be nearly 80%. Given this scenario, the goal for developing new or improved detection techniques should be to achieve a probability of detection level of at least 80%. If the confidence level is increased to 0.99 ($\alpha = 0.01$) to further reduce the misclassification error while retaining the detection probability at 80%, then the number of required visits to nest areas is three and is still a feasible management option (i.e., not cost prohibitive). McKelvey and Pearson (2001) examined a series of simulations for measuring small mammal populations with different detection probabilities and their results revealed the same general pattern as ours in that low detection probabilities require a large number of sampling sessions to attain confidence in the findings.

DISCUSSION

Our results were from occupied nest areas only. Although we controlled as much variation as possible, there were many sources of variation we did not control. We did not test for false positive detections at unoccupied sites (Kennedy and Stahlecker 1993), which are needed for a broader description of detection probabilities. Detection frequencies of goshawks at nest areas may vary for any number of reasons, but perhaps most important are changes in goshawk behavior as breeding season progresses (Squires and Reynolds 1997). Breeding goshawks become more defensive at nest areas later in the nesting season and generally are easier to detect (Squires and Reynolds 1997). Young goshawks also are easier to detect later in the breeding season as they grow and become more active (McClaren et al. 2003). Because detection methods may be temporally sensitive, managers must interpret the results cautiously (McClaren et al. 2003, Roberson et al. in press).

As the breeding season progresses from March through July, goshawk nest failures continue for a host of reasons. A difficult sampling problem is to account for these nest failures. Sampling after reproductive failure occurs may lead to misclassification of nest areas as inactive. In addition, nesting areas are occupied by adults that do not breed ev-

Table 1. Theoretical number of visits to Northern Goshawk nest areas to infer goshawk absence using different detection probabilities (ρ) and confidence levels (α).

	PROBABILITY OF DETECTION							
α	60	65	70	75	80	85	90	95
0.25	1.51	1.32	1.15	1.00	0.86	0.73	0.62	0.46
0.20	1.76	1.53	1.34	1.16	1.00	0.85	0.70	0.54
0 15	2.07	1.81	1.58	1.37	1.18	1.00	0.82	0.63
0.10	2.51	2.19	1.91	1.66	1.43	1.21	1.00	0.77
0.05	3.26	2.85	2.49	2.16	1.86	1.58	1.30	1.00
0.01	5.03	4.39	3.83	3.32	2.86	2.43	2.00	1.54

ery year and thus, detection probabilities at individual nest areas are likely to vary temporally (Boal et al. 2005, R. Reynolds pers. comm.). We did not test the ability to detect nonbreeding pairs occupying nest areas; we tested only the breeding portion of the population (i.e., actively nesting in pairs). This has important ramifications for understanding the population's status (Kennedy 1997) and for managers making decisions based on results for years when few pairs are breeding. The ability to detect nonbreeding goshawks and breeding goshawks that have failed are likely to be different. Improved probabilities of detection may be possible by regulating the timing of when different methods are used.

Another source of variation that affects detection probabilities is the timing of egg-laying by females within and between populations: variation in the timing of egg-laying introduces inherent error to detection rate estimates. Thus, there will likely be differential success in detecting goshawks because the detection method used will not be perfectly sequenced to the breeding phenology of all pairs within or between populations. We recommend that managers determine the breeding phenology of their target population before implementing goshawk surveys (see Dewey et al. 2003).

Variation also exists in the experience of field crews and therefore, accuracy and reliability of survey data. In addition, goshawks may move to alternate nesting areas within a territory; this constant shifting among alternate nests may result in a perceived decay in the number of occupied nests and a fallacious conclusion of population decline if only the historical nest areas are visited (R. Reynolds pers. comm.). Given that multiple factors influence detection probabilities, the implication for monitoring populations at regional scales is that detection protocols should consider these sources of variation so that data sets from different locations and times are comparable for later use in analyzing large-scale population trends.

None of the goshawk detection methods tested in this study, when applied once, were adequate to conclude goshawks were absent at nest areas. The usefulness of new detection methods is dependent on understanding the associated detection probabilities and error rates for different spatial and temporal scales. Future approaches might include combining several different methods in a temporal sequence that improves the cumulative probability of detection throughout the breeding season (Dewey et al. 2003). Highly accurate methods appropriate early in the breeding season (e.g., listening stations; Dewey et al. 2003) may be ineffective late in the breeding period. However, by combining methods and taking advantage of their strengths, improved results may be obtained, but this remains to be tested. Another approach is to test the detection probability of successive applications of the historical and tree-transect methods (i.e., multiple visits) and determine if the results match the outcome reported for the broadcast method (70%; Kennedy and Stahlacker 1993). The predictions in this paper related to cumulative detection probabilities from multiple applications of one technique should be tested. If these predictions are supported empirically, then managers could design a monitoring program that relies on multiple applications of a single technique (e.g., tree transects).

Detection success may be optimized by using listening stations prior to egg-laying (March and April; Penteriani 1999, Dewey et al. 2003), tree searches on parallel transects during incubation and the nestling stage (May–June), and broadcast calling (wail and food begging) during the post-fledging dependency period (Kennedy and Stahlecker 1993, McClaren et al. 2003). Although broadcast surveys are frequently used during the nestling stage, recent tests of this approach by Roberson et al. (in press) in Minnesota suggest broadcast surveys may not be an effective tool during this stage. Roberson et al. (in press) report high detection rates with broadcast surveys during courtship (70%) and fledgling-dependency phases (68%). Detection rates were lowest during the nestling phase (28%), when there appeared to be higher variation in likelihood of detecting individuals.

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