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RH: Effective Area Surveyed for Goshawks • *Roberson et al.*

DO BREEDING PHASE AND DETECTION DISTANCE INFLUENCE THE EFFECTIVE AREA SURVEYED FOR NORTHERN GOSHAWKS?

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Abstract: Broadcast surveys using conspecific calls are currently the most effective method for detecting northern goshawks (*Accipiter gentilis*) during the breeding season. These surveys typically use alarm calls during the nestling phase and juvenile food-begging calls during the fledgling-dependency phase. Because goshawks are most vocal during the

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courtship phase, we hypothesized that this phase would be an effective time to detect goshawks. Our objective was to improve current survey methodology by evaluating the probability of detecting goshawks at active nests in northern Minnesota in 3 breeding phases and at 4 broadcast distances and to determine the effective area surveyed per broadcast station. Unlike previous studies, we broadcast calls at only 1 distance per trial. This approach better quantifies: (1) the relationship between distance and probability of detection, and (2) the effective area surveyed (EAS) per broadcast station. We conducted 99 broadcast trials at 14 active breeding areas. When pooled over all distances, detection rates were highest during the 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. EAS per broadcast station was 39.8 ha during courtship and 24.8 ha during fledgling-dependency. Consequently, in northern Minnesota, broadcast stations may be spaced 712 m and 562 m apart when conducting systematic surveys during courtship and fledgling-dependency, respectively. We could not calculate EAS for the nestling phase because probability of detection was not a simple function of distance from nest. Calculation of EAS could be applied to other areas where the probability of detection is a known function of distance.

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Northern goshawks (hereafter referred to as goshawk) and other woodland raptors are difficult to detect because they nest in densely vegetated areas and have relatively large home ranges. Methods developed over the past 20 years use broadcast conspecific calls to detect presence of forest-dwelling raptors and locate nests (Fuller and Mosher 1981, Kimmel and Yahner 1990, Kennedy and Stahlecker 1993, Bosakowski and Smith 1998, McLeod and Andersen 1998, Watson et al. 1999). Protocols adapted from Kennedy and Stahlecker (1993) are currently being used by federal agencies and others to survey goshawks using a recorded alarm call during the nestling phase and a juvenile food-begging call during the fledgling-dependency phase (Bosakowski and Vaughn 1996). Results indicate that detection rates of goshawks are lower during courtship than during nestling or fledgling-dependency phases (Kennedy and Stahlecker 1993, McClaren et al. 2003); however, individuals that fail to lay eggs or that abandon nests during incubation typically go undetected when surveys occur during nestling and fledgling-dependency phases. Recent research in France indicates goshawks are more vocal during their courtship phase than at any other time of year (Penteriani 1999, 2001). Because goshawks are highly vocal during courtship and are less likely to respond to call broadcasts after nest failure (Kimmel and Yahner 1990, Kennedy and Stahlecker 1993), call broadcasts during courtship may be an effective means of detecting breeding goshawks before nest failure (Penteriani 1999). In addition, goshawks that do not lay eggs in a given year may still defend their nest area during the courtship phase. Using survey techniques with a high probability of detection during the courtship phase might result in greater accuracy in determining population densities and habitat preferences than would be achieved by surveys conducted later in the breeding season.

Our objective was to improve upon current survey methodology by evaluating the probability of detecting goshawks at active nests in northern Minnesota in 3 breeding phases and at 4 broadcast distances and to determine the effective area surveyed (EAS) per broadcast station. Existing methods used to assess goshawk detection rates (Kennedy and Stahlecker 1993, Watson et al. 1999, McClaren et al. 2003) involve broadcasting conspecific calls at consecutive stations on a transect line, starting at the farthest station from an active nest and progressing toward the nest until a detection occurs. This approach likely influences detection distance because birds may be responding both to call broadcasts approaching a nest and to a call at a specific distance from a nest. To avoid confounding distance and sequential broadcasting, we broadcast calls at only 1 distance from the nest during each trial. This approach allowed us to describe a probability of detection function for goshawks based on distance, which in turn can be used to estimate EAS and develop survey methodology to derive estimates of goshawk density.

STUDY AREA

Goshawk nests included in our study were located in the Chippewa National Forest, the Superior National Forest, and on private, county, and state lands in northcentral and northeast Minnesota. Vegetative communities across the study area represented the transition from hardwood to boreal forest and included northern hardwood and northern coniferous stands interspersed with wooded wetlands, marshes, lakes, and other wet areas.

Major overstory trees were sugar maple (*Acer saccharum*), American basswood (*Tilia americana*), paper birch (*Betula papyrifera*), ash (*Fraxinus* spp.), yellow birch (*B. alleghaniensis*), quaking aspen (*Populus tremuloides*), red maple (*A. rubrum*), red oak (*Quercus rubra*), big-tooth aspen (*P. grandidentata*), bur oak (*Q. macrocarpa*), white pine (*Pinus strobus*), red pine (*P. resinosa*), jack pine (*P. banksiana*), spruce (*Picea* spp.), balsam fir (*Abies balsamea*), and northern white-cedar (*Thuja occidentalis*).

METHODS

This project was conducted under University of Minnesota Institutional Animal Care and Use Committee, approved protocol no. 0201A15661.

Study Population

All active nests located as part of a concurrent goshawk habitat use study (Boal et al. 2003) were included in our sample of nests (*n* = 14 total nests, 8 nests in the courtship phase, 8 nests in the nestling phase, 10 nests in the fledgling-dependency phase). Nests were located by searching in areas where goshawks or nests had been observed by cooperating project personnel (federal, state, and private wildlife biologists and land managers) and by checking known goshawk breeding areas. As new nests were located during the breeding season, they were added to our sample, and nests were deleted from our sample after they failed. Although our sample was not randomly selected from goshawk nests in northern Minnesota, the manner in which they were located likely did not influence response behavior of breeding goshawks to call broadcasts. The majority of nests was not located using broadcast calls (11 breeding areas were located without using broadcast calls, 2 were located using broadcast calls, and the location method is unknown for 1).

At 7 nests, 1 or both goshawks had been equipped with radio transmitters as part of a concurrent study (Boal et al. 2003), and we used radio-telemetry during the courtship phase to assist in determining whether breeding areas used in previous years were active. These goshawks had been fitted with radio transmitters at least 8 months prior to our broadcast trials and thus their having been handled by researchers is unlikely to have influenced our results. We also evaluated site activity from late February through mid-March with dawn vocalization surveys, by sitting within 200 m of nests used within the previous two years and listening for goshawk vocalizations from 30 min prior to sunrise to 30 min after sunrise (Penteriani 1999, Dewey et al. 2003). Dawn vocalization surveys were conducted at 7 nests, 5 of which were determined to be active. Goshawks were detected at 4 of the 5 active nests on the first visit. We conducted dawn vocalization surveys twice at the remaining 3 breeding areas, one of which was determined to be active. In 2 breeding areas, no evidence of activity was observed during dawn vocalization surveys or during subsequent nest searches conducted during the nestling phase; these breeding areas were not included in our study.

Breeding areas were considered active during the courtship phase if radio-tagged females were located near nest sites or untagged females were seen or heard near nest sites during dawn vocalization surveys. The sex of individual goshawks was determined by vocalizations and size; female goshawks have a lower and more powerful call (Sutton

1925, Allen 1978) and are larger than males (Squires and Reynolds 1997). We confirmed goshawk occupation of a breeding area when we observed newly built nests or existing nests with new additions of fresh twigs or greenery.

We monitored nests at 3–7 day intervals throughout the breeding season (except during the incubation phase) to describe breeding phase and nest fate. We defined the end of courtship based on the first observation of a female in incubation posture. We determined that the nestling phase had begun when we first observed chicks in the nest. We determined that the fledgling-dependency phase had begun when we located fledglings beyond the nest tree. We considered nests active if nestlings or fledglings were observed. Chicks' ages were assessed from size, feather growth, general appearance, and activity (Boal 1994). We broadcast calls only during the first 25 days of the fledgling-dependency period; fledglings' flight feathers harden and they begin to venture >300 m from the nest after 25 days (Kenward et al. 1993, Kennedy and Ward 2003).

Call Broadcast Stations

Reported goshawk detection rates have been highest between 100 and 250 m from nests compared to distances beyond 300 m (Kennedy and Stahlecker 1993, Watson et al. 1999). Therefore, we broadcast goshawk calls at distances between 100 m and 325 m. Calls were broadcast at intermediate distances of 150 m and 225 m to describe the form of the relationship between distance and probability of detection over the range of distances at which goshawks have been reported to have a relatively high (>20%) probability of detection during broadcast call surveys (e.g., Kennedy and Stahlecker 1993, Watson et al.

1999). Because it was difficult to determine which nest in a breeding area would be active in 2000 during the courtship phase, we established call broadcast stations along a transect at 100, 150, 225, and 325 m from all nests known to have been active during 1999. The transect direction was determined randomly with the constraint that it did not fall entirely within non-forested areas such as large bodies of water or open fields. We established similar transects during the nestling and fledgling-dependency phases at active nests. We did not conduct broadcast trials during incubation because previous studies demonstrated female raptors are less likely to respond to broadcasts during this period (Fuller and Mosher 1981, Rosenfield et al. 1988, Speiser and Bosakowski 1991), and broadcasts may disturb incubating females and cause egg loss.

Broadcast Trials

We broadcast calls using a portable CD-player (Optimus AM/FM Stereo/Portable CD Player CD-3840, 42-5098, use of trade names does not imply endorsement by the U.S. Geological Survey, the University of Minnesota, or Colorado State University) and a megaphone (Radio Shack Powerhorn 32-2037) at 100–110 dB, 1 m from the source (C-weighting; Radio Shack Sound Level Meter 33-2050), as recommended by Fuller and Mosher (1987). The adult alarm call (*kak-kak-kak*; Squires and Reynolds 1997, Penteriani 2001) was recorded from a commercially available compact disk of bird calls (Peterson Field Guides to Western Birds Songs CD). In the absence of a commercially available recording, we used a juvenile food-begging call (*whee-whee-whee*; Schnell 1958, Penteriani 2001) recorded by A. C. Stewart (Sustainable Resource Management, Victoria, British Columbia, Canada) from Vancouver Island, British Columbia, Canada.

Broadcast trials were similar to those developed by McClaren et al. (2003) and consisted of an observer listening for 30 sec and then broadcasting the phase-appropriate conspecific call for approximately 10 sec, followed by 30 sec of silence and observation. This pattern was repeated 6 times. The direction of the initial broadcast was randomly selected, with the 5 remaining calls played in the following order and orientations from the original call: 120°, 240°, 60°, 180°, and 300°. After 6 broadcasts, for 5 min the observer systematically looked and listened in all directions to overcome the bias of having knowledge of the nest location. The observer spent a total of approximately 9 min at each broadcast station. Only 1 observer was present at most (95%) broadcast stations, which minimized observer bias and detection of the observer by goshawks prior to initiation of broadcasts. Broadcasting was not initiated if wind exceeded 20 km/h or rain was heavy or persistent because these conditions could affect detection. Detection occurred when a goshawk was heard or seen after a call was played during broadcast trials. If a goshawk was detected before broadcasts began, the trial was not conducted.

Because goshawks are most vocal near dawn during the courtship phase (Penteriani 1999, 2001; Dewey et al. 2003), we broadcast alarm calls between sunrise and 3 hr following sunrise during courtship. To make trials comparable between the courtship and nestling phases, we broadcast alarm calls during the same time-period in the nestling phase. We did not broadcast throughout the day to examine possible time of day effects during the courtship and nestling phases because our sample sizes during these phases were small and we were interested in trying to maximize the probability of detection. Because juvenile goshawks tend to be vocal throughout much of the day in the fledgling-dependency phase (Penteriani 2001), and are the age-class most likely to be detected during this phase (Kennedy and Stahlecker 1993, Watson et al. 1999), we broadcast the juvenile food-begging call during daylight hours randomly distributed among 3 time periods; morning (0600–1000 hr), mid-day (1001–1400 hr), and evening (1401 hr to 2 hr prior to sunset). We ended broadcast trials 2 hr prior to sunset to minimize the possibility of attracting nocturnal predators (i.e., great horned owls [*Bubo virginianus*], fishers [*Martes pennanti*]) to fledglings.

At active nests, calls were broadcast at 4 distances during each breeding phase. Calls were broadcast at a single distance from a nest during each broadcast trial. The order in which broadcast stations were visited for broadcast trials was determined randomly for each nest and each breeding phase. The order in which nests were visited during each breeding phase and the time of day they were visited during the fledgling-dependency phase were randomized within groups of nests in close geographic proximity to maximize efficiency and minimize travel time. There was a minimum of 2 days (range = 2–6 days) between broadcast trials at each nest to minimize possible associations between broadcasts and presence of the observer.

Data Analyses

Mixed logistic regression.--We used mixed logistic regression (PROC NLMIXED, SAS Version 8.2; Wolfinger 2000) to analyze the influence of the fixed effects of breeding phase (categorical), broadcast distance (both as a continuous and categorical variable), time of day (categorical; fledgling-dependency phase only), and their interaction, on the probability of detecting a goshawk. Nest was included as a random effect to analyze the influence of potential variability in detection rates caused by differences in detection probabilities of individual goshawks in different breeding areas. Incorporating nest as a random effect accommodated problems associated with repeated measures on the same nest sites (sampling the same nest sites at different distances and in multiple breeding phases). We fitted each logistic model used in our analyses both with and without this random effect to evaluate its importance in overall model fit. We assumed random effects in mixed logistic regression models were normally distributed. Our approach for these analyses was based on the approach developed by McClaren et al. (2003).

Using data from morning call broadcasts pooled across all breeding phases, we first fitted a global model, including all independent variables and their interactions, and then fitted reduced models with all combinations of independent variables. Due to differences in detection rates among breeding phases, we also analyzed the probability of detection within each phase and developed a logistic model of detection probability as a function of distance to be used in calculating EAS per broadcast station (described below). We compared models with distance as a continuous variable and with distance as a categorical variable to determine if we could use the continuous form of the model to calculate EAS. Analyses for the fledgling-dependency phase included distance, time of day (categorical data), and their interaction, as fixed effects in the global model.

Model selection.--We used the information-theoretic approach (Anderson et al. 2000, Burnham and Anderson 2000) to select the best fitting model in mixed logistic regression analyses. We used Akaike's Information Criterion (AIC_c model fit statistic; AIC adjusted for small sample sizes) to rank each model within a set of *a priori* models; all models with a difference in $AIC_c \leq 2$ ($\Delta_i \leq 2$) were considered competing models (Burnham and Anderson 2000). We also calculated Akaike weights (w_i), which can be interpreted as the approximate probability that model *i* is the Kullback-Leibler best model in the set, to allow for assessment of model selection certainty (Anderson et al. 2000, Burnham and Anderson 2000). For mixed logistic regression analyses, we estimated effect size and standard error using maximum likelihood techniques for each of the independent variables included in the best-fitting models.

Effective area surveyed.--We used probability of detection as a function of distance (as a continuous variable) within each phase to calculate the EAS per broadcast station. We modeled ideal probability of detection (P_i) as equal to 1 at a given distance (x, y) from the broadcast station (0, 0) and as zero beyond that distance. We set the double integral of P_i equal to that of P_t, the probability of detection as a function of distance based on our data:

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} P_i(\sqrt{(x^2 + y^2)})\, dx\, dy = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} P_t(\sqrt{(x^2 + y^2)})\, dx\, dy. \qquad (1)$$

The variables (x, y) form a Cartesian plane. We converted the Cartesian coordinate (x, y) to a polar coordinate (r, θ) (r = radius from the nest; θ = angle):

$$\int_0^{\infty}\int_0^{2\pi} P_i(r)\, r\, dr\, d\theta = \int_0^{\infty}\int_0^{2\pi} P_t(r)\, r\, dr\, d\theta \qquad (2)$$

We set $P_i(r) = 1$ (ideal probability of detection, as described above) and reduced equation 2:

$$\pi\, (r^*)^2 = 2\, \pi \int_0^{\infty} P_t(r)\, r\, dr \qquad (3)$$

We solved for the radius of the EAS (r*; using Mathcad, Version 3.1; MathSoft 1992), which is the distance at which the area under the probability of detection curve (P_t) up to that distance, plus the area under the curve beyond that distance, is equal to 1:

$$r^* = \sqrt{(2 \int_0^{\infty} P_t(r)\, r\, dr)}. \qquad (4)$$

Using this approach, we were able to determine the radius of an area in which the probability of detection approximated 100%, based on the logistic regression curve developed with our data.

To assess precision of the EAS, we calculated a 90% bootstrap confidence interval (CI) for the EAS radius by generating a sampling distribution of slope and intercept pairs from the probability of detection as a function of distance, as modeled for each breeding phase. We generated 200 data pairs (DATA step; SAS Version 8.2) for each breeding phase, using the parameter estimates, standard errors, and correlation coefficient of the 2 parameter estimates (β_0 and β_1 estimated using PROC NLMIXED, SAS Version 8.2). For analyses of detection probabilities during the courtship phase, a small number of pairs that were generated were not biologically meaningful [n = 12 (6.0 %)] because the intercept (β_0) was < 0.00 (resulting in a negative probability of detection) or the slope (β_1) was ≥ 0.00 (resulting in an increasing probability of detection with distance); these pairs did not accurately reflect our data and were not used in further analyses. We evaluated Equation 4 using 188 pairs of data for the courtship phase (using Mathcad 1992) and computed the 90% bootstrap CI.

RESULTS

We conducted 99 broadcast trials at 14 active goshawk nests between 8 March and 16 July 2000 (Table 1). For some nests, we were unable to broadcast in some phases, or at all distances in each phase because nests were located after courtship (n = 6), goshawks laid eggs before we could complete trials during courtship (n = 4), or nests failed during the nestling phase (n = 4). We broadcast the alarm call at 27 stations at 8 nests during the courtship phase and at 32 stations at 8 nests during the nestling phase, and we broadcast the juvenile food-begging call at 40 stations at 10 nests during the fledgling-dependency phase.

We detected goshawks or evidence of nest construction during our earliest visits to nests (26–28 February 2000; 8 nests). Initiation of incubation occurred between 31 March and 10 April (n = 6); nestlings were first observed between 8 and 25 May (n = 8), and fledglings were first observed between 26 June and 8 July (n = 10).

Goshawk Detections

Goshawk detections occurred during 55.6% of broadcast trials and at least once at all 14 nests (Table 2). We detected goshawks during 70% of trials in the courtship phase, 28% of broadcast trials in the nestling phase, and 68% of trials conducted throughout the day in the fledgling-dependency phase (data pooled for all distances; Table 2). We detected goshawks at least once at all nests (100%) in the courtship (n = 8) and fledgling-dependency phases (n = 10), but at only 5 of the 8 nests (63%) in the nestling phase (Table 2). During the fledgling-dependency phase, detection rates were 71% for morning trials, 67% for mid-day trials, and 63% for evening trials.

All goshawk detections during the courtship and nestling phases were of adult goshawks. All detections during the fledgling-dependency phase included vocalizations from fledglings; adults were only detected twice during the fledgling-dependency phase (an adult female responded along with fledglings on 2 occasions at the same nest). Eighty-seven percent of all goshawk detections (n = 55) occurred within 3 min of initiating broadcasts, 93% within 5 min, and 99% within 8 min.

The shape of the detection curve was different during the nestling phase than during the courtship and fledgling-dependency phases (Fig. 1). Instead of decreasing with increasing distance from the nest as in the other 2 phases, the detection rate during the nestling phase at 225 m (63.5%) was higher than at 100 m (12.5%), 150 m (12.5%), and 325 m (25.0%).

Factors Influencing the Probability of Detecting a Goshawk

Model selection using data from all breeding phases.–Breeding phase, distance, and their interaction influenced probability of detecting a goshawk (Table 3). Based on AIC_c, the best-fitting model (from trials conducted in the morning only) ($w_1 = 0.960$; Table 3) included fixed effects of distance as a categorical variable (estimated effect = –4.61 ± 1.33), breeding phase (estimated effect = –2.95 ± 0.98), and their interaction (distance x phase: estimated effect = 1.13 ± 0.39; intercept = 11.73 ± 3.37). Nest, a random effect, was not included in the best-fitting model.

Phase-specific model selection.--The best-fitting model for the nestling phase (w_1 = 0.991; Table 3) was the only best-fitting model that included nest as a random effect and distance as a categorical variable (estimated effect = –3.54 ± 2.59; intercept = 4.68 ± 4.17). Best-fitting models for courtship and fledgling-dependency phases did not include nest as a random effect.

For the courtship phase, a model with distance as a continuous variable (w_1 = 0.513; Table 3) and a model with distance as a categorical variable ($w_2 = 0.487$) were competing models ($\Delta_i = 0.1$; Table 3). Modeling distance as a continuous variable (estimated effect = –0.009 ± 0.006; intercept = 2.65 ± 1.24; correlation coefficient = –0.93) was similar to modeling distance as a categorical variable, which allowed us to use the continuous form to calculate EAS.

For the fledgling-dependency phase, modeling distance (continuous) as the only independent variable (w_1 = 0.527; Table 3), and modeling both distance and time of day as independent variables (w_2 = 0.336), produced similar results (Δ_i = 0.9). Thus, addition of time of day did not improve model fit. A model for the fledgling-dependency phase which used distance as a continuous variable (w_1 = 0.513; Table 3) (estimated effect = –0.017 ± 0.005; intercept = 4.43 ± 1.31; correlation coefficient = –0.95) and one which used distance as a categorical variable (w_2 = 0.487) were competing models (Δ_i = 0.1), indicating that we could use the continuous form to calculate EAS.

Effective Area Surveyed

The EAS had a radius of 356 m (90% bootstrap C.I. = 255–846 m) for the courtship phase and 281 m (90% bootstrap C.I. = 238–393 m) for the fledgling-dependency phase. We could not calculate EAS for the nestling phase because we could not fit a monotonically decreasing detection function (distance as a continuous variable) to the data.

For broadcast surveys conducted in northern Minnesota using phase-appropriate calls, the EAS for each broadcast station during the courtship phase (during the morning only) was 39.8 ha (90% bootstrap C.I. = 20–225 ha) and was 24.8 ha (90% bootstrap C.I. = 18–49 ha) during the fledgling-dependency phase (throughout the day).

DISCUSSION

Factors Influencing the Probability of Detecting a Goshawk

Time of day.--Our results indicate that during the fledgling-dependency phase, broadcasts using juvenile food-begging calls have a high probability of detecting fledgling goshawks throughout the day. We did not set up our study to examine the influence of time of day on detection during the courtship and nestling phases. However, if probability of detection differs with time of day during these phases, restricting broadcast trials to morning may have influenced our results. Our detection rates were not directly comparable to those found in other studies because of differing methodology, but our detection rates during courtship were higher and detection rates during the nestling phase were lower than those previously reported in studies that conducted broadcast trials throughout the day (Kennedy and Stahlecker 1993, McClaren et al. 2003).

Detection rates reported in other studies might have been confounded by time of day (Kennedy and Stahlecker 1993, McClaren et al. 2003). Kimmel and Yahner (1990) examined the influence of time of day on nesting goshawk detection rates using broadcast calls during nestling and fledgling-dependency phases. They found that detection rates (Fig. 3, Kimmel and Yahner 1990:110) during the nestling phase were twice as high during the late morning (~67%; n = 6; 1001 – 1200 hr) and late afternoon (~57%; n = 7; 1501 – 1800 hr) than during the early afternoon (~29%; n = 7; 1201 – 1500 hr) and were four times higher than during the early morning (~14%; n = 7; 0800 – 1000 hr). Using Fisher's exact test, Kimmel and Yahner (1990) concluded that time of day did not have a significant influence on detection probability during the nestling phase and during both phases pooled. However, their ability to detect differences in detection rates as a function of time of day was limited by small sample sizes (n = 7 nests and 27 broadcast trials during the nestling phase). Also, they did not employ alternatives to hypothesis testing (e.g., logistic regression modeling and information-theoretic approaches) to assess the influence of time of day. In contrast, McLeod and Andersen (1998) found that in broadcast surveys of red-shouldered hawks (*Buteo lineatus*), detection rates were highest in the morning (pooled across breeding phases). Differences between our results and those of other studies suggest that time of day may influence goshawk detection rates during the courtship and nestling phases and indicate that future investigations should probably examine effects of time of day on the probability of detecting goshawks in these breeding phases.

Breeding phase.--Unlike previous studies (Kennedy and Stahlecker 1993, McClaren et al. 2003), we found that the highest overall detection rate occurred during the courtship breeding phase, indicating that future broadcast surveys for goshawks in our study area may be effective if conducted during this time period. Detection rates recorded for other raptor species, such as red-shouldered hawks (McLeod and Andersen 1998) and great horned owls (Morrell et al. 1991), were also highest during the courtship phase.

The evidence from this study and others (Kennedy and Stahlecker 1993, Watson et al. 1999, McClaren et al. 2003) suggests that detection rates during the nestling phase vary extensively across the goshawk's range. In our study, the best fitting model for this phase included nest as a random effect, and this was the only phase in which <100% of active nests (5 of 8 nests) were detected at least once. Thus, fewer goshawks responded to broadcasts during this phase in comparison with other phases. This variation in probability of detection is likely influenced by parental care strategies, which may differ with nestling age, prolactin hormone levels (Goldsmith 1991), and food supply (Dewey and Kennedy 2001).

As reported by others (Kennedy and Stahlecker 1993, Watson et al. 1999, McClaren et al. 2003), the probability of detecting goshawks was high during the fledgling-dependency phase. Juvenile goshawks (which were heard vocalizing in 100% of detections during this phase) tend to be vocal throughout the day (Penteriani 2001) and call repeatedly after first responding to broadcasts (Watson et al. 1999, A. M. Roberson, unpublished data). Penteriani (2001) reported that the duration of vocalizations by fledglings increased rapidly from the nestling to the fledgling-dependency phase until approximately the tenth day after fledging, and then rapidly declined until about the fortieth day, after which no vocalizations were recorded. The accuracy of this observation may have been impacted by the increasing difficulty of detection as fledglings traveled farther from the nest. This finding confirms that broadcasts should be conducted during the early fledgling-dependency period (<30 days post-fledging), and highlights the importance of considering local breeding phenology in broadcast survey design.

Distance.--Perhaps the most interesting result of trials conducted during the nestling phase was the unexpectedly non-linear relationship between distance and probability of detection. Previous studies (Kennedy and Stahlecker 1993, Watson et al. 1999, McClaren et al. 2003) assumed that detection is a decreasing function of distance and that detections would have occurred at distances closer to the nest than the station where the detection was actually recorded. Our results indicate that detection rates may not always be a decreasing function of distance to the nest during the nestling phase. One possible explanation is that adult female goshawks may be less likely to respond to broadcasts close to the nest if they do not want to reveal the location of their nest to intruders.

Effective Area Surveyed

The EAS radius we calculated for courtship was beyond the distance over which we conducted broadcast trials. Kennedy and Stahlecker (1993) also developed a probability of detection function for goshawks based on broadcasts of the alarm call during courtship. They presented a logistic curve that declined dramatically between 200 and 300 m, steadily decreased at distances beyond 300 m, and dropped to 0 beyond 700 m. Our logistic curve exhibited a similar shape (Fig. 1) and the similarity between these logistic curves suggests our function approximates the true probability of detection beyond the distances we sampled. However, because our confidence in the estimated EAS radius for courtship is less than if it fell within the range of distances we sampled, our resulting EAS should be viewed as a maximum estimate when designing surveys.

These results indicate that surveys during these 2 phases could have broadcast stations spaced at 712 m (90% bootstrap C.I. = 510–1692 m) and 562 m (90% bootstrap C.I. = 476–786 m), respectively, and still result in a high probability of detection over the area surveyed. When conducting systematic, grid-type surveys during the courtship phase, transects could be separated by approximately 617 m, with stations on adjacent transects offset by approximately 356 m; during the fledgling-dependency phase, transects could be separated by approximately 486 m, with stations on adjacent transects offset by approximately 281 m.

Calculating EAS using probability of detection functions that are locally specific allows for comparisons of extensive surveys conducted in different locations and for calculations of relative density estimates. By multiplying EAS at each broadcast station by the number of stations surveyed, total area surveyed can be calculated and compared to results of similar surveys in other areas. Geographic variation in detection rates is probably related to vegetation density and topography, as suggested by McClaren et al. (2003), and may also be related to goshawk subspecies or breeding density. These factors should be considered when assessing whether probability of detection functions from one area could be used in other areas.

In addition, knowledge of a locally calibrated EAS can be incorporated into the design of extensive surveys to maximize the area surveyed while minimizing effort. One example would be the double sampling approach recommended recently by Bart and Earnst (2002) for estimating avian population densities. Survey protocol recommendations made by Kennedy and Stahlecker (1993), Joy et al. (1994) and McClaren et al. (2003) call for spacing broadcast stations and transects 200–400 m apart, with stations staggered by 100–200 m on adjacent transects to maximize the probability of detection when conducting systematic, grid-type surveys. When the goal of the survey is to estimate density, broadcast stations may be placed at greater distances from each other or along road transects if a locally calibrated EAS is incorporated into survey design.

MANAGEMENT IMPLICATIONS

With careful survey design, the probability of detecting an active goshawk nest with broadcast conspecific calls in northern Minnesota is high, particularly during the courtship (approximately 1 March–7 April) and fledgling-dependency phases (approximately 25 June–20 July). Depending on management goals, broadcast surveys can be conducted to maximize probability of detecting nesting attempts and calculate site occupancy and nesting success (during courtship), or to find successful nests (during fledgling-dependency). During the nestling phase, goshawk detectability varied among individuals, and the relationship between distance and probability of detection was not clear. In addition, some nests may fail prior to or during this phase and failed nesting attempts may not be easily detected. Depending on survey objectives, the nestling phase may not be an optimal time to conduct broadcast surveys for goshawks in the western Great Lakes region.

Detection probability functions could be incorporated into survey designs to help researchers and managers calibrate the results of extensive surveys. Differences in detection rates among studies conducted in different areas of the goshawks' range (McClaren et al. 2003) indicate these functions should be calibrated based on local probabilities of detection. The protocol described herein could be modified for application in other areas where probability of detection is known and can be used to derive locally-specific EASs, which in turn could be used to assess density of breeding goshawks.

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Table 1. Breeding phase in which breeding areas were determined to be active and distances (m) at which broadcast trials (n = 99 trials) were conducted at 14 goshawk nests during 2000 in northern Minnesota.

		Distances at which Broadcast Trials were Conducted[a]											
Nest	**Breeding Phase (date)**	**Courtship**				**Nestling**				**Fledgling-dependency**			
1	Nestling (May 15)					100	150	225	325	100	150	225	325
2	Courtship (Mar 2)	100	150	225	325								
3	Courtship (Mar 2)	100	150	225									
4	Nestling (May 5)					100	150	225	325	100	150	225	325
5	Nestling (June 10)									100	150	225	325
6	Nestling (May 11)					100	150	225	325	100	150	225	325
7	Courtship (Mar 4)	100	150	225	325								
8	Courtship (Mar 3)	100	150	225		100	150	225	325	100	150	225	325
9	Courtship (Mar 1)	100	150		325								
10	Courtship (Mar 7)		150	225		100	150	225	325	100	150	225	325
11	Courtship (Mar 1)	100	150	225	325	100	150	225	325	100	150	225	325
12	Fledgling-dependency (Jul 3)									100	150	225	325
13	Courtship (Feb 26)	100	150	225	325	100	150	225	325	100	150	225	325
14	Nestling (May 15)					100	150	225	325	100	150	225	325

[a]For some nests, we were unable to broadcast in some phases, or at all of our 4 possible test distances (100 m, 150 m, 225 m, 325 m) in each phase because nests were located after courtship (n = 6), goshawks laid eggs before we could complete trials during courtship (n = 4), or nests failed during the nestling phase (n = 4).

Table 2. Experimental design, sample size, and detection results for broadcast trials at 14 active goshawk nests during 2000 in northern Minnesota. A total of 99 trials was conducted during courtship (*n* = 8 nests[a]; 8 Mar–7 Apr; morning), nestling (*n* = 8 nests[a]; 11 May–31 Jun; morning), and fledgling-dependency phases (*n* = 10 nests[a]; 30 Jun–16 Jul; all day).

	Breeding phase											
	Courtship				**Nestling**				**Fledgling-dependency**			
Call Type	alarm				alarm				food-begging			
Distance	100	150	225	325	100	150	225	325	100	150	225	325
Detections / Trials	6/7	6/8	5/7	2/5	1/8	1/8	5/8	2/8	9/10	10/10	5/10	3/10
Total Detections / Trials (%)	19/27 (70)				9/32 (28)				27/40 (68)			
Nests with Detections	8				5				10			

[a]For some nests, we were unable to broadcast in some phases, or at all of our 4 possible test distances (100 m, 150 m, 225 m, 325 m) in each phase because goshawks laid eggs before we could complete trials during courtship (*n* = 4), nests were located after courtship (*n* = 6), or nests failed during the nestling phase (*n* = 4).

Table 3. Multi-model inference of mixed logistic regression models used to determine factors influencing the probability of detecting a northern goshawk in Minnesota, 2000.

Model	**K_i[a]**	**Δ_i[b]**	**w_i[c]**
All Phases (morning)			
$\{\Phi_{\text{phase * distance (c)}}\}$[d]	4	0.0	0.960
$\{\Phi_{\text{phase}}\}$	2	7.5	0.023
$\{\Phi_{\text{phase + distance (c)}}\}$	3	8.0	0.018
$\{\Phi_{\text{distance (c)}}\}$	2	20.6	0.000
Courtship Phase (morning)			
$\{\Phi_{\text{distance (v)}}\}$	2	0.0	0.513
$\{\Phi_{\text{distance (c)}}\}$	2	0.1	0.487
Nestling Phase (morning)			
$\{\Phi_{\text{distance (c) + u}}\}$	3	0.0	0.991
$\{\Phi_{\text{distance (v) + u}}\}$	3	9.4	0.009
Fledgling-Dependency Phase (all day), with time of day as an effect			
$\{\Phi_{\text{distance (v)}}\}$	2	0.0	0.527
$\{\Phi_{\text{distance (v) + time of day}}\}$	3	0.9	0.336
$\{\Phi_{\text{distance (v) * time of day}}\}$	4	2.7	0.136
$\{\Phi_{\text{time of day}}\}$	2	13.6	0.001
Fledgling-Dependency Phase (all day), without time of day as an effect			
$\{\Phi_{\text{distance (v)}}\}$	2	0.0	0.513
$\{\Phi_{\text{distance (c)}}\}$	2	0.1	0.487

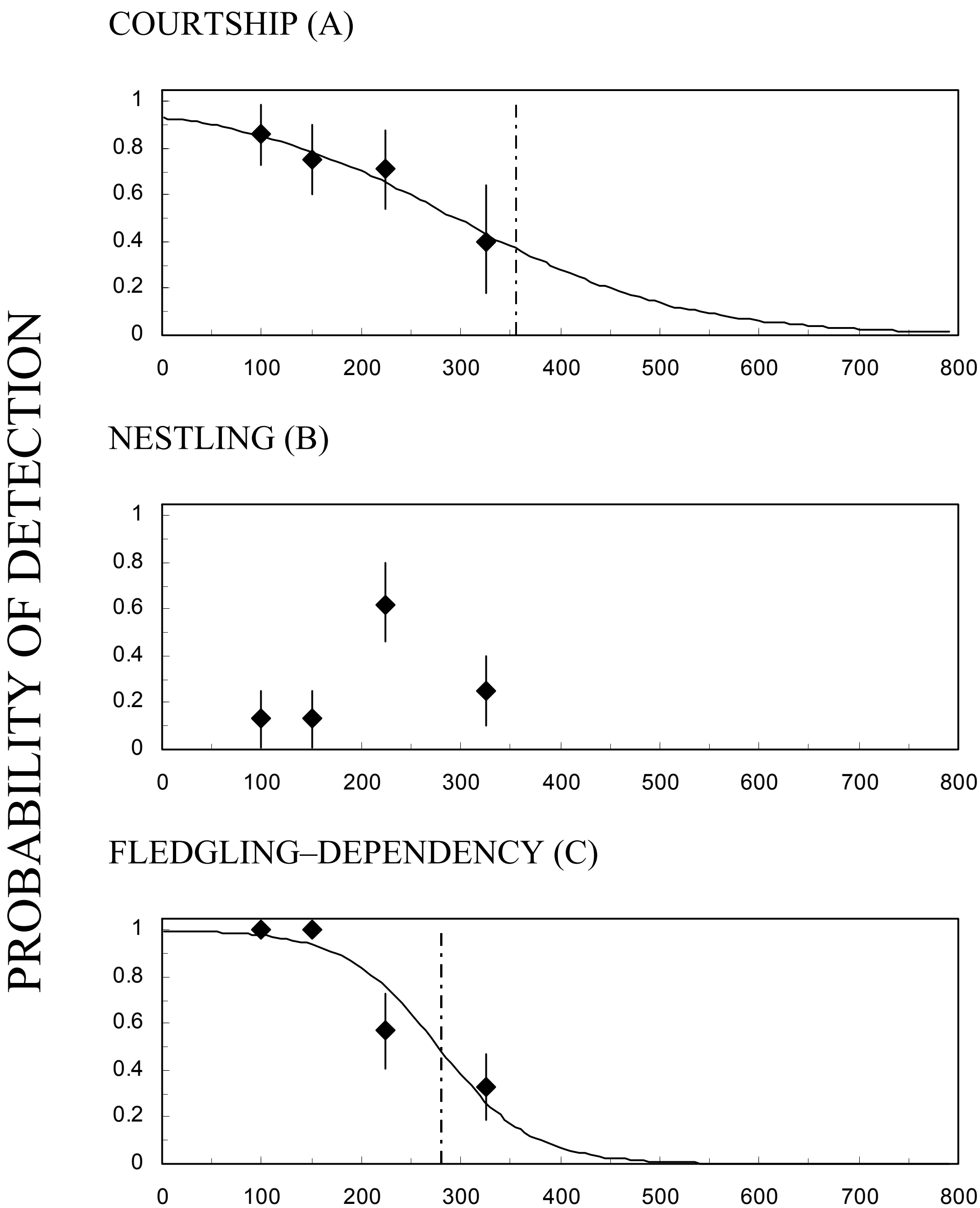
[a]K_i = number of parameters in each model, including an intercept for each model.

[b]$\Delta_i = AIC_{ci} - \min AIC_c$.

[c]w_i = Akaike weight, the approximate probability that the model is the best model in the set.

[d]Φ denotes a model and subscript letters represent effects (distance (v) = distance as continuous data; distance (c) = distance as categorical data; u = random nest effect, included only when it improved the model fit).

Figure 1. Probability of detecting a northern goshawk as a function of distance (m) from active northern goshawk nests during 3 breeding phases in northern Minnesota, 2000: courtship (A), nestling (B), and fledgling-dependency (C). Diamond symbols and associated 95% confidence intervals represent the observed detection rate (proportion of call broadcasts that resulted in a goshawk detection) for broadcast trials conducted at 100, 150, 225, and 325 m from active nests. Dashed vertical lines represent r* (radius [m] of the effective area surveyed per broadcast station) for trials conducted during courtship and fledgling-dependency phases and occur where the area above the curve at distances less than r* equals the area under the curve at distances greater than r*.


COURTSHIP (A)
NESTLING (B)
FLEDGLING–DEPENDENCY (C)
PROBABILITY OF DETECTION
0
0.2
0.4
0.6
0.8
1
0
100
200
300
400
500
600
700
800