# Evaluating and Developing Survey Techniques Using Broadcast Conspecific Calls for Northern Goshawks in Minnesota

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**This is to certify that I have examined this copy of a master's thesis by**

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**and have found it is complete and satisfactory in all respects, and that any and all revisions required by the final examining committee have been made.**

**David E. Andersen**

**Patricia L. Kennedy**

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# Abstract

Broadcast surveys are effective at detecting northern goshawks (*Accipiter gentilis*) during their breeding season. Goshawk surveys are generally conducted using the alarm call during the nestling phase and the juvenile food-begging call during the fledgling-dependency phase (referred to as "standard calls"). However, goshawks are more vocal during their courtship phase than at any other time of the year. Because the probability of detecting goshawks declines after a nest has failed, a reliable means of surveying goshawks during the courtship phase would be more likely to detect nesting pairs than surveys conducted later in the breeding season. To evaluate the influence of breeding phase, distance, and call type on the probability of detecting goshawks, I estimated goshawk detection rates during the courtship, nestling, and fledgling-dependency stages of the breeding season, using three conspecific calls (adult alarm call, male contact call, and juvenile food-begging call) at distances of 100, 150, 225, and 325 m from active nests in northern Minnesota. Unlike previous studies, broadcasts were conducted at only one distance per trial to better describe the relationship between distance and probability of detection and to estimate effective area surveyed per broadcast station. In 1999, 85 broadcast trials were conducted in 9 active nest areas. Detections occurred during 18.9% of broadcast trials and during at least one broadcast trial at 9 of 11 nests. In 2000, 132 broadcast trials were conducted in 16 active nest areas. Detections occurred during 48.5% of broadcast trials and during at least one broadcast trial at all 16 nests. When using standard calls during broadcast trials and when pooled over all distances, detection rates were highest during the courtship (70.4%) and fledgling-dependency phases (67.6%). Detection rates were lowest during the nestling phase (28.1%), when there appeared to be higher variation in the likelihood of response among individuals. During the courtship and fledgling-dependency phases, detection rates decreased with distance from goshawk nests, whereas during the nestling phase, detection rates were highest at 225 m from nests. Differences in detection rates among breeding phases highlight the importance of incorporating knowledge about local breeding phenology into survey design. The male contact call did not improve detection rates over the alarm and juvenile food-begging calls. Results from this study will assist in designing systematic landscape-level surveys with a known probability of detection in the Western Great Lakes Region (WGLR) and in defining a distance-detection relationship for calibrating results of extensive surveys. I used probability of detection as a function of distance in the courtship and fledgling-dependency phases to calculate the effective area surveyed per broadcast station using the survey techniques recommended in this paper. The effective area surveyed was 39.8 ha during the courtship phase and 34.4 ha during the fledgling-dependency phase. These results indicate that in Minnesota broadcast stations may be spaced 712 m and 662 m, respectively, when conducting systematic surveys during these two breeding phases. Calculation of the effective area surveyed could be applied to other regions where the probability of detection as a function of distance is known.

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## Introduction

Northern goshawks (*Accipiter gentilis*) and other woodland raptors are difficult to detect and survey because they nest in densely vegetated areas, have relatively large home ranges and tend to be secretive. Over the past twenty years, methods have been developed to locate forest-dwelling raptors by broadcasting conspecific calls (Fuller and Mosher 1981, Rosenfield et al. 1988, Kimmel and Yahner 1990, Kennedy and Stahlecker 1993, McLeod and Andersen 1998, Watson et al. 1999, McClaren 2001). This technique has been used to detect presence or absence of a species, locate nests, and survey and monitor raptor populations (Rosenfield et al. 1988, Mosher et al. 1990, Morrell et al. 1991, Mosher and Fuller 1996, Proudfoot and Beasom 1996, Bosakowski and Smith 1998, McLeod and Andersen 1998, Reid et al. 1999). Broadcast vocalizations have also been used to detect individuals and estimate population size and density of other species, such as black rails (*Laterallus jamaicensis*; Legare et al. 1999) and other waterbirds (Gibbs and Melvin 1993), marbled frogmouths (*Podargus ocellatus*; Smith and Jones 1997), lions (*Panthera leo*) and spotted hyaenas (*Crocuta crocuta*; Ogutu and Dublin 1998), and wolves (*Canis lupus*; Fuller and Sampson 1988). Although the broadcast method using conspecific calls has been effective in detecting the presence of northern goshawks (Kimmel and Yahner 1990, Kennedy and Stahlecker 1993, Joy et al. 1994, Watson et al. 1999, McClaren 2001), it is still time consuming and costly and thus, improvements to the current procedure need to be explored.

Kennedy and Stahlecker (1993) demonstrated that goshawk detection rates are higher when a conspecific call is broadcast than when an observer is silent. Protocols adapted from the methods used in their study are currently being used by federal agencies and others to survey goshawks using a taped alarm call during the nestling phase and a juvenile food-begging call during the fledgling-dependency phase (Bosakowski and Vaughn 1996). Although Kennedy and Stahlecker reported that detection rates were lower during courtship than the nestling or fledgling-dependency phases, recent research has indicated that goshawks in France are more vocal and have more consistent dawn and morning vocalizations during their courtship phase than at any other time of the year (Penteriani 1999, 2001). Therefore, the highest probability of detection may exist during this time and examination of the detection rates of goshawks during the courtship phase, compared with the nestling and fledgling-dependency phases, is warranted. Because studies have shown that goshawks are less likely to respond to broadcasts after a nest has failed (Kimmel and Yahner 1990, Kennedy and Stahlecker 1993), a reliable means of surveying goshawk pairs during the courtship phase would be more likely to detect goshawk breeding areas than surveys conducted later in the breeding season. In addition, goshawks that do not lay eggs in a given year may still be defensive of their nest area during the courtship phase. Using survey techniques with a high probability of detection during the courtship phase would help to more accurately determine population densities and habitat preferences.

Broadcast surveys have been evaluated in other areas of North America (Kennedy and Stahlecker 1993, Watson et al. 1999, McClaren 2001). I examined several aspects of using broadcast conspecific calls to survey goshawks in northern Minnesota. Detection rates differ among studies and they were unknown in the Western Great Lakes Region (WGLR) where topography and vegetation are different from that found in the other studies.

McClaren (2001) conducted broadcast trials on Vancouver Island and examined detection rates using the contact call, made by the male goshawk when he approaches the nest, in comparison to the frequently used adult alarm and juvenile food-begging calls. The female goshawk generally responds to the male contact call and approach to the nest with a recognition call (Kennedy, personal communication; Penteriani, unpublished data). The male contact call had not previously been used for broadcast surveys of goshawks or tested for its effectiveness in detecting goshawks. McClaren (2001) found that the male contact call did not improve detection rates during any phase of the breeding season on Vancouver Island. However, her sample size was small and thus further testing was warranted.

To evaluate the influence of breeding phase, distance, and call type on the probability of detecting a goshawk, I documented and compared detection rates during the courtship, nestling, and fledgling-dependency stages of the breeding season, using the frequently used alarm and juvenile food-begging calls, and the male contact call.

Previous studies examining goshawk detection rates using broadcast calls (Kennedy and Stahlecker 1993, Watson et al. 1999, McClaren 2001) have been designed such that broadcasts were played at consecutive stations on a transect line, starting at the furthest station from an active nest, until a detection occurred. Although broadcasting at consecutive stations along a transect mimics some goshawk survey procedures, it may confound the detection rate achieved at each station (distance) due to the influence of broadcasting at consecutive stations while approaching a nest. I designed this study so that with each visit to a nest, I broadcast one type of call from one distance. This approach allowed me to gauge the detection of goshawks to broadcast calls from each distance without the confounding influence of playing successive calls at different distances approaching a known nest. This information is helpful in determining the maximum distance with a high probability of detection between survey points and transect lines to design a systematic, efficient, and cost-effective survey method. It also allowed me to estimate the effective area surveyed at each broadcast station for calibrating the results of extensive surveys.

## Study Area

My study was conducted in north-central Minnesota. Nests where broadcasts where conducted were located in the Chippewa National Forest (CNF), the Superior National Forest (SNF), and on private, county, and state lands (Fig. 1). My study area was located in the transition zone from hardwood to boreal forest and included northern hardwood and northern coniferous stands interspersed with wooded wetlands, marshes, lakes, and other wet areas. Northern hardwood stands in the study area were comprised of 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*), and bur oak (*Q. macrocarpa*). Northern coniferous stands were primarily comprised of 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

### Broadcast Trials

I conducted broadcast trials at goshawk nests between 1 April and 15 July 1999, and 8 March and 16 July 2000. All nests that were known to be active in the study area were included in my sample. Goshawk nests used in broadcast trials were located by conducting nest searches in areas where goshawks or nests had been sighted and in historic nest areas. Although I did not use a random sample of nests, possible biases in the sample due to the manner in which they were located probably do not influence probability of detection. Goshawk locations determined by telemetry of previously radio-tagged birds (Boal et al., unpublished report) at 4 nests (5 individuals) in 1999 and 7 nests (10 individuals) in 2000 were also used to assist in determining if previously used breeding areas were active.

Penteriani (1999) suggested that a site where no vocalizations were heard between 30 minutes prior to sunrise and five minutes after sunrise during the two months prior to egg-laying could be considered unoccupied by nesting goshawks. I conducted dawn vocalization surveys during the courtship phase in 2000 by sitting within 200 m of nests occupied by goshawks in the previous year to help determine if previously used breeding areas were currently active.

A breeding area was 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. 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 also larger (Squires and Reynolds 1997) than males. I confirmed goshawk occupation of a breeding area when I observed newly built nests or historic nests with new additions of fresh twigs or greenery. Initiation of incubation, and therefore the end of courtship, was determined by visiting nests and observing the female in an incubating posture. Only one female was observed leaving the nest during a nest visit after eggs had been laid. The nestling phase began when eggs hatched and this was confirmed by observations of chicks in the nest. The fledgling-dependency phase began when fledglings were observed in flight or in trees other than the nest tree. I considered nests to be active during the nestling and fledgling-dependency phases if nestlings or fledglings were observed. Nests used in the study were monitored at 3 – 7 day intervals throughout the breeding season (with the exception of the incubation phase) to determine current breeding phase and fate of the nesting attempt. Chicks were aged based on size, feather growth, general appearance, and activity, as described by Boal (1994).

Broadcast stations were established along a transect at 100, 150, 225, and 325 m from active nests. The direction of the transect from the nest was randomly selected with the condition that it did not fall entirely within areas such as large bodies of water, large open areas, and roads, which may bias the probability of detection. Previous studies have shown goshawk detection rates to be highest between 100 m and 250 m from the nest, and to be significantly lower at distances beyond 300 m (Kennedy and Stahlecker 1993, Watson et al. 1999), thus, I broadcast at distances between 100 and 325 m. Intermediate distances of 150 and 225 m were chosen to assist in describing the relationship of distance to probability of detection and to accurately determine the shape of the detection function in this distance interval. I broadcast calls one distance per visit at each nest, and thus, eliminated the need to set the transect tangential from the nest as in other studies.

Because a pair of goshawks may build or add material to more than one nest during courtship, it is difficult to determine which nest will be used during the current year until the female lays eggs. Thus, during the courtship phase, nests occupied during the previous year were used to set up broadcast stations along transects. During the nestling and fledgling-dependency phases, nests that were active in the current year were used and the same broadcast stations were used for both phases.

Broadcast trials were not conducted during the incubation phase because evidence from previous studies indicated that the detection of Cooper's hawks (*Accipiter cooperii*; Rosenfield et al. 1988) and goshawks (Fuller and Mosher 1981) is lower during this phase than during the nestling phase. In addition, Speiser and Bosakowski (1991) found that during incubation, females usually stayed on their nests and rarely flushed when observers were near the nest, further supporting the notion that females may be less likely to respond to intruders or broadcasts during this time. Not broadcasting during this phase also eliminated the chance of disturbing female goshawks during incubation, which might cause them to leave their nest and could thus result in addled eggs or increased probability of nest predation (McClaren 2001).

For each visit to a broadcast station, I listened for 30 sec and then broadcast one type of conspecific call following the protocol of McClaren (2001). I broadcast the call for approximately 10 sec, followed by 30 sec of silence and observation and this pattern was repeated 6 times. The direction of the initial broadcast was randomly selected, with the five remaining calls played in the following order and orientations from the original call: 120°, 240°, 60°, 180°, and 300°. At the end of these six broadcasts, there was a five-minute period of observation in which I systematically looked and listened in all directions to overcome the bias of having knowledge of the nest location. Thus, I spent approximately 9 minutes at each survey point. Only one observer was present at most broadcast stations (95%). Observer bias was minimized because I was the primary person conducting broadcast trials, with the exception of some of the trials (n = 20) during the courtship phase of 2000, which were conducted by an experienced field technician. Broadcasting at survey points was not initiated if wind exceeded 20 km/h or rain was heavy or persistent because these conditions could affect detection of goshawks.

A detection occurred when goshawks were heard or seen after a call(s) was played during broadcast trials. If a detection was observed, time and duration of detection, age and sex of respondent, type of detection and other observed behavior, and distance and direction to respondent were recorded.

I broadcast calls using a small portable tape player (AIWA Stereo Radio Cassette Recorder HS-J470) in 1999 and a small portable CD-player (Optimus AM/FM Stereo/Portable CD Player CD-3840, 42-5098) in 2000. A megaphone (Radio Shack Powerhorn 32-2037) broadcasting at 100-110 dB (C-weighting; Radio Shack Sound Level Meter 33-2050) 1 m from the source was used in both years. The adult alarm call (kak-kak-kak; Squires and Reynolds 1997, Penteriani 2001) was recorded from a commercially available recording (Peterson Field Guides to Western Birds Songs CD) from a goshawk in Arizona. The alarm call is given by both adults and juveniles and is directed toward a conspecific intruder or predator (Kennedy and Stahlecker 1993) and is also used to excite mates (Penteriani 2001). The male contact call (chuuck; Sutton 1925, Palmer 1988, Squires and Reynolds 1997) was recorded from a captive male goshawk by Dr. Meg Robinson, a veterinarian from Waterford, WI, and is given by the male as he arrives at the nest. The juvenile food-begging call (whee-whee-whee; Schnell 1958, Penteriani 2001) was recorded from a goshawk fledgling on Vancouver Island, BC (A.C. Stewart, Ministry of Environment, Lands and Parks, Victoria, B.C.).

Kennedy and Stahlecker (1993) found that the alarm call was more effective than the female wail in detecting goshawks during the nestling phase and the juvenile food-begging call was similar to the wail, but more effective than the alarm call during the fledgling-dependency phase. For this study, I broadcast the alarm call during all three breeding phases in 1999 and during the courtship and nestling phases in 2000, and the juvenile food-begging call during the fledgling-dependency phase in 2000. I broadcast the male contact call during all 3 phases in 1999 and 2000.

Penteriani (1999, 2001) listened for vocalizations at goshawk nests throughout the year and found that there was one major peak of adult vocal events during the hour preceding and three hours following sunrise in the three months prior to egg laying. For this study, broadcasts were played between sunrise and 3 hours following sunrise during courtship to maximize the probability of detection. I also broadcast only in the morning hours during the nestling phase so that trials would be comparable between these two phases. During these phases, I broadcast the alarm call at all broadcast stations at nests that were active.

Because juvenile goshawks tend to be vocal throughout much of the day in the fledgling-dependency phase (C. W. Boal and P. L. Kennedy, personal communication), with a peak of vocal activity in the central hours of the day (Penteriani 2001), broadcasts in this phase were conducted during daylight hours and randomly distributed among three time periods; sunrise to 1030, 1031-1530, and 1531 to two hours prior to sunset (Table 1). I did not broadcast until sunset to minimize the possibility of drawing the attention of potential nocturnal predators (i.e., great horned owls, *Bubo virginianus*; fishers, *Martes pennanti*; Erdman et al. 1998) to fledglings. During the fledgling-dependency phase, I broadcast the alarm call at all distances per active nest in 1999 and the juvenile food-begging call was played at all distances per active nest in 2000. After the initial 25 days of the fledgling-dependency phase, fledglings' flight feathers harden and they begin to venture farther than 300 m from the nest (Kenward et al. 1993). Because they may be less likely to respond to broadcast calls near the nest after this time, broadcasts were played only during the initial 25 days of the fledgling-dependency phase.

For some nests, I was unable to broadcast at all distances because goshawks laid eggs before I could complete trials during the courtship phase, or nests failed during the nestling phase. I continued broadcast trials at nests that had failed in 1999 and during the nestling phase in 2000. I did not broadcast at failed nests during the fledgling-dependency phase in 2000 due to limited time and resources.

The order in which nests were visited during each breeding phase and the time of day they were visited during the fledgling-dependency phase was randomized within groups of geographically close nests to maximize efficiency and minimize travel time. Due to restraints in time and resources, I broadcast the male contact call at fewer broadcast stations per active nest (Table 1) than standard calls (alarm during courtship and nestling phases; juvenile food-begging during fledgling-dependency phase; Table 1). Although the male contact call was only broadcast at one or two distances per nest in each phase, it was broadcast at the same range of distances, distributed among all nests, as the other two calls. The call that I broadcast was also randomly selected for each broadcast trial. There was a minimum of two days (range = 2 – 6 days) between broadcast trials at each nest to minimize disturbance to the goshawks and possible associations with the broadcasts and the observer.

## Data Analyses

I examined experimental factors and their influence of probability of detection in two ways. I used chi-squared analysis (PROC FREQ, SAS Version 8.2) to compare the proportion of the number of detections per number of broadcast trials as a function of year, breeding phase, call type, time of day (fledgling-dependency phase only), and distance. I also used mixed logistic regression (PROC NLMIXED, SAS Version 8.2; Wolfinger 2000) to evaluate the influence of these factors on the probability of detection, which had a binomial distribution. For broadcast trials where detections occurred, I used mixed linear regression (PROC MIXED, SAS Version 8.2; Littell et al. 1996) to evaluate the influence of phase, distance, and their interaction, on latency of detection, which had an approximately normal linear distribution. My approach for the above analyses was based on the approach developed by McClaren (2001). Because my experimental design was unbalanced (e.g., different calls broadcast during fledgling-dependency in different years, fewer broadcast stations using the male contact call), I used various subsets of data in my analyses (Table 2). In addition, I used the probability of detection as a function of distance within each phase to calculate the effective area surveyed at each broadcast station. Because only 2 of 66 trials at failed nests in 1999 and 2000 resulted in detections, all statistical analyses were performed on broadcast trials conducted at active nests.

*Chi-squared analyses*. I tested for differences in detection rates between years (Dataset A; Table 2), using the alarm call only, pooled over phases and distances. I tested for differences among breeding phases (Dataset C; Table 2) and three time periods during the day (fledgling-dependency phase only; Dataset F; Table 2), pooled over all distances. I compared detection rates among distances pooled over all phases (Dataset C; Table 2), and also within each phase (Datasets D – G; Table 2). To test for differences between detection rates using the male contact call and standard calls, I used a data subset (Dataset H; Table 2) including all trials of the male contact call at active nests and trials of standard calls at the same stations at each nest where I broadcast the male contact call. I compared detection rates between the male contact call and standard calls, pooled over all phases, but did not make this comparison among phases or distances because the sample size using the male contact call was too small for meaningful comparisons. However, for all analyses where data were pooled over phase or distance, I also examined patterns in detection rates within each factor to ensure that patterns held at each distance or during each phase.

*Mixed logistic regression*. I analyzed the influence of the fixed effects of year (categorical), breeding phase (categorical), distance (both as a continuous variate and categorical), call type, time of day (categorical; fledgling-dependency phase only), and their interactions, on the probability of detecting a goshawk. With the exception of McClaren (2001), previous studies have treated trials conducted at the same nest site (at different distances, during different phases, and with different call types) as independent observations. By fitting logistic models to determine factors influencing probability of detection with the addition of nest site as a random effect, I evaluated experimental results while incorporating the influence of repeated measures made at a nest. This was important in determining if variability in the likelihood of responding exhibited by individual goshawks in different breeding areas was an important factor influencing the probability of detection. I fit each logistic model used in my analyses both with and without this random effect to evaluate its importance in overall model fit. I assumed random effects in mixed logistic regression models were normally distributed. In addition, the probability of detecting a goshawk was modeled as a logistic curve as a function of distance from the nest for each breeding phase.

To examine the influence of phase and distance on the probability of detection I used Dataset C (Table 2). I included the fixed effects of phase, distance, and their interaction, and the random effect of nest in the global model. To test whether call type influenced the probability of detection, I used Dataset H (Table 2). I included the fixed effects of phase, distance, call type, and their two-way interactions, and the random effect of nest in the global model.

Due to differences in detection rates among breeding phases, I also analyzed the factors influencing the probability of detection within each phase to develop a logistic model as a function of distance to be used in calculating the effective area surveyed per broadcast station (described below). Because the detection probability curve was different for the nestling phase than the courtship and fledgling-dependency phases (see Results for more details), I modeled the probability of detection with distance as an effect in two different ways. I modeled distance as a continuous variate and again with the addition of one distance as categorical data (Datasets D, E, F; Table 4). In this way, I was able to judge whether detection probability as a function of distance could be fit as a continuous curve, or if fitting each distance categorically would better fit the information in the data. For each phase I also fit a model with and without nest as a random effect. Analyses for the fledgling-dependency phase included time of day in the global model.

*Effective area surveyed.* I used probability of detection as a function of distance using standard calls within each phase to calculate the effective area surveyed at each broadcast station. I modeled ideal probability of detection ($P_i$) equal to one to a given distance (r*) and zero beyond that distance. To determine r*, I solved:

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

where $P_t$ is the probability of detection as a function of distance within each phase based on my data. The variables x and y are Cartesian coordinates and together represent a point at a distance from the broadcast station. The broadcast station is represented by the coordinates (x, y) equal to (0, 0). I converted this equation to polar coordinates and solved for the radius of the effective area surveyed (r*; using Mathematica Version 4.1):

$$r^* = \sqrt{(2 \int_{0}^{\infty} P_t(r)\, r\, dr)}$$

where r is the radius or distance from the broadcast station.

*Mixed linear regression.* I examined the influence of breeding phase (categorical) and distance (categorical) while using standard calls on detection latency. I did not include data from broadcast trials using the male contact call in this analysis because there were too few detections ($n = 10$ across all phases and distances) to give meaningful results. Nest site was included as a random effect, as described for mixed logistic regression. Each model was run with and without this random effect. Detection latency was entered as the call number (out of 6 total broadcast calls) after which a goshawk was detected because I did not record latency to the precision of seconds when detections occurred. Normality assumptions of mixed linear regression models were assessed with predicted-studentized residual plots. These plots indicated that the models used in these analyses were appropriate for the datasets. Least squares means tests (PROC MIXED, SAS Version 8.2) were used to compare mean detection latencies of broadcast calls among breeding phases and distances.

*Model selection*. Because of the limitations inherent in null hypothesis significance testing (e.g., arbitrary $\alpha$-level choice, dependence of p-value on sample size; Anderson et al. 2000), I used the information-theoretic approach described by Anderson et al. (2000) and Burnham and Anderson (2000), for selecting the best fitting model in both linear and logistic regression analyses. This approach is an extension of likelihood theory based on Kullback-Leibler information and does not rely on null hypothesis significance testing for inclusion of model parameters. Instead, this approach is based on the concept of a "best inference, given the data and the set of a priori models" (Anderson et al. 2000). The Akaike Information Criterion (AIC) approach was developed to produce models that give best predictive inference and tends to choose larger models than classical model hypothesis testing. I used both hypothesis testing (chi-squared analysis) and the AIC approach to examine the factors influencing the probability of detection so that I could consider the results from both methods.

For each dataset (Table 2) used in mixed linear and logistic regression analyses, I first fit the global model, including all predictor variables, and then fit reduced models with all combinations of predictor variables (Tables 4 – 6). I used the $AIC_c$ model fit statistic (AIC adjusted for small sample sizes; Anderson et al. 2000, Burnham and Andersen 2000) to rank each model within a dataset. I also calculated Akaike weights ($w_1$), 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 logistic regression analyses, I estimated effect size and standard error using maximum likelihood techniques for each of the predictor variables included in the best-fitting models.

## Results

### Dawn Vocalization Surveys

Out of 5 nests where dawn vocalization surveys were conducted, vocalizations were heard during the first visit at 3 nests and during the second visit at one nest. Each of these nest areas was later confirmed to be occupied by a goshawk pair based on sightings of individuals and evidence of nest-building. No vocalizations were heard during two dawn visits to one nest; an area of approximately 28 ha was searched around this nest during the nestling phase and an active nest was not found.

## Data Summary

In 1999, at 11 active nests, I broadcast the alarm call at 59 stations and the male contact call at 26 stations, respectively. In 2000, at 16 active nests, I broadcast the alarm call at 59 stations during the courtship and nestling phases, the juvenile food-begging call at 40 stations during the fledgling-dependency phase, and the male contact call at 33 stations during all three phases.

In 1999, I broadcast the male contact call at 6 stations at 5 failed nests during the nestling phase and at 3 stations at 2 failed nests during the fledgling-dependency phase. Also in 1999, I broadcast the alarm call at 26 stations at 7 failed nests during the nestling phase, and at 23 stations at 6 failed nests during the fledgling-dependency phase. There were only 2 detections out of 58 trials at failed nests in 1999, both using the alarm call during the nestling phase, one at 100 m and one at 150 m from the nest. I broadcast the alarm call at 8 stations at 3 failed nests during the nestling phase of 2000, resulting in no detections.

## Nesting Phenology

In my study area, I began broadcast trials during the courtship phase on 17 March in 1999 and on 8 March in 2000. Because I found evidence of nest site occupation during my earliest visits to nests in 1999 (17 and 18 March) and 2000 (26 – 28 February), I wanted to determine if nests were active earlier than these dates so that I could recommend a date for beginning broadcast surveys during courtship in Minnesota. Thus, in 2001, I visited five nest areas that had been active in 2000 on 17 and 18 February and broadcast calls at 150 m from the nest to determine if females were present in nest areas and responding to broadcast calls in mid-February. I detected an adult female at one nest. Adult females were radio-tagged at two of the other nests and no signal was detected in the vicinity of the nest. The remaining two nests did not have radio-tagged females and no detection occurred using the broadcast call, so it was unknown if they were in the area. These results suggest that females may not reliably occupy breeding areas before 1 March.

Initiation of incubation occurred between 14 and 23 April in 1999 (n = 5) and 31 March and 10 April (n = 6) in 2000. In 1999, nestlings were first observed after hatching between 13 and 23 May (n = 10) and in 2000 between 8 and 25 May (n = 8). Fledglings were first observed in 1999 between 24 and 30 June (n = 6) and between 26 June and 8 July in 2000 (n = 10).

## Goshawk Detections

I broadcast conspecific calls at 4 active nests during the courtship phase and 6 active nests during the nestling and fledgling-dependency phases in 1999 (n = 11 total nests). In 2000 (n = 16 total nests), broadcast trials were conducted at 8 active nests during the courtship phase, 8 active nests during the nestling phase, and 10 active nests during the fledgling-dependency phase. In 1999, 85 broadcast trials were conducted in 9 active nest areas. Detections occurred during 18.9% of broadcast trials and during at least one broadcast trial at 9 of 11 nests. In 2000, 132 broadcast trials were conducted in 16 active nest areas. Detections occurred during 48.5% of broadcast trials and during at least one broadcast trial at all 16 nests. There were a total of 81 detections over all broadcast trials (n = 217) in 1999 and 2000. During the courtship and nestling phases, most detections were of adult females (50 and 85%, respectively); whereas during the fledgling-dependency phase, almost all detections were from juveniles (94%; Table 3). Of all detections, 63 (77.8%) were vocal only, 3 (3.7%) were visual only, and 15 (18.5%) were both visual and vocal.

## Chi-squared Analyses

Dataset A (Table 2) was the only dataset that could be tested for a year effect. Although the male contact call was also used in broadcast trials in both years during both of these phases, there were no goshawk detections in response to the male contact call in 1999. In 1999, detections while using the alarm call (27.8% of broadcast trials; n = 36) were lower ($\chi^2 = 3.61$, P = 0.05) than in 2000 (47.5% of trials; n = 59). Because a higher quality recording was used in 2000, which probably resulted in higher detection rates, and because sample sizes were higher in 2000, I based subsequent data analyses on subsets of data collected in 2000 (Datasets B – H; Table 2).

Using Dataset B (Table 2), broadcast trials pooled over distances resulted in detections in 70.4% of trials (n = 27) during the courtship phase and 67.5% of trials (n = 40) during the fledgling-dependency phase. These detection rates were not significantly different ($\chi^2 = 0.062$, P = 0.804). There were detections during 28.1% of broadcast trials in the nestling phase (n = 32), resulting in a detection rate that was lower than in both the courtship phase ($\chi^2 = 10.48$, P = 0.001) and the fledgling-dependency phase ($\chi^2 = 11.03$, P = 0.0009). In addition, detections occurred during at least one broadcast trial using standard calls at all nests (100%) during the courtship (n = 8) and fledgling-dependency phases (n = 10), but at only 63% of nests during the nestling phase (n = 8; courtship: $\chi^2 = 3.69$, P = 0.054; fledgling-dependency: $\chi^2 = 4.50$, P = 0.034). Because broadcast trials during the fledgling-dependency phase were conducted throughout the day, but only in the morning during the courtship and nestling phases (Table 1), I also compared detection rates among breeding phases using trials conducted in the morning only (Dataset C; Table 2). Using this dataset, detections occurred during 77.8% (n = 18) of broadcast trials during the fledgling-dependency phase. This detection rate was not significantly different than that of the courtship phase ($\chi^2 = 0.30$, P = 0.58) and was still significantly higher than that of the nestling phase ($\chi^2 = 11.43$, P = 0.0007).

During the fledgling dependency phase, using the food-begging call (Dataset E; Table 2), detection rates were similar during the morning (77.8%), and mid-day (66.7%; $\chi^2 = 0.509$, P = 0.476). Detection rates were lower during the evening, but this difference was not statistically significant (42.9%; morning: $\chi^2 = 2.825$, P = 0.093; mid-day: $\chi^2 = 1.119$, P = 0.290).

When pooled over all phases and distances (Dataset H; Table 2), the male contact call resulted in detections in 30.3% of broadcast trials, which was less than ($\chi^2 = 3.97$, P = 0.046) the 54.6% of trials using standard calls in 2000. In addition, trials from this dataset using standard calls resulted in detections during at least one broadcast trial at 87.5% of nests during courtship and 88.9% of nests during the fledgling-dependency phase (n = 9); whereas the male contact call resulted in detections at only 62.5% and 44.4% of nests during the courtship and fledgling-dependency phases, respectively. Both the male contact and the alarm call resulted in detections at 14.3% of nests in this dataset during the nestling phase (n = 7).

When pooled over all phases (using standard calls, Dataset C; Table 2), detections occurred in 64.0%, 65.4%, 60.0%, and 30.4% of trials at 100 m, 150 m, 225 m, and 325 m, respectively. There were no significant differences among the distances 100 m, 150 m, and 225 m (100 m v. 150 m: $\chi^2 = 0.011$, P = 0.918; 100 m v. 225 m: $\chi^2 = 0.085$, P = 0.771; 150 m v. 225 m: $\chi^2 = 0.158$, P = 0.691;), but all of these were significantly higher than the detection rate at 325 m (100 m: $\chi^2 = 5.408$, P = 0.020; 150 m: $\chi^2 = 5.965$, P = 0.015; 225 m: $\chi^2 = 4.218$, P = 0.040).

When the data were divided into individual phases, there were no significant differences in detection rates among distances (85.7% at 100 m; 75.0% at 150 m; 71.4% at 225 m; 40.0% at 325 m) during the courtship phase (Dataset D; Table 2; 100 m v. 150 m: $\chi^2 = 0.268$, P = 0.605; 100 m v. 225 m: $\chi^2 = 0.424$, P = 0.515; 100 m v. 325 m: $\chi^2 = 2.743$, P = 0.098; 150 m v. 225 m: $\chi^2 = 0.024$, P = 0.876; 150 m v. 325 m: $\chi^2 = 1.593$, P = 0.207; 225 m v. 325 m: $\chi^2 = 1.185$, P = 0.276). The shape of the detection curve was different during the nestling phase (Dataset E; Table 2) than during the courtship and fledgling-dependency phases (Fig. 2). Instead of decreasing with increasing distance from the nest, the detection rate at 225 m (63.5%) was higher than at 100 m (12.5%; $\chi^2 = 4.267$, P = 0.039), 150 m (12.5%; $\chi^2 = 4.267$, P = 0.039), and 325 m (25.0%; $\chi^2 = 2.286$, P = 0.131). Detection rates did not differ among the other distances (100 m and 150 m v. 325 m: $\chi^2 = 0.410$, P = 0.522). During the fledgling-dependency phase (Dataset F; Table 2), detection rates at 100 m and 150 m were not different ($\chi^2 = 1.053$, P = 0.305), but were both higher than detection rates at 225 m (100 m: $\chi^2 = 3.810$, P = 0.051; 150 m: $\chi^2 = 6.670$, P = 0.010) and 325 m (100 m: $\chi^2 = 7.500$, P = 0.006; 150 m: $\chi^2 = 10.769$, P = 0.001). Detection rates at 225 m and 325 m did not differ ($\chi^2 = 0.833$, P = 0.361).

## Factors Influencing the Probability of Detecting a Goshawk

Breeding phase and distance both significantly influenced the probability of detection when standard calls were broadcast (Dataset C; Table 2). Using the $AIC_c$ (Anderson et al. 2000, Burnham and Andersen 2000) model fit criterion, the best-fitting model (Dataset C; Table 4), with an Akaike weight of $w_i = 0.960$, included the fixed effects of distance (estimated effect = –4.61 ± 1.33), phase (estimated effect = –2.95 ± 0.98), and their interaction (distance x phase: estimated effect = 1.13 ± 0.39).

Call type was also an important factor influencing the probability of detection (Dataset H; Table 2). The best fitting model (Table 4) included the fixed effects of call type (estimated effect = 0.67 ± 0.30), distance (estimated effect = –0.72 ± 0.27), and phase (estimated effect = –1.05 ± 0.41). For this model, a weight of 0.529 indicated there was some model selection uncertainty and the second best-fitting model ($w_2 = 0.223$) should be considered as a competing model. In this model, the interaction of call type and phase (estimated effect = –0.32 ± 0.40) was also included, which could reflect the fact that detection rates were different between call types in the courtship and fledgling-dependency phase, but not the nestling phase.

The best-fitting model ($w_1 = 0.612$; Table 4) for courtship (Dataset D; Table 2) included distance as a variate as the only effect (estimated effect = –0.009 ± 0.006). Similarly, the probability of detection during the fledgling-dependency phase (Dataset F; Table 2) was better modeled ($w_1 = 0.563$; Dataset F; Table 4) with distance as a variate (estimated effect = –0.02 ± 0.007), but also included time of day (estimated effect = –1.51 ± 0.71). In contrast, the best-fitting model for the nestling phase ($w_1 = 0.743$; Dataset E; Table 4) was the only dataset I analyzed for which the best-fitting model included nest as a random effect. This model was also fit with distance as categorical data (estimated effect = –3.54 ± 2.59), rather than as a continuous variate.

## Effective Area Surveyed

The effective area surveyed had a radius of 356 m for the courtship phase (Dataset D, Table 2; Fig. 3a) and 331 m for the fledgling-dependency phase when broadcasts were conducted in the morning (Dataset G, Table 2; Fig. 3b). I could not calculate the effective area surveyed for the nestling phase because there was not a continuous probability curve that would fit the data. The sample of broadcast trials using the male contact call was too small to be divided into individual phases for this type of analysis. Thus, for broadcast surveys conducted during the morning in northern Minnesota using standard calls and the protocol recommended in this manuscript, the effective area surveyed for each broadcast station during the courtship phase was 39.8 ha and was 34.4 ha during the fledgling-dependency phase.

### Factors Influencing Latency of Detection

Eighty-five percent of all broadcast trials that resulted in detections (n = 79) were detected within 3 minutes of the first broadcast call and 91% were detected within 5 minutes. When using the standard call for each breeding phase in 2000, 87% of detections (n = 55) were within 3 minutes of initiating broadcasts, and 93% were within five minutes.

In evaluating the factors influencing latency of detection (Dataset C, including broadcast trials with detections only), the best-fitting model ($w_i = 1.0$; Table 5) included all of the fixed effects: distance, phase, and phase x distance. Each model in the set was run with and without this random effect, and in all cases, the effect was estimated at zero and its inclusion in the models did not improve model fit. Comparisons among phases (Fig. 4b; courtship: least squares mean = 3.1, n = 19; nestling: least squares mean = 2.6, n = 9; fledgling-dependency: least squares mean = 2.3, n = 27) indicated that mean detection time did not differ (courtship v. nestling: t = 1.25, P = 0.222, courtship v. fledgling-dependency: t = 0.44, P = 0.662, nestling v. fledgling-dependency: t = –0.87, P = 0.392), and that the cumulative proportion of detections was not greater than 80% until after the fourth broadcast call (approximately 130 – 160 sec after initiation of broadcast series). In comparing distances with data pooled over phases (Fig. 4a; 100 m: least squares mean = 1.7, n = 16; 150 m: least squares mean = 2.7, n = 17; 225 m: least squares mean = 2.9, n = 15; 325 m: least squares mean = 3.7, n = 7), there was a difference between mean detection latencies at 100 m and 325 m (t = –2.16, P = 0.039). The mean detection latencies among the other distances were not different (100 m v. 150 m: t = –

0.90, P = 0.373; 100 m v. 225 m: t = –1.60, P = 0.120; 150 m v. 225 m: t = –0.59, P = 0.559; 150 m v. 325 m: t = –1.23, P = 0.229; 225 m v. 325 m: t = –0.46, P = 0.452). Also, at 100 m, the cumulative proportion of detections reached 100% after only the third broadcast (approximately 90 – 120 sec after initiation of broadcast series), whereas the cumulative proportion of detections did not reach 100% until after the sixth broadcast at all three of the other distances (≥ 200 sec after initiation of broadcast series).

## Discussion

### Factors Influencing the Probability of Detecting a Goshawk

Phase, distance, and call type were all important factors influencing the probability of detecting goshawks while broadcasting conspecific calls. My results shed new light on the relationship of distance and probability of detection and how it differs among phases. In addition, time of day (tested only during the fledgling-dependency phase), which several studies have over-looked, may also have an influence on probability of detection.

*Time of day*. Time of day was the only factor I examined in which results from hypothesis testing and the AIC approach differed. I examined the influence of time of day during the fledgling-dependency phase using the juvenile food-begging call. There was not a statistically significant difference between time periods as a result of chi-squared analyses. However, I found time of day to be a factor influencing the probability of detection in the best-fitting model when using the AIC approach, indicating that it may be a biologically important effect.

Kimmel and Yahner (1990) reported that detection rates using the alarm call during the fledgling-dependency phase did not differ with time of day (~29% early morning; ~14% late morning, ~29% early afternoon; ~29% late afternoon) and were fairly low overall (~25%). In my study, I broadcast the food-begging call during the fledgling-dependency phase in 2000, which resulted in high overall detection rates, with rate of detection decreasing throughout the day. Kimmel and Yahner (1990) used Fisher's exact test to determine whether time of day influenced detection rates. They concluded that time of day was not statistically significant for total trials during the nestling and fledgling dependency phase. Their observed detection rates during the nestling phase, however, indicate that there may be a biologically important difference in detection rates at different times of the day. It is possible that these differences were not significantly different because of small sample sizes (n = 27). In fact, from closer inspection of Figure 3 in their paper, it appears that detection rates may actually have been about twice as high during the late morning (~67%; n = 6; 1001 – 1200 H) and late afternoon (~57%; n = 7; 1501 – 1800 H) than early afternoon (~29%; n = 7; 1201 – 1500 H) and four times higher than during the early morning (~14%; n = 7; 0800 – 1000 H).

Interestingly, the higher detection rates reported by Kimmel and Yahner (1990) in the late morning and late afternoon roughly correspond with peaks in spontaneous vocalizations by goshawk nestlings (during the fourth and thirteenth hour after sunrise) reported by Penteriani (2001) and peaks in food-delivery times by the male goshawk reported by Schnell (1958). Penteriani (2001) reported that during the nestling and fledgling-dependency phases, prey delivery is probably related to vocal activity. Similar to Kimmel and Yahner's study (1990), all detections during the nestling phase were from adults. Perhaps the fact that their detection rates were highest during the times that have been reported as peak food delivery times actually reflect periods of high parental attentiveness. Or perhaps the female is more likely to leave the nest and vocalize in response to a broadcast call at times when the male is also near the nest. McLeod and Andersen (1998) found that broadcast surveys of red-shouldered hawks (*Buteo lineatus*) resulted in the highest detections in the morning (pooled across phases). My results indicate that additional investigations should probably be conducted to examine time of day effects during the courtship and nestling phases.

Although I had originally designed my broadcasting protocol so that broadcast trials would be conducted an equal number of times per time of day, this turned out to not be logistically feasible, primarily as a result of weather. Many of the broadcast trials that I had originally scheduled for the late afternoon to evening hours had to be reassigned because winds in the afternoon often exceeded 20 km/h. Windy conditions may have influenced detection rates during this time period and highlight the importance of considering local weather patterns and their effect on conditions for broadcasting when planning broadcast surveys.

*Breeding phase*. Unlike previous studies that conducted broadcast trials during courtship (Kennedy and Stahlecker 1993, McClaren 2001), the highest overall detection rate in my study occurred in this breeding phase. These results indicate that courtship is an effective time to conduct broadcast surveys for goshawks. My detection rates are not directly comparable to other studies because I conducted broadcast trials at only one distance per visit to a nest, and during the morning only during the courtship and nestling phases. Detection rates reported by Kennedy and Stahlecker (1993) and McClaren (2001) might be confounded by the time of day effect discussed in the previous section. Detection rates for other raptor species, such as red-shouldered hawks (McLeod and Andersen 1998) and great horned owls (Morrell et al. 1991) have been reported to be highest during the courtship phase. Due to the equivocal nature of the results of courtship broadcast trials among these studies, further studies should be conducted in other regions using a similar experimental design, restricting the broadcasts to the morning during peak vocalization times or testing for a time of day effect.

Kennedy and Stahlecker (1993) reported that detection rates were higher using standard calls during the nestling phase (93.3%) than during the fledgling-dependency phase (84.6%). Conversely, Watson et al. (1999) and McClaren (2001) both reported lower detection rates at active nests during the nestling phase (alarm call; 37% and 60.0%, respectively) in comparison to the fledgling dependency phase (food-begging call; 74% and 75.0%, respectively). In my study, detection rates during the nestling phase were lower than during the fledgling-dependency phase, and were lower than in other studies. If there is a difference in detections at different times of day during the nestling phase, the low detection rate for this phase may be due to only conducting broadcast trials during the morning.

The evidence from my and other studies suggests that detection rates in this period vary extensively across the goshawk's range. For this phase, the best fitting models were ones with nest as a random effect and this was the only phase in which <100% of all active nests were detected during at least one broadcast trial using the alarm call. Thus, there were more goshawks that were less likely to respond to broadcasts at all during this phase in comparison with other phases. Possible explanations for this include variation in strategies for protecting nestlings, which may differ with nestling age, as well as behavioral adaptations to food supply. Dewey and Kennedy (2001) found that adult female goshawks at active nests adjusted their behavior in response to food supplies; they hunted when they needed to and spent more time in the nest stand when food was more plentiful. The amount of time that the female is present in the nest stand during the nestling phase, and thus the ability of a broadcaster to detect a goshawk near a nest, may vary among nest sites or years in response to food supplies.

In an attempt to explain why the probability of detection is different for the nestling phase and why there appears to be more variation among individuals, I used mixed logistic regression to determine if the age of chicks influenced the probability of detection. Because this was a post-hoc analysis my inference is limited to my sample. However, this analysis provides some preliminary insight into why detection rates during this phase were different from the other two phases and why they were more variable among nests. I grouped nestlings into age groups of five days for this analysis. Analyses resulted in a best-fitting model ($w_i = 0.775$; Table 6) that included distance (categorical), age of nestlings (categorical), and their interaction, as well as the random effect of nest site. Detection rate as related to age of nestlings did not follow a clear pattern, but was highest during the second and fourth week after hatching. These results suggest that age of nestlings may be an important factor influencing the behavior of adults in response to broadcast calls. One possible explanation for lower detection rates during the first week after hatching is that prolactin hormone levels, which mediate incubation and brooding behavior (Goldsmith 1991) may still be high in the female, making her more likely to stay on the nest. Future research of the effectiveness of broadcast surveys during this phase should further examine the influence of age of chicks on goshawk detectability.

The probability of detecting goshawks was high overall during the fledgling-dependency phase. Juvenile goshawks tend to be vocal throughout the day (Penteriani 2001) and call incessantly after first responding to broadcasts (Watson et al. 1999, A. M. Roberson, unpublished data), however, detection rates differed by time of day, indicating that the highest probability of detection during this phase may be in the morning.

All but one of the detections during the fledgling-dependency phase with the food-begging call were from fledglings (an adult female responded along with fledglings on two occasions). 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. This confirms that broadcasts should be conducted during the early part of this phase (< 25-30 days post-fledging) and also highlights the importance of incorporating local breeding phenology into broadcast survey design.

*Distance*. Distance was included in all of the best-fitting models selected for each dataset (Table 4). Broadcast trials during the fledgling-dependency phase resulted in the clearest relationship between distance and detection rates (Fig. 2). Probability of detection per distance is difficult to calculate for the courtship phase because the actual nest that will be used is often unknown until late in the season and broadcast trials conducted throughout the season could have influenced where goshawks chose to nest. Distances from broadcast stations to nests where eggs where laid ranged from 70 – 499 m, with a majority (66.70%) falling between 150 – 350 m. Out of 11 trials conducted at stations that were 70 – 274 m from nests where eggs where laid, 8 (72.7%) resulted in detections. At 10 stations 279 – 499 m from nests where eggs where laid, 5 (50.0%) resulted in detections.

Perhaps the most interesting result of trials conducted during the nestling phase is the unexpected relationship between distance and probability of detection. Previous studies (Kennedy and Stahlecker 1993, Watson et al. 1999, McClaren 2001) assumed that detection rates would be cumulative and that detections would also have occurred at distances closer to the nest than the station where the detection was actually recorded. This assumption precluded detecting results to the contrary. My results indicate that detection rates may not always be highest at closer distances to the nest during the nestling phase. One explanation for this could be that female adult goshawks are less likely to respond to broadcasts at close distances to the nest because they do not want to reveal the location of their nest to intruders.

*Call type*. Although my sample size was small, my results supported those of McClaren (2001), who reported that the male contact call did not improve detection rates over standard calls. The male contact call is a low-pitched call that the male delivers when he enters the nest stand. Although the female and fledglings readily respond to this call, as McClaren (2001) pointed out, artificially loud broadcasts of this call at greater distances from the nest may be distorted and thus may not be recognizable. Additionally, females and fledglings may respond to the presence of males along with the call, or may recognize individual males' vocalizations. It should also be noted that inference may be limited to the recordings of calls used because differences in local dialects may affect the probability of detection. However, this has not been tested.

*Year*. The difference in detection rate between years in my study was probably biologically important. Although not specifically tested for, the annual difference in overall detection rates between years may have been due to a technological improvement in the broadcasting equipment that I used; in 1999 a taped recording was used and a CD-recording of higher quality with less background noise was used in 2000. I broadcast the male contact call during both years in both of these phases, but there were no detections using the male contact call in 1999. This also may have been due to the quality of the recording used in 1999. Previous studies that have conducted broadcast trials at the same nests in more than one year used the same broadcasting equipment in both years and did not find year to be a significant influence on the probability of detecting goshawks (Watson et al. 1999, McClaren 2001).

### Differences in Detection Rates Among Studies

Experimental procedure differed among studies examining detection rates of goshawks to broadcast calls; this precluded direct comparison and may influence reported detection rates. Detection rates may also vary with topographic and vegetative differences, such as slope, vegetation density, and nest tree height, as well as differences in levels of aggressiveness in nest-defense behavior (Knight et al. 1987), and call dialects among populations (McClaren 2001). Thus, it is important to consider differences in detection rates when comparing survey results from different areas.

### Effective Area Surveyed

Calculating the effective area surveyed using probability of detection functions that are regionally specific allow for comparisons of extensive surveys conducted in different locations and for relative density estimates to be calculated. By multiplying the effective area surveyed at each broadcast station by the number of stations surveyed, the total area surveyed can be calculated and compared to results of similar surveys in other areas.

In addition, knowledge of a locally calibrated effective area surveyed per broadcast station can be incorporated into the design of extensive surveys to maximize the area surveyed while minimizing effort. Survey protocol recommendations made by Kennedy and Stahlecker (1993) and Joy et al. (1994) call for spacing broadcast stations 300 m apart and transects 260 m apart, with stations staggered by 150 m on adjacent transects to maximize the probability of detection when conducting systematic, grid-type surveys. However, broadcast stations may be placed at greater distances from each other or along road transects if probability of detection is incorporated into survey results when estimates of density and relative abundance are goals of the survey.

## Management Implications

With careful survey design, the probability of detecting a goshawk with broadcast conspecific calls in Minnesota is high, particularly during the courtship (approx. 1 March – 7 April) and fledgling-dependency phases (approx. 25 June – 20 July). In any area where goshawk surveys are to be conducted, it is important to incorporate knowledge of local detection rates and differences between call types and among breeding phases, as well as local nesting phenology and weather patterns. Depending on management goals, broadcast surveys can be conducted in a way that maximizes the probability of detecting nesting attempts or successful nests within a specific area, or maximizes the probability of detection at a specific time to assist in determining if goshawks are present in an area (i.e., prior to a timber sale or other management activity).

To ensure that broadcast surveys are conducted in a biologically appropriate manner, a small sample of nests could be used to assess breeding phenology each year that surveys are to be conducted. Dawn vocalization surveys near nests during courtship can be used to determine whether a breeding area is active and to locate alternative nests in those areas (Penteriani 1999, this study). Nest progress can easily be verified after a nest is located. It is also important to understand local seasonal weather patterns because they may predictably result in conditions unsuitable for broadcast surveys during certain seasons or times of day. For example, in my study area, the late afternoons during the fledgling-dependency phase were not a good time to broadcast due to high winds.

If management goals include monitoring population trends or assessing abundance of nesting goshawks, conducting surveys during the courtship phase would maximize the detection of nesting attempts. Although courtship surveys may not be feasible in some regions, due to rugged terrain, snow depth, or remoteness, access in some areas of the WGLR may be physically and logistically easier during the courtship phase, when the many lakes and wetlands in the region are frozen and the vegetation is covered with snow. This would allow a surveyor to conduct systematic surveys along transects wearing snowshoes or cross-country skis and to access remote areas that are covered with water at other times of the breeding season by snowmobile or a 4-wheel drive vehicle. During my study, I found that many unpaved forest roads that were relatively easy to traverse during courtship often became impassible once thawing occurred. Additionally, the transmission of sound may be greater during the courtship phase before leaf emergence in the trees of the hardwood forests of north-central Minnesota (McLeod and Andersen 1998).

Surveys conducted during the fledgling-dependency phase have a high probability of detection and thus are appropriate for detecting successful nests. During the nestling phase, overall detection rates were lower than in other phases, the detectability of goshawks appeared to vary among individuals, and the relationship between distance and probability of detection was not clear. In addition, nests have begun to fail and may not be easily detected. Thus, this phase may not be an optimal time to conduct broadcast surveys.

My results do not support using the male contact call during broadcast surveys. Broadcast trials using this call did not improve detection rates observed while using standard calls. In addition, I recommend that a high-quality recording, preferably on CD, be used, as my results suggest that the quality of broadcasts may affect detection rates.

My data also support McClaren's (2001) recommendation to increase the amount of time spent per broadcast station from three minutes, as recommended by Kennedy and Stahlecker (1993), to five minutes. In my study, 93% of detections using standard calls were achieved within 5 minutes of initiating broadcasts, which was an improvement over the 87% detected within 3 minutes. This is important to survey design because probability of detection may be improved by increasing the time spent at each broadcast station. Latency increased with distance from the nest, so spending more time at each broadcast station may be particularly important when surveys are designed with broadcast stations set at greater distances from each other. McLeod and Andersen (1998) recommended six minutes per broadcast station for detecting red-shouldered hawks in Minnesota. Based on other studies (Watson et al. 1999, McClaren 2001), it may also be advisable to repeat surveys in an area at least twice per year and preferably again in consecutive years if relatively precise estimates of density and abundance are desired.

Detection probability functions should be incorporated into survey designs to help managers calibrate the results of extensive surveys. Differences in detection rates among studies conducted in different areas of the goshawks' range indicate that these functions should be calibrated based on local probabilities of detection. For broadcast surveys in Minnesota, my results indicate that the effective area surveyed at each point has a radius of 356 m during the courtship phase and 331 m during the fledgling-dependency phase. These results indicate that surveys during these two phases could have broadcast stations spaced at 712 m and 662 m, respectively, and still result in a high probability of detection over the area surveyed. Incorporating this knowledge into survey design improves the cost-effectiveness of surveys based on the current protocol (Kennedy and Stahlecker 1993, Joy et al. 1994), which calls for broadcast stations spaced at 300 m apart. This procedure could be repeated in other regions where the probability of detection as a function of distance is known.

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**Table 1. Experimental design for broadcast trials at active goshawk nests in northern Minnesota, 1999 – 2000.**

| **1999** | **BREEDING PHASE** Courtship ( 17 March – 17 April) | | Nestling (20 May – 20 June) | | Fledgling-dependency (24 June – 25 July) | |
|---|---|---|---|---|---|---|
| **TIME OF DAY** | morning [sunrise – (sunrise +3 hr)] | | morning [sunrise – (sunrise +3 hr)] | | all day [sunrise – (sunset – 2 hr)] | |
| **CALL TYPE**[1] | alarm | male contact | alarm | male contact | alarm | male contact |
| **NO. OF STATIONS/NEST**[2] | 4 | 1 | 4 | 1 | 4 | 1 |

| **2000** | **BREEDING PHASE** Courtship ( 8 March – 7 April) | | Nestling (11 May – 31 June) | | Fledgling-dependency (30 June – 16 July) | |
|---|---|---|---|---|---|---|
| **TIME OF DAY** | morning [sunrise – (sunrise +3 hr)] | | morning [sunrise – (sunrise +3 hr)] | | all day [sunrise – (sunset – 2 hr)] | |
| **CALL TYPE**[1] | alarm | male contact | alarm | male contact | food-begging | male contact |
| **NO. OF STATIONS/NEST**[2] | 4 | 2 | 4 | 1 | 4 | 2 |

[1] Fewer broadcast trials were conducted using the male contact call than standard calls (alarm, juvenile food-begging) due to limited time and resources.

[2] At some nests, I was unable to broadcast at all stations because goshawks laid eggs before I completed trials during the courtship phase, or nests failed during the nestling phase.

**Table 2. Data matrices used in chi-squared, mixed linear and mixed logistic regression analyses[1] to accommodate unbalanced experimental design of broadcast trials at active goshawk nests in northern Minnesota, 1999 – 2000.**

| | | | |
|---|---|---|---|
| **Dataset A** | **n = 95** | | |
| **Broadcast Call** | alarm | | |
| **Year** | 1999, 2000 | | |
| **Breeding Phase** | courtship | nestling | |
| **Time of Day** | morning | | |
| **Dataset B** | **n = 99** | | |
| **Broadcast Call** | standard[2] | | |
| **Year** | 2000 | | |
| **Breeding Phase** | courtship | nestling | fledgling-dependency |
| **Time of Day** | morning | morning | all day |
| **Dataset C** | **n = 77** | | |
| **Broadcast Call** | standard[2] | | |
| **Year** | 2000 | | |
| **Breeding Phase** | courtship | nestling | fledgling-dependency |
| **Time of Day** | morning | morning | morning |
| **Dataset D** | **n = 27** | | |
| **Broadcast Call** | alarm | | |
| **Year** | 2000 | | |
| **Breeding Phase** | courtship | | |
| **Time of Day** | morning | | |
| **Dataset E** | **n = 32** | | |
| **Broadcast Call** | alarm | | |
| **Year** | 2000 | | |
| **Breeding Phase** | nestling | | |
| **Time of Day** | morning | | |
| **Dataset F** | **n = 40** | | |
| **Broadcast Call** | juvenile food-begging | | |
| **Year** | 2000 | | |
| **Breeding Phase** | fledgling-dependency | | |
| **Time of Day** | all day | | |
| **Dataset G** | **n = 18** | | |
| **Broadcast Call** | juvenile food-begging | | |
| **Year** | 2000 | | |
| **Breeding Phase** | fledgling-dependency | | |
| **Time of Day** | morning | | |
| **Dataset H[3]** | **n = 33** | | |
| **Broadcast Call** | standard[2], male contact | | |
| **Year** | 2000 | | |
| **Breeding Phase** | courtship | nestling | fledgling-dependency |
| **Time of Day** | morning | morning | morning |

[1] Analyses described in more detail in the text.

[2] Standard calls are defined as the alarm call during the courtship and nestling phases and the juvenile food-begging call during the fledgling-dependency phase.

[3] Broadcast trials using the male contact call paired with trials using standard calls at the same stations/nest.

**Table 3. Number and percentage of goshawk detections by sex and age class during each breeding phase in northern Minnesota 1999 – 2000.**

| BREEDING PHASE | Adult female | Adult male | Both adults | Adult of unknown sex | Juvenile | Juvenile + adult female |
|---|---|---|---|---|---|---|
| **Courtship** | 15 (50%) | 3 (10%) | 4 (13%) | 8 (27%) | – | – |
| **Nestling** | 17 (85%) | – | 1 (5%) | 2 (10%) | – | – |
| **Fledgling-dependency** | 2 (6%) | – | – | – | 31 (88%) | 2 (6%) |

**Table 4. Multi-model inference of logistic regression models to determine factors influencing the probability of detecting a goshawk at active nests in northern Minnesota, 2000.**

**Dataset C (Table 2)**

| Model $g_i$ | $K_i$[1] | $\Delta_i$[2] | $w_i$[3] |
|---|---|---|---|
| $\{\Phi_{p*dc}\}$[4] | 4 | 0.0 | 0.960 |
| $\{\Phi_{p}\}$ | 2 | 7.5 | 0.023 |
| $\{\Phi_{p+dc}\}$ | 3 | 8.0 | 0.018 |
| $\{\Phi_{dc}\}$ | 2 | 20.6 | 0.000 |

**Dataset H (Table 2)**

| Model $g_i$ | $K_i$ | $\Delta_i$ | $w_i$ |
|---|---|---|---|
| $\{\Phi_{p+dc+c}\}$ | 4 | 0.0 | 0.529 |
| $\{\Phi_{p+dc+c+p*c}\}$ | 5 | 1.7 | 0.223 |
| $\{\Phi_{p+dc+c+dc*c+p*c}\}$ | 6 | 3.2 | 0.107 |
| $\{\Phi_{d+p}\}$ | 3 | 3.2 | 0.107 |
| $\{\Phi_{p+d+c+dc*p+dc*c+p*c}\}$ | 7 | 5.6 | 0.032 |

**Dataset D (Table 2)**

| Model $g_i$ | $K_i$ | $\Delta_i$ | $w_i$ |
|---|---|---|---|
| $\{\Phi_{dv}\}$ | 2 | 0.0 | 0.612 |
| $\{\Phi_{dv+u}\}$ | 3 | 2.2 | 0.204 |
| $\{\Phi_{dv+d4}\}$ | 3 | 2.4 | 0.184 |

**Dataset E (Table 2)**

| Model $g_i$ | $K_i$ | $\Delta_i$ | $w_i$ |
|---|---|---|---|
| $\{\Phi_{dc+u}\}$ | 3 | 0.0 | 0.743 |
| $\{\Phi_{dv+d4+u}\}$ | 4 | 2.6 | 0.203 |
| $\{\Phi_{dc}\}$ | 2 | 6.2 | 0.033 |
| $\{\Phi_{dc+d4}\}$ | 3 | 8.5 | 0.011 |
| $\{\Phi_{dv+u}\}$ | 3 | 9.4 | 0.007 |
| $\{\Phi_{dv}\}$ | 2 | 10.8 | 0.003 |

**Dataset F (Table 2)**

| Model $g_i$ | $K_i$ | $\Delta_i$ | $w_i$ |
|---|---|---|---|
| $\{\Phi_{dv+t}\}$ | 3 | 0.0 | 0.563 |
| $\{\Phi_{dv+d4+t}\}$ | 4 | 2.4 | 0.170 |
| $\{\Phi_{dv*t}\}$ | 4 | 2.4 | 0.170 |
| $\{\Phi_{dv}\}$ | 2 | 3.5 | 0.099 |

[1] $K_i$ denotes the number of parameters in each model.

[2] $\Delta_i = AIC_{ci} - minAIC_c$ and provides a way of ranking models by fit.

[3] $w_i$ denotes the Akaike weight and can be interpreted as the approximate probability that model *i* is the Kullback-Leibler best model in the set, allowing assessment of model selection certainty (Anderson et al. 2000, Burnham and Anderson 2000).

[4] Φ denotes a logistic regression model and subscript letters represent effects (p = phase, dv = distance as a variate, dc = distance as categorical data, d4 = 325 m as a fixed distance, c = call type, u = random nest effect, included only when it improved the model fit); together these notations represent individual models.

**Table 5. Multi-model inference of linear regression models to determine factors influencing latency of detection using standard calls[1] at active goshawk nests during courtship, nestling, and fledgling-dependency phases in northern Minnesota, 2000 (Dataset C; Table 2).**

| **Model $g_i$** | **$K_i$**[2] | **$\Delta_i$**[3] | **$w_i$**[4] |
|---|---|---|---|
| $\{\Phi_{d*p}\}$[5] | 4 | 0.0 | 1.000 |
| $\{\Phi_{d+p}\}$ | 3 | 19.2 | 0.000 |
| $\{\Phi_{d}\}$ | 2 | 22.7 | 0.000 |
| $\{\Phi_{p}\}$ | 2 | 29.8 | 0.000 |

[1] Standard calls are defined as the alarm call during the courtship and nestling phases and the juvenile food-begging call during the fledgling-dependency phase.

[2] $K_i$ denotes the number of parameters in each model.

[3] $\Delta_i = AIC_{ci} - minAIC_c$ and provides a way of ranking models by fit.

[4] $w_i$ denotes the Akaike weight and can be interpreted as the approximate probability that model *i* is the Kullback-Leibler best model in the set, allowing assessment of model selection certainty (Anderson et al. 2000, Burnham and Anderson 2000).

[5] $\Phi$ denotes a linear regression model and subscript letters represent effects (p = phase, d = distance); together these notations represent individual models.

**Table 6. Multi-model inference of logistic regression models using the alarm call at active goshawk nests during the nestling phase in northern Minnesota, 2000 (Dataset E; Table 2).**

| Model $g_i$ | $K_i$ [1] | $\Delta_i$ [2] | $w_i$ [3] |
|---|---|---|---|
| $\{\Phi_{dc*a+u}\}$ [4] | 5 | 0.0 | 0.775 |
| $\{\Phi_{dc+u}\}$ | 3 | 3.1 | 0.164 |
| $\{\Phi_{dc+a+u}\}$ | 4 | 5.5 | 0.049 |
| $\{\Phi_{dc}\}$ | 2 | 9.3 | 0.007 |
| $\{\Phi_{u}\}$ | 2 | 11.6 | 0.002 |
| $\{\Phi_{a+u}\}$ | 3 | 14.0 | 0.001 |
| $\{\Phi_{a}\}$ | 2 | 14.7 | 0.000 |

[1] $K_i$ denotes the number of parameters in each model.

[2] $\Delta_i = AIC_{ci} - minAIC_c$ and provides a way of ranking models by fit.

[3] $w_i$ denotes the Akaike weight and can be interpreted as the approximate probability that model *i* is the Kullback-Leibler best model in the set, allowing assessment of model selection certainty (Anderson et al. 2000, Burnham and Anderson 2000).

[4] Φ denotes a logistic regression model and subscript letters represent effects (a = age of chicks, p = phase, dc = distance as categorical data, c = call type, t = time of day, u = random nest effect, included only when it improved the model fit); together these notations represent individual models.

*Figure 1 removed from this document to protect the goshawk population, as it contained location information of goshawk nesting areas*

**Figure 2. Detection rate at 100, 150, 225, and 325 m from active goshawk nests using the alarm call during the courtship and nestling phases and the juvenile food-begging call during the fledgling-dependency phase in northern Minnesota, 2000.**

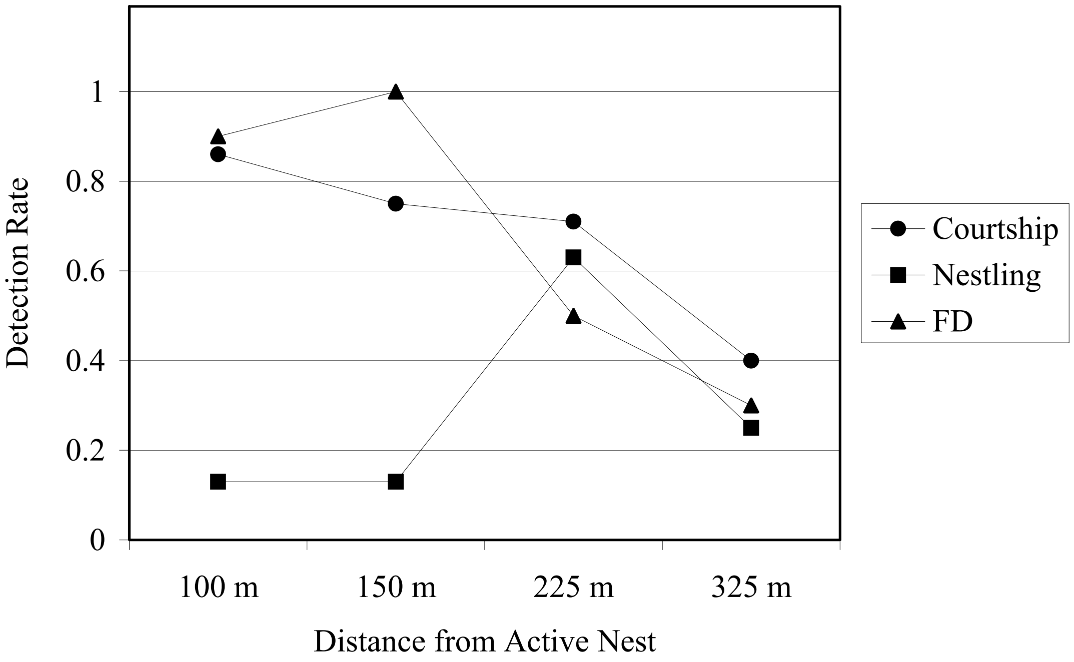
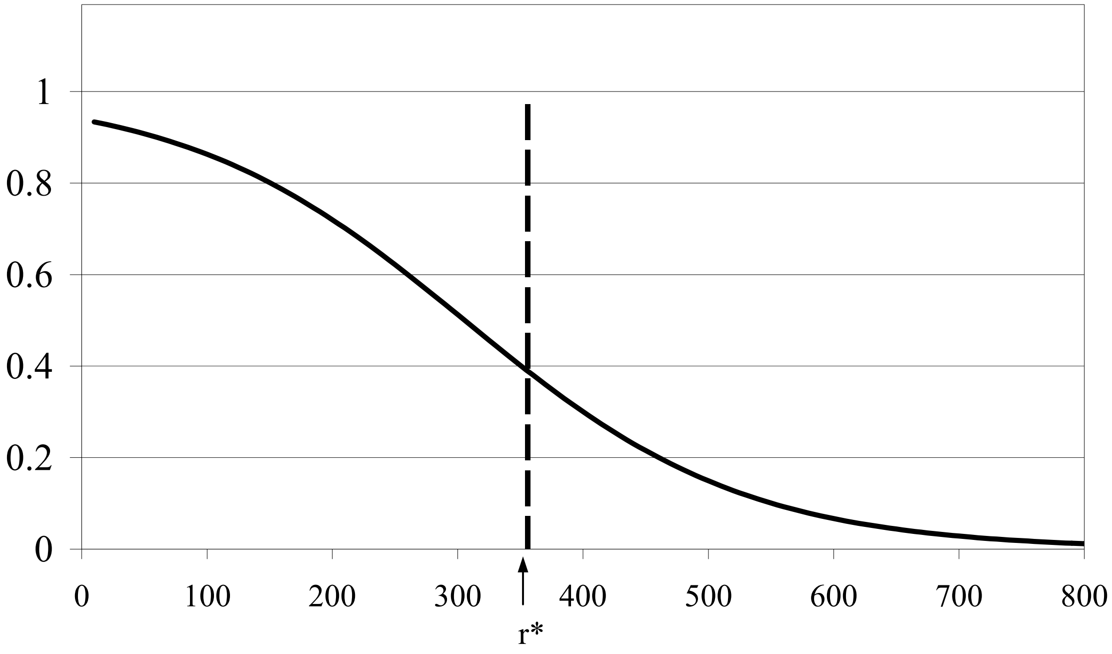


**Figure 3. Probability of detection as a function of distance and r* (radius of the effective area surveyed per broadcast station) for the courtship and fledgling-dependency phases.**

a) Courtship phase



b) Fledgling-dependency phase

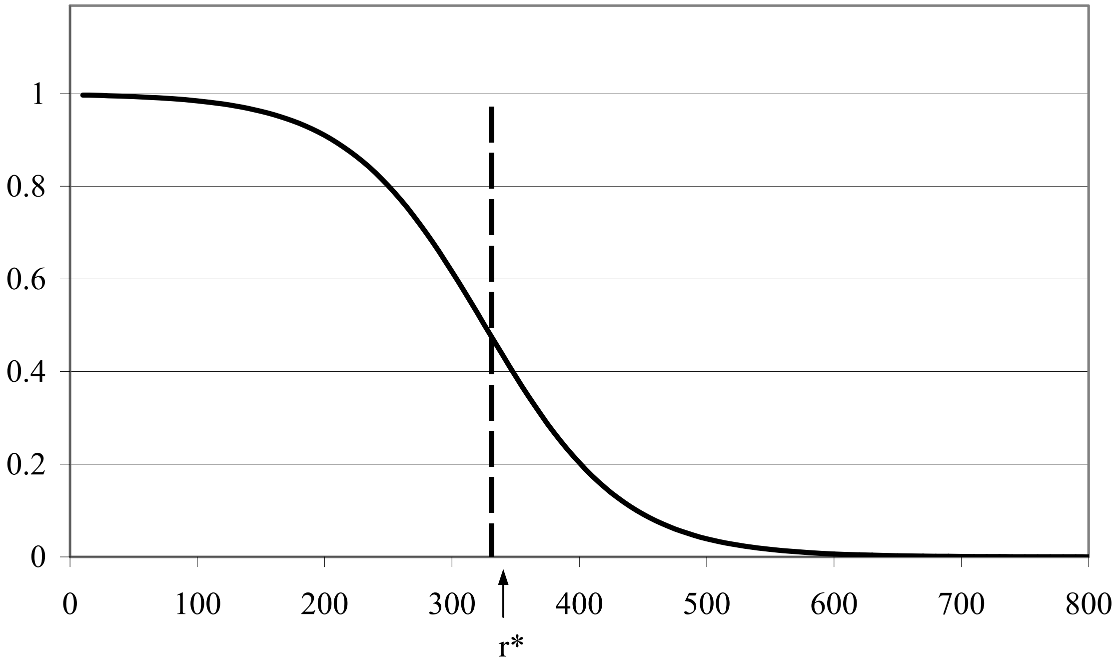
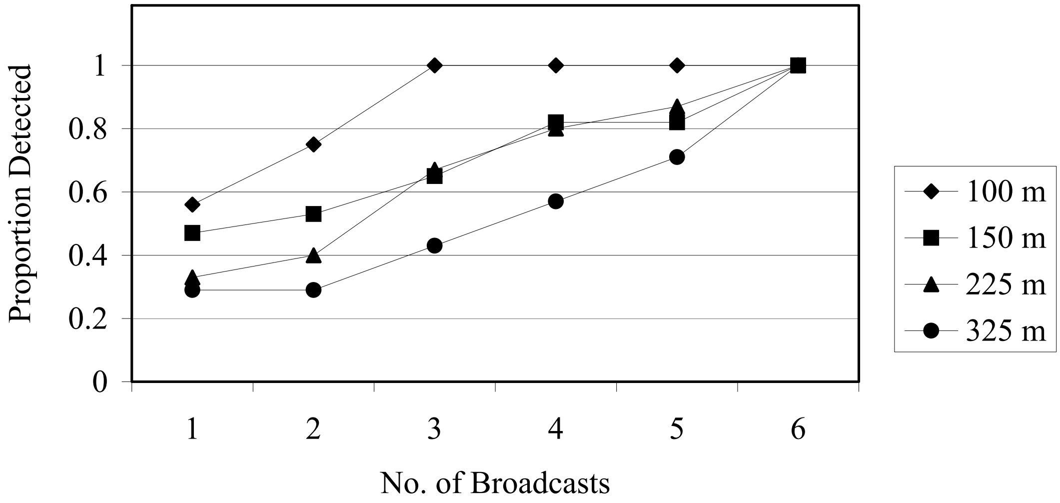


**Figure 4. Cumulative latency during broadcast trials where detections occurred (n = 55) conducted at active goshawk nests using standard calls in northern Minnesota, 2000.**

a) Latency at each distance. Data are pooled over all breeding phases.



b) Latency during each breeding phase. Data are pooled over all distances.