

RED-SHOULDERED HAWK BROADCAST SURVEYS: FACTORS AFFECTING DETECTION OF RESPONSES AND POPULATION TRENDS

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Abstract: Forest-nesting raptors are often difficult to detect and monitor because they can be secretive, and their nests can be difficult to locate. Some species, however, respond to broadcasts of taped calls, and these responses may be useful both in monitoring population trends and in locating nests. We conducted broadcast surveys on roads and at active red-shouldered hawk (*Buteo lineatus*) nests in northcentral Minnesota to determine effects of type of call (conspecific or great horned owl [*Bubo virginianus*]), time of day, and phase of the breeding cycle on red-shouldered hawk response behavior and to evaluate usefulness of broadcasts as a population monitoring tool using area occupied–probability-of-detection techniques. During the breeding seasons of 1994 and 1995, we surveyed 4 10-station road transects 59 times and conducted 76 surveys at 24 active nests. Results of these surveys indicated conspecific calls broadcast prior to hatch and early in the day were the most effective method of detecting red-shouldered hawks. Probability of detection via conspecific calls averaged 0.25, and area occupied was 100%. Computer simulations using these field data indicated broadcast surveys have the potential to be used as a population monitoring tool.

JOURNAL OF WILDLIFE MANAGEMENT 62(4):1385–1397

Key words: broadcast, *Buteo lineatus*, Minnesota, monitoring, red-shouldered hawk, survey.

Woodland raptors are often difficult to locate and monitor because they occupy areas with dense vegetation, have large home ranges, and are secretive. Broadcast surveys of conspecific or great horned owl (GHOW) calls to elicit responses from territorial pairs have been widely used to locate secretive woodland raptors (Fuller and Mosher 1981, Balding and Dibble 1984, Fuller and Mosher 1987, Rosenfield et al. 1988, Kimmel and Yahner 1990, Mosher et al. 1990, Kennedy and Stahlecker 1993). Broadcast surveys are particularly useful in locating red-shouldered hawks (RSHA), which are highly vocal in spring and can be heard and will respond from distances ≤ 1 km (A. R. Parker. 1990. Survey of woodland nesting raptors on the Hoosier National Forest, 1990, unpublished. U.S. Fish and Wildlife Service, Fort Snelling, Minnesota, USA, and Indiana Department of Natural Resources, Indianapolis, Indiana, USA). Surveys using GHOW and RSHA calls have been shown to increase detectability of RSHA (Johnson 1989, Devaul 1990, Mosher et al. 1990) and can

be used to locate breeding pairs and to help pinpoint nest locations.

Broadcast surveys, when used on standardized, repeated point counts, also have potential for use as a population monitoring tool. Repeated survey data can be used to calculate the probability of detecting a raptor given a raptor is present, and the probability of detection (PD) is used in conjunction with the percentage of stations at which birds were detected to calculate the area occupied (AO; Geissler and Fuller 1987). Changes in AO through time may be indicative of temporal changes in raptor populations (e.g., density). In species with a small PD, AO–PD techniques may result in confidence intervals too wide to be useful (Devaul 1990, Iverson and Fuller 1991). Red-shouldered hawks respond readily to broadcasts, and therefore may be a suitable species for AO–PD techniques.

The effectiveness of broadcast surveys in locating nesting areas or monitoring populations may vary with different survey techniques. Variables such as type of call (conspecific or GHOW), phase of the breeding cycle, and time of day may influence response behavior. Our study evaluated effects of these 3 variables on the response behavior of RSHA and investigat-

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ed the statistical power of broadcast surveys as a potential population monitoring tool.

STUDY AREA

We conducted the study at 2 sites in central Minnesota: the Camp Ripley Army National Guard Training Site (hereafter, Camp Ripley) and the Chippewa National Forest (hereafter, CNF). Camp Ripley covers approximately 20,000 ha in Morrison County. The southern two-thirds of the site is a flat, sandy outwash plain dominated by jack pine (*Pinus banksiana*), scrub oak (*Quercus* spp.), and grassland habitats. This portion of Camp Ripley is used intensively for military training activities and is generally unsuitable as nesting habitat for RSHA. The northern third of Camp Ripley is a glacial moraine with knob-and-kettle topography and interspersed wetlands. This area is vegetated primarily by 50–75-year-old upland hardwood forest with red oak (*Quercus rubra*), quaking aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), and sugar maple (*Acer saccharum*), in order of descending frequency, composing approximately 75% of the overstory trees. Big-tooth aspen (*P. grandidentata*), red maple (*A. rubrum*), bur oak (*Q. macrocarpa*), white oak (*Q. alba*), American basswood (*Tilia americana*), and green ash (*Fraxinus pennsylvanica*) composed the remaining 25%. Red pine (*Pinus resinosa*), black cherry (*Prunus serotina*), and American elm (*Ulmus americana*) occur sporadically. The far northern end of Camp Ripley, bounded by the Crow Wing and Mississippi rivers, contains a contiguous 350-ha area of mature hardwood forest.

The CNF covers approximately 600,000 ha of Cass and Itasca counties in northcentral Minnesota, in the transition zone from hardwood to boreal forest. Northern hardwood stands are scattered through the forest, generally in patches <30 ha, and are interspersed with wooded wetlands dominated by ash (*Fraxinus* spp.), and marshes and other wet areas. Sugar maple, American basswood, paper birch, ash, and yellow birch (*B. alleghaniensis*), in order of descending frequency, composed approximately 75% of the overstory trees, with quaking aspen, red maple, red oak, big-tooth aspen, bur oak, and northern white-cedar (*Thuja occidentalis*) composing the remaining 25%. Balsam poplar (*Populus balsamifera*), balsam fir (*Abies balsamea*), ironwood (*Ostrya virginiana*), white pine (*Pinus strobus*), and American elm occur spo-

radically. The most extensive area of hardwoods on the CNF occurs on the north side of Leech Lake and covers approximately 6,400 ha and contains several contiguous stands ≥ 100 ha. This area lies on the Guthrie till plain, where soils are wet and topography is generally flat. These stands were last logged early in the 20th century. Red-tailed hawks (*B. jamaicensis*), broad-winged hawks (*B. platypterus*), sharp-shinned hawks (*Accipiter striatus*), Cooper's hawks (*A. cooperii*), northern goshawks (*A. gentilis*), American kestrels (*Falco sparverius*), bald eagles (*Haliaeetus leucocephalus*), great horned owls, and barred owls (*Strix varia*) are present on both study sites during the breeding season.

METHODS

We established 4 road transects, 2 at Camp Ripley and 2 in the CNF, and surveyed these in 1994 and 1995. We chose locations of road transects based on accessibility during spring thaw, the presence of mature hardwoods, and sightings of RSHA prior to 1994. Following the protocol developed by Mosher et al. (1990), each transect was 7.2 km in length with 10 stations spaced at 0.8-km intervals, and was surveyed ("run") 6–9 times each year at intervals of ≥ 6 days. We randomly determined the direction of each run. In 1994, we randomly determined the type of call (RSHA or GHOW) for odd-numbered (first, third, etc.) runs and used the call that was not used the previous time on even-numbered runs. In 1995, we assigned RSHA calls randomly to 75% of the runs to provide a larger sample size for RSHA calls, and we used GHOW calls on the remaining 25%.

The protocol at each survey station followed a modification of methods outlined by Iverson and Fuller (1991). We broadcast 6 calls, each of 20-sec duration, at 1-min intervals with a 40-sec listening period between successive calls. After the final call, there was a listening period of 4 min and 40 sec; hence, we spent 10 min at each station. Observers looked and listened in all directions to reduce any bias that might arise from knowing nest locations. A commercially available recording (A Field Guide to Bird Songs of Eastern and Central North America, Houghton Mifflin Company, Boston, Massachusetts, USA) was the source for the RSHA alarm call and GHOW hoot. We broadcast recordings via a hand-held Fanon megaphone (Fanon Courier, Justin, California, USA; modified by Wildlife Callers, Bellevue, Washington, USA)

coupled to a Sony Walkman (Sony Electronics, Park Ridge, New Jersey, USA; use of these products does not imply endorsement by the state or federal government). We held the megaphone approximately 1.5 m above the ground and rotated it 120° between successive 20-sec broadcast. We adjusted the output to between 100 and 110 decibels at 1 m from the source via a Realistic sound-level meter (Tandy Corporation, Fort Worth, Texas, USA) set on slow response and C-weighting (Kimmel and Yahner 1990).

We surveyed all transects under conditions used for Breeding Bird Surveys: wind speed \leq Beaufort 3 (i.e., 12–19 km/hr) and no constant precipitation (Robbins et al. 1986). In addition, we did not survey if visibility was <1 km. We recorded temperature, wind speed, percent cloud cover, and presence of precipitation at the start of each transect and noted changes in wind speed, cloud cover, and precipitation as they occurred. We surveyed transects between 0600 and 1300, except when weather or logistical constraints necessitated surveying later in the day. We defined a response by a RSHA as vocalization after the broadcast had started, approach to the calling station, or circling overhead. Some RSHA detected after the start of the broadcast may not actually have been responding to the broadcast, but because it was not possible to distinguish these contacts from true responses to broadcasts, we considered all detections noted in the 10-min broadcast period as responses. We recorded all raptor responses with the following data: time elapsed since start of broadcast (latency); estimated distance and direction to the bird; species, age, and sex of bird; and type of response (vocal only, perch and call, flyby and call, silent perch, etc.). Age and sex of the bird were often unknown. We visually estimated distance to the responding bird if the bird could be seen, and aurally estimated distance if it could not.

The same observer surveyed all road transects in 1994. In 1995, we conducted 27% (7 of 26) of the road surveys with the primary observer plus 1 of 2 other observers. One observer (randomly selected for each station) operated the caller and the other observer stood out-of-sight of the first observer, each recording observations independently. The 2 additional observers had differing levels of experience: 1 had raptor handling experience but no survey experience, and the other had no experience with

raptors. Both had 1 morning of training that consisted of running transects with the primary observer. We conducted all 2-observer surveys prior to hatch.

We established transects at active nests to test for effects of time of day and phase of the breeding cycle on response behavior. We located nests by systematic helicopter searches, systematic ground searches, follow-ups to road-survey responses, and opportunistic sightings. We established each transect after an adult had been observed incubating, and we defined active nests as those where an adult was incubating, chicks were present in the nest, or chicks had recently fledged. Surveys completed after nest failures were not included in data analyses. Following methods described by Kennedy and Stahlecker (1993), each transect was oriented tangentially to the nest, with 8 stations spaced at 100-m intervals and the nearest station located 100 m from the nest in a direction perpendicular to the transect. We randomly determined the compass direction of each transect within restrictions imposed by the landscape. Nest surveys started at the station farthest from the nest and ended either when a response was detected or when the last station was surveyed. We surveyed each station according to the protocol described above. We divided time of day into 3 equal blocks between sunrise and sunset and randomly assigned each survey to 1 block. The first block ran from 0530–1030, the second from 1030–1530, and the third from 1530–2030. We did not survey nests within 1.6 km of a road transect station on the same day as that road transect was run.

We considered a response to come from the target nest if a bird vocalized or approached from the direction of the nest, circled over the nest area, or approached from a different direction and then called from or circled over the nest. We considered responses that did not follow 1 of these patterns to come from a bird not associated with the target nest, and we disregarded these responses. We determined type of call used on each survey as described above for road transects.

Data Analyses

We visited nests at 5–10-day intervals and estimated age of chicks at each visit. We determined hatch dates for individual nests by back-dating from the estimated age of the oldest chick in the nest as determined upon banding

or from observation of chicks, and we calculated the start of incubation as 28 days prior to the hatch date (Burns 1915). Age estimates were based on feather growth (J. W. Stravers, Midwest Raptor Foundation, personal communication). We determined fledge dates by direct observation, and we defined fledge date as the day halfway between the date on which we observed all chicks in the nest and the date we observed fledged chicks. We assumed chicks that reached 28 days of age and were not subsequently observed had fledged, and we calculated the fledge date for those nests as the day halfway between the date on which chicks ≥ 28 days old were observed in the nest and the date on which no chicks were observed. We estimated dates to be accurate to within 4 days. We used averages of the hatch and fledge dates for all nests in a study area to delineate phases of the breeding cycle for analysis of road transect data from that study area. In the CNF, where no nests were successful in 1994, we used the average hatch and fledge dates of the 1995 nests for both years. The time span between earliest and latest hatch dates of individual nests within a study site was 1 week in 1994 and 2 weeks in 1995.

We combined road transect data from both study sites and both years. Because of variation in behavior of individual birds, we included location as a blocking variable in all analyses of road transect data. We treated data from the same station in different years as if from different locations. We excluded stations at which no RSHA response was detected within a given year from the analyses of response probability for that year. We analyzed effects of call type and phase of the breeding cycle on response rate via nominal logistic regression likelihood-ratio tests (Fienberg 1980), and we analyzed effects on latency with 1-way analysis of variance (ANOVA; Montgomery 1991). We considered a response by >1 RSHA during a given 10-min broadcast as a single detection, and we defined latency as the time elapsed between start of the broadcast and earliest detection of a response.

We combined nest transect data from both years and sites and analyzed them for effects of type of call, phase of the breeding cycle, and time of day. We conducted multiple surveys at 15 nests and used nest site as a blocking variable in nominal linear regression likelihood-ratio tests for effects of type of call, phase, and time of day on response probability and in 1-

way ANOVA tests of effects of phase and time of day on latency and distance of response. Because of small sample sizes, our analyses of effects of call type on latency included data from nests where only a single survey was conducted. To test the effect of call type (RSHA vs. GHOW) on latency, we calculated the average response time for each call type at each nest. For each nest where we conducted trials with both calls, we calculated the difference in latency between call types and took the average (d_r) of these differences. For nests where only 1 call type was used, we averaged the latency values for RSHA and GHOW calls for all the nests and calculated the difference (d_s) of the averages. We then combined the 2 values, d_r and d_s , into a single measure,

$$d_c = (d_r + d_s)/2,$$

and used a 2-tailed *t*-test to test the hypothesis $d_c = 0$. We determined degrees of freedom as for a Welch ANOVA for unequal variances (SAS Institute 1994). In analyses for time of day effects, we assigned nest surveys that started in 1 time period and finished in the next to the time block in which the majority of stations were surveyed. All statistical analyses used JMP software (SAS Institute 1994).

Analyses of PD-AO used software developed by Geissler and Fuller (1987). The PD for an individual survey station is the proportion of surveys following the initial detection that resulted in a subsequent detection. Stations at which ≥ 1 response was detected are considered occupied. The PD for a transect is the arithmetic mean of the PDs from each station and estimates the probability of detecting a RSHA at any occupied stop with 1 visit. The probability of detecting a RSHA at an occupied stop in a given number of visits (m) is calculated as described by Geissler and Fuller (1987):

$$PD_m = 1 - (1 - PD)_m.$$

The proportion of area occupied by RSHA is calculated as

$$AO = (\text{no. of occupied stations}/PD_m)/\text{no. of stations}.$$

Dividing by PD_m adjusts the number of occupied stations upward to account for birds that are present but not detected, and AO is an estimate of the proportion of stations at which RSHA occur, regardless of whether they are detected.

We bootstrapped the data to provide variance estimates for PD and AO by taking 501 samples of n points with replacement from the actual sample of n points (Geissler and Fuller 1987). We calculated PD and AO estimates from each of the bootstrap samples. We then used these distributions to calculate a mean and median bootstrap estimate and to calculate a 95% confidence interval around the median bootstrap estimate. The bootstrap estimates do not rely on the assumption that PD does not vary among points, and Geissler and Fuller (1987) recommended using the median bootstrap estimate because it is the least biased; hence, median bootstrap estimates are reported here. We calculated PD and proportion of AO separately for RSHA and GHOW calls and considered stations to be occupied only if a RSHA had responded to that call type. Because of inadequate sample sizes, we did not analyze surveys that used GHOW calls in 1995.

We used the modeling program MONITOR (Gibbs and Melvin 1997), which uses Monte Carlo procedures to simulate count data, to test the statistical power of broadcast surveys to detect trends in AO values. The user enters the initial AO values and their standard deviations and sets the number of survey occasions, interval between surveys, type of trend (exponential or linear), alpha level, and whether a 1- or 2-tailed test is desired. All models reported here used 500 replications in the simulations, assumed no variation in the trend among routes or years, and used exponential trends, $\alpha = 0.10$, and 2-tailed tests. Initial models used the AO values and variances from the 1995 RSHA surveys. We then varied the variance, interval between surveys, and number of routes to determine effect on power. We determined AO values for additional routes by choosing values randomly from a normal distribution having the mean and standard error of the observed AO values. The variance associated with each value was similarly chosen from a normal distribution having the mean and standard error of the observed variances.

RESULTS

Road Transects

In 1994, we conducted 33 surveys on 4 road transects from 27 April to 5 July. In 1995, we conducted 26 surveys on the same transects between 9 April and 12 June. The majority ($n =$

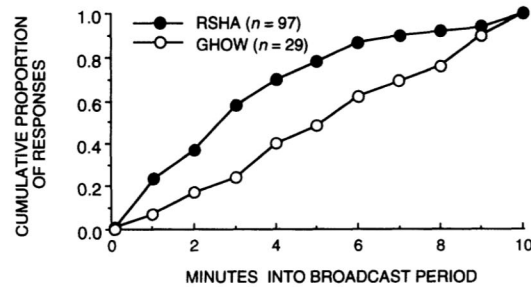


Fig. 1. Cumulative proportion of red-shouldered hawk (RSHA) responses detected within each minute of the 10-min broadcast period for RSHA and great-horned owl (GHOW) calls on road transect broadcast surveys, Chippewa National Forest and Camp Ripley, 1994 and 1995. Response time was defined as the time elapsed between the start of the broadcast and detection of the first RSHA response. Sample size indicates number of broadcasts that elicited a response.

49) of surveys took place during incubation ($n = 25$) or nestling phases ($n = 24$), and all but 9 (15%) occurred between 0600 and 1300.

Type of Call.—At stations where RSHA responded to taped vocalizations, RSHA responded to 97 (35.0%) of 277 RSHA broadcasts and 29 (20.0%) of 145 GHOW broadcasts ($\chi^2_1 = 13.80$, $P < 0.001$). The mean difference in latency at stations where birds responded to both types of calls was 122 sec, with birds responding faster to RSHA than GHOW calls ($t_{14} = 2.61$, $P = 0.020$). Nearly 90% of responses to RSHA calls came within the first 6 min of the broadcast period, whereas responses to GHOW calls were evenly distributed over the 10-min period (Fig. 1). Forty-six (48%) of the 97 responses to RSHA calls were vocal only, 45 (46%) were both vocal and visual, and 6 (6%) were visual only. For GHOW broadcasts, 20 (69%) of the 29 responses were vocal, 7 (24%) were both vocal and visual, and 2 (7%) were visual only. The distribution of response types did not vary by call type ($\chi^2_2 = 4.64$, $P = 0.098$). Sixty-six (68%) of the responses to RSHA calls involved a single bird, 19 (20%) involved 2 birds, 9 (9%) involved 3 birds, and 3 (3%) involved 4 birds. For GHOW calls, a single bird was detected in 19 (66%) of the responses, 2 birds were detected on 9 (31%) occasions, and 4 birds were detected on a single occasion (3%). These distributions did not differ by call type ($\chi^2_3 = 4.13$, $P = 0.248$).

Phase of Breeding Cycle.—Response rates to GHOW calls did not vary through the breeding season ($\chi^2_2 = 2.88$, $P = 0.237$), but response rates to RSHA calls dropped as the season progressed ($\chi^2_3 = 18.11$, $P < 0.001$; Fig. 2). Re-

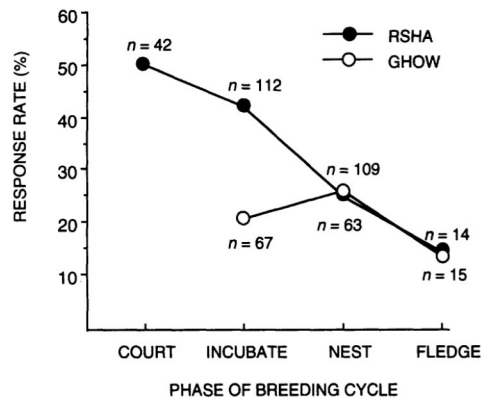


Fig. 2. Percentage of broadcast surveys using red-shouldered hawk (RSHA) and great-horned owl (GHOW) calls at occupied road transect stations for which a RSHA response was detected during courtship (COURT), incubation (INCUBATE), nestling (NEST), and fledgling (FLEDGE) phases of the breeding cycle, Chippewa National Forest and Camp Ripley, 1994 and 1995. Sample size is the number of broadcasts for each phase. Numbers above the figure refer to RSHA broadcasts, and those below the figure refer to GHOW broadcasts.

sponse rates to RSHA calls did not vary within pre-hatch ($\chi^2_1 = 2.42$, $P = 0.120$) or post-hatch ($\chi^2_1 = 0.54$, $P = 0.463$) periods, and RSHA calls were more effective than GHOW calls during pre-hatch ($\chi^2_1 = 23.70$, $P < 0.001$) but not post-hatch ($\chi^2_1 = 0.97$, $P = 0.325$). Latency did not

vary with phase for either RSHA calls ($F_{3,24} = 1.23$, $P = 0.321$) or GHOW calls ($F_{2,5} = 0.87$, $P = 0.472$).

Different Observers.—Of the 69 stations surveyed with 2 observers, a RSHA response was detected by both observers at 15 stations. At 51 stations, neither observer recorded a response, and at 3 of the 18 stations where a RSHA was detected, the primary observer recorded a RSHA response while the other observer (not the same individual in each case) recorded no response. All 3 discordant observations occurred when the response was vocal only, at an estimated distance of >400 m.

Probability of Detection and Area Occupied.—Bootstrap medians for PD of RSHA calls in 1994 varied from 0.17 to 0.33 and averaged 0.27; for GHOW calls, values ranged from 0.00 to 0.50 and averaged 0.28. In 1995, PDs for RSHA calls ranged from 0.13 to 0.41 and averaged 0.23. In 1995, PD estimates did not vary among routes ($F_{3,24} = 2.61$, $P = 0.075$). Bootstrap estimates of proportion of AO in 1994 ranged from 0.76 to 1.12 and averaged 0.92 for RSHA calls; for GHOW calls, AO values ranged from 0.47 to 0.68 and averaged 0.59. For RSHA calls in 1995, AO estimates ranged from 0.54 to 1.68 and averaged 1.11 (Table 1).

Table 1. Bootstrap medians and 95% confidence intervals for probability of detection (PD) and proportion of area occupied (AO) for red-shouldered hawks (RSHA) on road surveys conducted using red-shouldered hawk (RSHA) and great-horned owl (GHOW) calls, Chippewa National Forest (Routes 3 and 4) and Camp Ripley (Routes 1 and 2), 1994 and 1995. The PDs for each call type were calculated with observations after the initial detection of a RSHA at each station (Geissler and Fuller 1987) using that call type. Some confidence intervals do not include the estimated value because confidence intervals were truncated to include only values between 0 and 1.

Call and year	<i>m</i> ^a	<i>n</i> ^b	PD	95% CI	AO	95% CI
RSHA 1994						
Route 1	4	8	0.29	0.08–0.51	1.12	0.13–1.00
Route 2	4	7	0.29	0.18–0.40	0.95	0.37–1.00
Route 3	5	5	0.17	0.00–0.39	0.84	0.00–1.00
Route 4	4	6	0.33	0.00–0.78	0.76	0.00–1.00
Average			0.27		0.92	
RSHA 1995						
Route 1	5	7	0.25	0.04–0.46	0.92	0.00–1.00
Route 2	5	7	0.14	0.00–0.30	1.30	0.00–1.00
Route 3	6	9	0.13	0.02–0.23	1.68	0.00–1.00
Route 4	6	5	0.41	0.08–0.74	0.54	0.01–1.00
Average			0.23		1.11	
GHOW 1994						
Route 1	5	4	0.31	0.00–0.65	0.52	0.00–1.00
Route 2	3	2	0.00		NA ^c	
Route 3	4	4	0.50	0.00–1.00	0.47	0.00–1.00
Route 4	4	5	0.31	0.10–0.52	0.68	0.00–1.00
Average			0.28		0.56	

^a *m* = number of times each transect was surveyed.

^b *n* = number of stations at which a RSHA was detected.

^c Cannot be calculated because probability of detection was zero.

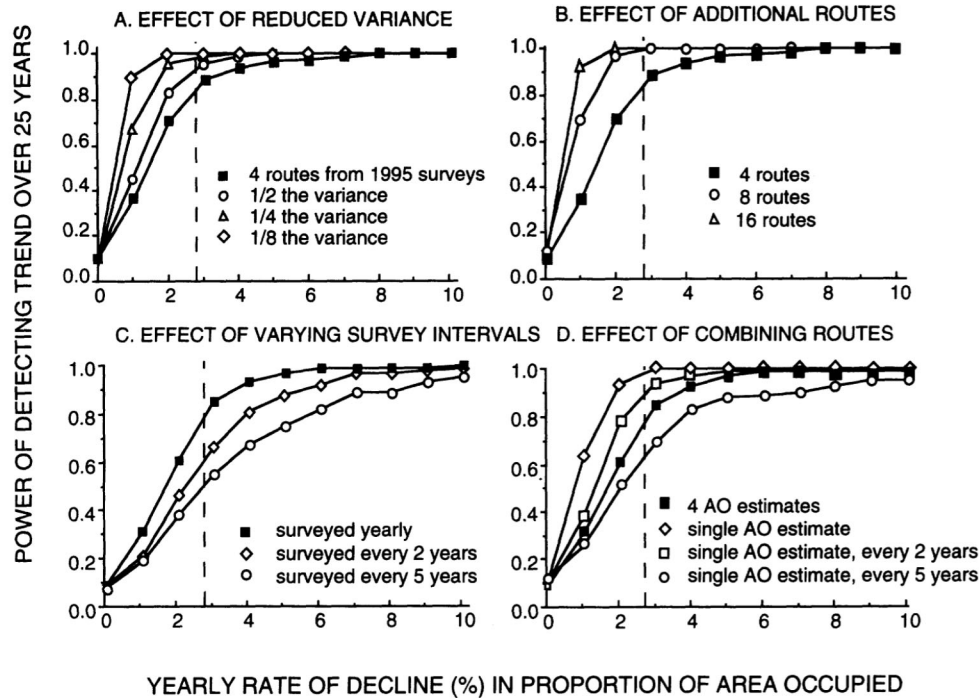


Fig. 3. Power of detecting negative trends in proportion of area occupied (AO), modeled using the program MONITOR. All models used 500 replicates, ran the simulation for 25 years, assumed no variation in trends among routes or years, and used $\alpha = 0.10$, 2-tailed tests, and exponential trends. In all graphs, solid squares indicate the power curve for the actual 1995 field data, and the vertical dashed line indicates the yearly exponential decline that results in a 50% reduction in AO over 25 years.

Trend Detection.—Models using the AO values and variances obtained in the 1995 surveys could detect a 2.7% yearly negative trend over 25 years, with a power of 0.8 (Fig. 3A). If variance of the original AO estimates was decreased, power went up (Fig. 3A). Power increased with increasing number of survey routes (Fig. 3B) and decreased with increasing intervals between surveys (Figs. 3C,D). Power increased when routes were combined to calculate a single AO estimate (Fig. 3D).

Nest Transects

Type of Call.—We conducted 76 surveys at 23 active nests (61 surveys at 14 nests in 1994 and 15 surveys at 12 nests in 1995—surveys were conducted at 3 nests in both years) during incubation ($n = 14$), nestling ($n = 43$), and fledgling ($n = 19$) periods. We detected responses for 62.2% (28 of 45) of trials using RSHA calls and 67.7% (21 of 31) of trials using GHOW calls ($\chi^2_1 = 1.05$, $P = 0.305$). All responses were from adult birds; none were from fledglings. We detected responses to RSHA calls an average of 133 sec sooner after the start

of the broadcast than responses to GHOW calls ($t_7 = 4.30$, $P = 0.004$), and the distribution of response times over the broadcast period was similar to that for road transects. Response distances to RSHA and GHOW calls were similar ($t_{10} = 0.88$, $P = 0.401$), with over half the responses detected >400 m from the nest. Of the surveys where no response was considered to have come from the target nest, RSHA deemed not to have come from the target nest were detected on 3 surveys using RSHA calls and on 4 surveys using GHOW calls.

Phase of Breeding Cycle.—Response rates decreased after fledging for RSHA calls ($\chi^2_2 = 12.92$, $P = 0.002$) and GHOW calls ($\chi^2_2 = 5.18$, $P = 0.075$; Fig. 4). Responses to RSHA and GHOW calls did not vary through the breeding season in distance of response (RSHA: $F_{2,5} = 1.10$, $P = 0.402$; GHOW: $F_{2,1} = 0.54$, $P = 0.859$) or latency (RSHA: $F_{2,5} = 1.36$, $P = 0.338$; GHOW: $F_{2,1} = 2.03$, $P = 0.445$).

Time of Day.—Response rates were lowest during the middle of the day to both RSHA ($\chi^2_2 = 9.36$, $P = 0.009$) and GHOW calls ($\chi^2_2 = 5.18$, $P = 0.075$; Fig. 5). Latency (Fig. 6) did

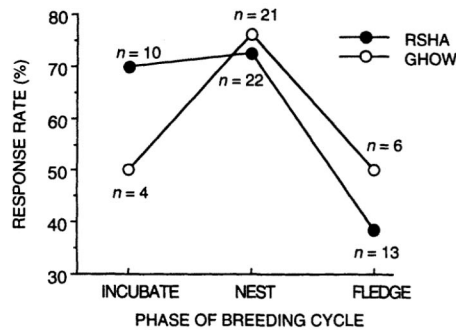


Fig. 4. Percentage of broadcast surveys using red-shouldered hawk (RSHA) and great-horned owl (GHOW) calls at active RSHA nests for which a RSHA was detected during incubation (INCUBATE), nestling (NEST), and fledgling (FLEDGE) periods, Chippewa National Forest and Camp Ripley, 1994 and 1995. Sample size indicates the number of trials.

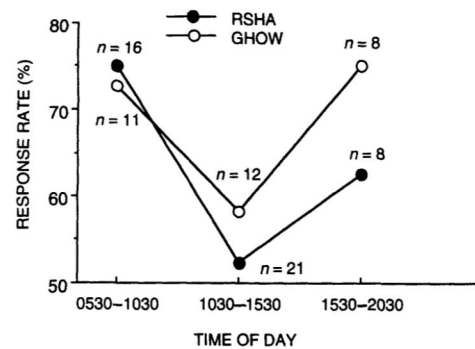


Fig. 5. Percentage of broadcast surveys using red-shouldered hawk (RSHA) and great-horned owl (GHOW) calls at active RSHA nests for which a response was detected during each of 3 time blocks, Chippewa National Forest and Camp Ripley, 1994 and 1995. Time blocks were designated by dividing hours between sunrise and sunset into 3 equal periods. Sample size is number of trials.

not vary for RSHA calls ($F_{2,6} = 0.59$, $P = 0.582$), but latency for GHOW calls tended to be longer during the third period than the first ($F_{2,5} = 3.20$, $P = 0.127$; Fig. 6). Distance of responses did not vary by time of day for RSHA calls ($F_{2,6} = 0.63$, $P = 0.570$) or GHOW calls ($F_{2,4} = 1.38$, $P = 0.350$).

DISCUSSION

Response rates on road transects in this study were higher for RSHA calls prior to hatch than for conspecific calls posthatch or for GHOW calls at any phase of the breeding cycle, and RSHA were less likely to respond to either conspecific calls or GHOW calls during the second daily time period. The most effective method for detecting RSHA, based on our results, is broadcasting conspecific calls early in the breeding season and early in the day. Other authors (e.g., Devaul 1989) have suggested surveying for diurnal raptors during morning hours. In our study, RSHA were usually below the canopy early in the morning, and responses obtained at this time, rather than later in the day when birds were often soaring on thermals, were useful in locating nests. Johnson (1989) found response rates to conspecific calls were highest early in the season and also reported limited success with preliminary testing of GHOW calls prior to hatch (G. Johnson, SUNY College of Environmental Science and Forestry, personal communication). In contrast, Mosher and Fuller (1996) reported GHOW calls were just as effective as conspecific calls when surveying for RSHA.

Other raptor species also respond to GHOW

calls. Mosher and Fuller (1996) reported GHOW calls to be as effective as conspecific calls in eliciting responses from Cooper's hawks, but Kimmel and Yahner (1990) reported GHOW calls to be less effective than conspecific calls for detecting northern goshawks. In this study, GHOW calls were more effective than RSHA calls in eliciting responses from broad-winged hawks ($\chi^2_1 = 13.00$, $P < 0.001$) and Cooper's hawks ($\chi^2_1 = 4.10$, $P = 0.043$; M. A. McLeod, unpublished data). Balding and Dibble (1984) found that, with the exception of red-tailed hawks responding to RSHA calls, broad-winged hawks, red-tailed hawks, and RSHA responded poorly to heterospecific calls. The type of call a researcher chooses to use may

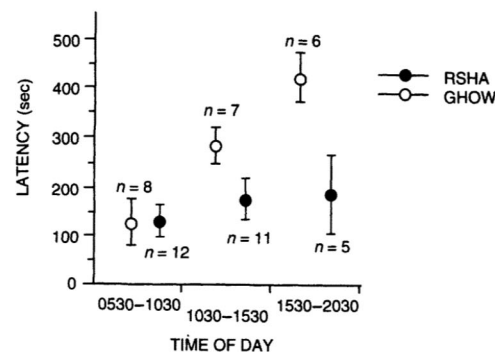


Fig. 6. Time elapsed (latency) between start of the broadcast and first detection of a response for broadcast surveys using red-shouldered hawk (RSHA) and great-horned owl (GHOW) calls at active RSHA nests, Chippewa National Forest and Camp Ripley, 1994 and 1995. Time blocks were designated by dividing hours between sunrise and sunset into 3 equal periods. Sample size is number of surveys at which a response was detected.

depend on the purpose of the survey. If a single species is targeted, a conspecific call may be the best choice because a number of species respond as well or better to conspecific calls than GHOW calls. If multiple species are targeted, however, a GHOW call may be the best choice because many raptor species respond to GHOW calls but not to calls of other diurnal raptors.

Although conspecific calls were more effective than GHOW calls during the pre-hatch period on road transects, we found no difference in effectiveness during nest surveys. Failure to detect a difference may be the result of small sample size. We detected no responses on 2 of 4 transects run during incubation with GHOW calls and 7 of 10 RSHA trials, but these response rates were not different ($\chi^2_1 = 0.50$, $P = 0.481$). Differences in protocol between the 2 types of surveys also may result in differences in response behavior. Nest transects did not test response behavior at distances >700 m, and RSHA may respond more readily to distant RSHA calls than to distant GHOW calls, resulting in higher response rates to RSHA calls on road surveys where transects are of unlimited width.

We detected only 13% of the responses to RSHA calls at road transect stations in the last 40% of the time spent at each station. Johnson (1989), who used a shorter call sequence and a 4-min listening period, also found response rates to RSHA calls were highest at the beginning of the broadcast sequence, with 90% of the responses detected in the first 3 min. In contrast, the distribution of response times to GHOW calls on road transects in this study was quite different, with responses distributed evenly through the 10-min survey period. We obtained similar results on nest transects, although responses to both calls tended to come earlier in the broadcast period. If RSHA calls are used, survey protocol could be made more efficient by eliminating the final 4 min of the 10-min broadcast period, and this time could be used surveying additional areas. If GHOW calls are used, however, truncating the final listening period would likely result in detecting significantly fewer responses. Extending the survey period when GHOW calls are used might result in more detections but would also reduce the number of stations that could be surveyed in a given amount of time.

Johnson et al. (1981) suggested that habitu-

ation to repeated calls may result in lower response rates. Joy et al. (1994) found evidence that response behavior to conspecific calls in northern goshawks varies depending on phase of the breeding cycle, and that such variation is not a result of habituation. In this study, responses to RSHA calls declined as the breeding season progressed for nest and road transects, but effects of phase cannot be separated from habituation. Mosher et al. (1990) found no difference among RSHA response rates to RSHA calls over the course of the breeding season and suggested this lack of difference indicated birds did not become habituated to the call. They reported lack of synchrony among breeding pairs, which may have obscured any phase effects. Johnson (1989) reported steady response rates to RSHA calls from incubation through fledging, which also suggests a lack of habituation. We noted no change in response rates to GHOW calls on either road or nest transects, indicating no phase effect and no evidence of habituation. Similarly, Devaul (1990) found no evidence of habituation to GHOW calls, and in Indiana, spacing surveys at intervals of >2 days prevented individuals from becoming habituated (A. R. Parker. 1990. Survey of woodland nesting raptors on the Hoosier National Forest, 1990, unpublished. U.S. Fish and Wildlife Service, Fort Snelling, Minnesota, USA, and Indiana Department of Natural Resources, Indianapolis, Indiana, USA).

There are a number of reasons RSHA might become less responsive as the breeding season progresses. Johnson (1989) suggested that high rates of RSHA activity early in the season might be the result of boundary disputes between pairs or disputes with floaters in new territories. Red-shouldered hawks are very vocal during courtship (Portnoy and Dodge 1979), when pairs are bonding and establishing territories. At this time, loss of a territory or mate could mean foregoing breeding for that season. Unpaired birds, with much to gain from taking over a territory, are likely to be aggressive. Therefore, paired birds during this phase in the breeding cycle should respond aggressively toward strangers. McCrary et al. (1992) reported 2 instances during courtship of male floaters trying to replace males being held for banding.

Another factor potentially influencing detection rate may be transmission of sound through hardwood forests, which may be reduced dramatically by the emergence of leaves. In north-

ern Minnesota, hatch dates for RSHA chicks coincide with leaf-out, and a change in acoustics could contribute to the reduction in response rates after hatch for RSHA calls on road transects. After leaf-out, RSHA may be less likely to hear a broadcast, and observers may be less able to detect responses. Response rates to GHOW calls did not decline after leaf-out, which may occur because the higher frequency sounds of RSHA calls are more easily attenuated and degraded by small obstructions such as leaves and branches than are lower frequency GHOW calls.

Kennedy and Stahlecker (1993) emphasized the need for experienced observers in northern goshawk surveys because jay (*Corvidae*) mimics or Cooper's hawks could be confused with northern goshawk responses. Red-shouldered hawk vocalizations cannot be confused with those of any other raptor, and the only 2 mimics in northern Minnesota are the yellow-bellied sapsucker (*Sphyrapicus varius*) and the blue jay (*Cyanocitta cristata*). With minimal observer experience, sapsuckers are easily distinguished from RSHA. More experience is needed to distinguish blue jay calls from RSHA calls, but jays often switch to other calls in their repertoire and do not imitate RSHA for long periods (Johnson 1989). Most (93%) responses in this study contained a vocal component, and Johnson (1989) reported that 94% of responses included vocalization, so the ability to identify RSHA by sight is not as critical as recognizing vocalizations. There did not appear to be a problem with inexperienced observers confusing mimics with RSHA vocalizations in this study, as there were no instances of 1 observer recording a RSHA and the other detecting a mimic. Although we did not record mimics, they were quite common, particularly early in the season (M. A. McLeod, personal observation).

Acuteness of hearing also may be important because RSHA respond readily from great distances, and vocalizations are often faint. All 3 instances in which 1 observer recorded a RSHA and the other did not occurred when the response was aural only, and at an estimated distance of >400 m. Ramsey and Scott (1981) found differences as large as an order of magnitude in the area surveyed by observers with different hearing capacities. Although in this study there was no obvious advantage in having multiple observers, multiple observers might

prove useful if the target species does not vocalize readily, and if surveys are being conducted after leaf-out or in habitats where visibility is restricted.

Our PD values correspond closely with those obtained by other researchers. Johnson (1989) obtained PD values to RSHA calls ranging from 0.13 to 0.41 and averaging 0.20, and Geissler and Fuller (1987) reported PDs to conspecific calls of 0.20 and 0.23. Studies where GHOW calls were used had PD estimates of 0.13 (Devaul 1990), 0.30–0.45 (A. R. Parker. 1990. Survey of woodland nesting raptors on the Hoosier National Forest, 1990, unpublished. U.S. Fish and Wildlife Service, Fort Snelling, Minnesota, USA, and Indiana Department of Natural Resources, Indianapolis, Indiana, USA), 0.12–0.33 (P. L. Malmberg and G. C. Vanderah. 1991. Illinois woodland raptor survey, unpublished. Illinois Department of Conservation, Springfield, Illinois, USA), and 0.11–0.45 (Iverson and Fuller 1991). Our PDs did not appear to differ between RSHA and GHOW calls, as average PDs for identical routes in the same year were 0.27 for RSHA and 0.28 for GHOW calls. Analysis of the data with nominal logistic regression, however, showed differences in the effectiveness of RSHA and GHOW calls. These differences appear when AO is calculated. For each road transect, AO calculated from responses to GHOW calls is lower than that calculated from responses to RSHA calls. Birds that respond to GHOW calls apparently do so with approximately the same frequency as they respond to RSHA calls, but other birds respond to RSHA calls but not GHOW calls. Red-shouldered hawks responded to RSHA calls but not to GHOW calls at 14 stations; RSHA responded to GHOW calls but not RSHA calls at 3 stations.

We used the 1995 survey data for statistical power modeling because PD–AO calculations assume PD is constant throughout the survey period, and the majority of the 1995 surveys were completed before hatch. If repeated broadcast surveys are to be used as a population monitoring tool, estimates of AO must be precise. Precise estimates are obtained if AO is high (Devaul 1989). Based on our results, when RSHA calls that result in a higher estimate of AO are used for repeated road surveys, smaller changes in AO could be detected than with the use of GHOW calls. The precision of AO estimates also is influenced by the number of rep-

etitions at each station and the number of stations surveyed. Devaul (1990) reported that doubling the number of repetitions from 5 to 10 on a 50-station survey reduced variance by half. Using this same increase in effort to survey twice as many routes, however, increases power more than does halving the variance (compare Figs. 3A,B). Conducting 10 surveys before hatch would not be possible if surveys are conducted at weekly intervals, and surveying additional areas has obvious advantages if locating nests or territories is important. However, if habituation is not a problem and surveying additional areas not a priority, surveys could be run at 3- or 4-day intervals to obtain ≥ 10 repetitions prior to hatch.

Combining routes to calculate a single AO value also reduces variance and increases power. Combining routes can be done as long as PD does not vary among routes (Iverson and Fuller 1991). In our study, combining our 4 routes resulted in an increase in power comparable to doubling the number of survey routes. If routes can be combined, surveys conducted every other year yield greater power than separate transects surveyed every year. If routes cannot be combined, surveying at intervals > 1 year greatly reduces power.

How changes in the actual population are reflected in changes in AO is unclear. Mosher and Fuller (1996) reported a significant linear relation between detection rates (the average number of detections per run with GHOW calls) and the density of summer-resident pairs, and Johnson (1989) found that AO and nesting density were highly correlated in New York. Both these studies used the road transect configuration described in this paper, and density estimates were calculated for the area extending 1.6 km to each side of the transect and a radius of 1.6 km beyond each terminal station. Estimates of AO in Johnson's study ranged from 40 to 103%, and nest densities ranged from 0.089 to 0.148 nests/km². Pair densities in Mosher and Fuller's study ranged from 0.03 to 0.13 nests/km². However, nesting densities in northcentral Minnesota can be much higher than these values. Density in portions of Camp Ripley was approximately 1 nest/km² (B. A. Belleman, University of Minnesota, unpublished data). Nest densities of 0.148 nests/km² and the much higher densities in northcentral Minnesota both resulted in AO estimates around 100%, suggesting that reductions in population and breeding den-

sity could occur with no effect on AO. This lack of relation between breeding density and AO at high breeding densities may be the result of the survey methods that did not differentiate between responses from multiple birds or from a single bird at a given station. Therefore, population declines might not be reflected in AO estimates until some stations are unoccupied instead of being occupied by fewer birds. In areas of high density, it may be necessary to develop a way of incorporating multiple responses into a density index.

Further work is needed to obtain a more complete understanding of the relation between AO and population levels. Additional studies where AO is compared with an independently obtained density estimate in areas of low, moderate, and high nesting densities would provide more insight into the relation between AO and population levels. This type of study could also be done over time at a given site, perhaps where logging or other habitat disturbance is expected to alter breeding density.

MANAGEMENT IMPLICATIONS

From our broadcast survey results, we make the following recommendations for detecting RSHA: (1) use conspecific calls if RSHA are the only target species, (2) survey prior to hatch, (3) limit the final listening period to 1 min if conspecific calls are used, (4) conduct surveys in the morning, and (5) use observers with acute hearing and who are able to recognize RSHA vocalizations.

Statistical power analyses that made simplifying assumptions about the consistency of trends among years indicated long-term negative trends in AO, on the scale of 1–2%/year, may be detectable by surveying as few as 40 stations/year. These analyses suggest broadcast surveys, in conjunction with analysis of PD–AO, may provide an effective tool for monitoring some RSHA populations. Areas where this technique is applicable, however, may be limited. In regions where nesting pairs are widely scattered and estimates of AO are low, broadcast surveys would be useful in locating nests and territories, but AO estimates would be too imprecise to provide an effective means of monitoring populations. In regions where nesting densities are very high, AO estimates would be sufficiently precise, but, in part because there is no accounting for responses from multiple birds, reductions in the population may not be imme-

diately reflected in AO estimates. In areas of high or low density, where PD-AO techniques cannot adequately monitor populations, other monitoring techniques such as migration counts or labor-intensive foot or aerial searches would have to be used to try to detect population trends. Even in areas of moderate nesting density, establishing the relation between AO and population density is necessary before the usefulness of AO-PD techniques in tracking population levels can be fully evaluated.

ACKNOWLEDGMENTS

The U.S. Forest Service, Chippewa National Forest, provided funding and logistical support for this project. Forest Biologist J. E. Mathisen was instrumental in securing funding and providing initial guidance. District Biologists J. E. Casson, J. D. Kelly, K. A. Cable, J. B. Cable, and J. A. Gallagher contributed their knowledge of the forest and undying enthusiasm. Funding was also provided through a University of Minnesota Graduate School Fellowship. Camp Ripley Army National Guard Training Site, the Department of Fisheries and Wildlife, and the Minnesota Cooperative Fish and Wildlife Research Unit contributed additional logistical and financial support. B. A. Belleman, J. M. Yackel, S. M. Flynn, D. M. Stemper, and R. M. McLeod put in long hours in the field, locating nests and assisting with surveys. Additional nest locations were reported by J. L. Alden, T. E. Dick, and G. J. Dodge. Invaluable statistical advice was provided by G. W. Oehlert, and M. R. Fuller reviewed an earlier draft of the manuscript.

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Received 5 March 1997.

Accepted 6 April 1998.

Associate Editor: Lutz.