



2008

## SANDHILL CRANE NEST HABITAT SELECTION AND FACTORS AFFECTING NEST SUCCESS IN NORTHWESTERN MINNESOTA

Stephen J. Maxson  
John R. Fieberg  
Michael R. Riggs

---

Maxson, S. J., J. R. Fieberg, and M. R. Riggs. 2008. Sandhill crane nest habitat selection and factors affecting nest success in northwestern Minnesota. Proceedings of the North American Crane Workshop 10:90-97.

---

*The **North American Crane Working Group** provides free and open access to articles in Proceedings of the North American Crane Workshop. No additional permission is required for unrestricted use, distribution, or reproduction in any medium, provided that the original work here is properly cited. Visit <http://www.nacwg.org> to download [individual articles](#) or to download or purchase [complete Proceedings](#).*

© 2008 North American Crane Working Group

# SANDHILL CRANE NEST HABITAT SELECTION AND FACTORS AFFECTING NEST SUCCESS IN NORTHWESTERN MINNESOTA

STEPHEN J. MAXSON<sup>1</sup>, Wetland Wildlife Populations and Research Group, Minnesota Department of Natural Resources, 102 23<sup>rd</sup> Street NE, Bemidji, MN 56601, USA

JOHN R. FIEBERG, Biometrics Unit, Minnesota Department of Natural Resources, 5463-C W. Broadway, Forest Lake, MN 55025, USA

MICHAEL R. RIGGS<sup>2</sup>, Biometrics Unit, Minnesota Department of Natural Resources, 5463-C W. Broadway, Forest Lake, MN 55025, USA

**Abstract:** We studied 62 greater sandhill crane (*Grus canadensis tabida*) nests in northwestern Minnesota during 1989-1991 to document nest habitat use and selection, nest success, and factors associated with nest success. We recorded 15 habitat variables at each nest and at a randomly selected site in the same wetland. Nests were in basins 0.01-601 ha (Median = 2.2 ha) and at water depths 0-35.7 cm (Median = 9.7 cm). Cattail (*Typha sp.*) was the dominant vegetation at 58.0% of nests while 21.0% were at sites dominated by phragmites (*Phragmites australis*). Conditional logistic regression models indicated that locations with lower concealment indices, lower log sedge (*Carex sp.*) stem counts, and higher log phragmites stem counts were more likely to be associated with nest sites. Estimated nest success was 56% (Apparent), 40% (Mayfield), and 47% (logistic-exposure model). Most nest failures appeared due to mammalian predation. Nest depredation appeared to increase as nest initiation dates became later, but after accounting for differences in exposure times, this difference was no longer evident. Year had the strongest effect on nest success with the lowest success recorded in 1990, a dry spring. Logistic exposure models suggested that nest success tended to increase with increasing water depth at the nest site or as concealment indices decreased.

## PROCEEDINGS OF THE NORTH AMERICAN CRANE WORKSHOP 10:90-97

**Key words:** *Grus canadensis*, habitat selection, Minnesota, nest success, sandhill crane.

Maintenance of essential habitats is critical for crane populations throughout North America (Tacha et al. 1992). Because humans frequently alter shallow marshes and bogs, which are important sandhill crane (*Grus canadensis*) nesting habitats, land managers and planners need to better understand sandhill crane nest habitat preferences and whether habitat changes influence nest success. In the Great Lakes region, nesting greater sandhill cranes (*G. c. tabida*) have been studied in Ontario (Tebbel 1981), Michigan (Walkinshaw 1973, Urbanek and Bookhout 1992), Wisconsin (Howard 1977, Bennett 1978), and Minnesota (DiMatteo 1991, Provost et al. 1992). Herr and Queen (1993) and Baker et al. (1995) studied greater sandhill crane nesting habitat at larger spatial scales. However, only Tebbel (1981), Provost et al. (1992), and Baker et al. (1995) attempted to determine nest habitat preferences by comparing nests with randomly selected sites and only Urbanek and Bookhout (1992) assessed whether nest habitat characteristics influenced nest success.

Our objectives were to determine: 1) habitat use and selection by nesting greater sandhill cranes, 2) nest success and causes of nest failure, and 3) factors associated with nest success.

## STUDY AREA

This study was conducted during April-July, 1989-1991

1 Present address: 4235 Carver Road NE, Bemidji, MN 56601, USA.

2 Present address: Department of Biostatistics, Rho. Inc., 6330 Quadrangle Drive, Suite 500, Chapel Hill, NC 27517, USA.

in portions of Kittson, Marshall, and Roseau Counties of northwestern Minnesota. All sites were within the aspen parkland landscape region of Minnesota (Kratz and Jensen 1983) characterized by flat topography with a mosaic of agricultural land (primarily small grain or Conservation Reserve Program fields), brushlands dominated by willow (*Salix sp.*), forests dominated by trembling aspen (*Populus tremuloides*), and shallow wetlands. Portions of the study area are described in further detail in Herr and Queen (1993).

## METHODS

We located sandhill crane nests by low-level (10-30 m) helicopter searches over shallow wetlands. Three searches were conducted in May of 1989 and 1990, but the 1991 search effort was cut short due to loss of the helicopter. Incubating cranes typically flushed a short distance ahead of the helicopter and were readily seen. We marked nest sites by dropping weighted strips of plastic flagging from the helicopter and by plotting locations on aerial photos. Three additional nests were reported to us by Minnesota Department of Natural Resources personnel. We later relocated nests from the ground and marked them with plastic flagging 5 m from the nest. At the initial ground visit, we floated eggs to determine their incubation stage (Fisher and Swengel 1991). We revisited nests shortly after the expected hatch date to determine their fate (Urbanek and Bookhout 1992). We estimated nest success using the Mayfield method (Klett et al. 1986) and also using a logistic-exposure model without any covariates (Shaffer 2004). The latter approach provided maximum likelihood estimates under the assumption of

constant daily survival (and no nest heterogeneity).

### Habitat Measurements

After nest fate was determined, we recorded 15 measurements of habitat structure at each nest. We ignored any current-year plant growth during these measurements because it was not present when nests were constructed and would not have been a factor in site selection. We used a 25 x 99 cm density board divided into 3 equal height increments (33 cm) to measure nest concealment (Provost et al. 1992). Each height increment was subdivided into 25 6.6 x 5.0 cm rectangles. We placed the density board on the nest, orientated it to the cardinal directions, and counted all rectangles more than 50% visible at a distance of 5 m and viewing height of 1 m. Totals from the 4 directions were averaged and subtracted from 25 to yield a concealment index for each of the 3 height increments. We randomly located a 0.25-m<sup>2</sup> quadrat within each of 4 strips (1 x 5 m) radiating from the nest in the cardinal directions. Within each quadrat, we counted residual stems of each herbaceous species. For analysis, we pooled herbaceous species into the following categories: cattail (*Typha* sp.), bulrush (*Scirpus* sp.), phragmites (*Phragmites australis*), sedge (*Carex* sp.), grass (*Poacea* exclusive of *Phragmites*), and other. We visually categorized the dominant vegetation within a 5-m radius of the nest as cattail, bulrush, phragmites, sedge, or grass. We computed mean water depth from measurements made 1 m from the nest in each cardinal direction. We recorded the number of shrub stems  $\geq 4$  mm in diameter that were within 1.5 m of the nest and the number of trees  $\geq 3$  cm in diameter within 5 m. We estimated basin size and measured distance to the nearest upland and distance to the nearest tree.

Immediately after completing habitat measurements at a nest, we made the same measurements at a randomly selected site within the same wetland basin. Random sites were selected in two ways. When nests were in large wetlands, we placed a transparent grid over an air photo and numbered each square falling inside the basin. One square was randomly selected and we located the approximate center of this square in the wetland. From this point, we walked a randomly predetermined direction and distance (1-10 m) to a second point that became the random site. In small wetlands, which did not show up well on air photos, we divided the basin into quarters in the field and randomly selected one quarter. From the center of this quarter, we walked a randomly predetermined direction and distance (1-10 m) to the random site.

### Statistical Analyses

Our study design for assessing nest site selection was

analogous to a stratified case-control study, with nest sites as cases, random locations as controls, and strata defined by the sampled basins (within each year). We used conditional logistic regression (CLR) (Breslow et al. 1978, Hosmer and Lemeshow 2000, Stokes et al. 2000) to test for habitat selection while controlling for stratification variables (i.e. year and basin). Heuristically, observations within the same strata were treated as matched sets, with regression parameters estimated by comparing nest sites and random points within strata and then averaging estimated effects of covariates across strata. Regression parameters associated with each covariate reflect the change in log odds of use per unit change in the covariate. Odds ratios, obtained by exponentiation of the regression parameters, will approximate relative probabilities of use when probability of use is low (Compton et al. 2002, Keating and Cherry 2004). Odds ratios = 1.0 imply no risk difference, therefore odds ratio confidence intervals that do not include 1.0 indicate statistically significant relationships between the covariate and the probability of use.

The performance of logistic regression models (e.g. in terms of bias and precision of regression coefficients and reliability of hypothesis tests) is largely dependent on the number of events (i.e., paired nests and random sites) per variable considered during the analysis, including interactions and terms to account for non-linearities (Harrell 2001); several studies have suggested a minimum of 10 events per variable for obtaining reliable conclusions (Peduzzi et al. 1996, Harrell 2001, Steyerberg et al. 2001). Following general recommendations for data reduction (Harrell 2001:66), we eliminated variables that varied little across observations (e.g. number of shrub stems and tree stems within 5 m of the nest site) or that were highly correlated with other predictors (e.g. dominant vegetation category was dropped in favor of including stem count densities for various vegetation categories). We averaged low, medium, and high concealment scores to create a single index, and log transformed stem counts (after adding 0.1 to eliminate zeros) because these measurements were highly skewed. After data reduction, our habitat selection CLR model included the following 6 predictors: mean water depth (cm), concealment index (higher values indicate more dense cover), and log transformed cattail, bulrush, phragmites, and sedge stem counts. Prior to fitting the model, we computed variance inflation factors using PROC REG (SAS Institute, Inc. 2002) to assess potential problems with multicollinearity (Freund and Littell 1991). We fit the model using PROC PHREG in SAS (Stokes et al. 2000), and used residual diagnostics and leverage statistics to assess model goodness-of-fit and to check for influential data points (Allison 1995).

We expected nest success to vary according to the age of the nest at initial discovery (nests discovered later in

the incubation stage had fewer days at risk to succumb to predation). We used logistic-exposure models (Shaffer 2004) assuming a 30-day incubation period to account for the effect of nest age on apparent success rates. When modeling the influence of habitat variables, we included 4 nests having addled/infertile eggs in the hatched category because all were incubated longer than the normal incubation period and would have hatched had the eggs been viable. We fit a series of single predictor models, including the following variables: basin size (ha), distance to nearest upland (m), nest initiation date (i.e. date the first egg was laid), mean water depth (cm), concealment index, and log stem counts of cattail, bulrush, phragmites, or sedge. We estimated odds ratios (for the probability of daily nest survival) by exponentiating regression parameters, and used SAS macros written by T. L. Shaffer (<http://www.npwr.usgs.gov/resource/birds/nestsurv/index.htm>) to rank the models using a second order variant of Akaike's Information Criterion ( $AIC_c$ ) (Burnham and Anderson 2002). Models with  $AIC_c$  values within 2 units of the best fitting model are generally interpreted as having relatively strong support (Burnham and Anderson 2002). Given the small sample size relative to the number of predictor variables (and also the need to correct for age of the nest at discovery), we considered the analysis of factors associated with nest success to be exploratory. We used the R programming language (R Core Development Team 2005) to construct all plots.

Table 1. Plant type occurrence and mean stem counts/0.25-m<sup>2</sup> quadrat at 62 greater sandhill crane nests and 62 random sites in northwestern Minnesota, 1989–1991.

Plant type	Nest sites			Random sites		
	n <sup>a</sup>	$\bar{x}$ <sup>b</sup>	SE	n	$\bar{x}$	SE
Cattail	50	7.71	0.89	53	7.76	0.93
Phragmites	22	4.69	1.61	16	3.29	0.94
Bulrush	17	2.40	1.11	19	4.37	1.25
Sedge	37	5.43	1.15	41	15.40	3.32
Grass	7	0.40	0.18	7	1.42	0.64

<sup>a</sup> Number of nests or random sites at which the plant type occurred in 1 or more/0.25-m<sup>2</sup> quadrats.

<sup>b</sup> Mean stem counts/0.25-m<sup>2</sup> quadrat.

## RESULTS

### Nest Habitat Use and Selection

We obtained habitat data from 62 greater sandhill crane nests (n = 22, 35, and 5 nests in 1989, 1990, and 1991, respectively) and an equal number of matched random sites. Nests were in wetland basins 0.01–601 ha (Median = 2.2 ha) and at water depths 0–35.7 cm (Median = 9.7 cm) (Fig. 1a). Water depth at nests averaged 13.8 cm (SE = 2.0), 8.1 cm (SE = 1.1), and 11.8 cm (SE = 4.7) in 1989, 1990, and 1991, respectively. We recorded water depths of zero at 8 nests. Two of these were on small islands within marshes. The other 6 (5 in 1990, a dry spring) were in wetlands that were already dry when nests were found in early to mid-May. Distance to the nearest upland was 3–245 m and was correlated with basin size ( $r_{60} = 0.78$ ,  $P < 0.001$ ) and distance to nearest tree ( $r_{60} = 0.85$ ,  $P < 0.001$ ) because trees often lined the upland edges of wetlands. Wetlands used for nesting were largely

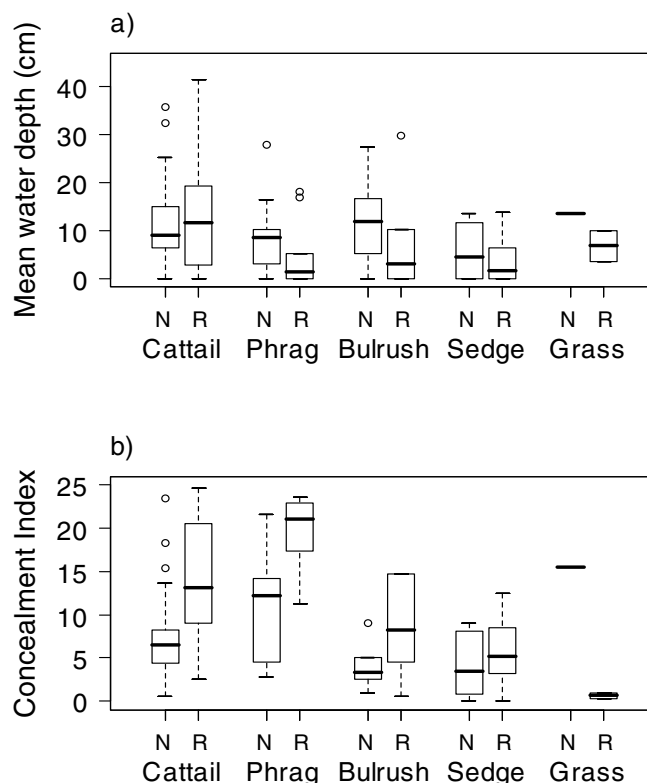


Figure 1. Distribution of: (a) water depth and (b) concealment index for greater sandhill crane nest sites (N) and random points (R) within each dominant vegetation category measured within a 5-m radius of the nest or random site. Boxes bound the 25<sup>th</sup> and 75<sup>th</sup> percentiles, solid lines within the boxes indicate the median, and whiskers extend to 1.5 times the interquartile range of the observations. Sample sizes in Cattail, Phragmites, Bulrush, Sedge, and Grass were (N = 36, R = 33), (N = 13, R = 9), (N = 7, R = 5), (N = 5, R = 13) and (N = 1, R = 2), respectively.

free of trees and large shrubs. Only 1 nest and 1 random site had trees within 5 m. Similarly, only 7 nests and 5 random sites had any shrub stems within 1.5 m. Concealment indices were quite variable, but were generally lower at nest sites than random locations within the same dominant vegetation category (Fig. 1b). Cattail was the dominant vegetation within a 5-m radius of most nests (58.0%) while 21.0% of nests were at sites dominated by phragmites. Sites dominated by bulrush, sedge, and grass accounted for 11.3%, 8.1%, and 1.6% of nests, respectively. Cattail had the highest mean stem counts at nests whereas sedge had the highest mean stem counts at random sites (Table 1).

Estimated odds ratios from the CLR nest habitat selection model suggested that locations with higher log phragmites stem counts, lower log sedge stem counts, and lower concealment indices were more likely to be associated with nest sites (Table 2). Water depth and log stem counts of cattails and bulrush were not significantly associated with the log odds of use as a nest site (i.e. confidence intervals included 1.0; Table 2).

### Nest Success

Clutch size was either 1 (7.3%) or 2 (92.7%). Of 62 nests, 35 (56.5%) hatched, 23 (37.1%) were depredated,

and 4 (6.4%) had infertile or addled eggs. Mayfield nest success was 40% (57 nests, 788 exposure days, 95% CL = 23%, 52%). Nest success estimated using an intercept only logistic-exposure model was 47% (95% CL = 30%, 62%). Based on evidence remaining at depredated nests (Rearden 1951, Trevor et al. 1991), it appeared that only 1 nest was destroyed by an avian predator (likely common raven, *Corvus corax* or American crow, *C. brachyrhynchos*). The remaining 22 nests were likely depredated by mammals. Potential local mammalian predators included raccoons (*Procyon lotor*), striped skunks (*Mephitis mephitis*), red foxes (*Vulpes vulpes*), coyotes (*Canis latrans*), and gray wolves (*Canis lupus*). Ten nests contained no remnants of eggs suggesting that the eggs were removed and eaten elsewhere, a pattern typical of coyotes (Littlefield 1995) and sometimes red foxes (Trevor et al. 1991).

### Factors Associated with Nest Success

We estimated dates of nest initiation and age of the nest when first discovered for 53 nests. Nest initiation dates ranged from 23 April - 29 May. Total nests initiated during the last week of April ( $n = 22$ ) was similar to the number begun during the first half of May ( $n = 23$ ), but nest starts dropped off sharply during the latter half of May ( $n = 8$ ).

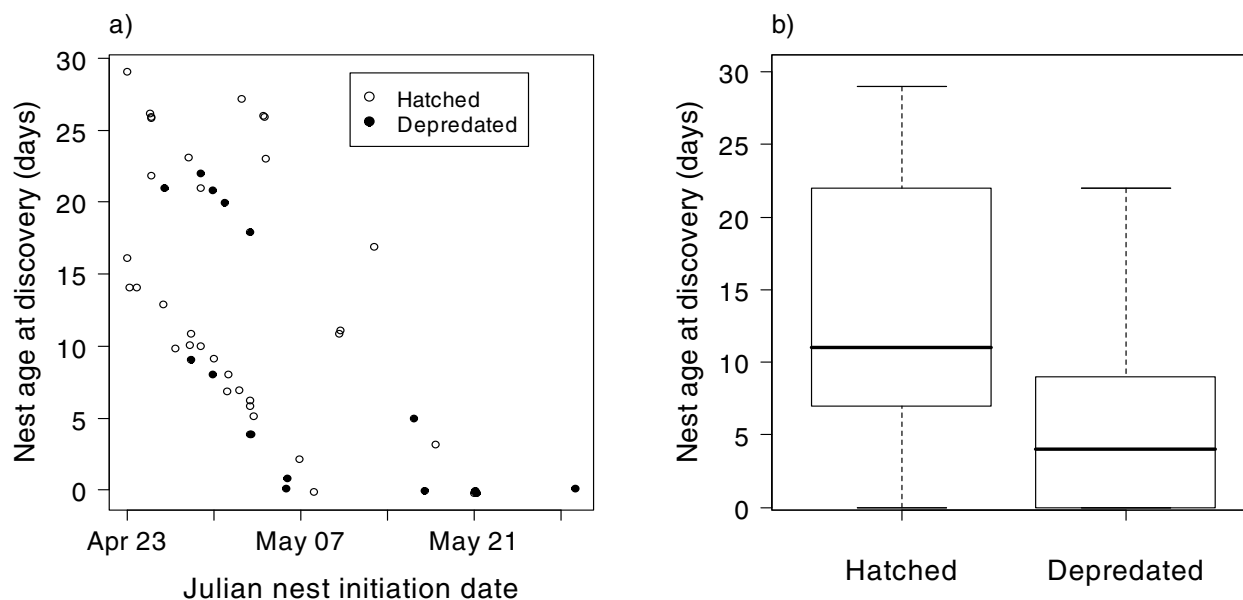


Figure 2. Distribution of nest ages (at discovery) versus (a) Julian nest initiation date and (b) apparent nest success for 53 greater sandhill cranes in northwestern Minnesota, 1989-1991. Four nests having addled/infertile eggs were included in the hatched category because all were incubated longer than the normal incubation period and would have hatched had the eggs been viable. Nests discovered early in the incubation period tended to have later nest initiation dates (a) and lower apparent success rates (b). Nest ages and initiation dates were jittered slightly in (a) to allow viewing of multiple observations with the same age and initiation date. In (b), boxes bound the 25<sup>th</sup> and 75<sup>th</sup> percentiles, solid lines within the boxes indicate the median, and whiskers extend to 1.5 times the interquartile range of the observations.



Table 2. Effect of habitat variables on relative probability of nest site selection by greater sandhill cranes in northwestern Minnesota, 1989–1991. Odds ratios estimated from a conditional logistic regression model fit to 62 nests and 62 matched random sites.

Variable	Odds ratio (95% CL)
Mean water depth	1.0 (0.93, 1.07)
Concealment index	0.77 (0.69, 0.87)
Log(stem counts + 0.1)	
Cattail	1.17 (0.82, 1.68)
Bulrush	1.07 (0.80, 1.42)
Phragmites	1.64 (1.06, 2.53)
Sedge	0.68 (0.50, 0.92)

However, distribution of observed nest initiation dates may have been influenced by the number and scheduling of helicopter searches (e.g. nests were more likely to be active [and hence found] if they were initiated shortly before a search was conducted). The percentage of nests that were depredated exhibited an increasing trend as nest initiations became later (23–30 April = 13.6%, 1–15 May = 34.8%, 16–29 May = 50.0%). However, nests initiated late in the study tended to be found earlier in the nesting cycle (Fig. 2a) and, as expected, nests found early in the nest cycle had lower apparent survival rates (Fig. 2b). After accounting for differences in exposure times, we detected no relationship between nest initiation date and the daily probability of survival (Table 3).

Logistic-exposure models provided some evidence that the probability of nest success increased as mean water depths (cm) increased and as concealment indices decreased (confidence intervals for the odds of survival did not include 1.0 for either of these variables in their single-predictor models; Table 3). However, a model that included a year effect [ $I(\text{year} = 1989) = 1$  if the nest was initiated in 1989 and 0 otherwise] had an  $AIC_c$  value that was over 4 units smaller than either of these models (Table 3). In 1989, 19 of 22 nests (86%) were successful, compared to 13 of 35 (49%) in 1990, and 3 of 5 (60%) in 1991.

## DISCUSSION

### Nest Habitat Use and Selection

In our study, greater sandhill cranes primarily nested in shallow wetland sites dominated by cattail or phragmites. These wetlands varied considerably in size, but generally contained few trees or large shrubs. We found that, after

controlling for concealment index, the probability of a site being used for nesting increased as the log stem counts of phragmites increased (i.e. while higher concealment indices were generally associated with random sites, if 2 sites had the same concealment index, the site with more phragmites stems was more likely to be a nest site). Further, 35 % of nests had phragmites in one or more of the 4 0.25-m<sup>2</sup> quadrats compared to 26% of random points. Although the majority of nests were found at sites dominated by cattail and no nest had a mean water depth exceeding 35.7 cm, our CLR nest habitat selection model did not indicate that log stem counts of cattail or water depth were associated with nest site selection. However, most wetlands where crane nests were found in cattail were dominated by cattail throughout the majority of the basin. Thus, there would be a high likelihood that the random site in the same wetland would also be in cattail. Likewise, the topography in our study area was flat and wetlands used for nesting tended to be shallow throughout (e.g. no mean depth at random sites exceeded 41.5 cm). Therefore, depth at a random site, in the same wetland, would likely also be shallow. Although we did not detect selection for cattail or water depth, we cannot rule out the possibility that nest habitat selection was

Table 3. Effect of habitat variables and nest characteristics on daily survival probabilities for greater sandhill crane nests in northwestern Minnesota, 1989–1991. Odds ratios estimated from logistic-exposure models fit to 37 successful and 14 depredated nests.

Model (i.e., variable) <sup>a</sup>	Odds ratio <sup>b</sup> (95% CL)	$\Delta AIC_c$
$I(\text{year} = 1989)^c$	11.3 (1.47, 87.6)	0
Mean water depth (cm)	1.08 (1.0, 1.17) <sup>d</sup>	4.42
Concealment index	0.89 (0.80, 0.98)	5.24
Log(cattail stems + 0.1)	0.65 (0.37, 1.13)	5.46
No habitat variable (intercept only model)	NA	6.96
Basin size (ha)	1.00 (1.00, 1.00)	7.58
Julian nest initiation date	0.98 (0.93, 1.03)	9.62
Log(phragmites stem counts + 0.1)	0.94 (0.74, 1.20)	9.82
Log(sedge stem counts + 0.1)	0.96 (0.75, 1.22)	10.09
Log(bulrush stem counts + 0.1)	1.04 (0.76, 1.42)	10.21

<sup>a</sup> Only single predictor logistic-exposure models (Shaffer 2004) were considered.

<sup>b</sup> Odds ratio (for the probability of daily survival) resulting from a unit increase in the predictor variable.

<sup>c</sup>  $I(\text{year} = 1989) = 1$  if the nest was initiated in 1989 and 0 otherwise.

<sup>d</sup> CI includes 1.0 due to round-off error.

occurring at a larger spatial scale (e.g. a higher likelihood of nests being located in shallow wetlands dominated by cattail). Others (Bennett 1978, Tebbel 1981, Urbanek and Bookhout 1992, DiMatteo 1991, Provost *et al.* 1992) found that greater sandhill cranes used a variety of wetland habitats and dominant plant species for nesting and nest habitat selection appears based on vegetative structure rather than species composition. Further, greater sandhill cranes appear to exhibit variable nesting habitat selection depending on the wetland types available. Whereas Tebbel (1982) reported that cranes preferred to nest at sites containing *Sphagnum* *sp.* and leatherleaf (*Chamaedaphna calyculata*) in an area where bogs were prevalent, these plants were not recorded in our study nor at nest sites nearby (Provost *et al.* 1992). In our study, cattail, phragmites, and bulrush were the primary plant species that provided vertical structural cover at crane nests. Although sedge was recorded at over half of the nests, the probability of a site being used for nesting decreased as log stem counts increased. None of our nests were in broad expanses of sedge or grass, although some nesting wetlands did contain this habitat feature. In our study area, residual sedge stems (as well as grass stems) lay close to the ground and provided virtually no concealment for an incubating crane. The probability of a site being used for nesting decreased as concealment indices increased. This counterintuitive result may be due, in part, to the fact that cranes collect nest construction materials close to their nests (Tacha *et al.* 1992) and thereby thin out the nearby vegetation; a pattern noted by others (Bennett 1978, DiMatteo 1991, Provost *et al.* 1992). On the other hand, cranes in our study clearly did not nest in very dense stands of cattail or phragmites. Bennett (1978) noted that potential nesting vegetation was avoided if its density or height restricted free movement by the cranes. Thus, greater sandhill cranes appeared to select nest sites that provided some vertical cover (i.e. cattail, phragmites, bulrush) for concealment while also allowing the birds a view of their immediate surroundings and ease of access to and from the nest. Given that most predation appeared to be caused by mammals, this degree of habitat openness may be important to cranes in northwestern Minnesota because it allows them to observe potential predators approaching their nest in time to react appropriately by flight, distraction, or defense.

### Factors Associated with Nest Success

We noted that nest success appeared to decrease for nests initiated later in the spring. However, these late nests typically were found earlier in the incubation period and when we accounted for differences in exposure times, the relationship between nest initiation date and nest success was no longer evident. Thus, the observed effect of nest

initiation date may be an artifact of nests initiated late in the study period generally having longer (observed) exposure times (Shaffer 2004).

Given our relatively small sample of depredated nests, our analyses of factors associated with nest success should be viewed as exploratory. Urbanek and Bookhout (1992) noted that nests in Michigan cattail marshes suffered greater predation than those in sedge marshes, but water depth or concealment scores were not associated with nest fate. Our model with cattail stem density suggested a negative effect on the odds of nest survival, although the confidence interval was rather wide (reflecting the small sample size) and included 1.0. In our study, year had the strongest effect on nest success with the lowest success recorded in 1990. Further, nest success appeared to increase as mean annual water depth increased. 1990 was a dry spring on our study area and mean water depths at nests (and random sites) were lower that year than either 1989 or 1991. As most nest predation in our study appeared to be caused by mammals, the lower water depths, and in some cases nesting wetlands that dried up during incubation, may have caused nests to be more accessible to these predators.

Nest success also appeared to increase as concealment indices decreased which initially seems counterintuitive. However, the importance of water depth and the lesser importance of vegetative concealment, in our study, are consistent with studies of nesting waterfowl. Water often constitutes a barrier to many mammalian predators (Sargeant and Arnold 1984) and overwater-nesting ducks typically have higher nest success than upland nesters (Bouffard *et al.* 1988, Maxson and Riggs 1996). Further, where mammalian nest predators predominate over avian predators, as in our study, nest concealment typically is of little importance to nest success (Clark and Nudds 1991).

### MANAGEMENT IMPLICATIONS

Greater sandhill cranes, in northwestern Minnesota, used a variety of wetland habitats and dominant plant species for nesting. Within habitat complexes suitable for breeding cranes, land managers should provide shallow (i.e. depths < about 50 cm) wetlands dominated by cattail, phragmites, and bulrush; the predominant plants that cranes use as vertical concealment cover at nests. Such wetlands should contain varying densities of these plant species as cranes will not nest in sites with extremely dense vegetation. Wetlands dominated by sedge or grass, other than phragmites, are less useful to nesting cranes unless they also contain sizeable patches of cattail, phragmites, or bulrush where cranes could locate their nest. The majority of the wetland basin should be free of trees and large shrubs. Wetland size appears less important than water depth and vegetation characteristics. If

possible, these wetlands should be in situations where water levels can be maintained throughout the nesting season as this may reduce nest predation by mammals.

## ACKNOWLEDGMENTS

This study was supported by the Minnesota Department of Natural Resources, Division of Fish and Wildlife and Division of Ecological Services, Nongame Program. We are grateful for the cooperation and assistance of G.H. Davis, C.G. Forester, G. M. Mehmehl, L. G. Petersen, L. A. Pfannmuller, T. P. Rusch, and P. B. Telander. T. Petersen piloted the helicopter. We thank J. J. DiMatteo, A. M. Herr, and T. Simpson, Jr. for assistance in the field. K. G. Beal, R. T. Eberhardt, B. C. Eliason, M. A. Hanson, J. S. Lawrence, C. D. Littlefield, and M. C. Zicus made helpful comments on the manuscript.

## LITERATURE CITED

- Allison, P. D. 1995. Survival analysis using the SAS system: a practical guide. SAS Institute, Cary, North Carolina, USA.
- Baker, B. W., B. S. Cade, W. L. Mangus, and J. L. McMillen. 1995. Spatial analysis of sandhill crane nesting habitat. *Journal of Wildlife Management* 59:752-758.
- Bennett, A. J. 1978. Ecology and status of greater sandhill cranes in southeastern Wisconsin. Thesis, University of Wisconsin, Stevens Point, Wisconsin, USA.
- Bouffard, S. H., D. E. Sharp, and C.C. Evans. 1988. Overwater nesting by ducks: a review and management implications. Pages 153-158 in D. W. Ursek, G. L. Schenbeck, and R. Cefkin, technical coordinators. Proceedings of eighth Great Plains wildlife damage control workshop. U.S. Forest Service General Technical Report RM-154.
- Breslow, N. E., N. E. Day, K. T. Halvorsen, R. L. Prentice, and C. Sabai. 1978. Estimation of multiple relative risk functions in matched case-control studies. *American Journal of Epidemiology* 108:299-307.
- Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second edition. Springer-Verlag, New York, New York, USA.
- Clark, R. G., and T. D. Nudds. 1991. Habitat patch size and duck nesting success: the critical experiments have not been performed. *Wildlife Society Bulletin* 19:534-543.
- Compton, B. W., J. M. Rhymer, and M. McCollough. 2002. Habitat selection by Wood Turtles (*Clemmys insculpta*): an application of paired logistic regression. *Ecology* 83:833-843.
- DiMatteo, J. J. 1991. Biology of the greater sandhill cranes of Agassiz National Wildlife Refuge, Marshall County, Minnesota. Thesis, St. Cloud State University, St. Cloud, Minnesota, USA.
- Fisher, I. J., and S. R. Swengel. 1991. A guide for aging sandhill crane eggs. *Wildlife Society Bulletin* 19: 494-497.
- Freund, R. J., and R. C. Littell. 1991. SAS system for regression. Second edition. SAS Institute, Cary, North Carolina, USA.
- Harrell, F. E. 2001. Regression modeling strategies with applications to linear models, logistic regression, and survival analysis. Springer, New York, New York, USA.
- Herr, A. M., and L. P. Queen. 1993. Crane habitat evaluation using GIS and remote sensing. *Photogrammetric Engineering and Remote Sensing* 59:1531-1538.
- Hosmer, D. W., and S. Lemeshow. 2000. Applied logistic regression. Second edition. John Wiley and Sons, New York, New York, USA.
- Howard, T. J. 1977. Ecology of the greater sandhill crane in central Wisconsin. Thesis, University of Wisconsin, Stevens Point, Wisconsin, USA.
- Keating, K. A., and S. Cherry. 2004. Use and interpretation of logistic regression in habitat-selection studies. *Journal of Wildlife Management* 68:774-789.
- Klett, A. T., H. F. Duebbert, C. A. Faanes, and K. F. Higgins. 1986. Techniques for studying nest success of ducks in upland habitats in the Prairie Pothole Region. U.S. Fish and Wildlife Service Resource Publication 158, Washington D.C., USA.
- Kratz, T. K., and G. L. Jensen. 1983. Minnesota's landscape regions. *Natural Areas Journal* 3:33-44.
- Littlefield, C. D. 1995. Demographics of a declining flock of greater sandhill cranes in Oregon. *Wilson Bulletin* 107:667-674.
- Maxson, S. J., and M. R. Riggs. 1996. Habitat use and nest success of overwater nesting ducks in west central Minnesota. *Journal of Wildlife Management* 60:108-119.
- Peduzzi, P., J. Concato, E. Kemper, T. R. Holford, and A. R. Feinstein. 1996. A simulation study of the number of events per variable in logistic regression analysis. *Journal of Clinical Epidemiology* 49:1373-1379.
- Provost, J. L., T. A. Provost, S. J. Maxson, and R. D. Crawford. 1992. Breeding biology of greater sandhill cranes on the Roseau River Wildlife Management Area, Minnesota. Proceedings of the North American Crane Workshop 6:69-74.
- R Core Development Team. 2005. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-00-3, <<http://www.R-project.org>>. Accessed 31 October 2006.
- Rearden, J. D. 1951. Identification of waterfowl nest predators. *Journal of Wildlife Management* 15:386-395.
- Sargeant, A. B., and P. M. Arnold. 1984. Predator management for ducks on waterfowl production areas in the northern plains. *Vertebrate Pest Conference* 11:161-167.
- SAS Institute, Inc. 2002. SAS/Stat Users Guide, Version 9.1. Cary, North Carolina, USA.
- Shaffer, T. L. 2004. A unified approach to analyzing nest success.



Auk 121:526–540.

Steyerberg, E. W., M. J. C. Eijkemans, F. E., Harrell, and J. D. F. Habbema. 2001. Prognostic modeling with logistic regression analysis: in search of a sensible strategy in small data sets. *Medical Decision Making* 21:45–56.

Stokes, M. E., C. S. Davis, and G. G. Koch. 2000. Categorical data analysis using the SAS system. Second edition SAS Institute, Cary, North Carolina, USA.

Tacha, T. C., S. A. Nesbitt, and P. A. Vohs. 1992. Sandhill crane, *Grus canadensis*. A. Poole, P. Stettenheim, and F. Gill, editors. *The Birds of North America*, No. 31. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and The American Ornithologists' Union, Washington D.C., USA.

Tebbel, P. D. 1981. The status, distribution and nesting ecology of sandhill cranes in the Algoma District of Ontario. Thesis, University of Western Ontario, London, Ontario, Canada.

Trevor, J. T., R. W. Seabloom, and R. D. Saylor. 1991. Identification of mammalian predators at artificial waterfowl nests. *Prairie Naturalist* 23:93–99.

Urbanek, R. P., and T. A. Bookhout. 1992. Nesting of greater sandhill cranes on Seney National Wildlife Refuge. Pages 161–172 in D. A. Wood, editor. *Proceedings of the 1988 North American Crane Workshop*. Florida Game and Freshwater Fish Commission, Nongame Wildlife Program Technical Report No. 12. Tallahassee, Florida, USA.

Walkinshaw, L. H. 1973. *Cranes of the World*. Winchester Press, New York, New York, USA.



Laguna de Babicora, Chihuahua, Mexico, 7,000 ft elevation, the most important sandhill wintering area in Mexico, wintering up to 50,000 cranes. Photo by Roderick C. Drewien.