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VIGILANCE OF NESTING WHOOPING CRANES IN JUNEAU COUNTY, WISCONSIN

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Abstract: Vigilance plays an important role in the detection of possible threats and reducing the risk of predation, including during the incubation period. We examined the visual vigilance of incubating whooping cranes (*Grus americana*) in Juneau County, Wisconsin, during the 2019 nesting season. We deployed 9 trail cameras and tagged crane presence and behavior in 32,801 photos which were used in our analysis. We assessed individual nest and environmental variables and their effects on vigilant behavior of incubating cranes using linear mixed-models. Vigilant behavior was defined by a posture in which the crane's head was up, neck was erect, and bill was horizontal to the ground. Nesting whooping cranes were less vigilant during the night ($\bar{x}$ = 14.3 ± 1.4% [SE]) than during the day (25.0 ± 0.7%), and cranes were less vigilant during precipitation events. Cranes nesting closer to closed forest were 11-12% less vigilant than those nesting at medium or far distances from forest. Lastly, cranes nesting in medium-sized wetlands were 4-5% more vigilant than cranes in small or large wetlands. Further research to determine if levels of vigilance affect nest success could help increase productivity for this population.

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Key words: behavior, *Grus americana*, habitat, nesting, reintroduction, reproduction, vigilance, whooping crane, Wisconsin.

Vigilant behavior at nesting sites has been studied in a variety of avian species (semipalmated plover [*Charadrius semipalmatus*], Blanken and Nol 1998; mallard [*Anas platyrhynchos*], Javůrková et al. 2011; common tern [*Sterna hirundo*], Diehl et al. 2020). Levels of vigilance are affected by risk of predation and visibility related to habitat structure (Amat and Masero 2004, Griesser and Nystrand 2009, Diehl et al. 2020). Ultimately, an animal's vigilance, or awareness of its surroundings, can help it detect potential predators and respond appropriately, reducing the risk of predation (Cowlishaw 1998, Lima and Bednekoff 1999).

Although vigilance has been studied in different nesting bird species, it has not been studied in depth for whooping cranes (*Grus americana*). The Eastern Migratory Population (EMP) of whooping cranes is a small, reintroduced population that breeds in central Wisconsin. This population is not yet self-sustaining due to low reproductive success (Converse et al. 2019, Thompson et al. 2022). Vigilance can be a disturbance-induced behavior that reduces valuable time otherwise available for foraging and resting during the nesting and chick rearing periods (Bradter et al. 2007, Javůrková et al. 2011). However, if there is too little vigilance, nests could be at greater risk from predators. Individuals must balance their time in order to self-preserve and increase reproductive success.

Other factors such as the age, nesting experience, or habitat may also be contributing factors to low reproductive success (Ivey and Dugger 2007). Nests located in more suitable habitat have a greater chance of success since parents may spend less time vigilant and more time on foraging and parenting (Picman 1988, Bradter et al. 2007). It is important to determine if these factors correlate with vigilance to identify management actions that might help increase reproductive success and population growth in the EMP. Habitat management may improve reproductive outcome, not only at Necedah NWR but also in the new nesting areas in eastern Wisconsin. The objective of this study was to determine how individual nest characteristics and environmental variables influence time spent in visual vigilant behavior by nesting whooping cranes in Juneau County, Wisconsin, particularly at Necedah NWR and the neighboring Meadow Valley Wildlife Area from April-May 2019. All of the nests we monitored for this study successfully hatched, therefore we could not assess the influence of vigilance on nest success; however, our findings could be used to compare to unsuccessful nests in the future or can provide baseline rates of vigilance for successful nests.

STUDY AREA

The study was conducted on Necedah NWR (44°04′N, 90°10′W) and Meadow Valley Wildlife

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Area (44°14′N, 90°14′W) in Juneau County, Wisconsin. Necedah NWR consists of 17,683 ha of sedge meadow wetland, savanna, prairie, and oak, pine, and aspen forest (USFWS 2004). Meadow Valley Wildlife Area is a 23,472-ha property managed by the Wisconsin Department of Natural Resources and containing emergent wetland, grassland, and oak (*Quercus*), pine (*Pinus*), and aspen (*Populus*) forest (WDNR 2011). The nesting areas of cranes in these 2 locations are primarily open wetlands in or near impoundments and dominated by coarse sedge (*Carex* spp.) and other species (Urbanek et al. 2018). Potential nest or chick predators in the area include raccoon (*Procyon lotor*), coyote (*Canis latrans*), gray wolf *(Canis lupus*), bobcat (*Lynx rufus*), mink (*Mustela vison*), bald eagle (*Haliaeetus leucocephalus*), and raven (*Corvus corax*) (Urbanek 2015).

METHODS

Bird Identification and Nest Monitoring

With few exceptions, all whooping cranes in the EMP are identified by a unique combination of colored leg bands as well as a leg-band mounted VHF transmitter or satellite transmitter (Urbanek 2018). Whooping cranes were monitored by International Crane Foundation (ICF) staff, Necedah NWR staff, pilots flying aerial surveys, volunteer trackers, and the general public, through VHF telemetry, satellite telemetry, or visual leg-band identification. Through this network, we were able to identify the location and behavior of birds, which helped in tracking their migration, nesting, or associations with other cranes.

Nests were found through aerial surveys, visual observations from the ground, or by data from satellite transmitters showing the bird in 1 location for a long period of time and confirmed by visual observations. All of the nests studied were initiated after egg removal to facilitate re-nesting. Removal occurred on 20 April 2019, except for 1 nest that had not yet been found when eggs in other nests were being removed; nest initiation dates ranged from 16 April to 30 May 2019. Once a whooping crane nest was located, we waited a minimum of 5 days to deploy a trail camera (Reconyx HyperFire HC600, Reconyx Inc., Holmen, WI, USA) near the nest to avoid nest abandonment (McKinney 2014, Jaworski 2016). The camera was programmed to take 1 photograph every 5 minutes, 24 hours per day. It was attached to a T-post and placed roughly 5-10 m from the nest facing north or south to avoid glare, similar to methods used by McKinney (2014), Jaworski (2016), and Thompson and Gordon (2020). Recorded time from when the incubating crane flushed to when we left each nest was less than 20 minutes. We recorded nest concealment score, number of eggs, and GPS coordinates at each nest. Concealment score was categorized by the numbers 1-4 from least concealed to most concealed. In category 1 the nest was visible to a human observer >50 m away, in category 2 the nest was visible from 10-50 m, category 3 from 2-10 m, and in category 4 the nest was only visible from within 2 m (Littlefield 2001).

Photograph Tagging

After completion of incubation was confirmed by the observation of the pair away from the nest site, we collected the camera and tagged the photographs. The file name, date, and time were extracted for each photograph. We tagged each photograph with the number of cranes (0, 1, 2), crane behavior (incubating, incubation swap, or standing), if the crane was in a vigilant behavior as defined below (yes or no), and any valuable notes, similar to McKinney (2014), Jaworski (2016), and Thompson and Gordon (2020). Behavioral data were only recorded for the bird on the nest. We did this for each photograph until the incubation period ended, e.g., when a chick was observed.

In this study we looked at only 1 aspect of vigilance, visual vigilance, because we were able to measure this from still photos. We did not include any aspect of auditory vigilance, nor the stimuli to which a crane may be responding. Vigilant behavior was defined by a posture in which the incubating crane's head was up, neck was erect, and bill was horizontal to the ground (Fig. 1). A crane with its head up but looking down was not classified as vigilant (e.g., preening or egg and nest manipulation). If we were unable to determine the position of the head due to the direction the bird was facing, vegetation obstruction, or the time of day, we would classify it as unknown. Additionally, photos were coded with "NA" if there were no cranes present. Unlike McKinney (2014), our analysis of vigilance did not include birds that were off nest or "other" behaviors when the head was up (e.g., head up but neck curved, not surveying surroundings). This is based on the idea that a crane in a tall alert position is focusing on threats while a decrease in head height could be a resting behavior (Voss 1976). Due to the categorization

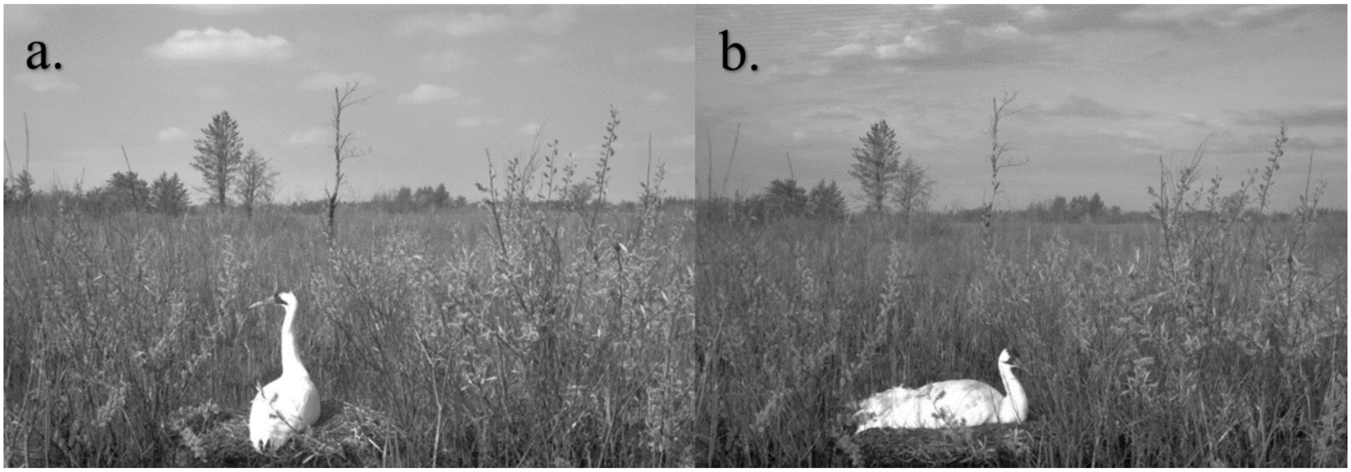

Figure 1. Examples of tagging visually vigilant behavior of whooping cranes from 2019 nest camera photographs in Juneau County, Wisconsin. The photos show vigilant (a) versus not vigilant (b) behaviors.

of vigilance being relatively subjective and potentially influenced by an observer's definition, only 2 of the 4 people tagging photographs recorded vigilance data, and they had 97.5% agreement after tagging 200 of the same photos.

Nest Characteristics

Habitat around a crane's nest may influence the viewscape for incubating cranes and the visibility of predators, or other causes of disturbance, and thus may affect vigilance at the nest. We measured habitat characteristics for each nest using remote data layers, such as the distance to the nearest road, the distance to the nearest patch of closed forest, and the size of the wetland impoundment. We used the Wisconsin Department of Natural Resources roads layer and the Near tool in ArcGIS to calculate distances from the nest to the nearest paved road, top of dike, or 2-track (Esri 2011). Similarly, we used the National Wetlands Inventory and a Spatial Join in ArcGIS to calculate wetland size for each nest (Esri 2011). All wetland polygons that were contiguous and bordered by uplands, forests, or a dike road were considered 1 wetland, and the sizes of contiguous polygons were summed to calculate wetland size. Adjacent wetlands, including those with small islands or upland patches, that were part of a single managed impoundment and had a similar viewscape were considered to be a single wetland (i.e., bordered by the same uplands, forests, or roads). The distance to a patch of closed forest was measured using aerial imagery and the Measure Tool in ArcGIS (Esri 2011). We defined a closed forest patch as a dense stand of trees that obstructed a crane's view. Due to small sample size and wide range of distances to roads and forests as well as wetland sizes, we grouped measurements into categories for analysis. Categories were based on natural breaks in the data as well as our knowledge of the landscape. Measurements were grouped into 3 categories for distance to roads (close: 37-94 m; medium: 190-431 m; far: 955-1,408 m), distance to forests (close: 25-30 m; medium: 144-284 m; far: 403-822 m) and wetland sizes (small: 4-39 ha; medium: 81-193 ha; large: 1,138 ha). All measurements were calculated in ArcGIS 10.6.1 (Esri 2011).

Weather or the amount of moonlight may affect visibility of predators and thus vigilance of incubating cranes (Beauchamp 2007, Eldred 2009). Additionally, weather variables such as temperature, wind, and precipitation, may pose energetic trade-offs for cranes, where cranes may need to prioritize behaviors related to maintaining body or egg temperature at the expense of vigilance (Fitzpatrick 2016). We used weather data from the Necedah NWR weather station (44°01′43″N, 90°04′59″W) to determine the average temperature (°C), the amount of precipitation (cm), and the maximum wind speed (km/hr) throughout the nesting season. Cloud cover was not used in our analysis because the weather station did not collect these data. The amount of moonlight on a given night was based on the moon phase, where 0 represented no light (new moon) and 1 represented the most light (full moon). Nights between the new moon and full moon were given a decimal value between 0 and 1 in proportion to the amount of moonlight present.

Lastly, we recorded data on the individual cranes of each nesting pair as well as the incubation day for each nest. Specifically, we recorded the identification number of each crane and used the female's ID number as the "PairID". We also recorded if the nest was a first nest of the season or a renest, and the incubation day from day 0 (egg laid) to day 30 (egg hatched). We compared characteristics of individual cranes' nesting or chick rearing experience, including the age and years nesting experience of each member of the pair, the summed total age of the pair, the summed total years of nesting experience of the pair, and the number of years nesting experience they had together as a pair. We also noted if either or both birds in the pair had previously hatched a chick.

Data Analysis

Similar to Javůrková et al. (2011), each day was divided into 6, 4-hour periods and the data were summarized within each period. Periods were designated as "Day 1" from 0500-0900, "Day 2" from 0900-1300, "Day 3" from 1300-1700, "Day 4" from 1700-2100, "Night 1" from 2100-0100, and "Night 2" from 0100-0500. The daytime periods started approximately 30 minutes before sunrise and ended 30 minutes after sunset. Nighttime periods spanned 2 dates, and in order to consider variables such as incubation day or moon phase the same for both periods, Night 1 and Night 2 were considered a part of the previous date. We then summarized weather data for each period by calculating the average temperature, the total amount of precipitation, and the maximum wind speed.

For each period, we calculated the proportion of photographs in which the incubating crane was vigilant, excluding photos designated "NA" or "unknown", which was used for the rest of the data analysis. To reduce bias in the proportion of time spent vigilant during periods with low visibility, we did not use periods with fewer than 40 photographs that met our criteria of having cranes present and behavior that could be assessed. Of the 756 periods during which we recorded data, 56 periods were excluded from analysis, resulting in a loss of 7% of the data.

All data summaries and analyses were conducted in R version 4.0.2, and we reported means and standard errors for all summary statistics (R Core Team 2018). We calculated if independent variables were correlated by using a series of analysis of variance (ANOVA), *t*-test, chi-squared tests, and correlation matrices (R Core Team 2018). We used generalized linear mixed-effects models ("glmer" function in the lme4 package) with a gamma distribution and a log link to assess the influence of independent variables on the proportion of photos during each period in which cranes were vigilant (Bates et al. 2015). To reduce pseudo replication, we included PairID as a random effect. Correlated independent variables were not included in the same linear models. To determine the top model, we used a corrected Akaike Information Criterion (AIC_c) model selection process for small sample sizes and the "model.sel" function in the MuMIn package (Barton 2018, R Core Team 2018). All models within 2 AIC_c of the top model were considered valid (Burnham and Anderson 2002). To assess the importance of each independent variable in the top model(s), we used the "drop1" function in base R (R Core Team 2018). We simulated residuals of the fitted model using the "simulateResiduals" function in the DHARMa package to test for normality (Hartig 2018). Lastly, for significant categorical variables in the top models, we conducted pairwise comparisons of groups using ANOVA and Tukey Honest Significant Difference (HSD) tests (R Core Team 2018).

RESULTS

We collected data from 9 nests in Juneau County, Wisconsin, during the 2019 nesting season: 8 were located in Necedah NWR and 1 was located in Meadow Valley Wildlife Area. We recorded data from a total of 41,311 camera photos. After we excluded periods in which cranes were not present or visibility was limited, 32,801 photos remained for analysis. Of the 9 nests, 3 were first nests and 6 were renests, and all nests hatched at least 1 chick. Therefore, we were not able to assess the effect of vigilance on nest success. Four nests had a concealment score of 1 (least concealed), 1 nest had a score of 2, 2 nests had a score of 3, and 2 nests had a score of 4 (most concealed). There were 2 nests that were categorized as close to roads, 5 were a medium distance to roads, and 2 were far from roads. Four, 3, and 2 nests were in small, medium-sized, and large wetlands, respectively. The 2 nests in a large wetland were in different parts of the same 1,138-ha wetland. Two nests were close to the nearest forest, 4 were a medium distance, and 3 were far from forests. Only 4 of these birds had never previously hatched a chick. On

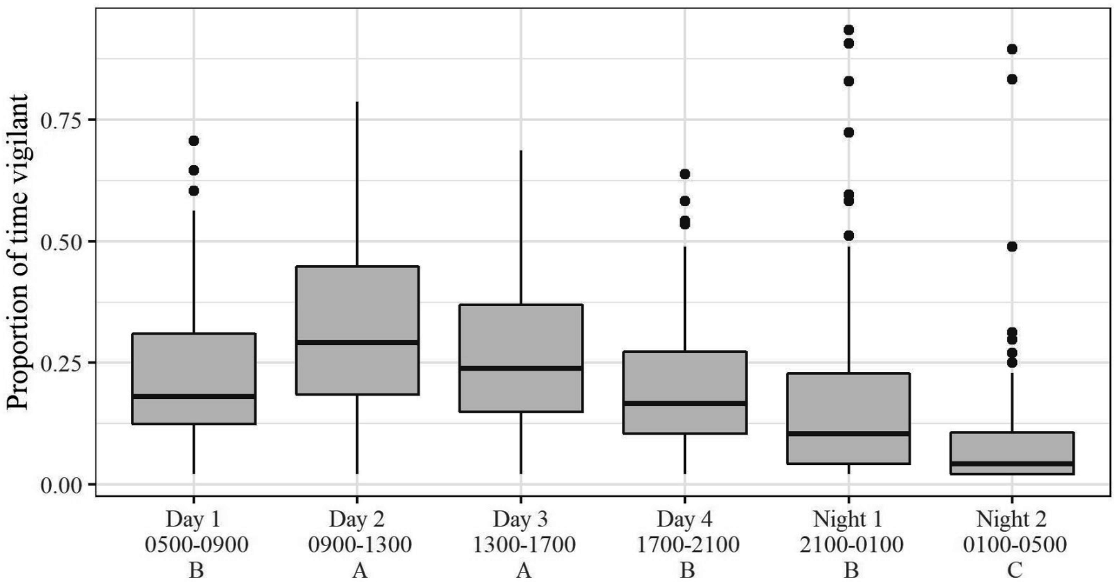

Figure 2. Proportion of time spent in vigilant behavior by nesting whooping cranes throughout the day. Each day was divided into 4 daytime (Day 1-4) and 2 nighttime (Night 1-2) 4-hour periods. Data were from 9 nesting pairs of whooping cranes in Juneau County, Wisconsin, monitored from April-May of 2019. Letters below the time periods on the x-axis (A-C) designate the periods that were statistically different from other periods; periods with the same letter had similar rates of vigilance. The upper and lower bounds of the boxes represent quartiles, the bold horizontal lines represent the median, 1.5× Interquartile Range are within the vertical lines extending from boxes, and outliers are represented by solid circles.

average, the pairs' total experience nesting was 15.2 years (range 1-22 years) and pairs had 4.1 years (range 0-11 years) of previous experience nesting together. The average total pair age (male age + female age) was 25.1 years old (range 13-31 years old).

Vigilance of nesting whooping cranes was most affected by the time of day (period, $P < 0.001$), the amount of precipitation ($P = 0.010$), the size of the wetland ($P = 0.020$), and the distance to forest ($P < 0.001$). The single best model included all of these variables as well as moon phase; however, moon phase was not a significant predictor of vigilance ($P = 0.094$). Overall, incubating whooping cranes were vigilant on average 22.4 ± 0.6% of the time and were more vigilant during daytime than nighttime periods (25.0 ± 0.7% vs. 14.3 ± 1.4%). Cranes were most vigilant during Day 2 and Day 3 periods (0900-1700) compared to all other periods (Fig. 2, $P < 0.001$ for all pairwise comparisons). There was no difference in vigilance between Day 2 and Day 3 periods ($P = 0.347$) or between Day 2, Day 3, and Night 2 periods ($P > 0.200$ for pairwise comparisons of Day 1-Day 4, Day 4-Night 1, and Day 1-Night 1, respectively). Incubating cranes were least vigilant during the Night 2 period (0100-0500) (Fig. 2, $P < 0.05$ for all pairwise comparisons). Whooping cranes were on average 42.4% (29.9-60.0%) less vigilant per centimeter of precipitation accumulated during a period ($P = 0.014$). Cranes nesting close to forests (25-30 m) were on average 11-12% less vigilant than cranes nesting a medium distance or far from forests (Fig. 3, $P < 0.001$ for both pairwise comparisons including nests close to forests, $P = 0.903$ for the comparison of medium to far distances to forests). Lastly, cranes were on average 4-5% more vigilant if they were nesting in medium-sized wetlands, compared to small or large wetlands ($P = 0.009$ and $P = 0.025$, respectively, $P = 0.979$ for the comparison of small and large wetlands).

DISCUSSION

The vigilance rates of nesting whooping cranes in our study were lower compared to those reported in other crane studies; however, this could be due to different definitions of vigilance and data collection methods. While there are many sensory factors involved in vigilance, we examined a visual vigilant behavior in which a crane is using sight to potentially detect predators or other disturbances. Olfactory or auditory vigilant cues were not detectible through still photos. Cranes are aware of their surroundings to some extent while awake but exhibiting other non-vigilant behaviors, which we were also not able to measure. In

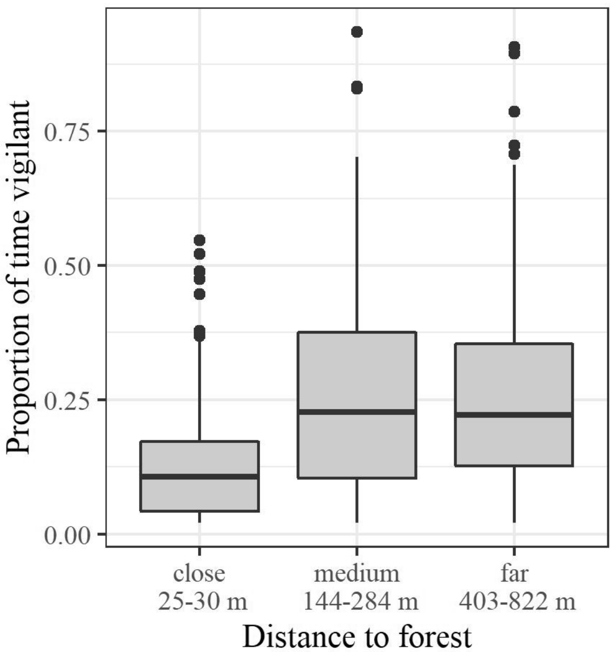

Figure 3. Proportion of time spent in a vigilant behavior by 9 nesting pairs of whooping cranes compared to the distance their nests were to a closed forest patch, Juneau County, Wisconsin, April-May 2019. The upper and lower bounds of the boxes represent quartiles, the bold horizontal lines represent the median, 1.5× Interquartile Range are within the vertical lines extending from boxes, and outliers are represented by solid circles.

this study, whooping cranes were in a vigilant behavior 25% of the daytime hours. However, McKinney (2014) reported EMP nesting whooping cranes in Wisconsin spent approximately 59.3% and sandhill cranes (*Grus canadensis*) spent 49.7% of their time being vigilant during the day. We only considered vigilance of incubating cranes, while McKinney (2014) included off-nest behaviors in their assessment of vigilance. McKinney (2014) also included other "head up" behaviors in which the crane's head was not tucked but its neck was not straight or bill was not horizontal, while the crane may have been awake but resting. Our study defined a vigilant behavior as when the incubating crane had a fairly straight neck and its bill was horizontal, indicating examination of its surroundings or a reaction to a stimulus. Like this study, McKinney (2014) also did not include a measurement of a response to a specific stimulus, or record exactly what may have elicited a response. However, not all vigilant behaviors measured were necessarily in response to a stimulus, but included behaviors while cranes were surveying for a potential threat.

Similar to our study, Eldred (2009) examined factors affecting alert postures of sandhill cranes; however, they focused on non-incubating cranes and separated vigilance into 2 categories, "alert investigative" and "tall alert." A crane in an investigative alert position had its head up, bill horizontal, with its neck not fully extended but still looking at surroundings, while tall alert had a fully extended neck. In Eldred (2009), breeding cranes without chicks spent 30.03% and 5.70% of their time during the day in alert investigative and tall alert stances, respectively. Our definition of vigilance would include tall alert behavior as defined by Eldred (2009); however, our definition did not include all behaviors considered alert investigative. Additionally, Eldred (2009) recorded data from a greater distance and from video footage only recorded in the afternoon, which may have contributed to differences in vigilance between the 2 studies. Overall, vigilance rates in our study were comparable to Eldred (2009).

Nesting whooping cranes in the EMP were less vigilant at night or while it was raining and most vigilant during the middle of the day. When visual awareness was restricted by rain or darkness, levels of vigilance decreased (Beauchamp 2007, Javůrková et al. 2011), indicating that when cranes are not able to see as much, they are less vigilant and may spend more time in other behaviors. Javůrková et al. (2011) found incubating mallards were also less vigilant at night, and Beauchamp (2007) found that the majority of the 14 non-nesting bird species assessed in their study were also less vigilant at night. Alternatively, common terns studied on 2 different islands showed higher levels of vigilance at night on the island where predation risk was higher (Diehl et al. 2020). Eldred (2009) found a non-significant trend of decreased rates of vigilance of sandhill cranes while it was raining.

A lack of vigilance could cause increased vulnerability to predation events at night; however, predators may also be limited in their ability to successfully hunt in these conditions. Additionally, activity patterns of predators may also vary with daylight (nocturnal, diurnal, or crepuscular predators) and weather. The Florida scrub-jay (*Aphelocoma coerulescens*) population is threatened by nocturnal nest predation possibly due to deficiency in vigilant behavior at that time (Carter et al. 2007). However, a large, protective waterbird, the trumpeter swan (*Cygnus buccinator*), rarely encountered predators at night (Henson and Cooper 1994). The theory that reduced visibility causes decreased rates of vigilance does not explain why there was not a change in vigilance during a new moon versus a full moon. Perhaps the moonlight is not bright enough to change behavior or the restorative sleeping behavior is too important (Tworkowski and Lesku 2019). Lastly, we were not able to consider cloud cover in this study, which could have also affected the brightness of the moonlight and the ability of cranes or predators to see.

Habitat factors such as distance to closed forest and size of nesting wetland affected the vigilance of cranes. We suspected greater distances to forests and roads, larger wetland sizes, and less nest concealment could decrease rates of disturbance and increase visibility of predators, thus decreasing rates of vigilance; however, we found that whooping cranes nesting closer to forested areas were less vigilant and cranes in medium-sized wetlands were slightly more vigilant. Being close to closed forest means cranes could be closer to terrestrial predators; however, they have a more limited visual field, which could decrease the amount of time spent in vigilant behavior. Breeding Siberian jays (*Perisoreus infaustus*) with offspring behaved similarly, in that they were more vigilant in territories with large-scale open habitat (Griesser and Nystrand 2009). Being in an open area can put animals at risk for aerial predators and therefore cause an increase in vigilance. The cranes nesting in medium-sized wetlands were also farthest away from the forest and thus in more open wetlands. Although the nests in the large wetland were farther from roads, they had patches of closed forest within the wetland, causing them to be less visually open. Cranes being more vigilant in medium-sized wetlands compared to small and large wetlands could also be due to a small sample size of nests included in this study ($n = 9$).

Furthermore, pair characteristics thought to influence vigilance, such as age and experience, did not have a significant effect. The sex of the incubating bird could be further assessed for whooping cranes; however, in our study we could not always be certain of the sex of the incubating individual and did not include it in our analyses. Eldred (2009) reported male sandhill cranes to be more vigilant than females, which may also be true for whooping cranes.

Vigilance may not be a determining factor of nest success because all the nests we monitored were successful and hatched at least 1 chick; however, vigilance still varied among pairs. McKinney (2014) found a slight but nonsignificant increase in vigilance with successful nests of both sandhill cranes and whooping cranes. We monitored the same number of whooping crane nests in the same location as McKinney (2014). Vigilance might be found to have a significant influence on nesting success if there was a larger sample size or if we incorporated a different study area. It is important to continue to assess factors influencing nest success, which ultimately affect recruitment and population growth. In the future, behaviors of whooping cranes nesting in eastern Wisconsin could be compared to those in this study of cranes in Juneau County. This would give us the opportunity to look at less experienced birds, a variety of habitat characteristics, and an area with different predator communities.

MANAGEMENT IMPLICATIONS

Our study can be used as a comparison for future studies to determine if whooping cranes are exhibiting proper behavior while nesting and if vigilance affects nest success. If vigilance is significant to a successful nest, it is possible to modify their nesting habitat or release cranes in different areas with more suitable habitat. Future efforts to assess predator populations near nesting sites, studies that evaluate incubation behavior during black fly (*Simulium* spp.) emergence, or studies that include information about the stimuli to which cranes may be responding would also be valuable to determine if rates of vigilance are affected by predator activities, risks of predation, disturbance by black flies, or other threats.

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