How much can the number of jabiru stork (Ciconiidae) nests vary due to change of flood extension in a large Neotropical floodplain?

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ABSTRACT. The jabiru stork, *Jabiru mycteria* (Lichtenstein, 1819), a large, long-legged wading bird occurring in lowland wetlands from southern Mexico to northern Argentina, is considered endangered in a large portion of its distribution range. We conducted aerial surveys to estimate the number of jabiru active nests in the Brazilian Pantanal (140,000 km²) in September of 1991-1993, 1998, 2000-2002, and 2004. Corrected densities of active nests were regressed against the annual hydrologic index (AHI), an index of flood extension in the Pantanal based on the water level of the Paraguay River. Annual nest density was a non-linear function of the AHI, modeled by the equation $6.5 \cdot 10^{-8} \cdot \text{AHI}^{1.99}$ (corrected $r^2 = 0.72, n = 7$). We applied this model to the AHI between 1900 and 2004. The results indicate that the number of jabiru nests may have varied from about 220 in 1971 to more than 23,000 in the nesting season of 1921, and the estimates for our study period (1991 to 2004) averaged about 12,400 nests. Our model indicates that the inter-annual variations in flooding extent can determine dramatic changes in the number of active jabiru nests. Since the jabiru stork responds negatively to drier conditions in the Pantanal, direct human-induced changes in the hydrological patterns, as well as the effects of global climate change, may strongly jeopardize the population in the region.

KEY WORDS. Flood; jabiru nesting; *Jabiru mycteria*; Neotropical wetlands; Pantanal.
wading birds is higher, and last longer, in wet years when compared with dry years. In fact, jabiru nests have been found to be active every year (Antas & Nascimento 1996, González 1996) or every other year (Campos & Coutinho 2004, Antas & Nascimento 1996), depending on habitat conditions (González 1996). Since Ciconiforms generally forage in relatively shallow water (Sick 1997), they synchronize their nesting with the draining stage of seasonal wetlands (David 1994, González 1996, Barnhill et al. 2005) to warrant food supply during the period of reproduction (Frederick & Ogden 2001). Therefore, the abundance and reproductive performance of the jabiru stork are expected to be related to the extent of floods and the hydrological characteristics of the major wetlands in which this bird occurs.

The aim of this study was to investigate the temporal variation in the jabiru stork nest density in the Pantanal wetland and its relationship with the flood extension in the region. We hypothesized that flooding extension affects positively the jabiru nest densities in the Pantanal, resulting in large variations in the number of active nests among years.

MATERIAL AND METHODS

The Pantanal is a large wetland (~160,000 km²) located in central South America (Brazil, Bolivia and Paraguay), with nearly 140,000 km² of its area in Brazil (Silva & Abdon 1998, Junk & Cunha 2005). The floodplains occupy about one third of the Paraguay River hydrographic basin (Silva & Abdon 1998), and the most distinct characteristics of this region are low altitude (75 to 200 m a.s.l.), flatness, alternated periods of flood and drought, high annual thermal amplitudes, and strong seasonality in precipitation (Harris et al. 2005). There is also interannual variation in flood intensity (Mourão et al. 2002, Junk et al. 2006b) resulting from consecutive years of high precipitation followed by years of less intense rainfall (Da Silva & Girad 2004, Harris et al. 2005).

Aerial survey was used to estimate the density of jabiru nests along transects covering the Pantanal wetland in Brazil, between parallels 16° and 20°S (about 140,000 km²), in September of 1991, 1992, 1993, 1998, 2000, 2001, 2002, and 2004. The surveys were designed to monitor the marsh deer, Blastosfercus dichotomus (Illiger, 1815), pampas deer, Ozotoceros bezoarticus (Linnaeus, 1758), and yacare caiman, Caiman yacare (Daudin, 1801), populations (see Mourão et al. 2000), as well as active nests of the jabiru stork. As the jabiruses reuse nests for many nesting seasons, we attempted, in each survey, to detect whether each nest was active or not. We considered a nest active when hatchlings, eggs, or adults were observed in the nests. This assessment was possible due to the white, conspicuous color of the large eggs or nestlings that contrast sharply with the brownish color of the nest background. Additionally, most nests were built on large deciduous Tabebuia (Gomez ex de Candolle, 1838) or Sterculia (Linnaeus, 1753) trees (Antas & Nascimento 1996), which are usually leafless (Fig. 1) by September in the Pantanal (Pott & Pott 1994), coinciding with the peak of the jabiru nesting season. All counts were made from a fix-winged aircraft (Cessna 182 or Cessna 206) flying 61 m above the ground at 200 km/h. Nests were counted in a 200 m wide strip at ground level, which was delimited by a rod with reference marks in the airplane. Transects were spaced six geographic minutes from one another during the 1991-1993 surveys, and about 12 geographic minutes in the later surveys. Sampling intensity was defined as the ratio of the area actually sampled (i.e., the sum of the strip transect areas) and the total area surveyed. As the transect lengths were unequal and their numbers varied among the years, the resulting sample intensities ranged from 1.4-1.7% in the 1991-1993, and 0.7-0.8% in the later surveys.

The double-count technique, a method derived from the Lincoln-Petersen estimate (Magnussen et al. 1978, Caughley & Groce 1982, Bayless & Yomans 1989, Graham & Bell 1989, Potvin et al. 2004) was used to improve the accuracy of the estimates. In this technique, two observers placed at the same side of the airplane conducted independent counts, and each transect was divided into subunits of approximately 3 km in which sightings were recorded. By comparing the records of both observers in each sub-unit, we separated the nests into three categories: B (sighted by both observers), S₁ (sighted only by observer 1), and S₂ (observed only by observer 2). The detection probability (P) was obtained according Graham & Bell (1989). Then, the multiplicative correction factor for the counts was estimated as CF = 1/P and was applied to the total number of nests recorded in each transect (S₁+S₂+B) to obtain the corrected counts (y) (Graham & Bell 1989). We estimated corrected nest abundance (Y), corrected density (D), and their standard errors (SE) using the equations of Sinclair et al. (2006) for sample units of different sizes and without replications.

We obtained an annual hydrologic index (AHI) (Valderrama & Petrere 1994) as the sum of the daily Paraguay River water level (in meters) measured at Ladário, Mato Grosso do Sul, Brazil (57°35’W, 19°00’S). The data recorded at Ladário is especially convenient for our analyses, as it correlates with the flooded area of the Pantanal (Hamilton et al. 1996). Then, AHI expresses the extension and duration of the floods in the Pantanal. Because our surveys always took place in early September, coinciding with the peak of the jabiru stork nesting period, our “hydrologic year” started every September 1st of the previous year and ended on August 31st of the modeled year. Also, we examined the Pearson correlation between the AHI and its corresponding 24-month hydrologic index (i.e., the summation of the given AHI with a preceding one). This is a precaution we adopted, as there were reports of bi-annual nesting cycles by jabiru storks (Antas & Nascimento 1996, Campos & Coutinho 2004).

We used the NONLIN procedure of Systat 11 (Systat Inc. 2004, Illinois) to iteratively estimate parameters a and b of the model $D = a \cdot D_H^b$, where D is the corrected jabiru nest density. We identified one outlier corresponding to the 1998 survey, a year in which the Tabebuia trees sprouted early, resulting
in a lower nest visibility from the air. We excluded this point and re-ran the analysis. The resulting models were used to retrospectively estimate the abundance of nests based on the historical data-set of the Paraguay River level at Ladário (1900 to 2004). Finally, we compared the abundance estimates obtained from the models, including and excluding the outlier, using the Kolmogorov-Smirnoff two-sample test (KS).

RESULTS

In the historical series comprising the period from 1900 to 2004, the AHI varied about ten-fold from its minimum to its maximum in the Pantanal, ranging from 165.5 m in 1971 to 1654.1 m in 1921 (Fig. 2), with a mean of 989.3 m (SD = 364.0 m). The period from 1962 to 1973 was unusually dry, and was fol-
DISCUSSION

Our model is simple and does not take into account complex feedback processes expected to occur in population dynamics (e.g., Sinclair et al. 2006). However, our goal was not to build an accurate model to predict the number of jabiru nests from a single factor. Instead, we examined the magnitude of change in nest density in a scenario of natural or artificial changes in flooding extension affecting large wetlands such as the Pantanal. The nesting interval of jabirus did not restrict our modeling approach, since the AHI and the 24-month HI were highly correlated in the Pantanal. Our model indicates that the multiyear variations in the flooding extent may determine dramatic changes in jabiru nest numbers in the Pantanal. It also indicates that, during the long dry period of the 1960s and early 1970s, the number of jabiru nests in the Pantanal may have fallen to nearly 200, as estimated from our density model applied to the whole area covered by the surveys (i.e., 140,000 km²). In the same period, the average number of nests was estimated to be about 1,700. During the period in which we surveyed jabiru nests in the Pantanal (1991-2004), active nest abundance was estimated to be relatively high, and at least 30,000 reproductive individuals may have inhabited the Pantanal.

Large-scale direct human interventions may cause strongly negative impacts on jabiru stork conservation. Hamilton (1999) pointed out that interventions in the Paraguay River channel to improve navigation, such as those planned for the “Paraguay Hydrosia Project”, may change the pattern and extent of flooding in the Pantanal. The Hydrosia project was officially abandoned by the Federal Government in 1996, but the construction of dams in headwaters of the rivers that flow through the Pantanal now poses
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Since 2002, a 212 MW power station in the Manso River has been in operation, which has resulted in an artificial lake of about 420 km². This dam has already changed the hydrology of the Cuiabá River (Junk et al. 2006b), the most important tributary of the Paraguay River. Recently, the Government has allowed the construction of 44 small dams for hydroelectric production purposes (0.12 to 29.1 MW), and there are plans to build additional 71 dams along the headwaters of the tributaries of the Paraguay River. The potential impact of each of these individual plants is relatively small, but pooled together they may severely alter the flood pulse in the Pantanal. This type of change in the ecosystem may affect directly the number of jabiru nests in the floodplain, given the strong relationship between water availability, flood regime and nesting by the jabiru stork. It is not unlikely that other animal species that are highly dependent on the floods, such as the yacare caiman (Campos & Magnusson 1995) or the endangered marsh deer (Tomas et al. 2001) would be negatively affected by such a large-scale environmental change.

Global climate change projections for the Pantanal region indicate a two-month delay in the rainy season (Marengo 2007). Some scenarios also suggest a 0.5 mm/day reduction in rainfall, as well as negative anomalies (severe decrease in rainfall) after 2060, and a 3-6°C increase in the average temperature (Marengo 2007). Although these models are not conclusive, they suggest changes that may lead to a strong impact in the characteristics of the floods in the Pantanal. Our predictions, based on historical records of the Paraguay River levels, show that extended dryer periods would severely affect the number of jabiru nests in the Pantanal. Consequently, the population of this species may be in jeopardy in the future. It will be of special concern if both threats, dams and climate change, conjugate to deeply change the functioning of the Pantanal wetlands.

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