ATTACHMENT D

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Implications of Spring Water Levels on the Production of American White Pelicans Nesting at Marsh Lake, Minnesota (2015)

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Research Article

Implications of Spring Water Levels on the Production of American White Pelicans Nesting at Marsh Lake, Minnesota

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ABSTRACT We investigated the relationship between spring water levels and production of American white pelicans (*Pelecanus erythrorhynchos*) nesting colonially at Marsh Lake in southwest Minnesota during 2003–2012. We obtained estimates of pelican nest and chick numbers from aerial photographs to determine population levels. We used historical streamflow data to characterize April water conditions, a period when nest-site selection typically occurs. Pelicans used 4 islands and 1 peninsula for nesting, ranging from relatively high-elevation sites connected to or near the mainland to more distant low-elevation sites in the middle of the lake. The number and proportion of nests on high-elevation sites are positively related to discharge in the Upper Minnesota River during April. In years when high water inundates low-elevation sites during pelican nest-site selection, pelican nests were located on the high-elevation locations near or connected to the mainland. Over 90% of the variation in the number of nests on high-elevation sites is related to the mean daily discharge in the Upper Minnesota River during April. In addition, the proportion of nests on high-elevation sites also increases as mean daily discharge during April increases. However, chick production was negatively related to discharge during April. More than 84% of the variation in the number of near-fledged chicks produced per nest was related to mean daily discharge during April. Although high-elevation sites in close proximity to the mainland offered nesting pelicans refuge from high water levels, they also expose American white pelican nests to greater predator risk. Nest camera monitoring indicated that high-elevation sites exhibited significantly higher predator activity than low-elevation sites, and experienced lower nest success (i.e., probability that at least 1 egg from the nest hatched). Proposed changes in the management of Marsh Lake call for the installation of a water control structure at the Marsh Lake dam that will allow for active management of lake levels. Our study provides managers with models for predicting impacts of water levels on American white pelican production.

KEY WORDS American white pelican, disturbance, Marsh Lake, Minnesota, nest-site selection, *Pelecanus erythrorhynchos*, production, spring water levels.

The American white pelican (*Pelecanus erythrorhynchos*) is a species of management interest, yet much of its reproductive ecology remains unknown (Evans and Knopf 2004). American white pelicans lay 2 eggs per clutch in a nest on the ground (Evans and Knopf 2004) in large, mixed flock colonies in the Upper Midwest, where it is listed as a species of conservation concern in Minnesota (Minnesota Department of Natural Resources [MN DNR] 2006), North Dakota (Hagen et al. 2005) and South Dakota (South Dakota Department of Game, Fish and Parks 2005). Anecdotal observations suggest American white pelicans prefer to nest on islands to minimize disturbance during the nesting period (Evans and Knopf 2004). Habitat availability on islands and proximity to mainland will vary with water level, especially in riverine systems or reservoirs. However, the effects of nest-site location on nest success, pelican reaction to disturbance, and water-level effects on island habitat and chick production have not been quantified for American white pelicans.

Insular nesting habitat may provide protection from predators but may expose American white pelican colonies to flooding. Vermeer (1970) hypothesized that the distribution of American white pelican colonies in Canada was determined by the availability of remote, isolated islands, which provided refuge from mammalian predators that outweighed the cost in distance to food resources (the island hypothesis). Diem and Pugesek (1994) observed no fledgling

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production in years with high inflows to Yellowstone Lake, Wyoming, USA that flooded the Molly Islands' nesting colony of the American white pelicans. However, at Pyramid Lake, Nevada, USA, production of the American white pelican nesting colony on Anaho Island was positively correlated with spring flows on the lower Truckee River (Murphy and Tracy 2005). At Chase Lake, North Dakota, USA, rising lake levels in the mid-1990s flooded the islands where American white pelicans historically nested, and the colony relocated to a nearby peninsula where evidence of mammalian predation was observed (Sovada et al. 2005). High rates of predation at the peninsula site are hypothesized to have caused subsequent colony abandonment in 2004 (Cohn 2006). Effects of river flow and predator presence on nest distribution have not been quantified at American white pelican colonies.

The American white pelican colony on Marsh Lake (an impoundment along the Minnesota River) in the Lac qui Parle Wildlife Management Area (WMA), Minnesota, USA is among the largest in North America. Recent estimates of the number of nesting adults at Marsh Lake (this study) indicate this colony annually supports at least 15,000 breeding pairs, which is comparable to the number of breeding pairs in the largest American white pelican colonies in North America (Evans and Knopf 2004, King and Anderson 2005). Based on these estimates, the colony at Lac qui Parle WMA is an integral component of the continental American white pelican population. Changes in the management of spring river flows in the Upper Minnesota River have recently been proposed by the United States Army Corps of Engineers (USACE 2011), and we investigate the implications for American white pelican nesting and production at Marsh Lake. Moreover, the most recent survey of American white pelican colonies in North America found approximately 30% (13 of 45) of the colonies were located on rivers, reservoirs, or impoundments (King and Anderson 2005). Thus, our findings may have implications for management of nesting habitat at many of the North American colonies. We examined historical streamflow data, nest counts, nesting behavior, nesting success, and chick production to 1) determine if pelican preference for insular nesting habitat was consistent with the island hypothesis, 2) quantify the effects of streamflow on colony production, and 3) evaluate potential density limitations in island habitat at the Marsh Lake American white pelican colony. We discuss the implications of our findings for the management of American white pelicans and more broadly for colony-nesting waterbirds.

STUDY AREA

We monitored American white pelican nesting on Marsh Lake at Lac qui Parle WMA (N 45° 11′, W 096° 09′) in southwestern Minnesota, USA from 2003–2012. Lac qui Parle WMA is a 12,545 ha area along the Upper Minnesota River in Chippewa, Swift, Big Stone, and Lac qui Parle counties, Minnesota managed by the Minnesota Department of Natural Resources for waterbirds and other resources MN DNR 1997). Prior to the discovery of American white pelicans nesting at Marsh Lake in 1968 (Breckenridge 1968), the last report of pelicans nesting in the vicinity was approximately 80 km north-northwest of Marsh Lake on the Mustinka River in 1878 (Roberts and Benner 1880).

Marsh Lake is a river floodplain lake originally formed behind the alluvial sediment deposited at the confluence of the Pomme de Terre and Minnesota rivers (Covert et al. 1912). Approximately 6.5-km long and 1.5-km wide, the shallow lake dominated by emergent vegetation was mostly drained by 1920 (Upham 1920). The Marsh Lake dam was constructed between 1936 and 1939 by the Works Progress Administration, and improved by the United States Army Corps of Engineers between 1941 and 1951. The dam was originally intended to serve flood control and recreational purposes by creating a static pool on the river; however, its flood control benefits are minimal because of downstream capacity of the Lac qui Parle reservoir (USACE 2011). There are currently no means to manipulate outflow or to manage water levels on Marsh Lake.

METHODS

Streamflow Data

To characterize spring water conditions at Marsh Lake, we calculated the mean rate of daily discharge during April from historical streamflow data in the Upper Minnesota River. We obtained mean daily discharge (m^3/s) for 2003–2012 for the Minnesota River at Ortonville (United States Geological Survey [USGS] site 05292000, available at http://waterdata.usgs.gov/mn/nwis/uv/?site_no=05292000&PARAmeter_cd=00065,00060), which is approximately 26 km upstream from Marsh Lake. We then computed the monthly mean daily discharge (m^3/s) for 1 April–30 April for each year to compare with nest and chick counts. We obtained mean monthly water levels from USACE station MLDM5, which is at the Marsh Lake dam near Appelton, Minnesota, USA (available at http://rivergages.mvr.usace.army.mil/WaterControl/stationinfo2.cfm?sid=MLDM5&fid=MLDM5&dt=S). Mean monthly discharge was significantly related to mean monthly water-level elevations at Marsh Lake (mean April water-level elevation [m] = 286.0–0.07 × [1–mean monthly discharge in April$^{0.71}$]; $F_{2,12} = 222.0$, $P < 0.001$, $r^2 = 0.97$). However, the water-level elevations were not available for parts of April in both 2007 and 2010, and we elected to use discharge data to obtain a longer record for comparison. Mean daily discharge for April was selected to represent water conditions during the period when pelican nest-site selection typically occurs. We combined a digital elevation model (available via http://arcgis.dnr.state.mn.us/gis/lidarviewer/) with the mean water-level elevation at Marsh Lake during April to estimate the area (ha) of each island and the Peninsula site that was above water during April so that nest density (number/ha) could be calculated from the nest count data at each site.

Within the WMA, Marsh Lake is a 1,820–2,470-ha impoundment on the Minnesota River, characterized by shallow, eutrophic waters (MN DNR 1997). There are 4 islands present in Marsh Lake which have been used intermittently for nesting by American white pelicans since at least 1968 (Orr 1980): One-acre Island, approximately 0.3 ha (all island areas determined when water level elevation is 286.5 m above mean sea level); Big Island, approximately 3.9 ha; Eight-acre Island, approximately 3.4 ha; and Currie Island, approximately 8.8 ha. A fifth island (Hermit Island, approx. 0.5 ha) was used by pelicans for nesting only through 1996 (A. H. Grewe, Jr., St. Cloud State University, personal communication), and thus we did not include it in the analysis presented here. In addition to the insular nesting sites, pelicans also have nested on a peninsula (approx. 12.6 ha and henceforth referred to as the Peninsula site) adjacent to these islands (Fig. 1). Of the nesting sites used by the pelican colony, both Currie Island (mean = 287.6 m, max. = 289.7 m above mean sea level) and the Peninsula site (mean = 288.6 and max. = 289.8 m) have higher elevations than One-acre (mean = 286.7 m and max. = 287.4 m), Big (mean = 286.7 m and max. = 288.7 m) and Eight-acre (mean = 287.5 m and max. = 288.3 m) islands. Therefore, we considered Currie Island and the Peninsula site as high-elevation sites, and the remaining islands as low-elevation sites. American white pelicans typically initiate nesting at Marsh Lake by early or mid-April (J. J. DiMatteo, North Dakota State University, personal observations).

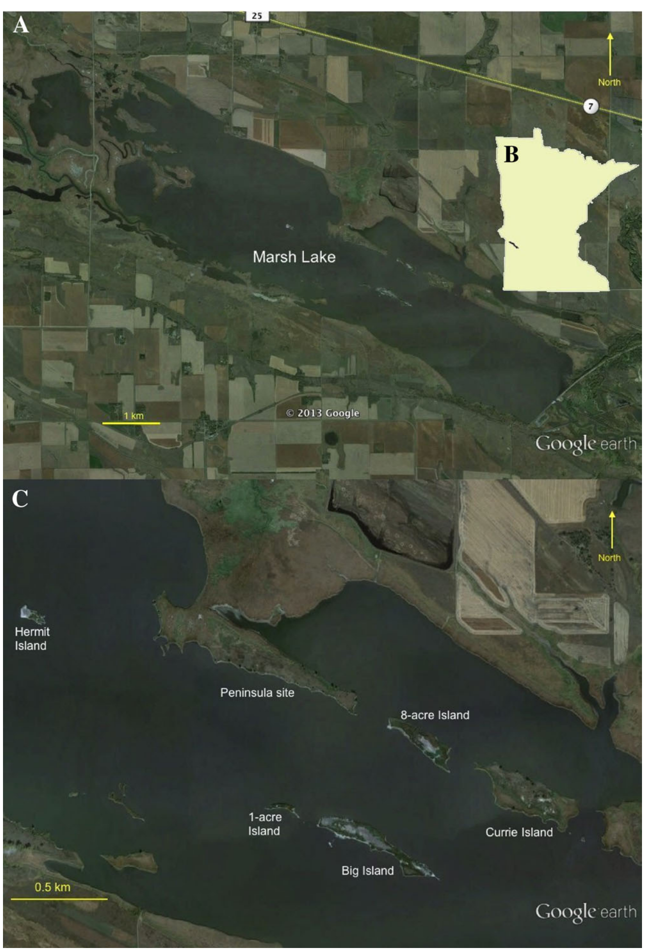

Figure 1. Marsh Lake impoundment on the Upper Minnesota River (A), located in southwestern Minnesota (inset B), and detailed view of the nesting sites (C) used by American white pelicans, 2003–2012. Map data: Google, U.S. Department of Agriculture Farm Service Agency.

Nest and Chick Counts

We estimated the number of American white pelican nests on Marsh Lake from aerial photographs of the colony. We obtained photographs and counts of nests for 2003 and 2006–2012; no flights occurred in 2004 and 2005 because of logistical complications. Based on ground observations of the colony, we scheduled flights to occur mid- to late May near the peak of nesting when chicks were beginning to hatch in the earliest initiated nests, and adults were beginning continuous incubation in the latest initiated nests. Flights occurred between 0830–0930 CDT when adults were most likely on the nests to brood young chicks or incubate eggs but prior to any changeover bouts between mates, which occur later in the day (J. J. DiMatteo, personal observations). A photographer produced near-vertical oriented photographs taken at an altitude of 150–200 m. We scanned traditional 35-mm film photographs taken through 2009 to produce digital images for counts. We obtained digital photographs in 2010 and afterwards.

We estimated counts of nesting birds from digital images using UTHSCSA ImageTool software (University of Texas Health Science Center, San Antonio, Texas, USA). We made manual counts as well as automated counts from the UTHSCSA ImageTool count routine (Laliberte and Ripple 2003). Manual and automated counts were significantly correlated ($\rho^2 = 0.89$, $P = 0.008$ for counts from 2003, 2006–2008, and 2010–2012), but we report (and analyze) only results of manual counts here. Adult pelicans that are not tending eggs or chicks at a nest do not loaf or linger in the colony, nor do they forage on Marsh Lake, so we assumed each pelican identified on land that displayed a uniform spacing between adjacent birds in nesting areas occupied a nest (Fig. 2A). We assumed each nest indicated a breeding pair so that the number of breeding adults would be twice the number of nests identified in the images. We also noted the island or Peninsula site that the nest was located.

We also determined the number of American white pelican chicks produced at the Marsh Lake colony from aerial photographs. Since 2006, we used a second flight (in late Jul or early Aug at 150–200 m altitude) to obtain photographs of near-fledged chicks at a time (approx. 0900 CDT) when previous observations suggest few adults were present in the colony. However, the second flight in 2008 was delayed because of scheduling difficulties beyond the point of fledging and we could not obtain reliable aerial images of chicks. As with nesting pelicans earlier, adult pelicans that are not in the colony to feed chicks do not loaf or linger in the colony, so we determined chick counts in the same manner as the nest counts, assuming all birds counted were chicks (Fig. 2B). Photographs from 2011 and 2013 were of sufficient quality to distinguish adults from chicks based on the orange coloration of the bill and legs, and gray coloration of the crown and nape in adults compared to gray coloration of the bill and legs, and white coloration of the crown and nape in chicks (Evans and Knopf 2004), and comparisons of total counts with chick-only counts differed by less than 5% for both years. We did not assign chick counts to individual islands or the Peninsula site, because at that age chicks can swim or walk among the islands or nesting areas during the day.

Nest Monitoring

In 2011 and 2012, we monitored 37 and 35 nests, respectively, to determine nest success rates at contrasting sites in the colony. We searched the islands and Peninsula site for nests (beginning in Apr) in the early stages of incubation, determined by the number of eggs in the nest or staining and texture of the eggs (Evans and Knopf 2004). We marked selected nests using small stakes adjacent to the nest and with a code written on the blunt end of each egg, recorded the location (latitude, longitude, and elevation) using a handheld global positioning system (GPS), and returned to the location at 7–10-day intervals to monitor progress of the nest to determine fate. In subsequent visits to a nest, we recorded the date and whether the nest was still viable. If we observed a hatching (or less than 1-week-old) chick in the nest, we recorded the date, designated the nest as successfully producing a chick, and ceased monitoring the nest. To compare nest success between high-elevation sites near the mainland with low-elevation sites farther from the mainland, we located 17 nests on the Peninsula site (a high-elevation, mainland site) and 20 nests on Eight-acre Island (a low-elevation site approx. 235 m from the nearest mainland) in 2011. We monitored an additional 10 nests on Currie Island (a high-elevation site approx. 127 m from the nearest mainland and 188 m from Eight-acre Island), 4 nests on the Peninsula site, and 25 nests on Big Island (a low-elevation site approx. 746 m from the nearest mainland) in 2012. We used the latitude and longitude coordinates for each monitored nest to determine the distance to the nearest mainland shoreline (which was 0 m for nests located at the Peninsula site). We did not monitor nests on One-acre Island.

Figure 2. Aerial photographs of incubating adult American white pelicans (A) and a crèche (pod) of near-fledged chicks (B) at Marsh Lake, Minnesota, 2011.

Nest Camera Monitoring

In 2012, we used digital trail cameras to record disturbance, predator presence, and the behaviors of adults and chicks around nests. We placed cameras (Model MFH-DGS-M80, Moultrie, Alabaster, AL, USA) near clusters of nests, programmed to take 2 digital images every 10 minutes if the motion sensor was triggered, which was sufficient to detect any changes in pelican or predator activities. We replaced 8-gigabyte memory cards approximately every 10 days. Each image was digitally stamped with the date and time it was recorded. We deployed cameras on various dates during the early nesting period, and they remained active through 31 August. We used only images captured prior to 1 July to document disturbance, predator presence, and adult and chick behaviors because after that date, few adults were present in the colony and chicks became increasingly mobile and disconnected from their immediate nest locations. Two cameras monitored activities on the Peninsula site from 31 March until all nesting pelicans abandoned the site in late April in response to coyote (*Canis latrans*) predation. We placed 6 cameras on Big Island between 11 April and 12 May, 1 camera on One-acre Island on 6 May, 3 cameras on Currie Island between 6 May, and 12 June, and 3 cameras on Eight-acre Island between 19 May and 25 May.

We categorized disturbance events from the digital images recorded by the nest cameras in 7 different categories. When an image captured a specific predator (Fig. 3A), we categorized the event as striped skunk (*Mephitis mephitis*), raccoon (*Procyon lotor*), or coyote. If incubating (or brooding) adults or chicks abruptly left the nest locations at the time researchers were known to be visiting the colony (or seen in the image), we categorized the event as human disturbance. If incubating (or brooding) adults or chicks abruptly left the nest locations but no predator or human visit could be verified, we categorized the event as unknown disturbance (Fig. 3B). If the image was of routine behaviors (e.g., preening) associated with incubating (or brooding) adults or chicks at the nest locations, we categorized the event as undisturbed (Fig. 3C). Finally, in some instances cameras malfunctioned during the recording of the digital image because of lighting, weather, or battery power, and a clear image could not be discerned. We categorized these events as malfunction.

Using the date and time record for each categorized event, we tabulated the number of camera-days for each disturbance category for each island: we assigned a camera-day for an event if that event occurred on that day. For instance, if a

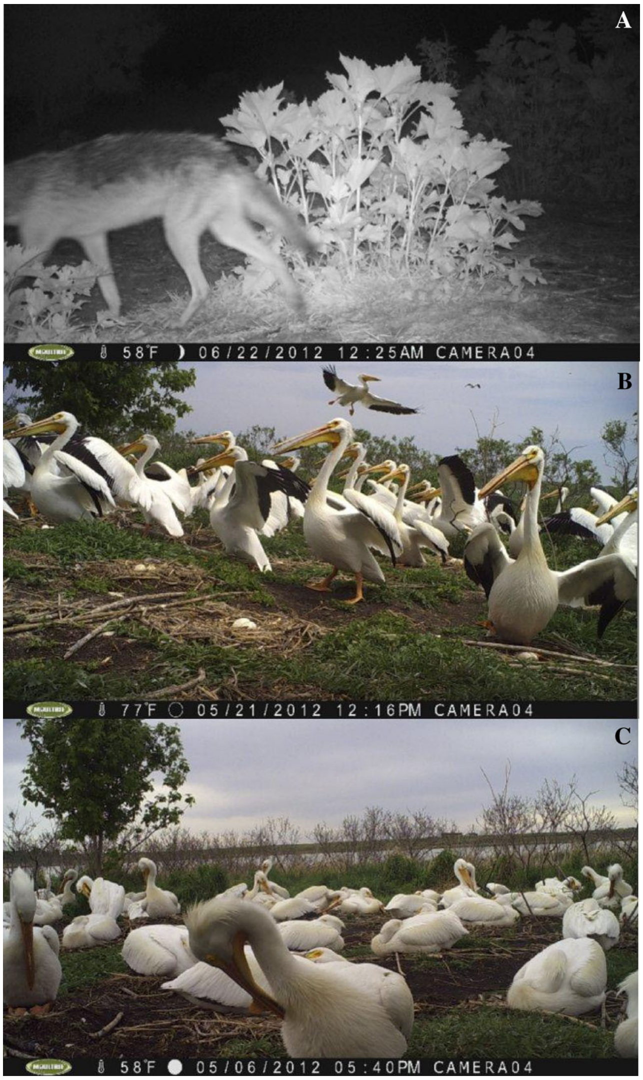

Figure 3. Images captured by remote nest cameras at Marsh Lake, Minnesota in 2012 showing coyote (predator) disturbance event (A), unknown disturbance event (B), and undisturbed incubating adult American white pelicans (C).

coyote was recorded by a camera on a day, then we assigned 1 coyote disturbance camera-day for the site on which the camera was located. We assigned only 1 category disturbance for a particular camera-day. When multiple events were recorded on a single day for a particular camera, we prioritized the category disturbance given for the camera-day such that documentation of known predator (i.e., skunk, raccoon, or coyote) events were given higher priority over all other categories of disturbance. Thus, if a skunk event and another event (e.g., undisturbed event, unknown event) were recorded by a camera on a particular day, we assigned a skunk disturbance camera-day for that camera. If multiple predator events occurred on the same day for a particular camera, we assigned the predator disturbance camera-day based on the first predator recorded. Similarly, we assigned unknown disturbance event if undisturbed event or malfunction event also occurred. We assigned a malfunction event even if an undisturbed event occurred as well. Because some nest sites (e.g., Big Island, Eight-acre Island) had more than 1 camera deployed, multiple different disturbance event camera-days could occur on a single day for some nesting sites.

Statistical Analysis

We used a general linear model to analyze the relationship between April water flow and nest distribution and chick production. We modeled the number (and proportion) of nests on high-elevation sites (Currie Island and Peninsula site) as a function of mean daily discharge in April. We also modeled the number of chicks per nest (computed from the ratio of the annual total chick count and the annual total nest count) as a function of mean daily discharge in April.

We modeled nest success for 2011 and 2012 to compare location effects on the probability that a nest successfully produced a chick. We used Program MARK to compute the daily probability of nest survival from our nest observations in 2011 and 2012 (Mayfield 1975, White and Burnham 1999). We excluded the 4 nests on the Peninsula site in 2012 from the analysis because all of these nests failed and adults abandoned the site (Table 1). We considered 11 models in which daily nest survival was modeled with effects for 1) year, high-elevation versus low-elevation site, and interaction, 2) year and high-elevation versus low-elevation site, 3) year, 4) high-elevation versus low-elevation site, 5) year and distance of the nest to nearest mainland shoreline, 6) year and distance of the island to nearest mainland shoreline, 7) year and nest elevation, 8) distance of the nest to nearest mainland shoreline, 9) distance of the island to the nearest mainland shoreline, 10) nest elevation, and 11) no other effects (i.e., constant daily nest survival rate for all years, locations, and nests). We used the relative Akaike's Information Criterion adjusted for small sample size (ΔAIC_c; Burnham and Anderson 2002) to select the most parsimonious model given the data.

Table 1. Estimated number of American white pelican nests by nest site, near-fledged chicks, and near-fledged chicks per nest at Marsh Lake, Minnesota for 2003 and 2006–2012. Counts of near-fledged chicks were not available for 2003 and 2008.

Year	One-acre Island	Big Island	Peninsula site	Eight-acre Island	Currie Island	All sites	Chicks	Chicks per nest
2003	0	9,040	2,602	5,300	0	16,942		
2006	0	4,424	4,748	5,444	4,780	19,396	11,339	0.58
2007	0	3,537	4,850	4,645	5,719	18,751	9,960	0.53
2008	210	3,720	4,091	3,162	4,286	15,469		
2009	400	5,430	3,701	2,400	5,709	17,640	9,818	0.56
2010	36	1,253	6,282	555	6,029	14,155	7,446	0.53
2011	0	339	9,524	1,140	6,755	17,758	8,931	0.50
2012	333	6,375	0	3,579	5,119	15,406	9,344	0.61

We modeled total nest counts from 1968 to 2012 using a sigmoidal function and an exponential function with year as the independent variable to assess trends in the American white pelican breeding colony size at Marsh Lake. We used maximum likelihood methods to determine the coefficients for each model, determined significance of the model in explaining variation in the number of nests observed in a year using an F test, and compared the 2-parameter sigmoid model, in which the

$$\text{number of nests} = \frac{25 \cdot e^{r \cdot (\text{year}-1968)}}{K + (25 \cdot e^{r \cdot (\text{year}-1968)} - 1)},$$

with the single-parameter exponential model, in which the number of nests $= 25 \cdot e^{r \cdot (\text{year}-1968)}$, using the ΔAIC_c based on least-squares regression (Burnham and Anderson 2002) to determine the most parsimonious model.

We compared disturbance event camera-day totals among sites using a likelihood ratio test. For the disturbance event camera-day totals, we compared the distribution of disturbance event camera-days among nest sites using all events as well as reduced comparisons for known predators (i.e., skunk event camera-days combined with raccoon event camera-days and coyote event camera-days), non-human disturbance (i.e., combined predator events and unknown event camera-days), and both of these reduced comparisons with the malfunction and human event camera-days removed.

We used a general linear model to analyze the relationship between nest density and nest-site area. We modeled the density of nests as a function of nest-site area (during Apr) for the Peninsula site, Currie Island, Eight-acre Island, and Big Island. We conducted statistical analyses using either SAS (SAS Institute, Inc., Cary, NC, USA) or JMP (SAS Institute, Inc.) analysis software. We assumed significance at or below the 0.05 level. This research was conducted in accordance with North Dakota State University Institutional Animal Care and Use Committee (A13057).

RESULTS

Nests and young of American white pelicans varied temporally and spatially at Marsh Lake (Table 1). Nest counts indicated between 14,000 and 20,000 breeding pairs have occupied Marsh Lake since 2003. Chick counts indicated between 7,000 and 12,000 chicks were produced annually at Marsh Lake since 2003, with chick production varying from 0.50–0.61 chicks per breeding pair per year.

Nest-Site Distribution and Production

The number and proportion of nests on high-elevation sites were positively related to discharge in the Upper Minnesota River during April. Over 80% of the variation in the number of nests located on the Peninsula site was explained by a linear regression of mean daily discharge in the Upper Minnesota River during April (number of Peninsula site nests $= 1{,}209.5 + 101.7 \times$ mean daily discharge in April; $F_{1,6} = 26.9$, $P = 0.002$, $r^2 = 0.82$). Similarly, over 93% of the variation in the number of nests on high-elevation sites (i.e., Currie Island and Peninsula site) was explained by a linear regression of mean daily discharge in the Upper Minnesota River during April (number of Currie Island and Peninsula site nests $= 3{,}961.4 + 165.4 \times$ mean daily discharge in April; $F_{1,6} = 93.7$, $P < 0.001$, $r^2 = 0.94$). Finally, the proportion of nests on high-elevation sites increased significantly as mean daily discharge in the Upper Minnesota River during April increased ($F_{1,6} = 36.2$, $P = 0.001$; Fig. 4). In contrast, nests on low-elevation sites declined as April flow increased. For instance, the number of nests on Big Island decreased as mean daily discharge in the Upper Minnesota River during April increased (number of nests on Big Island $= 7{,}571.5 - 103.0 \times$ mean daily discharge in April; $F_{1,6} = 28.8$, $P = 0.002$, $r^2 = 0.83$).

Chick production was negatively related to discharge in the Upper Minnesota River during April (Fig. 5). More than 84% of variation in the colony's annual reproductive rate (number of chicks produced/nest) was explained by a linear regression of mean daily discharge in the Upper Minnesota River during April ($F_{1,4} = 22.2$, $P = 0.009$; Fig. 5).

Nest success was lower on high-elevation sites in close proximity to the mainland. The most parsimonious model in our candidate set assumed nest daily survival rate differed between high-elevation sites and low-elevation sites, and accounted for over 35% of the evidence given the data (Table 2, Fig. 6). However, the second-most parsimonious model (accounting for approx. 15% of the evidence given the data; Table 2) assumed nest daily survival rate increased with the distance of the nest from mainland shoreline (Fig. 6). Models in which the nest daily survival rate varied as a function of nest elevation per se were the least parsimonious models in the candidate set, accounting for less than 2% of the evidence given the data (Table 2). High-elevation sites are nearer to the mainland shoreline, and models in which nest daily survival rate varied with distance from the shoreline (either as mean island distance, individual nest distance, or site category) were more parsimonious than all

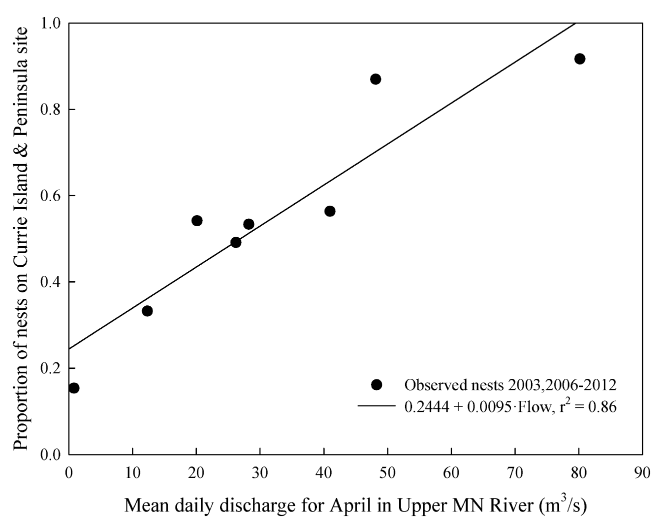

Figure 4. Proportion of American white pelican nests located on Currie Island and the Peninsula site (high-elevation sites near the mainland) at Marsh Lake, Minnesota during 2003 and 2006–2012 was positively related to mean daily discharge in April in the Upper Minnesota (MN) River.

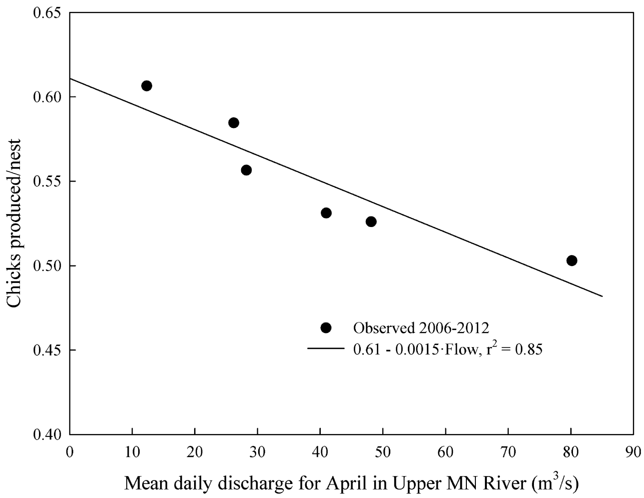

Figure 5. The number of near-fledged American white pelican chicks produced per nest at Marsh Lake, Minnesota during 2006–2012 was negatively related to mean daily discharge in April in the Upper Minnesota (MN) River.

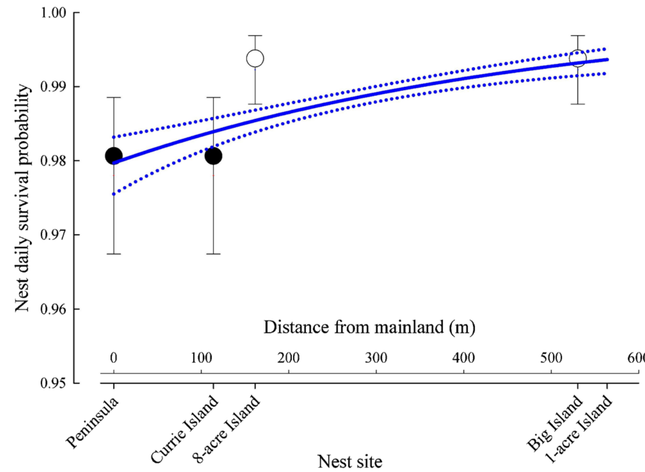

Figure 6. American white pelican nest daily survival probability (S) at Marsh Lake, Minnesota during 2011 and 2012 for the highest ranked model in the candidate set assumed differences between the high-elevation, near-mainland sites (i.e., Peninsula site and Currie Island; filled circles with 95% CIs given by the bars) and the low-elevation sites (i.e., Eight-acre and Big islands; open circles with 95% CIs given by the bars). Nest daily survival probability for the second highest ranked model assumed S increased with distance of the nest from the mainland shoreline (solid blue line, with 95% CIs indicated by the dashed blue lines).

other models of nest daily survival rate, accounting for more than 94% of the evidence given the data (Table 2).

Nest camera monitoring in 2012 indicated high-elevation sites in close proximity to the mainland experienced significantly more disturbance than low-elevation sites away from the mainland. The number of disturbance event camera-days differed among nesting sites ($\chi^2_{24,810} = 157.11$, $P < 0.001$; Table 3) because there were fewer disturbance event camera-days at low-elevation sites farther from the mainland (e.g., One-acre and Big islands). Furthermore, we found differences in disturbances between the Peninsula site, Currie Island, Eight-acre Island, Big Island, and One-acre Island (Table 3). These included reduced comparisons for known predators ($\chi^2_{16,810} = 150.04$, $P < 0.001$), non-human disturbance ($\chi^2_{12,810} = 106.16$, $P < 0.001$), known predators with malfunction and human event camera-days removed ($\chi^2_{8,629} = 112.81$, $P < 0.001$), non-human disturbance with malfunction and human event camera-days removed ($\chi^2_{4,8629} = 69.85$, $P < 0.001$), and sites combined as high-elevation (Peninsula site and Currie Island) or low-elevation (One-acre, Big, and Eight-acre islands) with human event camera-days removed ($\chi^2_{3,734} = 23.16$, $P < 0.001$; Table 3). Only 1 low-elevation site (Eight-acre Island, which is located between the Peninsula site and Currie Island; Fig. 1) experienced known predator event camera-days.

Pre-2003 Nest Counts

We obtained nest count estimates at the Marsh Lake colony prior to 2003 from the literature, personal communications, and unpublished data. Nest counts increased from a low of 25 in 1968 to a high of 6,000 in 2001 (Table 4). All counts were from ground surveys in the colony.

Since 1968, nest numbers (based on pre-2003 ground counts and post-2003 counts from aerial imagery) at Marsh Lake have increased, but since 2000 nest numbers have varied around a plateau. The 2-parameter sigmoid model (with $K = 18725.66 \pm 1476.56$ and $r = 0.215 \pm 0.010$) explained over 90% of the variation in historical nest numbers ($F_{1,20} = 133.51$,

Table 2. Candidate models of nest daily survival probability (S), functional form (β_i terms represent parameters), relative Akaike's Information Criterion adjusted for small sample size (ΔAIC_c), normalized Akaike weight (w_i), and model likelihood (i.e., evidence ratio compared to the model with lowest ΔAIC_c) from observations of 37 American white pelican nests in 2011 and 35 nests in 2012 at Marsh Lake, Minnesota. High-elevation site group includes the Peninsula site and Currie Island; low-elevation site group includes Big Island and Eight-acre Island. Island distance to mainland is 0 for the Peninsula site.

Model	Functional form	ΔAIC_c	w_i	Model likelihood
S(High/low site)	$\text{logit(S)} = \beta_0 + \beta_1 \cdot \text{site}$	0.00	0.35	1.00
S(Nest distance to mainland)	$\text{logit(S)} = \beta_0 + \beta_1 \cdot \text{nest distance}$	1.64	0.16	0.44
S(Year + high/low site)	$\text{logit(S)} = \beta_0 + \beta_1 \cdot \text{year} + \beta_2 \cdot \text{Site}$	1.99	0.13	0.37
S(Year + nest distance to mainland)	$\text{logit(S)} = \beta_0 + \beta_1 \cdot \text{year} + \beta_2 \cdot \text{nest distance}$	2.25	0.11	0.33
S(Island distance to mainland)	$\text{logit(S)} = \beta_0 + \beta_1 \cdot \text{Island distance}$	3.00	0.08	0.22
S(Year + Island distance to mainland)	$\text{logit(S)} = \beta0 + \beta1 \cdot \text{year} + \beta_2 \cdot \text{Island distance}$	3.42	0.06	0.18
S(Year × high/low site)	$\text{logit(S)} = \beta_0 + \beta_1 \cdot \text{year} + \beta_2 \cdot \text{site} + \beta_3 \cdot \text{year-site}$	3.99	0.05	0.14
S()	$\text{logit(S)} = \beta_0$	4.98	0.03	0.08
S(Year)	$\text{logit(S)} = \beta_0 + \beta_1 \cdot \text{year}$	6.81	0.01	0.03
S(Nest elevation)	$\text{logit(S)} = \beta_0 + \beta_1 \cdot \text{nest elevation}$	6.92	0.01	0.03
S(Year + nest elevation)	$\text{logit(S)} = \beta_0 + \beta_1 \cdot \text{year} + \beta_2 \cdot \text{nest elevation}$	8.57	0.00	0.01

Table 3. Disturbance event camera-days by nesting site for observations of American white pelican nests at Marsh Lake, Minnesota in 2012. Combined categories used in reduced contingency analyses are indicated with footnotes.

	Disturbance event									
Site	Human	Coyote	Raccoon	Skunk	Unknown	Malfunction	Undisturbed	Predator[a]	Non-human[b]	Total
Peninsula site	8	1	1	0	24	0	44	2	26	78
Currie Island	11	2	8	13	9	31	78	23	32	152
High-elevation[c]	19	3	9	13	33	31	122	25	58	230
Big Island	25	0	0	0	5	38	186	0	5	254
One-acre Island	12	0	0	0	5	0	48	0	5	65
Eight-acre Island	20	0	6	16	40	36	143	22	62	261
Low-elevation[d]	57	0	6	16	50	74	377	22	72	580
Total	76	3	15	29	83	105	499	47	130	810

[a] Coyote + Raccoon + Skunk (and not included in the Total column).
[b] Predator + Unknown (and not included in the Total column).
[c] Peninsula site + Currie Island (and not included in the Total row).
[d] Big Island + One-acre Island + Eight-acre Island (and not included in the Total row).

$P < 0.001$, $r^2 = 0.93$; Fig. 7). The single-parameter exponential model (with $r = 0.156 \pm 0.002$) explained only 63% of the variation in nest number ($F_{1,\,20} = 36.38$, $P < 0.001$, $r^2 = 0.63$). Given the data, the sigmoid model was more parsimonious (i.e., $\Delta AIC_c = 0$) than the exponential model ($\Delta AIC_c = 33.4$).

Number of nests and nest density were negatively related to nest-site area at the Peninsula site and Currie Island. Estimated area (in ha) available for nesting at the site during April explained over 75% of the variation in the number of nests (number of nests = 13,045.9–2,803.0 × estimated area; $F_{1,6} = 19.6$, $P = 0.005$, $r^2 = 0.77$) and nest density for the Peninsula site ($F_{1,6} = 19.4$, $P = 0.005$; Fig. 8A) and over 80% of the variation in the number of nests (number of nests = 9,742.1–631.9 × estimated area; $F_{1,6} = 26.2$, $P = 0.002$, $r^2 = 0.81$) and nest density for Currie Island ($F_{1,6} = 47.4$, $P < 0.001$; Fig. 8B). However, the number of nests was positively related to area available at both Eight-acre Island (number of nests = −1,113.3 + 1,436.1 × estimated area; $F_{1,6} = 5.0$, $P = 0.067$, $r^2 = 0.46$) and Big Island (number of nests = −2,780.1 + 1,929.8 × estimated area; $F_{1,6} = 15.1$, $P = 0.008$, $r^2 = 0.72$), and the estimated area available in April did not explain the variation in nest density at Eight-acre Island ($F_{1,6} = 0.4$, $P = 0.557$, $r^2 = 0.06$; Fig. 8C) nor Big Island ($F_{1,6} = 2.4$, $P = 0.170$, $r^2 = 0.29$; Fig. 8D).

Table 4. American white pelican nest count estimates reported from ground surveys conducted at Marsh Lake, Minnesota prior to 2003.

Year	Number of nests	Source
1968	25	Breckenridge (1968)
1972	150	Sloan (1982)
1974	75	A. H. Grewe, Jr. and J. C. Dorio, unpublished data
1976	276	Orr (1980)
1977	349	Orr (1980)
1978	465	Orr (1980)
1979	500	Sloan (1982)
1980	961	Sidle et al. (1985)
1983	1,450	Schladweiler (1984)
1984	1,465	A. H. Grewe, Jr., personal communication
1992	5,000	A. H. Grewe, Jr., personal communication
1996	5,000	Braud (1997)
2001	6,000	King and Anderson (2005)

DISCUSSION

Many factors affect nest-site selection and production in colonial nesting birds, and the distribution of American white pelican nests at Marsh Lake varies annually. Nest-site selection may vary with water level, available nesting space, vegetation, risk of depredation, or individual habitat preferences. However, our observations indicate that the majority of the variation in nest-site selection is explained by April flows in the Upper Minnesota River. Our nest counts may be biased because early nests that failed prior to the census, late nests initiated after the census, and nests obscured from view in the images would not be counted. However, we maintained consistent census methods for 8 years, and during this period the relative proportion of nests located on sites near the mainland increases with increasing April flows (Fig. 4). Higher spring flow inundates parts or all of the low-elevation, insular nesting habitat, and pelicans then select higher-elevation sites closer (or connected) to the mainland. These data support the hypothesis that American

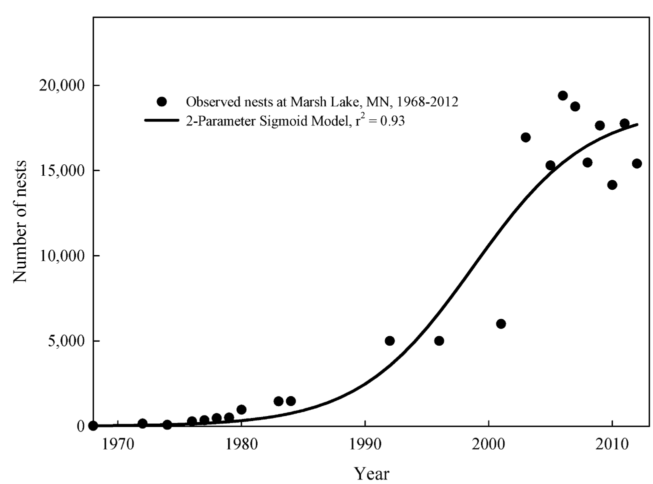

Figure 7. The number of annual American white pelican nests at Marsh Lake, Minnesota has increased to a plateau for 1968–2012, with a sigmoid model explaining more than 90% of the annual variation in the number of nests observed.

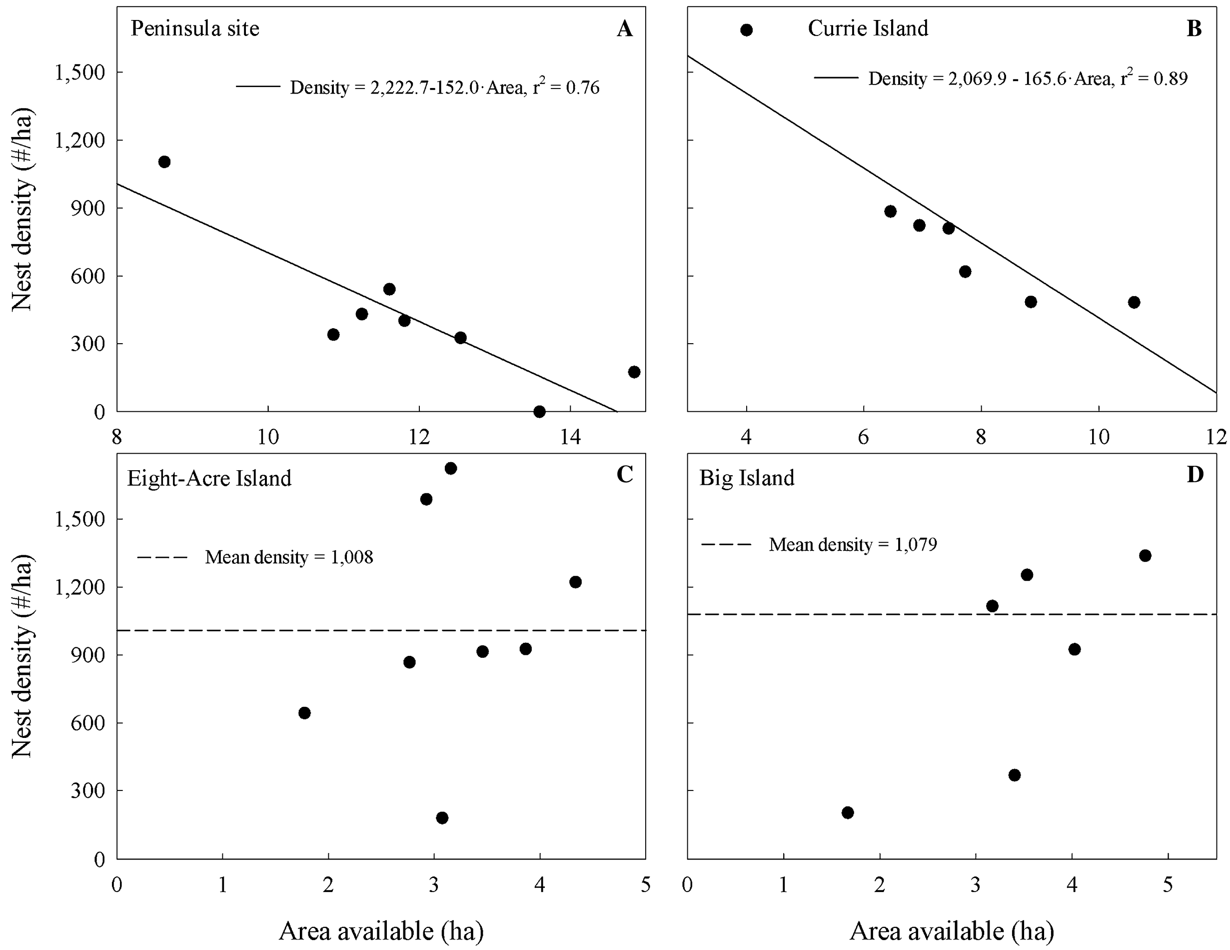

Figure 8. Nest density for American white pelicans at Marsh Lake, Minnesota during 2003 and 2006–2012 was negatively related to area available at the high-elevation, near-mainland Peninsula site (A) and Currie Island (B) but was not related to area available for nesting at the low-elevation Eight-acre Island (C) and Big Island (D), which are located farther from the mainland.

white pelicans prefer islands distant from the mainland for nesting (Vermeer 1970, Evans and Knopf 2004).

Although high-elevation sites offer protection from flooding, nests on these sites were less productive. We observed lower nest daily survival rates from the high-elevation sites in 2 years at Marsh Lake (Table 2, Fig. 6). At Marsh Lake, the high-elevation nesting areas (e.g., the Peninsula site and Currie Island) safe from flooding exhibited nest success of approximately 60%, whereas nest success at 2 low-elevation sites (Eight-acre Island and Big Island) exceeded 80% (Table 2, Fig. 6). Furthermore, cameras used to monitor nesting activity indicate rates of all disturbances, but especially predator disturbance, are significantly higher on the near-mainland, high-elevation nesting sites than on the low-elevation islands (Table 3). In fact, the only predator event camera-days observed on a low-elevation site occurred at Eight-acre Island, which is located between and near the Peninsula site and Currie Island (Fig. 1) where predator event camera-days were frequently observed (Table 3). Based on these observations, we conclude that nests nearer the mainland (which are high-elevation sites at Marsh Lake) experience lower rates of success because of depredation, supporting hypotheses that distant islands offer protection from predators (Vermeer 1970, Evans and Knopf 2004).

Because the number of pelicans nesting at Marsh Lake appears to have plateaued, April flows in the Upper Minnesota River affect fledgling production. Modeling growth in nesting (using pre-2003 nest counts and recent census counts from aerial photographs) indicates that the American white pelican colony at Marsh Lake supports approximately 18,725 nests annually (Fig. 7). April river flows upstream of Marsh Lake determine the proportion of those nests on high-elevation sites (closer to the mainland) with lower nest success versus low-elevation sites (farther from the mainland) with higher nest success. When flows are high, more nests are located on high-elevation, near-mainland sites and production declines. Indeed, April river flows are negatively related to colony productivity (Fig. 5).

The availability of nesting habitat on preferred sites may be limiting the population at Marsh Lake. The number of nests on the low-elevation sites away from the mainland (Eight-acre and Big islands) is positively related to area available (i.e., area of the island above water), a pattern observed in other colonial nesting bird populations in which there are density-dependent dynamics affecting reproduction (Sherley et al. 2014). At Marsh Lake, nest density on Eight-acre and Big islands was not related to area available (Fig. 8C and 8D), similar to patterns observed in little terns (*Sternula albifrons*) because of habitat preferences for small islands (Eason et al. 2012). We hypothesize that the mean nest densities observed on Big and Eight-acre islands (approx. 1,000 nests per hectare; Fig. 8C and 8D) may represent maximum nesting densities for American white pelicans. Nest densities at the Peninsula site and Currie Island only approached these levels (Fig. 8A and 8B) in 2011, when upstream flows in the Upper Minnesota River were highest for the survey period and therefore the least amount of total area was above the water level in Marsh Lake.

Limitations due to nest density and area available on preferred nesting sites could thereby restrict reproductive output and future growth of the Marsh Lake pelican colony. In waterfowl, insular nesting habitat provides protection from mammalian nest predators if the islands are sufficiently isolated to prevent access by mainland predators (Zoellick et al. 2004). Our observations from nest cameras and nest survival rates support a similar hypothesis for American white pelican nesting at Marsh Lake. In other colony-nesting birds, the benefits of island nesting (Koczur et al. 2014, Anteau et al. 2014) or nesting farther from mainland areas (Skorka et al. 2014) are consistent with our findings for American white pelicans at Marsh Lake.

These data show that water management in the Upper Minnesota River basin likely affects nesting and production in the American white pelican colony at Marsh Lake. Currently, water levels in Marsh Lake are positively related to April flow in the Upper Minnesota River. Recent evidence indicates American white pelicans are shifting the timing of nesting earlier at Chase Lake, North Dakota, USA (Sovada et al. 2014). If a similar pattern occurs at Marsh Lake, we would predict that the positive relationship between production and April flow in the Upper Minnesota River might shift such that late-Mar or early-April flow better predicts production. However, flow in the Upper Minnesota River would remain the primary factor influencing production in the Marsh Lake colony. The proposed Marsh Lake Ecosystem Restoration Project (USACE 2011) will attempt to return the lake to conditions experienced prior to impoundment (i.e., a shallow, vegetated lake), including the water-level regimes. This will be accomplished by installing a water control structure at the Marsh Lake dam that will allow for active management of lake levels, including periodic winter and growing-season drawdowns intended to enhance growth of aquatic vegetation and native fish populations while improving water clarity (USACE 2011), rather than the current situation in which lake levels are principally determined by upstream flow. Based on our quantification of the relationship between nest distribution (and productivity) and April discharge in the Upper Minnesota River (and therefore water level elevation in Marsh Lake under current conditions), managers can estimate the effects of different water-level scenarios under the proposed management plan on American white pelican production. Although project planners recognized the need to maintain adequate water levels during the breeding season to ensure that pelican nesting islands remain isolated from the mainland and potential mammalian predators (USACE 2011), they were unable to estimate how different water-level scenarios would alter chick production in the colony. Our findings enable managers to quantify expected production under the plan, and therefore assess the effects of other outcomes of the plan.

If other outcomes of the Marsh Lake Ecosystem Restoration plan alter human disturbance or predator activity on the islands, our findings indicate changes in production will follow. For instance, another goal of the plan is to increase public recreational opportunities on the lake. An increase in boating activity at lakes used for foraging by American white pelicans breeding in Canada did not affect foraging success or behavior (Gaudet and Somers 2014). However, human disturbance (Johnson and Sloan 1976, Boellstorff et al. 1988) and low-flying aircraft (Bunnell et al. 1981) can disrupt pelican nesting, and nesting colonies are considered sensitive to human activity (Evans and Knopf 2004). Our findings indicate the low-elevation sites away from the mainland (i.e., Eight-acre, Big, and One-acre islands) are most preferred for nesting and contribute differentially to production than other nesting areas, which is practical guidance for managers regulating recreation at Marsh Lake. For instance, Carney and Sydeman (1999) recommended a buffer of 100–600 m between human activities and pelican nests. If a 600-m buffer was adopted at Marsh Lake, however, it would restrict recreation in Marsh Lake to areas upstream and downstream of Big Island and preclude movement between the upper and lower zones from early April to early July.

Effective adaptive management requires the ability to make predictions of expected outcomes to which observed outcomes can be compared. Our findings provide the means to make predictions of American white pelican production at Marsh Lake based on spring water levels. With potential lake-level management capability, maintaining lower lake levels during typical spring flooding would allow pelicans to select nest sites on preferred low-elevation islands farther from the mainland, thereby reducing mammalian predation and enhancing pelican production on the lake. American white pelicans nest at several reservoir or riverine sites (King and Anderson 2005), including sites where managers have some control over flow or water levels (Findholt and Anderson 1995, Moreno-Matiella and Anderson 2005, Adkins et al. 2014). It is not known if American white pelicans will renest after early nest failure (Evans and Knopf 2004), so protection from nest loss early in the season could be critical. Furthermore, many other colony-nesting birds (including species with threatened or endangered status) use riverine or reservoir habitat for nesting (Stahlecker 2009, Anteau et al. 2012, Hunt et al. 2013) where water levels can be managed. As such, our study demonstrates potentially broad applications for models of productivity, nesting dynamics, discharge, and water levels as a tool for resource managers working with colonial waterbirds. Indeed, nest success of piping plovers (*Charadrius melodus*) and least terns (*Sternula antillarum*) has been linked to discharge in the Missouri River (Anteau et al. 2012, Buenau et al. 2014). Colonial nesting birds are also susceptible to disease outbreaks (Sovada et al. 2008, Johnson et al. 2010), exposure to contaminants (Boellstorff et al. 1985, Pietz et al. 2008) or vulnerability to human disturbance (Johnson and Sloan 1976, Boellstorff et al. 1988), and modeling how water-level changes relate to these factors could prove useful for future research.

MANAGEMENT IMPLICATIONS

Nest distribution and productivity of American white pelicans can be quantified by spring flow and water levels in the Marsh Lake system. Our findings provide a new method for resource managers to evaluate proposed changes for water management in the Upper Minnesota River. In addition, our study provides a framework for modeling nesting dynamics and productivity for other breeding waterbirds using water level or discharge data.

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