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NEST INITIATION AND CLUTCH SIZE OF GREAT BLUE HERONS ON THE MISSISSIPPI RIVER IN RELATION TO THE 1993 FLOOD[1]

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Abstract. Great Blue Heron (*Ardea herodias*) eggs were collected from ten colonies between Clinton, Iowa and Royalton, Minnesota on the Mississippi River in 1993, a year of record floods in the midwestern United States. In the five southernmost colonies where record flooding occurred, Great Blue Herons initiated nesting two weeks later than herons nesting in the five northernmost colonies that were less affected by flooding. The southern nests had a smaller average clutch size than the northern nests, but egg size was similar between south and north. Weather patterns in 1993 were similar between northern and southern colonies. We suspect that flooding of the available feeding habitat influenced nest initiation and clutch size. Data from 1995, a year without record flooding on the Mississippi River, support this hypothesis. In 1995, timing of nesting and number of eggs per clutch were similar between sites that had record flooding and sites that were less affected by flooding in 1993.

Key words: Great Blue Herons; Ardea herodias; *Mississippi River; flooding; clutch size; egg size; nesting chronology.*

INTRODUCTION

The flood of 1993 in the midwestern United States (MN, WI, IA, IL, and MO) surpassed all previous floods in the United States in amount of precipitation, river levels, flood duration and area of flooding. Record flooding occurred at 95 National Weather Service forecast points throughout the region including the reach upstream from St. Louis, MO (181 river miles above Cairo, IL) to Minneapolis, MN (river mile 851) (U.S. Department of Commerce 1994); the peak discharge rate at 46 U.S. Geological Survey gaging stations exceeded the 100-year flood value (Parrett et al. 1993). The reach from Clinton, IA (river mile 519) to Lansing, IA (river mile 663) included locations where peak stages exceeded previous record levels (Fig. 1, U.S. Department of Commerce 1994).

Feeding habitat seems to be a limiting factor for nesting Great Blue Herons (*Ardea herodias*). Colony location has been correlated with the distribution of feeding habitats in two geographically distinct locations (Butler 1991, Gibbs 1991), and colony size was correlated with the amount of nearby feeding habitat (Butler 1991, Wersch-kul et al. 1977, Gibbs et al. 1987, Gibbs 1991). When supplemental food was made available to breeding Great White Herons (*A. h. occidentalis*), a subspecies of the Great Blue Heron, clutch size and fledging success increased significantly (Powell 1983).

Changes in water levels can alter the foraging habitat available to wading birds (David 1994, Powell 1987) and have been associated with negative impacts on wading bird reproduction (Kahl 1964, Clark 1978, Frederick and Collopy 1989). Fish densities may also be reduced during high water conditions (Kushlan et al. 1975) and could result in lowered prey capture rates by feeding Great Blue Herons. The objective of this study was to evaluate the effects of the 1993 flood on nesting Great Blue Herons.

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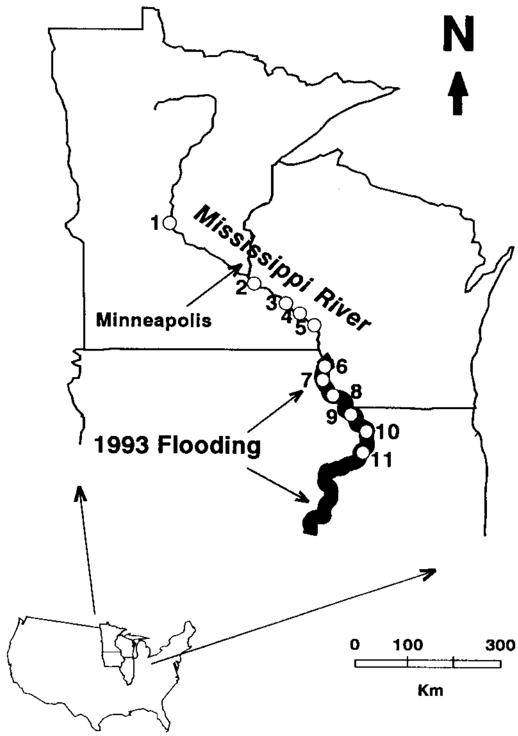

FIGURE 1. Locations (open circles) on the Mississippi River where Great Blue Heron eggs were collected. Colonies 1 to 5 and 7 to 11 were sampled in 1993. Colonies 3, 4, and 8 were also sampled in 1995. Colony 6 was only sampled in 1995. The names for each numbered colony are given in the Methods and Table 1. An area which included record flooding on the Mississippi River in 1993 (U.S. Department of Commerce 1994) is highlighted in black.

METHODS

Between 30 April and 13 May 1993, from 14 to 20 Great Blue Heron eggs (one per nest) were collected from each of ten colonies (Fig. 1) under appropriate state and federal permits. The colonies, numbered from north to south (Fig. 1), were: 1—MacDougall, MN (45°51′N, 94°21′W); 2—Pig's Eye, MN (44°54′N, 93°02′W); 3—Zumbro, MN (44°18′N, 91°56′W); 4—Mertes Slough, WI (44°04′N, 91°38′W); 5—Root River, MN (43°46′N, 91°15′W); 7—Vogt Lake, WI (43°07′N, 91°11′W); 8—Brinkmans, IA (42°44′N, 91°04′W); 9—Catfish Island, IL (42°27′N, 90°37′W); 10—Kellers Island, IA (42°05′N, 90°11′W); and 11—Beaver Island, IA (41°47′N, 90°11′W). Between 25 April and 2 May 1995, from three to 22 eggs per colony (one per nest) were collected from the Zumbro (colony 3, Fig. 1), Mertes Slough (colony 4), Brinkmans (colony 8), and Butler Lake (colony 6; 43°12′N, 90°16′W), a colony not sampled in 1993.

Except for the most northern colony at MacDougall, MN, all colonies were flooded by spring rains and were reached by boat. Professional tree climbers ascended 25–40 m-tall nest trees and collected a random egg from accessible nests. A 2–8 m extendable pole with a nylon stocking cup attached to the end of the pole (Hines and Custer 1995) was used to collect eggs that were out of reach. Chicks were present in 23 of 231 nests where eggs were collected. The climbers recorded the number of eggs and chicks in nests where eggs were removed. Climbers also counted the number of active nests, including those that had chicks, within the collection distance of the 8—m pole. Miscommunication between the climbers and the ground crew precluded the use of clutch size data for the Pig's Eye colony. Once collected, eggs were placed in foam-lined containers, and lowered to the ground.

In 1993, the eggs were placed in a temperature-controlled (37°C) portable incubator, transported to the Upper Mississippi Science Center, LaCrosse, WI, measured (length, width and weight), and placed into a laboratory incubator. Eggs were artificially incubated (37.5°C, 60–65% humidity) and checked at least daily until pipping. Selected embryos and the contents of eggs that failed to hatch were later analyzed for environmental contaminants. In 1995, eggs were measured (length, width and weight) in the field and then returned to the nest.

The length and width of 1993 and 1995 eggs were measured with a caliper (± 0.01 mm), and eggs were weighed on an electronic balance (± 0.1 g). Volume of each egg was estimated based on the equation: volume = 0.51 length × width^2 (Hoyt 1979). Specific gravity was estimated by dividing the mass of the egg by the estimated volume. In order to ensure a random sample, only eggs from completed clutches and eggs from nests without chicks were included in the analysis of volume, length and width.

In 1993, the nest initiation date was estimated based, in order, on the presence of chicks (n = 45), the pipping date ($n = 97$), and specific gravity (n = 67). In 1995, nest initiation date was estimated from presence of chicks (n = 19), specific gravity (n = 43), and eggs observed pipping (n = 1). For purposes of estimating the nest initiation date, day of hatching was treated as day 28 (Pratt 1970), day of pipping was day 27, and day of laying was day zero. Back-dating eggs based on these criteria seemed reasonable, because the incubation period among eggs within clutches of herons and egrets did not differ by more than one to two days (Custer et al. 1992). Because chicks were generally reported by climbers to be small at the time of egg collection, we assigned each an age of three days-of-age. Chick age did not affect the estimated median date of nest initiation in later statistical analysis.

The nest initiation date was estimated from specific gravity using the following equation developed from eggs that pipped in the incubator ($n = 58$, $P = 0.0001$, $R^2 = 0.667$): Day of incubation = 250.2 − 232.2 × specific gravity. Specific gravity of eggs predicted hatching date to within 3.8 days for Snowy Egrets (*Egretta thula*) and 4.7 days for Black-crowned Night-Herons (*Nycticorax nycticorax*) and Great Egrets (*Casmerodius albus*) (Custer et al. 1992).

Only clutches considered complete were used in the analysis of clutch size. Clutches were considered complete when the eggs were estimated to be equal or greater than ten days into incubation. Because the number of completed clutches at Zumbro River ($n = 1$) and Brinkmans ($n = 2$) colonies was low in 1995, these colonies were not included in the analysis of clutch size.

Daily water level elevation (m) were collected by the U.S. Army Corps of Engineers. The data included daily 08:00 hr April records at the headwaters of pools on the Mississippi River for the periods 1973–1992, 1993, and 1995. The water elevation data should be viewed as an indicator of the relative water depth in each pool rather than actual water depth of habitat surrounding respective colonies.

Weather data at the nearest (< 25 km) weather recording station to each of the 1993 Great Blue Heron colonies were obtained from the National Climate Data Center, Federal Building, Asheville, North Carolina. Weather data included the March and April 1993 summaries of the mean daily maximum and minimum temperatures (°C); the mean daily rainfall and snowfall (cm); the number of days that the maximum temperature was <0°C, the minimum temperature was <−18°C, the rainfall was >2.5 cm, and the snowfall was >2.5 cm; and the number of days of fog and hail.

Chi-square tests were used for comparisons of the number of eggs per clutch. Clutches of one and two eggs and four and five eggs were combined in order to avoid sample sizes of zero or one for the Chi-square analysis. To test for differences in nest initiation dates, the number of clutches for each group above and below the combined median date for both groups was compared between groups with a Chi-square test. A two-way analysis of variance (ANOVA) (colony [northern vs. southern] and month [March 1993 vs. April 1993]) with interaction (colony·month) was used to test for differences in weather patterns between 1993 northern and southern colonies. Bonferoni mean separation tests were used in conjunction with ANOVA. The significance level for all tests was $P \leq 0.05$.

RESULTS

The intensity of flooding was greatest in the southernmost colonies of the study area (Fig. 1). The five southernmost colonies were located in an area where record flooding occurred in 1993, whereas the five northernmost colonies were not (U.S. Department of Commerce 1994). In 1993, the average April water depth was significantly greater in the southernmost (mean = 1.3 m above the 1973–1992 April average) than the northernmost pools (0.8 m) (Table 1). In 1995, the average April water depth was above the 1973–1992 average but not different between the northern and southern pools (0.4 versus 0.2 m); water depths in the 1995 northern and southern pools were significantly lower than the 1993 northern and southern pools (Table 1; ANOVA; df = 3, 14; $F = 38.06$, $P = 0.0001$).

Weather patterns during March and April 1993 were similar or more severe in the northern than southern colonies (Table 2). The average monthly minimum temperature was significantly colder in the northern colonies. However, other measures of temperature, rainfall, snowfall, fog, and hail were not significantly different between northern and southern colonies in 1993 (Table 2). Except for the number of days the minimum temperature was <−18°C, all ANOVA colony*month interactions were not significantly different. The northern and southern colonies did not differ in the number of days the minimum temperature was <−18°C when tested separately by month (1-way ANOVA).

In 1993, clutches were significantly larger in the northern (mean ± SE = 3.5 ± 0.10) than southern (2.7 ± 0.14) colonies (Table 3, χ^2 =

TABLE 1. Colony name and number (see Methods and Figure 1), pool number, river mile, number of active nests sampled, and tree species used for nesting by Great Blue Herons on the Mississippi River in 1993 and 1995. Also presented are the deviations of the mean April 1993 and 1995 water elevations from the 1973–1992 April water elevations for 9 pools on the upper Mississippi River.

Colony (no.)	Pool (no.)[a]	River mile[b]	No. active nests sampled (mo-d visited)		Tree species used for nests	Deviation (m) of mean April water elevation from mean of April 1973–92	
			1993	1995		1993	1995
MacDougall (1)	—[c]	954	14 (5-11)	nv[d]	White Pine[e]	—[c]	—
Pig's Eye (2)	2	834	20 (5-5)	nv	cottonwood, ash	1.08	0.83
Zumbro (3)	5	751	19 (5-5)	3 (5-1)	maple, ash	0.69	0.30
Mertes Slough (4)	6	727	19 (5-5)	28 (4-28)	maple	0.72	0.25
Root River (5)	8	695	18 (4-30)	nv	maple, oak	0.79	0.19
Butler Lake (6)	10	647	nv	14 (4-25)	maple	1.22	0.30
Vogt Lake (7)	10	641	16 (5-13)	nv	maple	1.22	0.30
Brinkmans (8)	11	609	21 (5-12)	18 (5-2)	maple, ash	1.20	0.23
Catfish Is. (9)	12	576	21 (5-12)	nv	cottonwood, maple	1.50	0.14
Kellers Is. (10)	13	538	40 (5-11)	nv	oak, maple, ash	1.32	0.22
Beaver Is. (11)	14	515	21 (5-11)	nv	oak	1.48	0.18

[a] Pool no. is the number given to a pool formed by a lock and dam on the Mississippi River.
[b] River mile is the number of miles on the river above Cairo, IL.
[c] Dashes indicate that the colony was not in a pool and water level information was not available for this location.
[d] nv = not visited.
[e] Tree species include White Pine (*Pinus strobus*), cottonwood (*Populus* spp.), maple (*Acer* spp.), ash (*Fraxinus* spp.), and oak (*Quercus* spp.).

24.5, df = 2, $P < 0.001$). In 1995, clutch sizes at the northern colony, Mertes Slough (3.5 ± 0.17), and the southern colony, Butler Lake (3.2 ± 0.21) were not significantly different ($\chi^2 = 1.4$, df = 2, $P = 0.497$) (Table 3). Clutch size in the northern colony in 1995 was not significantly different than the overall frequency of clutch sizes for northern colonies in 1993 ($\chi^2 = 2.5$, df = 2, $P = 0.283$) but was significantly larger than that for southern colonies ($\chi^2 = 12.5$, df = 2, $P = 0.002$) in 1993. Clutch size in the southern colony in 1995 was not significantly different than the overall frequency of clutch sizes for northern colonies in 1993 ($\chi^2 = 3.1$, df = 2, $P = 0.210$) or for southern colonies in 1993 ($\chi^2 = 3.7$, df = 2, $P = 0.155$).

The five one-egg clutches represented completed clutches (i.e., they were greater than ten days into incubation when collected). Two of the five eggs pipped in the incubator and embryos in two were alive when candled.

Egg size did not differ between the northern and southern colonies or between 1993 and 1995 (2-way ANOVA with interaction; $F = 1.58$; 3,115

TABLE 2. 1993 weather information from locations associated with 5 southern Great Blue Heron colonies where record flooding occurred and 4 northern colonies that were less affected by flooding (Fig. 1).

Weather variables	Mean ± SE (*n*)		Significance level
	Northern colonies	Southern colonies	
Max temp (°C)	8.4 ± 1.4 (10)	8.5 ± 1.4 (10)	ns[1]
Min temp (°C)	−2.6 ± 1.3 (10)	−1.2 ± 1.1 (10)	*
No. d max temp < 0 °C	3.5 ± 1.2 (10)	3.1 ± 0.9 (10)	ns
No. d min temp < −18 °C	1.4 ± 0.6 (10)	0.4 ± 0.3 (10)	ns
Rainfall (cm)	7.6 ± 1.8 (10)	9.4 ± 1.0 (10)	ns
Snowfall (cm)	14.2 ± 2.8 (10)	18.3 ± 3.8 (10)	ns
No. d rain > 2.5 cm	0.7 ± 0.3 (10)	0.7 ± 0.2 (10)	ns
No. d snow > 2.5 cm	0.8 ± 0.3 (8)	0.7 ± 0.2 (10)	ns
No. d fog	8.2 ± 3.0 (6)	8.2 ± 2.7 (6)	ns
No. d hail	0.3 ± 0.2 (6)	0.7 ± 0.3 (6)	ns

[1] Means between southern and northern colonies were (*) or were not (ns) significantly different (2-way ANOVA; colony [northern vs. southern], month [March 1993 vs. April 1993], and interaction [colony*month]).

TABLE 3. Clutch sizes of Great Blue Herons nesting on the Mississippi River in 1993 from 5 southern colonies where record flooding occurred and 4 northern colonies that were less affected by flooding (Figure 1). Clutch size from one northern and one southern colony in 1995 are also presented.

Year	Colony	Number of eggs 1	2	3	4	5	*n*	Mean
1993	Northern colonies:							
	MacDougall Homestead	0	2	3	9	0	14	3.5
	Zumbro	0	3	4	10	2	19	3.6
	Mertes Slough	0	2	8	10	0	20	3.4
	Root River	0	2	2	6	1	11	3.5
	Total	0	9	17	35	3	64	3.5
1993	Southern colonies:							
	Vogt Lake	1	1	2	0	0	4	2.3
	Brinkmans	2	1	3	0	0	6	2.2
	Catfish Island	0	2	7	0	0	9	2.8
	Kellers Island	1	1	8	2	0	12	2.9
	Beaver Island	1	5	3	2	1	12	2.8
	Total	5	10	23	4	1	43	2.7
1995	Northern colony:							
	Mertes Slough	0	1	8	8	1	18	3.5
1995	Southern colony:							
	Butler Lake	0	2	6	4	0	12	3.2

df; $P = 0.199$). The volume was 66.9 ± 0.48 cm³, the width was 45.22 ± 0.12 mm, and the length was 64.09 ± 0.25 mm (n = 119).

In 1993, the estimated nest initiation date ranged from 4 April to 6 May in the five northern colonies (median = 13 April, n = 90) and 9 April to 18 May in the five southern colonies (median = 29 April, n = 119) (Fig. 2). More nests were initiated before the overall median date (19 April) in the five northern colonies (61 of 90 nests, 68%) than in the five southern colonies (44 of 119 nests, 37%) ($\chi^2 = 19.4$, df = 1, $P = <0.001$).

In 1995, the estimated nest initiation date for 63 nests ranged from 28 March to 27 April (median = 9 April) in clutches at two northern colonies (n = 31) and 25 March to 1 May (median = 5 April) in two southern colonies (n = 32, Fig. 2). The estimated nest initiation date before the overall median date (7 April) was not significantly different between clutches in the northern and southern colonies ($\chi^2 = 0.775$, $P = 0.379$).

The estimated number of nests initiated before the overall median nest initiation date for 1993 and 1995 combined (17 April, n = 271) was not different between northern colonies in 1993 and northern colonies in 1995 ($\chi^2 = 1.7$, $P = 0.18$) or southern colonies in 1995 ($\chi^2 = 0.014$, $P = 0.90$). However, nesting was initiated later in southern colonies in 1993 than both southern colonies in 1995 ($\chi^2 = 10.7$, $P = 0.001$) and northern colonies in 1995 ($\chi^2 = 19.3$, $P < 0.001$).

DISCUSSION

Record flooding of the midwestern United States in 1993 probably contributed to lower reproductive performance of Great Blue Herons nesting in the southern colonies of the study area. Herons at the southern colonies, where record

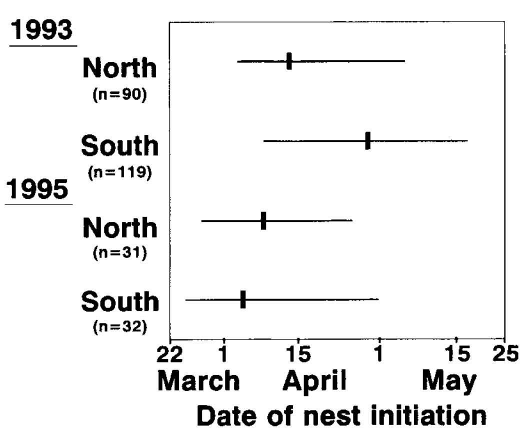

FIGURE 2. Range and median nest initiation date (vertical bar) for eggs collected on the Mississippi River in northern and southern colonies in 1993 and 1995.

flooding occurred in 1993, began nesting later and had fewer eggs per clutch than herons nesting in the northern colonies, an area less impacted by the 1993 flood. In 1995, a year without flooding, there were no differences between timing of nesting or number of eggs per clutch between northern and southern colonies.

Flooding seems to be the main environmental difference between the northern and southern colonies in 1993. Weather patterns were similar or more severe (average minimum daily temperature) in the northern than southern colonies (Table 2). Environmental contaminants (organochlorines, mercury and selenium) in eggs of great blue herons were at background concentrations in both the northern and southern colonies (T. Custer, unpubl.).

Clutch sizes in 1993 were abnormally small in the flooded southern colonies (mean = 2.2–2.9 eggs per clutch), compared with northern colonies (3.4–3.6). Clutches of Great Blue Herons from elsewhere in the North America were greater than three eggs per clutch (mean = 3.16 eggs per clutch, Pratt and Winkler 1985; 3.6, Mitchell et al. 1981; 4.1, DesGranges 1979; 4.2, Henny and Beathers 1971; 4.2, McAloney 1973; 3.9–4.2, Butler 1989; 4.3, Miller 1943; 3.7–4.6, Blus et al. 1980; and 5.0 Vermeer 1969). The smaller clutch size in southern colonies in 1993 was probably related to food availability. When supplemental food was made available to breeding Great White Herons, clutch size increased significantly (Powell 1983).

Delayed nesting of Great Blue Herons in the five southern sites compared to the five northern colonies in 1993 was probably related to a loss of feeding habitat caused by the record flooding. As mentioned above, initiation of nesting did not differ between northern and southern colonies in 1995, a non-flood year. Changes in water levels can alter the foraging habitat available to wading birds (David 1994, Powell 1987) and delayed nest initiation by Wood Storks (*Mycteria americana*) was correlated to water levels in two Florida studies (Kahl 1964, Clark 1978). Also, evidence suggests that female Great Blue Herons initiate laying soon after an energy threshold has been exceeded (Butler 1993).

The large variation in eggs size among nests combined with a mixture of eggs of various laying orders may have masked differences in egg size relative to the flood event. Interclutch differences and laying order accounted for 69–79% and 8–11%, respectively, of the total variation (R^2) in egg volume of Black-crowned Night-Herons, Great Egrets and Snowy Egrets (Custer and Frederick 1990). The last eggs laid in clutches of these three species were 4–6% smaller than the first eggs laid. Colonial waterbirds that produce a small final egg may be nutrient-limited (Birkhead and Nettleship 1982) or it is possible that the small final eggs may be an adaptation to reduce the degree of hatching asynchrony (Parsons 1972). Female age and time of laying has been correlated to egg size in other colonial waterbirds (Coulson 1963, Coulson et al. 1969), but no information is available for herons.

Although we did not monitor hatching or fledging success of Great Blue Herons nesting on the Mississippi River in 1993, information from other species on the river suggests negative effects. In 1993, four of 11 (36%) Red-shoulder Hawk (*Buteo lineatus*) nests, near the Mississippi River, were successful and produced 0.45 fledglings per nesting attempt (Stravers and McKay 1993). In contrast, for the period 1983–1992, 33 of 44 (75%) Red-shouldered Hawk nests were successful and 1.61 fledglings were produced per nesting attempt. Knutson (1995), in a study of breeding birds in the floodplain forests of the Mississippi River, suggested that a decline in species richness overall and relative abundance of several groups of birds in 1994 resulted from the 1993 flood.

We suspect that the flood conditions in the southern portions of the study area in 1993 severely reduced the availability and possibly the quality of feeding habitat for Great Blue Herons. Because most wading birds require shallow water to forage successfully (Custer and Osborn 1978a, 1978b), high water levels probably restricted foraging habitat especially in the study area. Except for the McDougall, MN, the most northern colony, all colonies occur within the Driftless Area of southeastern Minnesota, southwestern Wisconsin and northeastern Iowa, an area characterized by deep valleys and extensive alluvial terraces flanking the Mississippi River (Fremling and Claflin 1984). Under high water conditions riparian and marshland habitat is unavailable to wading birds and feeding habitat is generally restricted to a narrow band of terrace edges. In addition, fish densities may have been reduced during high water conditions (Kushlan et al. 1975) and resulted in lower prey capture rates by nesting Great Blue Herons.

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