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ORGANOCHLORINE CONTAMINANTS AND REPRODUCTIVE SUCCESS OF BLACK SKIMMERS IN SOUTH TEXAS, 1984

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Abstract.—Ninety-four Black Skimmer (*Rhynchops niger*) nests on a dredged-material island colony near Laguna Vista, Texas, were fenced and monitored in 1984 from early incubation until 21 d after the last egg hatched. The daily probability of success was greater during the nestling (99.7%/d/nest) period than during the incubation (98.5%) or hatching (98.5%) periods. By contrast, the success of eggs or young in successful nests was greater during the incubation (91.3%) and hatching (84.3%) periods than the nestling period (63.8%). An estimated 1.1 young/nest survived to 21 d of age. DDE concentrations in eggs were lower in 1984 than in eggs from the same colony in 1979–1981. DDE was higher in eggs taken from nests where none of the remaining eggs hatched ($\bar{x}$ = 5.9 ppm) compared to eggs taken from nests where all the remaining eggs hatched ($\bar{x}$ = 1.9 ppm).

CONTAMINANTES ORGANOCLORINADOS Y EL ÉXITO REPRODUCTIVO DE *RHYNCHOPS NIGER* DURANTE EL 1984 EN EL SUR DE TEXAS

Sinopsis.—Durante el 1984 se estudió una colonia de rayadores de agua (*Rhynchops niger*) cerca de Laguna Vista, Texas. Noventa y cuatro nidos fueron monitoreados desde comienzos del periodo de incubación hasta 21 días después de los huevos haber eclosionado. La probabilidad diaria de éxito de nidos fue mayor durante la época de presencia de polluelos (99.7%/d/nido) que durante las épocas de incubación (98.5%) o de eclosionamiento (98.5%). Por el contrario el éxito de huevos o crías en nidos exitosos fue mayor durante la incubación (91.3%) y eclosionamiento (84.3%) que durante el periodo de polluelos. Un estamado de 1.1 polluelos/nido sobrevivieron hasta la edad de 21 días. La concentración de DDE en huevos resultó ser menor en 1984 que en ánalisis similar sobre la colonia en 1979–1981. La cantidad de DDE resultó mayor en huevos tomado de nidos en donde ninguno de los restantes eclosionó ($\bar{x}$ = 5.9 ppm), que en huevos en donde el remanente de la camada produjo pichones ($\bar{x}$ = 1.9 ppm).

Populations of breeding Black Skimmers (*Rynchops niger*) declined 24% from 11,540 to 8760 breeding pairs between 1974 and 1980 (Texas Colonial Waterbird Society 1982). A study of skimmers at three Texas colonies in 1978–1981 (White et al. 1984) found that DDE concentrations in eggs were high, and were not correlated with eggshell thickness. DDE concentrations in eggs and fledging success on a colony basis were not related; a relationship, however, could have been hidden by other variables that affect nest success such as storm tides (Blus and Stafford 1980, Burger 1982, King and Krynitsky 1986, White et al. 1984), starvation (Erwin 1977), or predation (Blus and Stafford 1980, Burger 1982, DePue 1974, King and Krynitsky 1986). DDE concentrations and hatching success were not compared, because young could not be assigned to specific nests.

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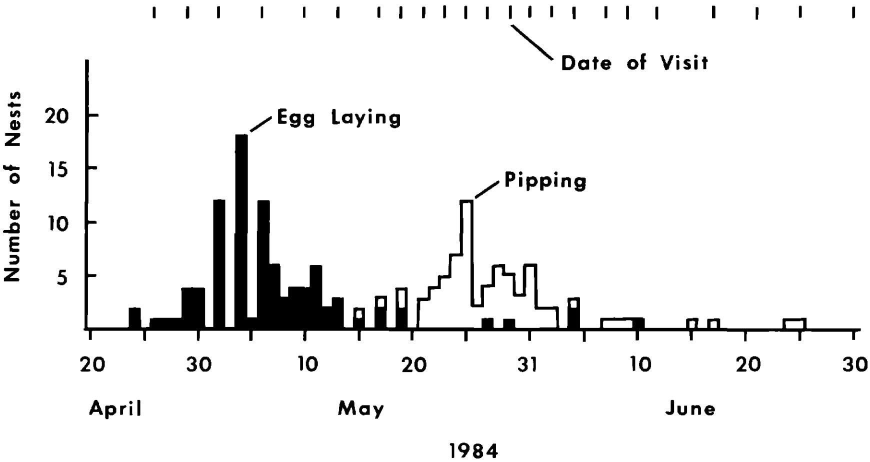

FIGURE 1. Frequency distribution for date of first egg laid and first egg pipped in individual nests of Black Skimmers near Laguna Vista, Texas, 1984.

Our objective was to further quantify the effects of organochlorine contaminants on hatching and fledging success of Texas skimmers.

METHODS

This study was conducted at a dredged-material island near Laguna Vista, Texas (26°06′N, 97°18′W; colony 618-220, Texas Colonial Waterbird Society 1982). Active nests with 1 or more eggs were located during egg laying or early incubation and rechecked every 2–5 d from 26 Apr. to 10 Jul. 1984 (Fig. 1). Nests were marked with 20-cm spikes flagged with numbered ribbons. Eight 0.3 m high 0.6-cm wire-mesh fences were constructed around groups of nests (6–17 nests/enclosure) during mid-incubation (White et al. 1984).

We used the "sample egg method" (Blus 1982) where one egg is collected per nest from a series of nests and the contaminants in each egg are compared to the success of the eggs remaining in the nest. Of the marked nests, we randomly collected one egg from 77 3-, 4-, and 5-egg clutches after the clutch size remained the same for 2 visits. Eggs that failed to hatch in study nests were also collected.

Young were banded with U.S. Fish and Wildlife Service bands. Some newly hatched individuals, whose legs were too small to band, were marked with nail polish on their toenails and banded on subsequent visits. When 2 or more newly hatched young were present in a nest, the sequence of hatching was determined by the size difference.

All collected eggs were placed inside a moistened plastic bag and refrigerated. The eggs were then lightly cleaned and kept for 6 d in a desiccator at room temperature over anhydrous calcium chloride. Eggs were weighed when first placed in the desiccator and at days 3 and 6.

The surface area of the egg was calculated using the equation 4.835 $W^{0.662}$ (Paganelli et al. 1974), where W is the fresh egg weight (g). Evaporative water loss was then calculated in mg cm^{-2} d^{-1} (Fox 1976).

After desiccation, the egg contents were placed in chemically cleaned jars (acetone and hexane rinsed) and frozen until analysis. Eggs were analyzed for organochlorine contaminants at the Patuxent Wildlife Research Center, Laurel, Maryland, following methods described by Cromartie et al. (1975) and Kaiser et al. (1980). The lower limit of detection was 0.1 ppm for pesticides (p,p'-DDT, p,p'-DDE, p,p'DDD, dieldrin, endrin, toxaphene, heptachlor epoxide, *cis*-chlordane, *cis*-nonachlor, oxychlordane, *trans*-nonachlor) and 0.5 ppm for polychlorinated biphenyls (PCBs) on a wet weight basis. Organochlorine concentrations were adjusted for moisture loss (Stickel et al. 1973).

Eggshell thickness was measured to the nearest 0.01 mm with a micrometer after shells had dried at room temperature for at least 1 month. Three measurements were taken at the "equator" of each egg and included the shell and shell membranes; a mean thickness value was derived from these three measurements. Eggshells were weighed and thickness indices computed (Ratcliff 1967).

For statistical comparisons, clutches were categorized as large (4 or 5 eggs), intermediate (3 eggs), or small (1 or 2 eggs) because of small sample size. Early and late clutches were determined by dividing the nesting period into four quartiles based on the date the first egg was laid. Chi-square tests were used to compare clutch size among categories. Some nests could not be used in all analyses, because they were either lost during egg laying or the laying date of the first egg could not be calculated.

Nest success was estimated by the Mayfield method (Mayfield 1961, 1975); appropriate variance estimates and comparisons of daily survival rates were determined (Hensler and Nichols 1981). The nesting phase was divided into incubation, hatching, and nestling periods by using the number of days determined for the median 4-egg clutch. The incubation period (19 d, pers. obs.) was defined as the number of days from the date the first egg was laid until the day before the first egg pipped. The hatching period (5 d, pers. obs.) was considered as the day the first egg pipped to the day the last egg hatched. The nestling period was monitored to 21 d after the last egg hatched. Skimmers fledge 27–39 d after hatching (DePue 1974); however, we were only confident that our enclosures confined young to 21 d after the last egg hatched. Estimates of daily survival rate and corresponding variance of these estimates were calculated for the three periods of the nesting cycle. An estimate of the overall survival rate for the entire nesting cycle was calculated from the daily rates and comparisons of these estimates were made as described earlier (Custer et al. 1983). Comparisons among nest success were made using Z-tests with an overall $\alpha = 0.05$.

Of the 77 eggs collected, 53 were analyzed for organochlorine contaminants based on three categories of hatching success: all eggs hatch, some eggs hatch, and no eggs hatch. Because mean organochlorine contaminant levels differed among success categories, estimates of organochlorine contaminants in the population were based on a weighted proportion of the number analyzed to the total number available in each success category (Cochran 1977).

Concentrations of DDE and PCBs were transformed to logarithms for statistical comparisons. Retransformed means are presented in the tables. A value of one-half the detection limit was assigned to the non-detected values of DDE and PCBs before logarithmic transformations.

Frequencies were compared using chi-square tests. To determine where differences existed within a significant chi-square test of more than two groups, pairwise comparisons were made using a significance level of 0.05 divided by the number of comparisons. Correlations and means of contaminants were determined when 50% or more of the samples had detectable levels. Correlation among variables was done using the Pearson correlation coefficient. A one-way analysis of variance (ANOVA) was used to compare organochlorine means among nests differing in success. The Bonferroni multiple comparison method (Miller 1981) was used to separate means.

RESULTS

Clutches were initiated from 24 Apr. to 10 Jun. 1984 (Fig. 1). The median date was 6 May. For those nests where clutch size was determined, there were 3 1-egg, 5 2-egg, 35 3-egg, 50 4-egg, and 1 5-egg clutches ($\bar{x} = 3.44$). The frequency of clutch sizes was similar ($\chi^2 = 8.77$, df = 6, $P > 0.05$) among the four quartiles of the nesting period.

Of the 94 nests (323 eggs) monitored, one egg was collected from 77 nests for residue analysis. Of the remaining 246 eggs, 156 hatched and 82 hatchlings survived to 21 d of age (Table 1).

The third young to hatch in 3-young broods was missing or found dead before 21 d of age more frequently (75%, 21 of 28 young) than either the first (36%, 10 of 28; $\chi^2 = 8.74$, df = 1, $P < 0.05$) or second (18%, 5 of 28; $\chi^2 = 18.38$, df = 1, $P < 0.05$) young; no difference occurred between the first and second young ($\chi^2 = 2.28$, df = 1, $P > 0.05$). The frequency of first (43%, 12 of 25) and second (46%, 13 of 25) hatched young discovered missing or found dead before 21 d of age was similar ($\chi^2 = 0.07$, df = 1, $P > 0.05$) in 2-young broods.

The daily probability of nest success was significantly ($P < 0.05$) lower during the incubation (0.98486) and hatching (0.98549) periods than the nestling (0.99687) period (Z-test incubation-hatching = 0.09, incubation-nestling = 3.80, hatching-nestling = 2.08). The probability of survival of an egg or young in a successful nest (Table 2) was lower in the nestling period (46 of 126 young lost) than the incubation (16 of 184 eggs lost) or hatching (25 of 159 eggs or young lost) periods. The estimated overall survival of eggs or young was 68, 78, and 60% during incubation, hatching, and nestling periods, respectively (Table 2). The product of these 3 nesting periods (32%) and the mean clutch size (3.44) was 1.1, an estimate of the number of young produced per nest to 21 d of age.

TABLE 1. Egg and nestling losses of 94 Black Skimmer nests in south Texas, 1984.

Category	Total
Eggs laid	323
Eggs collected for residues	77
Eggs monitored until hatching	246
Losses (laying to hatching)	
Disappeared	38
Cracked	24
Did not hatch	18
Abandoned	4
Depredated	4
Rolled out	2
Eggs hatched	156
Losses (hatching to 21 d of age)	
Disappeared	49
Died	25
Young surviving to 21 d	82

Correlations between eggshell weight and eggshell thickness ($n = 80$, $r = 0.52$), eggshell weight and thickness index ($n = 80$, $r = 0.72$), eggshell thickness and thickness index ($n = 80$, $r = 0.59$), and log DDE and log PCB ($n = 56$, $r = 0.5$) were significant (Pearson correlation coefficient, $P < 0.05$). No other combination of these variables, desiccation rate, or percent lipid weight were significantly correlated ($P > 0.05$). Egg characteristics were as follows ($\bar{x} \pm$ SD): Eggshell weight = 1.76 ± 0.11 g ($n = 80$), eggshell thickness = 0.24 ± 0.01 mm ($n = 80$), thickness index = 1.12 ± 0.06 ($n = 80$), percent lipid = 8.01 ± 0.86 ($n = 53$), and desiccation rate = 2.78 ± 0.79 mg cm^{-2} d^{-1} ($n = 75$).

The weighted means for DDE and PCBs were 3.2 and 0.7 ppm (Table 3) and were lower than eggs collected from 1979–1981 in the same colony (White et al. 1984). The percent of eggs with DDE concentrations ≥ 10 ppm was higher in 1979, 1980, and 1981 than in 1984 (Table 3).

Based on weighted frequencies, DDE (max = 28.4 ppm) was detected in 98.5% of all eggs, PCB (max = 9.1) in 72.6%, toxaphene (max = 0.72) in 18.1%, dieldrin (max = 0.33) in 9.8%, oxychlordane (max = 0.21) in 5.2%, and *trans*-nonachlor (max = 0.09) in 2.5%; no other organochlorine contaminants measured (see Methods) were detected.

In comparing means for DDE in sample eggs by each of the 3 hatching success categories, the only relationship was higher DDE residues in clutches where none of the eggs hatched in comparison to clutches where all eggs hatched (Table 4). Log PCB, desiccation rate ($F = 0.92$; df = 2, 68), eggshell weight ($F = 1.01$; df = 2, 73), eggshell thickness ($F = 1.44$; df = 2, 73), thickness index ($F = 2.29$; df = 2, 73), and percent lipids by weight ($F = 0.52$; df = 2, 51), were similar (ANOVA, $P > 0.05$) among the 3 hatching success categories. When clutches were divided into groups

TABLE 2. Nest and egg success of Black Skimmers in south Texas, 1984.

Nesting period	Percent nest success[a]	Percent surviving in successful nests[bc]	Percent overall success
Incubation	74.8	91.3 A	68.3
Hatching	93.0	84.3 A	78.4
Nestling	93.6	63.8 B	59.7
Overall	65.1	49.1	32.0

[a] Successful nests have at least one egg hatch or one young survive the 21 d nestling period.
[b] Percent of eggs or young surviving given that the nest is successful.
[c] Frequencies different from one another ($P < 0.05$) do not share a common letter (χ^2 incubation-hatching = 4.00, incubation-nestling = 35.66, hatching-nestling = 15.89; df = 1).

where all nestlings survived to 21 d ($n = 9$), some nestlings survived to 21 d ($n = 28$), and no nestlings survived to 21 d ($n = 3$), log DDE (ANOVA; $F = 0.41$; df = 2, 37; $P > 0.05$) and log PCB ($F = 0.12$; df = 2, 37; $P > 0.05$) were similar among groups.

Log DDE concentrations were significantly (ANOVA LDDE; $F = 4.11$; df = 2, 50; $P < 0.05$; Bonferroni multiple comparison method; $P < 0.05$) higher in eggs from clutches where no remaining eggs hatched and survived to 21 d ($\bar{x} = 5.61$ ppm, $n = 16$) than from clutches where some remaining eggs hatched and survived to 21 d ($\bar{x} = 2.47$ ppm, $n = 34$); log DDE concentrations in eggs from clutches where all remaining eggs hatched and survived to 21 d ($\bar{x} = 3.21$ ppm, $n = 3$) were not significantly different from the other 2 categories of egg success to 21 d.

DISCUSSION

Concentrations of DDE in skimmer eggs were correlated with decreased hatching success independent of demonstrable changes in eggshells. DDE was higher in sample eggs from nests where no eggs hatched than in

TABLE 3. Concentrations of DDE and PCBs by year in Black Skimmer eggs at Laguna Vista, Texas.

Year[a]	n	Geometric mean (ppm) DDE	Geometric mean (ppm) PCBs	Percent of[b] eggs with DDE ≥10 ppm
1979	22	5.0	1.3	32 A
1980	20	9.4	2.2	50 A
1981	15	9.8	0.9	60 A
1984[c]	53	3.2	0.7	4 B

[a] Data for years 1979, 1980, and 1981 from White et al. 1984. Means were recalculated using samples with nondetected residues (see Methods).
[b] Frequencies different from one another ($P < 0.05$) do not share a common letter (χ^2 1979–1980 = 1.44, df = 1; 1979–1981 = 1.71; 1979–1984 = 9.84; 1980–1981 = 0.03; 1980–1984 = 20.71; 1981–1984 = 20.79).
[c] Data based on weighted means and frequencies (see Methods).

TABLE 4. Geometric mean concentrations of DDE and PCBs in relation to hatching success category of Black Skimmers in south Texas, 1984.

Success category	Number nests	Mean (min–max)	
		DDE[a]	PCBs
All eggs hatch	20	1.9 B (nd–7.4)	0.6 A (nd–2.5)
Some eggs hatch	20	3.6 AB (1.0–28.4)	0.8 A (nd–6.2)
No eggs hatch	13	5.9 A (2.3–17.9)	1.0 A (nd–9.1)

[a] Means different from one another (Bonferroni multiple comparison method, $P < 0.05$) do not share a common letter (ANOVA LDDE $F = 6.11$; df = 2, 50; $P < 0.05$. ANOVA LPCB $F = 0.81$; df = 2, 50; $P > 0.05$).

nests where all eggs hatched. In contrast, eggshell thickness, thickness index, and evaporative water loss were not related to DDE concentrations or hatching success. DDE was not correlated to eggshell thickness in 2 other studies of skimmers (King and Krynitsky 1986, White et al. 1984). The effect of DDE on egg success independent of changes in eggshell characteristics has been noted in other studies (Fox 1976, Heath et al. 1969, Longcore et al. 1971).

In our study egg concentrations of DDE were related to hatching and fledging success of eggs. In contrast, an earlier study (White et al. 1984) did not show a relationship between DDE and fledging success, even though DDE concentrations were higher than in our study. The sample egg method used in our study may account for the difference. The sample egg method uses the nest as the sampling unit and seems to be a sensitive technique for determining the effects of contaminants on reproduction (Blus 1982). In addition, the sample size in our study ($n = 53$ eggs) was several times larger than the earlier study ($n = 10$; three colonies over 3, 3, and 4 yrs, respectively).

The sample egg method assumes that the sample egg represents the remaining eggs in the clutch (Blus 1982). Data from other species suggest that this assumption is met (Blus et al. 1974, Potts 1968, Vermeer and Reynolds 1970); however, this relationship has not been tested for Black Skimmers.

The mean DDE concentration in eggs was three times greater in 1981 than 1984 (9.8 vs. 3.2 ppm DDE), and the percent of eggs having ≥ 10 ppm DDE decreased from 1981 to 1984 (60% to 4%). The reason for this decline in DDE residues is unknown. Residues may have decreased in the food chain or perhaps the skimmers shifted their diet to other species of fish that were less contaminated. The winter freeze of 1983–1984 killed an estimated 14.4 million Texas coastal fish (Anonymous 1984) and may have been responsible for a shift in diet. Further monitoring of south Texas skimmers is required to determine trends in DDE concentrations.

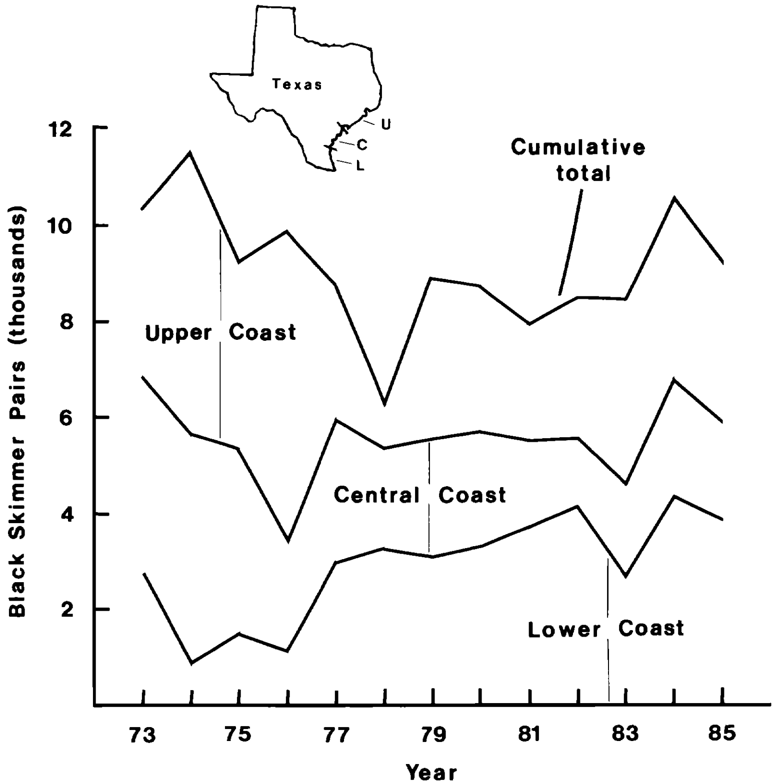

FIGURE 2. Estimated breeding pairs of Black Skimmers along the Texas Coast 1973–1985 obtained from Blacklock et al. (1978), Texas Colonial Waterbird Society (1982), and unpublished reports of the Texas Colonial Waterbird Society. The Texas Coast was divided into upper, middle, and lower sections based on Blacklock et al. (1978).

The breeding population of Black Skimmers in Texas does not seem to be declining nor does DDT contamination seem to be a major influence on skimmer numbers. Estimates of breeding skimmers in Texas in 1984–1985 were similar to estimates in 1973–1974 (Fig. 2). Also, the decline of skimmers during 1973–1980 did not occur along the lower Texas coast, the area considered to be most heavily contaminated with DDT (White et al. 1984).

Mean clutch size in our study (3.4 eggs per clutch) was similar to that reported earlier for the Texas coast (3.4 eggs/clutch for early nests, White et al. 1984; 3.1–3.4, DePue 1974; 2.7–3.5, King and Krynitsky 1986). Hatching success in our study (63%) was similar to the 50–60% found in a 2-yr study in Baffin Bay, Texas (DePue 1974), but lower than 84% reported in Virginia (Erwin 1977). Our estimate of the percent of eggs that produced fledglings (33%) was intermediate to that found in Baffin Bay (26–45%, DePue 1974).

Our estimate of fledging success (1.1 young per nest) was lower than estimates in 2 of 3 yrs at the Laguna Vista colony (0.6, 1.4, 2.0 young per nest) and similar to the mean for three south Texas colonies over 3 yrs (1.0, White et al. 1984). Our estimate was equal or greater than estimates from Baffin Bay, Texas (0.9, DePue 1974), Galveston Bay, Texas (0.0–1.5, King and Krynitsky 1986), South Carolina (0.9–1.2, Blus and Stafford 1980), New Jersey (0.0–0.4, Burger 1982), and Virginia (0.4, Erwin 1977).

Our estimates of success are based mainly on nests that had one egg removed. Removal of one egg did not affect nest success of Black-crowned Night-Herons (*Nycticorax nycticorax*; Custer et al. 1983, Henny et al. 1984). In our study, egg removal probably did not have a major effect on the estimate of hatching success of remaining eggs, but it may have affected the estimate of survival of young to 21 d of age. Because young seemed to die of starvation (see below) and brood size was artificially reduced, the estimate of survival to 21 d of age may be an overestimate.

Losses of young seemed related to starvation. Most of the young found dead were emaciated. Losses of young were mainly from partial brood losses. During the nestling period, 94% of nests had at least 1 young survive to 21 d of age but only 64% of fledglings from eggs that hatched in these "successful" nests survived to 21 d of age. In addition, the youngest nestling in 3-young broods had lower survival to 21 d than the first or second nestlings. The extensive fish kill during the winter of 1983–1984 (Anonymous 1984) may have been responsible for low prey abundance. Erwin (1977) attributed low fledging success of skimmers in Virginia to limited prey availability because most of the young that survived were the first to hatch.

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