CLUTCH SIZE, REPRODUCTIVE SUCCESS, AND ORGANOCHLORINE CONTAMINANTS IN ATLANTIC COAST BLACK-CROWNED NIGHT-HERONS

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ABSTRACT.—In 1979, we gathered clutch-size and reproductive-success data on Black-crowned Night-Herons (*Nycticorax nycticorax*) nesting in three New England and two North Carolina colonies. In 1975, we gathered similar data from one of the New England and one of the North Carolina colonies. Latitudinal differences in clutch initiation were not evident. Mean clutch size was larger in the New England than in the North Carolina colonies. Mean clutch size was smaller in late nests from one New England colony studied in both years and another New England colony studied in 1979; seasonal trends in clutch size for other colonies were not found. In 1979, nest success was greater in two New England colonies than in one North Carolina colony. Within-season differences in nest success occurred but were inconsistent among colonies. In the four instances where statistical comparisons could be made, larger clutches were more successful than smaller ones in two colonies; large and small clutches had similar success in two other colonies. One egg was collected from each of several nests in each colony in 1979 for organochlorine contaminant analysis, and the fate of the remaining eggs was recorded. Concentrations of DDE and PCBs did not differ with clutch size; concentrations of PCBs were lower, however, in eggs laid late in the season. Although the data suggest an effect of DDE on hatching success in the northern more contaminated colonies, the impact of environmental contaminants on overall reproductive success appears to be minimal. *Received 17 June 1982, accepted 21 March 1983.*

A SUSPECTED decline in populations of Black-crowned Night-Herons (*Nycticorax nycticorax*) in the northeastern U.S. (Peterson 1969) and reports of substantial decreases in eggshell thickness (Anderson and Hickey 1972) led to a collection of night-heron eggs for organochlorine analysis in 1972 and 1973 (Ohlendorf et al. 1978, 1979). Concentrations of PCBs and DDE were significantly higher in eggs from the northern than from the southern Atlantic Coast colonies and were present at levels associated with decreased reproductive success in other species of birds. When the 1972–1973 eggs were compared with others collected before the DDT era (pre-1947), significant decreases in eggshell thickness were found along the Atlantic Coast except for Maryland, Virginia, and North Carolina.

In 1979, as a follow-up to the 1972–1973 egg collections, we measured heron reproductive success and collected eggs for chemical analysis in three of the more contaminated northern colonies and in two of the less contaminated southern colonies of the Atlantic Coast (Fig. 1). PCBs and DDE were present in 93 and 100% of the samples, respectively. Nine other organochlorine contaminants were present in 4–44% of the samples. For 2 northern colonies from which eggs were collected in both 1973 and 1979, PCBs decreased in 1 colony, DDE decreased in both, and eggshell thickness increased in 1 of the 2 (Custer et al. in prep.).

Decreased reproductive success in night-herons was linked to organochlorine contaminants in eastern Lake Ontario (Price 1977) and in the northwestern U.S. (Findholt 1981, Henny in prep.), but no effect was found in two colonies in the Saint Lawrence Estuary (Tremblay and Ellison 1980). Reproductive data for Black-crowned Night-Herons are available from a few locations (Teal 1965, Wolford and Boag 1971, Price 1977, Tremblay and Ellison 1980, Findholt 1981); detailed information on latitudinal, seasonal, and yearly trends for clutch size and nest success, however, is limited, because only a few studies involve more than one colony, and data for more than one year are available for only a few colonies. The objective of this report is to present information on the relationship of clutch size, reproductive success,

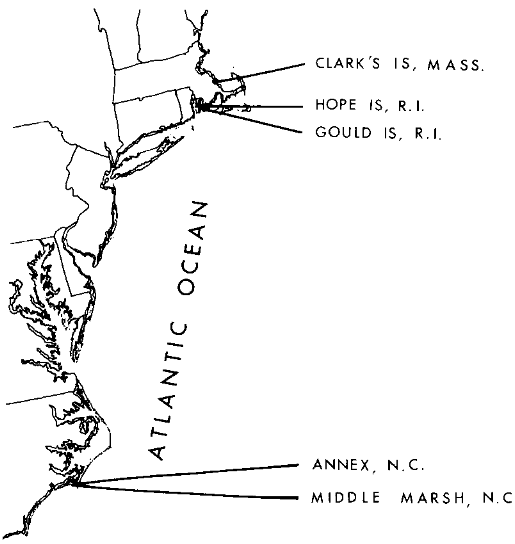

Fig. 1. Location of Atlantic Coast Black-crowned Night-Heron colonies investigated in this study.

and organochlorine contaminants among Atlantic Coast colonies, among periods of the nesting season, and between years.

METHODS

We usually located nests during the egg-laying or incubation periods and then rechecked them every 3–7 days from 27 March to 12 July 1979 at five mixed-species colonies (Fig. 1): Clark's Island, Massachusetts (colony number 324001, Osborn and Custer 1978); Hope Island, Rhode Island (colony number 352004); Gould Island, Rhode Island (colony number 352003); Annex subcolony of Newport River, North Carolina (colony number 523008); and Middle Marsh, North Carolina (colony number 523006). Nests on Annex and Clark's Island were studied in a similar manner in 1975 (Custer and Osborn 1977). Additional information on individual colonies is given elsewhere for Annex (McCrimmon 1978), Middle Marsh and Clark's Island (Beaver et al. 1980), and Hope Island and Gould Island (Custer et al. 1980).

Nests found with one or more eggs were considered to be active. Laying date of the first egg was estimated by allowing 2 days for each egg laid (Tremblay and Ellison 1980). The time period between laying and hatching was assumed to be 25 days (Gross 1923).

The nesting cycle was divided into laying, incubation, and nestling periods. The laying period was defined as the number of days from the day the first egg was laid to the day the last egg was laid. The incubation period extended from the day after the last egg was laid to 1 day before hatching of the first egg. The nestling period extended from the date the first egg hatched to 15 days from that date. (We were unable to follow some nests beyond 15 days, because young readily moved away from the nests when we approached.) Because of infrequent nest visits, unmarked young, and asynchronous hatching, we found our definition of the incubation period easier to work with than that given by Nice (1954), i.e. from laying of the last egg until it hatched.

In 1979, one egg was randomly collected from each of 50 or fewer nests in each colony after the clutches were completed. Eggs that failed to hatch were also collected. All eggs were refrigerated until the contents could be removed. The contents were then placed in chemically clean jars (acetone and hexane rinsed) and frozen until analysis. A maximum of 25 fresh eggs per colony was analyzed for organochlorines at the Patuxent Wildlife Research Center following methods described by Cromartie et al. (1975) and Kaiser et al. (1980). Because nest success was not affected by the removal of one egg for organochlorine analysis (see results), nests from which one egg was removed were included in all analyses except the comparison of clutch size with reproductive success. Organochlorine concentrations in eggs were adjusted to account for moisture loss during incubation (Stickel et al. 1973).

We made comparisons of clutch size by using Chi-square tests. Clutch size was catagorized as large (4 or 5 eggs) or small (2 or 3 eggs) because of small sample size. Early and late clutches within colonies were determined by dividing nests into four quartiles based on the date the first egg was laid. Some nests could not be used in all analyses, because they were destroyed during egg laying or because the laying date of the first egg could not be calculated.

Nest success was estimated by the Mayfield method (Mayfield 1961, 1975), with appropriate variance estimates and comparisons of daily survival rates (Hensler and Nichols 1981). We found that, compared with the traditional method of calculating reproductive success (number of young raised per nest to 15 d), the Mayfield method gave estimates of between 0.07 and 0.46 (mean 0.20) young fledged per nest lower for Black-crowned Night-Herons (Erwin and Custer 1982). We estimated nest success for the laying, incubation, and nestling periods by using periods determined for the median four-egg clutch, i.e. 7 days for the laying period, 18 days for the incubation period, and 15 days for the nestling period. Estimates of daily survival rate and corresponding variances of these estimates were calculated for each colony for each of the three periods of the nesting cycle. An estimate of the overall survival rate for each colony for the entire nesting cycle was calculated from the daily rates, and comparisons of these estimates were made among colonies as follows. Suppose the nesting cycle has two periods of lengths J_1 and J_2

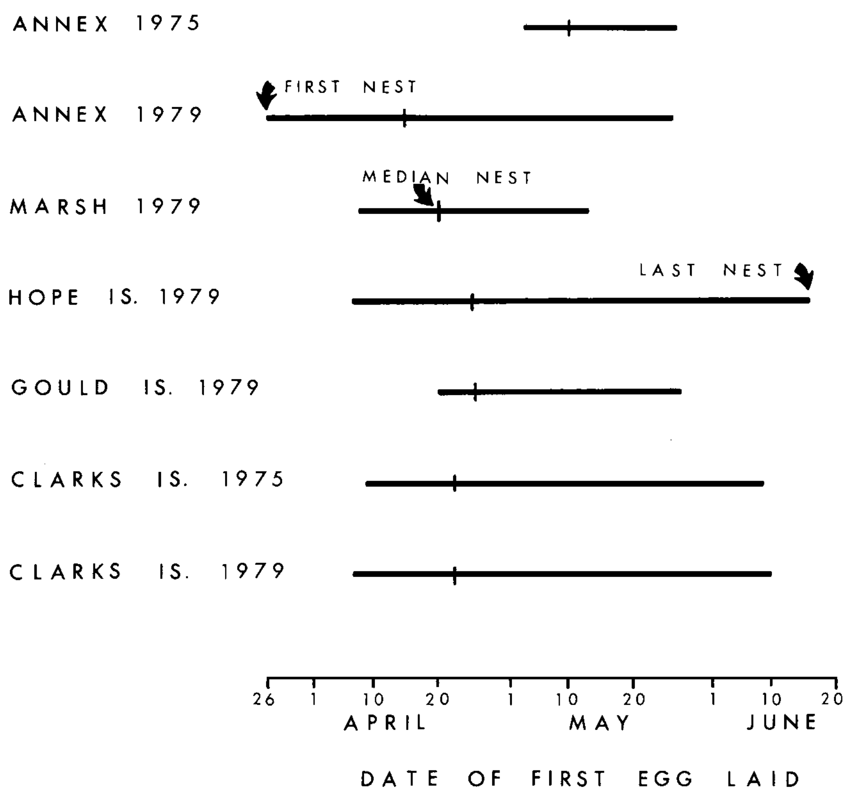

Fig. 2. Range and median date of first egg laid by Black-crowned Night-Herons nesting in five Atlantic Coast colonies.

days, with differing survival rates, p_1 and p_2, which are estimated as $\hat{p}_1$ and $\hat{p}_2$, with estimated variances $\hat{v}_1$ and $\hat{v}_2$; it can be shown using maximum likelihood theory that an appropriate estimate of overall success (i.e. $s = p_1^{J_1} p_2^{J_2}$) is $\hat{s} = \hat{p}_1^{J_1} \hat{p}_2^{J_2}$ (Roussas 1973). An estimate of the variance of $\hat{s}$ is:

$$\hat{p}_1^{2J_1} \hat{v}_2 (J_2 \hat{p}_2^{J_2 - 1})^2 + \hat{p}_2^{2J_2} \hat{v}_1 (J_1 \hat{p}_1^{J_1 - 1})^2 + \hat{v}_1 (J_1 \hat{p}_1^{J_1 - 1})^2 \hat{v}_2 (J_2 \hat{p}_2^{J_2 - 1})^2.$$

Extensions of these results to three periods were used in comparing overall success between areas.

Concentrations of organochlorines that were detected in more than 50% of the samples were transformed to logarithms for comparisons using t-tests and analysis of variance (ANOVA). The retransformed means are presented in the tables. ANOVA and an analysis of covariance were used to compare the organochlorine concentrations as functions of the date the first egg was laid and clutch size. For some organochlorine comparisons, colonies were grouped into two regions: northern (three New England colonies) and southern (two North Carolina colonies). Because organochlorines can reduce success without complete nest failure (Longcore and Stendell 1977), we compared mean organochlorine concentrations in nests where 100% of the eggs survived from laying to hatching and where 100% of young survived from hatching to 15 days of age with nests where less than 100% survived these periods. We also modeled the percentage of eggs in a nest that survived laying to hatching and the percentage of young that survived hatching to 15 days of age as a function of DDE and PCB concentrations in an egg randomly selected from each nest. We used a segmented regression model, which generated a threshold value below which a horizontal line (no effect) was fitted and above which a quadratic decreasing function was fitted. Nonlinear regression using SAS (1982) was employed to fit the model.

Results

Nesting chronology and clutch size.—No consistent differences in the date of clutch initiation occurred between the three New England and two North Carolina colonies (Fig. 2). The first nest on Annex in 1979 was initiated 12 days

TABLE 1. Variation in the distribution of clutch size of Black-crowned Night-Herons in Atlantic Coast colonies.

Colony	Year	Number of eggs 2	3	4	5	n	Mean[a]
Clark's Island, MA	1975	2	19	37	10	68	3.81 A
Annex, NC	1975	1	22	3		26	3.08 B
Total	1975	3	41	40	10	94	3.61
Clark's Island, MA	1979	7	34	71	12	124	3.71 A
Hope Island, RI	1979	5	50	92	7	154	3.66 A
Gould Island, RI	1979	1	4	16	5	26	3.96 A
Annex, NC	1979		51	29	1	81	3.38 B
Middle Marsh, NC	1979		9	3	2	14	3.50 AB
Total	1979	13	148	211	27	399	3.63

[a] Distributions of clutch-size values that are significantly different (Chi-square, overall $\alpha = 0.05$) from one another do not share the same letters.

earlier than that of any other colony, and the median date of egg laying there was 7 days earlier than at any of the three New England colonies. The first egg was laid in the Middle Marsh colony, however, on essentially the same day as in two New England colonies. Furthermore, the first date for Annex in 1975 was later than even the median date of any other colony; we suspect that this late nesting was due to renesting following failure elsewhere. We also suspect that the late nesting in both Middle Marsh and Gould Island colonies in 1979 was due to the Frasier Darling Effect (Ryder 1980), as these were both small colonies.

The clutch size of 493 nests in two colonies in 1975 and five colonies in 1979 varied from 2 to 5 eggs (modal size = 4) and was larger in northern than in southern colonies (Table 1). In 1975, clutch size was significantly greater (i.e. proportionately more large than small clutches) for Clark's Island than for Annex. Each of the three northern colonies in 1979 had larger clutch sizes than did Annex. In addition, in 1979 the three northern colonies combined had significantly larger clutch sizes than did the two southern colonies combined (Chi-square, $P < 0.01$). Significant between-year differences were found for Annex (Chi-square, $P < 0.05$) but not for Clark's Island. The higher frequency of smaller clutch sizes in Annex in 1975 may have been due to late nesting; the nesting patterns on Clark's Island in 1975 and 1979 were almost identical (Fig. 2).

When clutches for each colony and year were divided into quartiles based on the date the first egg was laid, significant seasonal differences in clutch size were found for Clark's Island in 1975 and 1979 and Hope Island (Table 2). In all three instances, clutches initiated in the last quartile of the season had fewer eggs than did earlier clutches.

Nest success.—The random removal of one egg

TABLE 2. Effect of season on the distribution of Black-crowned Night-Heron clutch sizes by colony and year.

Colony	Year	Number of nests	Proportion of large clutches (4 or 5 eggs) — Quartiles based on date the first egg was laid[a] 1	2	3	4
Clark's Island, MA	1975	59	1.0 A	0.87 A	0.71 AB	0.33 B
Annex, NC	1975	18	0.0	0.25	0.5	0.00
Clark's Island, MA	1979	118	0.88 A	0.77 AB	0.64 AB	0.48 B
Hope Island, RI	1979	150	0.63 AB	0.84 A	0.64 AB	0.54 B
Gould Island, RI	1979	24	0.86	1.0	0.83	0.83
Annex, NC	1979	75	0.38	0.47	0.36	0.37
Middle Marsh, NC	1979	13	1.0	0.25	0.75	0.0

[a] Distributions of clutch size values significantly different (Chi-square, overall $\alpha = 0.05$) from one another do not share the same letters.

for organochlorine analysis did not affect nest success (the probability that at least one egg hatched and survived to 15 days of age). For Clark's Island and Hope Island there were no significant differences (Bonferroni Multiple Comparison method, $P > 0.05$) in nest success between 4-egg clutches from which no eggs were removed and 4-egg clutches from which one egg was removed. For this comparison, four-egg clutches were chosen, because they were the most frequent clutch size (Table 1), and clutch size may affect nest success (see later results); Clark's Island and Hope Island were chosen, because we had the largest sample size in those colonies. Henny (in prep.) also found that removing one egg had no effect on Black-crowned Night-Heron nest success.

Nest success, the product of the probabilities that nests survive the laying (A), incubation (B), and nestling (C) periods (Table 3), was not significantly different between colonies in 1975. In 1979, nest success was significantly greater on Hope Island and Clark's Island than at Annex. No significant differences in nest success occurred between years for either Annex or Clark's Island ($\alpha = 0.05$).

Patterns of success among the three periods of the nesting cycle (A, B, or C; Table 3) were inconsistent. There were no significant differences ($\alpha = 0.05$) among the three periods for Clark's Island in 1975 or 1979 or for Gould Island or Middle Marsh. For Annex in 1975, however, success during the laying period was significantly greater than during the nestling period; for Annex in 1979 the nestling period was significantly more successful than the incubation period was; for Hope Island the incubation and nestling periods were significantly more successful than the laying period was.

The date of clutch initiation influenced overall nest success, but the pattern was inconsistent among colonies. On Clark's Island in 1975 and on Hope Island, nests initiated in the last quartile were less successful than those initiated earlier (Table 4). In contrast, nests initiated in the first quartile on Annex in 1979 were less successful than later nests. There were no significant differences among quartiles for Clark's Island in 1979. Other colonies were not tested because of small sample size.

Clutch size also influenced nest success. Larger clutches on Clark's Island in 1979 and on Hope Island had higher nest success than

TABLE 3. Nest success, egg success, and number of Black-crowned Night-Heron young raised per nest to 15 days of age.[a]

Year	Colony	Number of nests	Nest success: Laying (A)	Nest success: Incubation (B)	Nest success: Nestling (C)	Nest success (A × B × C)[b]	D[c]	E[d]	Egg success (A × B × C × D × E)	Mean clutch size (F)	Number young to 15 days (A × B × C × D × E × F)
1975	Clark's Island, MA	71	0.793	0.929	1.000	0.737	0.866	0.943	0.598	3.81	2.29
1975	Annex, NC	29	1.000	0.736	0.758	0.558	0.895	0.771	0.385	3.08	1.19
1979	Clark's Island, MA	127	0.956	0.943	0.961	0.867 A	0.865	0.954	0.716	3.71	2.65
1979	Hope Island, RI	165	0.849	0.956	0.985	0.799 A	0.852	0.956	0.650	3.66	2.38
1979	Gould Island, RI	31	0.680	0.839	1.000	0.570 AB	0.917	1.000	0.523	3.96	2.07
1979	Annex, NC	93	0.731	0.748	0.970	0.530 B	0.889	0.927	0.457	3.38	1.48
1979	Middle Marsh, NC	15	0.789	0.928	0.924	0.676 AB	0.903	0.885	0.540	3.50	1.89

[a] Based on days of nest exposure (see Hensler and Nichols 1981).
[b] Nest success values significantly different (Bonferroni Multiple Comparison method, overall $\alpha = 0.05$) from one another do not share the same letters.
[c] The probability of an egg hatching given that the nest is successful.
[d] The probability of young living to 15 days of age given that the nest is successful.

TABLE 4. Effect of season on Black-crowned Night-Heron nesting success by colony and year.

		Percentage nest success			
		Quartiles based on date of first egg[a]			
Colony	Year	1	2	3	4
Clark's Island, MA	1975	100 A	95 A	100 A	45 B
Clark's Island, MA	1979	73	88	91	83
Hope Island, RI	1979	100 A	88 AB	75 AB	69 B
Annex, NC	1979	23 B	49 AB	78 A	56 AB

[a] Nest success values for quartiles within colonies significantly different (Bonferroni Multiple Comparison method, overall $\alpha = 0.05$) from one another do not share the same letters.

did smaller clutches (Table 5). However, no relationship between clutch size and nest success was found for Clark's Island in 1975 or Annex in 1979. Other colonies were not tested because of small sample size.

Egg success and production of young.—Of the 1,598 eggs laid, 1,234 (77.2%) hatched, 239 (15.0%) disappeared, 54 (3.4%) were infertile, 37 (2.3%) were found outside the nest, and 20 (1.3%) were fertile but failed to hatch (Table 6). Other less frequent losses included eggs that were cracked, abandoned, or pecked. One runt egg was discovered on Hope Island in 1979. Of 1,122 chicks followed from hatching, 1,025 (91.4%) survived to 15 days of age, 80 (7.1%) disappeared, 16 (1.4%) were found dead from unknown causes in or near the nest, and 1 apparently choked to death on a fish.

To estimate egg success, nest success was multiplied by the probability that eggs in successful nests would hatch (Table 3, D) and that chicks in successful nests would survive to 15 days of age (E). The number of young surviving to 15 days of age, the product of egg success and mean clutch size (F), was consistently lower (less than 1.9 per active nest) in the North Carolina than in the New England colonies (greater than 2.0 per active nest, Table 3). This pattern occurred because both major components, clutch size and egg success, were generally lower in the two North Carolina colonies than the three New England colonies.

Clutch size, nest success, and contaminants.—A series of two-factor (date the first egg was laid and clutch size) analyses was run to examine the relationship of clutch size with concentrations of PCBs and DDE. Neither concentrations of DDE nor of PCBs differed significantly with clutch size; for the North Carolina colonies, however, PCBs were significantly greater earlier than later in the nesting season (Table 7). Moreover, a significant negative correlation between date the first egg was laid and PCB concentration was found in both the New England (Analysis of Covariance, $P = 0.02$, $r^2 = 0.10$) and North Carolina ($P = 0.04$, $r^2 = 0.18$) colonies. Neither date of laying nor clutch size was significantly correlated with DDE concentrations.

At $\alpha = 0.05$, no significant within-region (north or south) contaminant (DDE or PCB) dif-

TABLE 5. Effect of clutch size on Black-crowned Night-Heron nesting success by colony and year.

Colony	Year	Clutch size	Number of nests	Percentage nesting success[a]
Clark's Island, MA	1975	2 and 3	21	84.9
		4 and 5	47	97.3
Clark's Island, MA	1979	2 and 3	26	85.6 B
		4	46	93.1 AB
		5	7	100.0 A
Hope Island, RI	1979	2 and 3	47	91.3 B
		4 and 5	59	100.0 A
Annex, NC	1979	3	24	80.1
		4 and 5	15	67.8

[a] Nest success values among clutch sizes that are significantly different (Bonferroni Multiple Comparison method, $\alpha = 0.05$) from one another do not share the same letters.

TABLE 6. Egg and nestling losses of Atlantic Coast Black-crowned Night-Herons by year and colony.

	1975		1979							
	Clark's Island, MA	Annex, NC	Clark's Island, MA	Hope Island, RI	Gould Island, RI	Annex, NC	Middle Marsh, NC	Total	Percentage losses by category	Percentage losses of all eggs
Eggs laid	247	88	391	495	85	255	37	1,598		
Losses										
Infertile	4	2	16	23	1	7	1	54	14.8	3.4
Out of nest	1	1	7	8	3	15	2	37	10.2	2.3
Cracked		1	3	2	1	1		8	2.2	0.5
Fertile, didn't hatch			4	13	1	2		20	5.5	1.3
Pecked				1				1	0.3	0.1
Runt egg				1				1	0.3	0.1
Abandoned				2		2		4	1.1	0.2
Unknown	42	17	48	53	13	60	6	239	65.7	15.0
Total egg losses	47	21	78	100	18	85	9	364	100.0	22.8
Eggs hatched	200	67	313	395	67	170	28	1,234		
Nestlings observed from hatching to 15 days of age	157	63	281	365	60	168	28	1,122		
Losses										
Found dead (cause unknown)		10		4		1	1	16	16.5	1.4
Choked on fish						1		1	1.0	0.1
Disappeared	9	16	20	17		14	4	80	82.5	7.1
Total young losses	9	26	20	21	0	16	5	97	100.0	

ferences existed between nests in which all eggs hatched and nests in which less than 100% of the eggs hatched or between nests in which all the nestlings survived to 15 days of age and nests in which less than 100% of nestlings survived to 15 days of age (Table 8). DDE concentrations were higher ($P = 0.07$), however, in northern nests in which less than 100% of the eggs hatched (2.29 ppm wet weight, $n = 34$) than in northern nests in which all eggs hatched (1.78 ppm, $n = 36$).

A segmented regression was used to model the percentage of eggs in a nest that survived to hatching and the percentage of young in a nest that survived to 15 days of age as a function of DDE and PCB concentrations in one randomly selected egg from that nest (see Methods). Models were fit for both the northern and southern colonies. In no case could we show a significant ($\alpha = 0.05$) improvement (i.e. reduction in sum of squared residuals) of the segmented regression over the no-affect (horizontal) model. For the percentage of eggs that survived to hatching and DDE concentrations in the northern colonies, however (Fig. 3), the improvement was significant at $P = 0.09$.

DISCUSSION

Because of the difficulty in marking and observing night-herons, researchers have not been able to obtain the detailed information that is available for other colonially nesting birds (Ryder 1980). Even without marked individuals, our data on clutch size and nesting success show significant trends that are consistent with the general theory of nesting in colonial birds and birds in general.

The north-south clutch-size differences we report have been observed in other species, and our mean clutch size values of 3.1–4.0 are consistent with existing records. For many birds, mean clutch size increases as distance from the equator increases (Lack 1954), and a north-south gradient in clutch size has been suggested for ardeid species (Jenni 1969, Custer and Osborn 1977). The mean clutch sizes of night-herons from other locations include: 3.0–4.0 in Alberta (Wolford and Boag 1971), 3.9–4.2 in the St. Lawrence Estuary (Tremblay and Ellison 1980), 3.1 in Sandy Neck, Massachusetts (Gross 1923), 4.5 in New England before 1945 (Henny 1972), 4.1 in New York (Palmer 1962), 3.0 in Georgia

TABLE 7. Effect of season on PCB and DDE concentrations in Black-crowned Night-Heron eggs from New England and North Carolina colonies, 1979.

		Geometric mean concentration, ppm wet weight (sample size)			
		Quartile based on date the first egg was laid[a]			
Location	Chemical	1	2	3	4
New England	PCB	8.44 (19)	8.13 (21)	6.93 (19)	5.45 (10)
	DDE	2.54	2.04	1.78	1.64
North Carolina	PCB	2.65 A (3)	2.03 AB (5)	1.43 AB (16)	0.55 B (12)
	DDE	0.86	0.82	0.77	0.68

[a] Mean concentrations significantly different (Bonferroni Multiple Comparison method, overall $\alpha = 0.05$) from one another do not share the same letters.

(Teal 1965), and 3.4–4.1 in Idaho (Findholt 1981).

Ohlendorf et al. (1978) reported a reduction in night-heron clutch size from pre-1947 (mean = 4.1) to 1972–1973 (mean = 3.2). This difference may have resulted from a lower proportion (12%) of southern clutches in the pre-1947 sample than in the 1972–1973 sample (37%).

The occurrence of smaller clutch sizes late in the season on Clark's Island and Hope Island may have resulted from a high proportion of younger birds nesting late in the season or from renesting attempts. Late nesting night-herons (Gross 1923, Braithwaite and Clayton 1976, Custer and Davis 1982) and other colonial birds (Ryder 1980) included a high proportion of younger individuals nesting for the first time, and older individuals tend to lay larger clutches (Lack 1968, Ryder 1980). In addition, replacement clutches of night-herons in Alberta (Wolford and Boag 1971) and late clutches of Snowy Egrets (*Egretta thula*) and Little Blue Herons (*Egretta caerulea*, Jenni 1969) were smaller.

Nest success at the extremes of the nesting season was sometimes lower than in other periods. In 2 of 4 colonies, where the data base was large enough to make comparisons, pairs that nested late in the season had significantly lower success; in 1 colony, birds nesting early had significantly lower success. Early nests of other colonial species generally have higher reproductive success and are mainly those of older more experienced individuals (Coulson and White 1958, Ryder 1975, Blus and Keahey 1978, Lloyd 1979, Manuwal 1979). Early-nesting Black-crowned Night-Herons were more

TABLE 8. Geometric mean concentrations of PCBs and DDE (ppm, wet weight) in one egg collected from nests in which 100% of the eggs hatched, nests in which less than 100% of the eggs hatched, nests in which 100% of nestlings survived to 15 days of age, and nests in which less than 100% of nestlings survived to 15 days of age.

	Mean DDE				Mean PCB			
	Egg survival to hatching		Nestling survival to 15 days		Egg survival to hatching		Nestling survival to 15 days	
Location	100%	<100%	100%	<100%	100%	<100%	100%	<100%
New England colonies (3)[a]	1.78[b] (36)[c]	2.29 (34)	2.04 (53)	2.04 (9)	7.58 (36)	7.20 (34)	7.45 (53)	8.25 (9)
North Carolina colonies (2)	0.78 (23)	0.75 (13)	0.69 (26)	1.09 (4)	1.16 (23)	1.12 (13)	1.27 (26)	0.98 (4)

[a] Number of colonies in parentheses.
[b] Significantly different from nests in which less than 100% of the eggs hatched at $P = 0.07$ (one-tailed t-test).
[c] Number of nests.

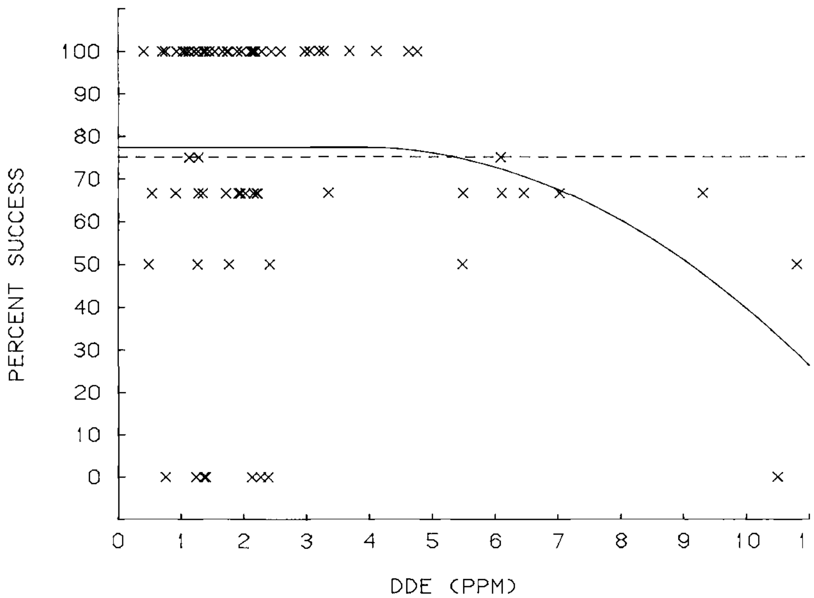

Fig. 3. For 71 nests in the northern colonies, the percentage of Black-crowned Night-Heron eggs per nest that survived to hatching is graphed as a function of the concentration of DDE measured in one egg collected from the nest. Two models are shown: a no-affect model (dashed line) and a segmented regression model (solid line) that allows a threshold value of DDE (3.86) below which DDE has no affect on hatching success and above which hatching success decreases as a function of DDE. The second model fits the data better at $P = 0.09$.

successful than late-nesters in raising broods of even-aged young (Parsons and Burger 1981). Early night-heron nests in Alberta (Wolford and Boag 1971), however, were less successful than later nests due to intense nest predation by Ring-billed Gulls (*Larus delawarensis*).

Production of young in this study was similar to or higher than that recorded from other locations. Other data on the number of fledged Black-crowned Night-Herons include: 0.5–2.1 young per active nest in a colony on the St. Lawrence River (Tremblay and Ellison 1980), 0.1–1.1 in Alberta (Wolford and Boag 1971), 2.1 in a Georgia colony (Teal 1965), 0.5–1.4 in a colony on Lake Ontario (Price 1977), and 1.1–2.5 in Idaho (Findholt 1981). Reproduction in the Alberta colonies was low because of nest predation by Ring-billed Gulls. The Lake Ontario data were considered low because of the high residues of DDE, PCBs, and dieldrin.

The higher proportion of renesting attempts and nesting by immature herons late in the season (see earlier discussion) may account for the lower concentrations of PCBs we observed in eggs as the season progressed. Eggs appear to be a major compartment for excretion of body burdens of organochlorines (Newton et al. 1981), and, as a result, second clutches may have lower concentrations. DDE concentrations in the wings of adult Mallards (*Anas platyrhynchos*) and American Black Ducks (*Anas rubripes*) were twice as high as in immatures (Heath and Prouty 1967), and organochlorines were generally higher in tissues of adult than in those of immature herons (Ohlendorf et al. 1981). In contrast, concentrations of DDE in eggs of Common Terns (*Sterna hirundo*) nesting in Hamilton Harbour, Ontario, increased during the nesting season (Gilbertson 1974). Gilbertson suggested that the seasonal increase in DDE was because late-nesting birds were at the colony longer before laying and accumulated residues at the breeding site. No relationship between the date of the first egg laid and organochlorines was found for European Sparrowhawks (*Accipiter nisus*, Newton and Bogan 1978).

One hypothesis was that if concentrations of contaminants in Atlantic Coast Black-crowned Night-Herons did not affect nesting success, herons nesting in the more contaminated New England colonies (Ohlendorf et al. 1978, 1979; Custer in prep.) should have the same reproductive success as those in less-contaminated North Carolina colonies. A second hypothesis was that organochlorine concentrations should be the same in eggs from nests with high as with low nesting success. Because reproductive success was significantly lower in the North Carolina colonies, we could not reject the first hypothesis in favor of the alternative that the more contaminated colonies had lower nest success. Our data allow us to reject the second hypothesis (at $0.10 < P < 0.05$) for the northern more contaminated colonies; DDE was higher ($P = 0.07$) in eggs from nests that hatched less than 100% of the eggs than in nests in which all eggs hatched. In addition, a segmented regression model for the northern colonies of percentage of hatching success as a function of DDE concentrations fit the data better ($P = 0.09$) than did a no-affect model. Two factors may account for the lack of significant difference at the $P = 0.05$ level: (1) the presence of important but unobserved variables, such as nest predation, which may cause nests with low DDE levels to show losses; and (2) the lack of enough nests with high levels of DDE in our sample.

The model suggests a possible effect of DDE levels above 4 ppm on hatching success that could be confirmed (or denied) by having data on more nests with eggs containing higher levels of DDE. DDE was higher in eggs from unsuccessful (mean = 3.43 ppm) than successful (2.97) Brown Pelican (*Pelecanus occidentalis*) nests (Blus et al. 1974). DDE has also been shown experimentally to affect reproductive success in other avian species (Heath et al. 1969, Porter and Wiemeyer 1969, Longcore et al. 1971, Haegele and Hudson 1973).

If hatching success in the more contaminated New England colonies is affected by DDE contamination, the impact of DDE on Atlantic Coast night-heron populations appears negligible. First, the production of 2.07–2.65 young to 15 days of age per nesting attempt in the northern, more contaminated colonies appears to be adequate to maintain a stable population. Henny (1972) estimated that 2.0–2.1 night-heron young had to be fledged per nesting female to maintain a stable population. Our values actually reflect lower production rates to fledging, because we followed the young only to 2 weeks of age and night-herons fledge at 6 weeks (Wolford and Boag 1971). Losses of young from 2 to 6 weeks of age were 10–15% in a 2-yr study of night-herons in Alberta (Wolford and Boag 1971) and 5–11% from 2 to 4 weeks of age in two night-heron colonies in Idaho (Findholt 1981). Even with a maximum of 15% mortality from 2 to 6 weeks, however, our estimate would still be 1.76–2.25 young per nesting attempt. On the other hand, because our data are estimates of success per nesting attempt rather than per female and because night-herons may renest (Wolford and Boag 1971), production rates for our colonies are probably higher. In the Lapland Longspur (*Calcarius lapponicus*), the estimate of the number of young fledged per female was 0.1–0.6 times higher than the estimate of the number of young fledged per nest (Custer and Pitelka 1977). Also, Henny's (1972) values of 2.0–2.1 may be too high, because he did not take into account nesting by 1-yr-old individuals, which does occur (Custer and Davis 1982). Second, concentrations of DDE (means for five colonies = 0.7–2.6 ppm) and PCBs (0.8–10.0 ppm) in Atlantic Coast Black-crowned Night-Heron eggs are similar in magnitude to those from a colony in the Saint Lawrence Estuary where organochlorines had no apparent effect on reproductive success (Tremblay and Ellison 1980, mean DDE = 2.2 ppm, mean PCB = 13.6 ppm). In contrast, between 1972 and 1976 night-heron eggs from a colony on eastern Lake Ontario had much higher concentrations of DDE (mean = 4.5–12.4 ppm) and PCBs (mean = 9.8–63.0 ppm, Price 1977), and nesting success was less than one young fledged per nest. Finally, Black-crowned Night-Heron populations are either stable or increasing in Massachusetts, Rhode Island (Erwin 1979), and Long Island (Buckley and Buckley 1980).

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LITERATURE CITED

ANDERSON, D. W., & J. J. HICKEY. 1972. Eggshell changes in certain North American birds. Proc. Intern. Ornithol. Congr. 15: 514–540.

BEAVER, D. A., R. G. OSBORN, & T. W. CUSTER. 1980. Nest-site and colony characteristics of wading birds in selected Atlantic Coast colonies. Wilson Bull. 92: 200–220.

BLUS, L. J., & J. A. KEAHEY. 1978. Variation in reproductivity with age in the Brown Pelican. Auk 95: 128–134.

———, B. S. NEELY, JR., A. A. BELISLE, & R. M. PROUTY. 1974. Organochlorine residues in Brown Pelican eggs: relation to reproductive success. Environ. Pollut. 7: 81–91.

BRAITHWAITE, L. W., & M. CLAYTON. 1976. Breeding of the Nankeen Night Heron *Nycticorax caledonicus* while in juvenile plumage. Ibis 118: 584–586.

BUCKLEY, P. A., & F. G. BUCKLEY. 1980. Population and colony-site trends of Long Island waterbirds for five years in the mid 1970s. Trans. Linnaean Soc. New York 9: 23–56.

COULSON, J. C., & E. WHITE. 1958. The effect of age on the breeding biology of the kittiwake *Rissa tridactyla*. Ibis 100: 40–51.

CROMARTIE, E., W. L. REICHEL, L. N. LOCKE, A. A. BELISLE, T. E. KAISER, T. G. LAMONT, B. M. MULHERN, R. M. PROUTY, & D. M. SWINEFORD. 1975. Residues of organochlorine pesticide and polychlorinated biphenyls and autopsy data for Bald Eagles, 1971–1972. Pestic. Monit. J. 9: 11–14.

CUSTER, T. W., & W. E. DAVIS, JR. 1982. Nesting by 1-year-old Black-crowned Night Herons on Hope Island, Rhode Island. Auk 99: 784–786.

———, & R. G. OSBORN. 1977. Wading birds as biological indicators: 1975 colony survey. U.S. Fish Wildl. Serv. Spec. Sci. Rept. Wildl. No. 206.

———, & F. A. PITELKA. 1977. Demographic features of a Lapland Longspur population near Barrow, Alaska. Auk 94: 505–525.

———, J. E. MYERS, & C. C. ALLIN. 1980. New Black-crowned Night Heron colony found in Rhode Island. Audubon Soc. Rhode Island 15: 10.

ERWIN, R. M. 1979. Coastal waterbird colonies: Cape Elizabeth, Maine to Virginia. Biol. Serv. Prog. U.S. Fish Wildl. Serv. FWS/OBS-79-10.

———, & T. W. CUSTER. 1982. Estimating reproductive success in water birds: some biases and alternatives. Colonial Waterbirds 5: 49–56.

FINDHOLT, S. L. 1981. Organochlorine pollutants, eggshell quality and reproductive success in Black-crowned Night Herons. Unpublished M.S. Thesis, Pocatello, Idaho, Idaho State Univ.

GILBERTSON, M. 1974. Seasonal changes in organochlorine compounds and mercury in Common Terns of Hamilton Harbour, Ontario. Bull. Environ. Contam. Toxicol. 12: 726–732.

GROSS, A. O. 1923. The Black-crowned Night Heron (*Nycticorax nycticorax naevius*) of Sandy Neck. Auk 40: 1–30; 191–214.

HAEGELE, M. A., & R. H. HUDSON. 1973. DDE effects on reproduction of Ring Doves. Environ. Pollut. 4: 53–57.

HEATH, R. G., & R. M. PROUTY. 1967. Trial monitoring of pesticides in wings of Mallards and Black Ducks. Bull. Environ. Contam. Toxicol. 2: 101–110.

———, J. W. SPANN, & J. F. KREITZER. 1969. Marked DDE impairment of Mallard reproduction in controlled studies. Nature 224: 47–48.

HENNY, C. J. 1972. An analysis of the population dynamics of selected avian species, with special reference to changes during the modern pesticide era. U.S. Fish Wildl. Serv. Wildl. Res. Rept. 1.

HENSLER, G., & J. D. NICHOLS. 1981. The Mayfield method of estimating nesting success: a model, estimators and simulation results. Wilson Bull. 93: 42–53.

JENNI, D. A. 1969. A study of the ecology of four species of herons during the breeding season at Lake Alice, Alachua County, Florida. Ecol. Monogr. 39: 245–270.

KAISER, T. E., W. L. REICHEL, L. N. LOCKE, E. CROMARTIE, A. J. KRYNITSKY, T. G. LAMONT, B. M. MULHERN, R. M. PROUTY, C. J. STAFFORD, & D. M. SWINEFORD. 1980. Organochlorine pesticide, PCB, and PBB residues and necropsy data for Bald Eagles from 29 states—1975–77. Pestic. Monit. J. 13: 145–149.

LACK, D. 1954. The natural regulation of animal numbers. Oxford, England, Oxford Clarendon Press.

———. 1968. Population studies of birds. Oxford, England, Oxford Clarendon Press.

LLOYD, C. S. 1979. Factors affecting breeding of Razorbills *Alca torda* on Skockholm. Ibis 121: 165–176.

LONGCORE, J. R., & R. C. STENDELL. 1977. Shell thinning and reproductive impairment in Black Ducks after cessation of DDE dosage. Arch. Environ. Contam. Toxicol. 6: 293–304.

———, F. B. SAMSON, & T. W. WHITTENDALE, JR. 1971. DDE thins eggshells and lowers reproductive success of captive Black Ducks. Bull. Environ. Contam. Toxicol. 6: 485–490.

MANUWAL, D. A. 1979. Reproductive commitment and success of Cassin's Auklet. Condor 81: 111–121.

MAYFIELD, H. F. 1961. Nesting success calculated from exposure. Wilson Bull. 73: 255–261.

———. 1975. Suggestions for calculating nest success. Wilson Bull. 87: 456–466.

MCCRIMMON, D. A., JR. 1978. Nest site characteristics among five species of herons on the North Carolina coast. Auk 95: 267-280.

NEWTON, I., & J. BOGAN. 1978. The role of different organo-chlorine compounds in the breeding of British Sparrowhawks. J. Appl. Ecol. 15: 105-116.

———, ———, & M. Marquiss. 1981. Organochlorine contamination and age in Sparrowhawks. Environ. Pollut. Ser. A. 25: 155-160.

NICE, M. M. 1954. Problems of incubation periods in North American birds. Condor 56: 173-197.

OHLENDORF, H. M., E. E. KLAAS, & T. E. KAISER. 1978. Environmental pollutants and eggshell thinning in the Black-crowned Night Heron. Pp. 63-82 *in* Wading birds (A. Sprunt, IV, J. C. Ogden, and S. Winckler, Eds.). Natl. Audubon Soc. Res. Rept. No. 7.

———, ———, & ———. 1979. Environmental pollutants and eggshell thickness: Anhingas and wading birds in the Eastern United States. U.S. Fish Wildl. Serv. Spec. Sci. Rept. Wildl. No. 216.

———, D. M. SWINEFORD, & L. N. LOCKE. 1981. Organochlorine residues and mortality in herons. Pestic. Monit. J. 14: 125-135.

OSBORN, R. G., & T. W. CUSTER. 1978. Herons and their allies: atlas of Atlantic coast colonies: 1975 and 1976. Biol. Serv. Prog. U.S. Fish Wildl. Serv. FWS/OBS-77/08.

PALMER, R. S. 1962. Handbook of North American birds. I. New Haven, Connecticut, Yale Univ. Press.

PARSONS, K. C., & J. BURGER. 1981. Nestling growth in early- and late-nesting Black-crowned Night Herons. Colonial Waterbirds 4: 120-125.

PETERSON, R. T. 1969. Population trends of Ospreys in the northeastern United States. Pp. 333-337 *in* Peregrine Falcon populations—their biology and decline (J. J. Hickey, Ed.). Madison, Wisconsin, Univ. Wisconsin Press.

PORTER, R. D., & S. N. WIEMEYER. 1969. Dieldrin and DDT: effects on Sparrow Hawk eggshells and reproduction. Science 165: 199-200.

PRICE, I. M. 1977. Environmental contaminants in relation to Canadian wildlife. Trans. North Amer. Wildl. Nat. Resources Conf. 42: 382-396.

ROUSSAS, G. G. 1973. A first course in mathematical statistics. Reading, Massachusetts, Addison-Wesley.

RYDER, J. P. 1975. Egg laying, egg size, and success in relation to immature-mature plumage of Ring-billed Gulls. Wilson Bull. 87: 534-542.

———. 1980. The influence of age on the breeding biology of colonial nesting seabirds. Pp. 153-168 *in* Behavior of marine animals. Vol. 4: Marine birds (J. Burger, B. L. Olla, and H. E. Winn, Eds.). London, Plenum Press.

SAS. 1982. SAS user's guide: statistics. Cary, North Carolina, SAS Institute.

STICKEL, L. F., S. N. WIEMEYER, & L. J. BLUS. 1973. Pesticide residues in eggs of wild birds: adjustment for loss of moisture and lipid. Bull. Environ. Contam. Toxicol. 9: 193-196.

TEAL, J. M. 1965. Nesting success of egrets and herons in Georgia. Wilson Bull. 77: 257-263.

TREMBLAY, J., & L. N. ELLISON. 1980. Breeding success of the Black-crowned Night Heron in the St. Lawrence Estuary. Can. J. Zool. 58: 1259-1263.

WOLFORD, J. W., & D. A. BOAG. 1971. Distribution and biology of Black-crowned Night Herons in Alberta. Can. Field-Natur. 85: 13-19.