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Reproductive Success of the White-Faced Ibis: The Effects of Pesticides and Colony Characteristics

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REPRODUCTIVE SUCCESS OF THE WHITE-FACED IBIS: THE EFFECTS OF PESTICIDES AND COLONY CHARACTERISTICS

by

Benjamin B. Steele

A thesis submitted in partial fulfillment
of the requirements for the degree

of

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in

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Benjamin B. Steele

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ABSTRACT

Reproductive Success of the White-faced Ibis: Effects of Pesticides and Colony Characteristics

by

Benjamin B. Steele, Master of Science
Utah State University, 1980

Major Professor: Dr. John A. Kadlec
Department: Wildlife Science

Reproductive success of white-faced ibis (Plegadis chihi) was measured in nine colonies on marshes in northern Utah during 1979. The effects of pesticides and characteristics of colonies and subcolonies on reproductive success were examined.

DDE was present in all 80 eggs sampled and had a geometric mean concentration of 1.25 ppm. Shell thickness of 176 eggs was 4.3 percent below pre-1945 thickness. Shell thickness was weakly correlated with residues of DDT, DDE, Dieldrin, and heptachlor epoxide. Residues of these four pesticides were all correlated with each other. However, because of the stronger correlations between shell thickness and two residues, DDE and DDT, and because of studies in the literature, it was concluded that these two residues were responsible for the observed shell thinning. Observed levels of pesticides did not cause sufficient shell thinning to reduce hatching success, but clutch size was negatively correlated with pesticide residues.

Only two characteristics of colonies were observed to be associated with differences in reproductive success. Earlier subcolonies had larger clutches and larger colonies suffered higher rates of predation. If there are effects of subcolony size, degree of nesting synchrony, vegetation type, or avian species association on reproductive success, they may not be detectable with one year of data.

(64 pages)

INTRODUCTION

Recruitment into a bird population must equal mortality if the population is at equilibrium. In the short term, however, recruitment as well as reproductive success may vary widely from year to year or from place to place while mortality remains constant. Reproductive success may fluctuate depending on environmental conditions or attributes of the birds. Environmental factors that affect reproduction include precipitation, temperature, habitat, disturbance, and chemical poisoning. Attributes of birds that may affect reproductive success include age, experience, and genetic make-up. These attributes are often reflected by the timing of breeding or the characteristics of the nest site. This study looked at two factors that affect reproduction in the white-faced ibis (*Plegadis chihi*): pesticides and characteristics of nesting associations.

Ibises have been found to carry pesticide residues and produce thin shelled eggs. Recent declines in population (Ryder 1967, King et al. 1978) are potentially due to pesticides. Ibises also nest in a variety of colony sizes and vegetation types, providing an opportunity to compare reproductive success in different groups of nesting birds.

Reproductive success is generally defined as the number of offspring produced per mated pair of adults. In this study reproductive success was measured by three components of reproduction: clutch size (number of eggs laid per nest), hatching success (the percentage of eggs that successfully hatch), and chicks per nest (the number of chicks that hatch per nest).

Pesticides

Organochlorine pesticide effects on reproduction have been documented for many bird species, and in some cases have been associated with population declines (Hickey 1969, Blus et al. 1975). Pesticide effects on birds include direct killing (Hickey and Hunt 1960, Keith 1966), delayed ovulation (Jefferies 1967), reduction in clutch size (Haegle and Hudson 1973), embryo mortality (Endersen and Berger 1970, Blus et al. 1974a), and poor chick survival (Stickel 1973, but most well known is the thinning of eggshells and consequent crushing of eggs (Enderson and Berger 1970, Ratcliff 1970, Blus et al. 1972, 1979).

In 1965 Ryder (1967) reported white-faced ibis colonies in fewer places than in previous years. Capen (1977a) suspected that this population decrease was due to the presence of organochlorines in the environment. Residues of DDE, a metabolite of DDT, were found in eggs and tissues of ibises in Utah from 1968 to 1971. Large numbers of abnormal eggs were also found during this period (A. G. Smith, unpublished reports 1968, 1969, 1970; K. King and M. Friend, unpublished report 1971, Denver Wildlife Research Center, U.S. Fish and Wildlife Service). In 1971, DDT was banned in Utah and in 1974 eggshell thickness was the same as that of eggs collected before widespread use of DDT (Capen 1977a). In 1975 and 1976, high residues of DDE were again found in tissues and eggs, abnormal eggs were common, and shell thickness had decreased. Capen (1977a) postulated that ibises contacted DDT while wintering on agricultural areas in Mexico where DDT is still used.

The present study was conducted to determine the current levels of DDE and other organochlorine pesticide residues in white-faced ibis eggs and to assess the effect of residues on reproductive success. Specifically, it was expected that high DDE levels would be associated with thinner eggshells, smaller clutch size, and poorer hatching success.

Characteristics of Colonies

Variation in breeding success between colonies of birds may be related to the timing of breeding, the size of the colonies, the degree of nest synchrony within colonies, vegetation, and co-occurring avian species. These factors do not necessarily affect reproduction directly. Birds that are intrinsically better at producing offspring often select a certain type of nesting situation and thus are located together.

Coulson and White (1958, 1960) found that earlier nesting blacklegged kittiwakes (*Rissa tridactyla*) had better reproductive success. Early nesters were usually in the center of the colony and late arrivals colonized peripheral areas. Cliff swallows (*Petrochelidon pyrrhonota*) nesting in the center of a colony had better success than those on the edges (Emlen 1971).

Birds nesting in larger colonies may have better reproductive success because more nests may increase the benefits of colonial nesting or because birds may tend to aggregate in better habitat.

Fisher (1963) suggested that older birds capable of producing more offspring nested in larger colonies. Smith (1943) and Langham (1974) found better reproduction in large colonies of red-winged blackbirds (*Agelaius phoeniceus*) and Sandwich terns (*Thalasseus sandwichensis*), respectively.

Colonies in which laying is more synchronous should have better reproductive success because chicks and eggs within these colonies are vulnerable to predation for a shorter period of time. When they are vulnerable there are many more than are needed to satiate a predator and a lower percentage of nests are destroyed. The reduction of predation by satiation of the predator was first described by Holling (1959). Better success in more synchronous nests was found for red-winged blackbirds (Robertson 1973) and yellow warblers (*Dendroica petechia*, Clark and Robertson 1979).

Habitat differences were related to reproductive success in several studies (Alford 1978, Vehrencamp 1978). Also, association with certain other avian species can be an advantage (Larson 1960, Evans 1970, Gochfeld 1977, Sears 1978).

Most comparisons of breeding success among or within colonies have been done with the family *Laridae*. Only a few studies have dealt with wading birds (Alford 1978, Blus and Keahey 1978). The variety of nesting associations of white-faced ibises provide an opportunity to examine the effect of colony characteristics on reproductive success.

Ibis colonies can be broken down into smaller units called subcolonies. A colony was defined as an aggregation of nests separated spatially from other aggregations. In this study, subcolony refers to a subunit of a colony within which nesting is synchronous. Subcolonies are separated from each other either temporally by a period of no nest initiation or spatially by nests of a different initiation period. Nests were considered initiated when eggs appeared in them. White-faced ibises nested in a variety of sizes of colonies (50 to 3000 nests) and subcolonies (50 to 1000 nests). Mean initiation date of subcolonies within a single colony differed by up to 40 days.

This study evaluated reproductive success in both colonies and subcolonies in terms of their mean initiation date, size, degree of synchrony, vegetation type, and associated avian species.

The White-faced Ibis

Distribution and habitat

The white-faced ibis has a discontinuous distribution, breeding in North America and in southern South America. In North America, major breeding concentrations are located on the gulf coast of Texas and Louisiana, and in marshes in Nevada and northern Utah. Scattered colonies occur in six other states (Ryder 1967). On the eastern edge of their breeding range in Louisiana they are replaced by the ecologically and morphologically similar glossy ibis (*P. falcinellus*).

White-faced ibises almost always nest in colonies. Recently expressed ideas on the adaptive significance of colonial nesting include avoidance of predation (Tinbergen 1951, Kruuk 1964, Patterson 1965, Sears 1978, 1979), better exploitation of ephemeral food resources (Horn 1968, Emlen 1971, Ward and Zahavi 1973, Krebs 1974, Hunt and Hunt 1976), and aggregation in preferred nesting habitat (Lack 1968, Emlen 1971). The food resources used by the white-faced ibis are ephemeral in nature and birds evidently use each other to find available food. Birds often leave the colony in groups and land in areas where others are feeding. Ibises may also nest in colonies to protect themselves from predators, but habitat does not seem to be limiting, as many areas that appear suitable are not colonized.

The northern Utah population of white-faced ibis is centered around the marshes at the mouth of the Bear River on the Great Salt Lake. Colonies also occur in other marshes around the Great Salt Lake, on Utah Lake, and on Cutler Marsh in Cache County.

In Utah, ibises have taken advantage of agricultural practices by feeding on invertebrates in irrigated fields. Insects and earthworms are the most common food items taken (Capen 1977a).

Colonies occur in two distinct types of vegetation. Each type supports a different association of avian species. Colonies occurring in hardstem bulrush (*Scirpus acutus*) and cattail (*Typha latifolia*) over standing water also have snowy egrets (*Leucophoyx thula*), black-crowned night herons (*Nycticorax nycticorax*), and occasionally great blue herons (*Ardea herodias*). Colony sites in alkali bulrush (*C. paludosus*) usually are drier and contain a large number of nesting Franklin's gulls (*Larus pipixcan*).

Locations of colonies often change between years. Relocation occasionally occurs because of obvious factors such as insufficient water, but often the cause is not apparent.

Breeding and migration

Ibises arrive in northern Utah in April and May. Colonies are established between late April and mid-June. The incubation period is 20 to 22 days and chicks fledge in 28 to 35 days (Belknap 1957, Kotter 1970). Fledged immatures and adults roost in marshes at night during late summer. Migration begins in September and by October, most ibises have left northern Utah. Birds migrate through the Colorado Valley (Ryder 1967) and band returns indicate that they winter in the states of Sinaloa, Nayarit, Jalisco, Michoacan, Guanajuanto and Guerrero in south-central Mexico, a largely agricultural district (Capen 1977a).

Ibises usually lay three to four eggs, although occasionally five or six eggs appear in a nest. Possibly, these larger clutches are due to two adults laying in the same nest. Hatching success varies widely, some colonies being almost completely destroyed by predators. There is some indication that birds whose nests are destroyed early in the season will renest (Capen 1977a).

Few data on the longevity of the white-faced ibis are available although one captive bird lived 14 years (Stott 1948). The oldest recovered band was from a 9 year old bird (Ryder 1967). A sample of birds color banded by Capen (1977a) indicated that ibises probably do not breed in their first year, but at least some do in their second.

Population status

White-faced ibis populations have evidently declined over the past several decades (Ryder 1967). Ryder (1959) reported 10,000 birds on Ogden Bay and Howard Slough near the Great Salt Lake in the 1950's. Between 1969 and 1976, Capen (1977a) recorded 450 to 3100 nesting pairs north of Ogden Bay and very few ibises in the colonies censused by Ryder.

Recent data indicate an increase in the northern Utah ibis population (Table 1). Between 1976 and 1979, censuses in the marshes of the Salt Lake Valley north of the Great Salt Lake indicate a 100 percent population increase. The numbers in Table 1 should not be taken as exact population levels as several factors make censuses of ibis nests difficult. Colonies are difficult to locate and estimates of a dark, ground nesting bird are unreliable. Even actual counts of all nests can be low because of new nests appearing after a census is made.

Despite these difficulties, I believe that the magnitude of the increase in 1979 must indicate an increase in the number of breeding birds in northern Utah. This increase and the severe fluctuations before 1979 seem to be too rapid to be due entirely to mortality and recruitment. Large numbers of birds must have moved into and out of the area. Some evidence indicates that ibises do not have strong ties to the areas where they were fledged. Between 1973 and 1975, 2800 birds were color banded as chicks by Capen (1977a). In 1978, 1680 adults in the Salt Lake Valley (population 7000 to 8000) were examined, only nine of which were banded. As the ibis is a long-lived bird, one would expect a much higher rate of band return if the birds breed in the same areas where they were fledged. This implied lack of fidelity to nesting locations may help explain the recent increase in Utah. In 1977, a colony at Carson Lake that

Table 1. Number of white-faced ibis nests in the northern Salt Lake Valley and Cache Valley, 1968-1979.

Year	Knudson's Marsh	Bear River Club	Bear River Refuge	Cutler[a] Reservoir	Total
1968[b]	100	3000	0		3100
1969[b]	540	350	10		900
1970[b]	0	350	100		450
1971[c]	200	2850	0		3050
1973[d]	30	2890	80		3000
1974[d]	10	1500	100		1610
1975[d]	810	120	760		1690
1976[d]	120	0	2560		2680
1978[e]	700-950	1390-1590	950	400	3440-3890
1979[f]	100	4980	1460	2150	8690

[a] Data previous to 1978 are not available but no more than 75 nests occurred here (Capen, personal communication).

[b] Data from Smith (unpublished reports 1968, 1969, 1970 Denver Wildlife Research Center). Census by aerial counts.

[c] Data from King and Friend (unpublished report 1971, Denver Wildlife Research Center). Census by ground counts.

[d] Data from Capen (1977a). Census by nest counts.

[e] Data from the present study. Census by nest counts and estimates.

[f] Data from the present study. Census by nest counts.

previously numbered 6000 birds disappeared when water was diverted from the lake for irrigation during a drought (unpublished progress report, 1978, by Mark Barber, Stillwater Wildlife Management Area, Fallon, Nev.). Birds from this colony may have relocated in northern Utah.

STUDY AREA AND METHODS

Study Area

The study area included three large marshes near the delta of the Bear River on the Great Salt Lake, Box Elder County, and the Cutler Reservoir marsh in Cache County, Utah. Marshes near the Bear River delta were on the Bear River Migratory Bird Refuge; the Bear River Club Company, a private club; and Knudson's Marsh, a privately owned marsh. The nine colonies located in these areas were subdivided into 22 subcolonies with a variety of characteristics (Table 2).

Methods

Except for one colony (BRC-S), all data were collected during 1979. Colonies were located by aerial surveys on May 12, May 26, and June 9, 1979, and numerous ground surveys.

Censuses were conducted by walking through each colony and marking each nest with a spot of spray paint as it was counted. Repeated visits were made to each colony to insure that late subcolonies were included.

Reproductive success was measured in a sample of nests located on a 6 m wide transect running through each subcolony. Sample size ranged from 23 to 85 nests depending on the size of the subcolony. Nests were marked with numbered plastic-coated tags wired to vegetation. Tags were placed below each nest to decrease disturbance

Table 2. Characteristics of 22 white-faced ibis subcolonies in northern Utah. All data are from 1979 except colony BRC-S which is from 1978.

Colony	Sub-colony	Initiation date	Number of nests	Other avian species	Vege-tation	Synchrony[a]
BRR-5	1	6/8	519	FG	A	3.18
"	2	4/30	54	FG	A	2.92
"	3	5/11	95	FG	A	3.31
"	4	5/24	102	FG	A	1.70
BRR-1A		5/6	63	SE + BCNH	C	3.16
BRR-2		6/8	50	SE + BCNH	C	1.03
Knudson's		5/4	103	SE + BCNH	C	--
BRC-E[b]		5/27	966	SE + BCNH	C	1.73
BRC-W		6/6	45	SE + BCNH	C	4.61
BRC-N	1	5/16	796	SE + BCNH	C	1.17
"	2	5/10	662	SE + BCNH	C	3.73
"	3	5/18	389	FG	A	1.47
"	4	5/5	1000	FG	C	2.27
"	5	5/20	691	--	C	2.30
"	6	6/11	176	--	C	2.71
"	7	5/24	50	SE + BCNH	C	1.99
"	8	5/22	251	--	A	1.67
GSL	1	5/15	403	FG	A	4.70
"	2	6/3	--	FG	A	4.06
Cutler	1	5/13	--	SE + BCNH	C	1.39
"	2	5/9	--	SE + BCNH	C	--
BRC-S		6/17	550	SE + BCNH	C	1.83
Median value		5/19	200			2.28

[a] Standard deviation of laying dates of first eggs.

[b] Located where BRC-S was in 1978.

Abbreviations:

BRR - Bear River Refuge
BRC - Bear River Club
GSL - Great Salt Lake
FG - Franklin's gull

SE - snowy egret
BCNH - black-crowned night heron
A - alkali bulrush
C - cattail

of the adult. Nests were visited every two to three days during laying and every five to eight days thereafter. Nest checking was done as quickly as possible to minimize disturbance. Trembley and Ellison (1979) found that black-crowned night heron nests visited every three to four days before and during laying had more abandonment than nests visited only twice during the season. In this study, nest disturbance was judged to be minor because there was no obvious difference in the number of chicks per nest between nests which were visited from four to eight times and nests visited only once. The fact that white-faced ibises return quickly to their nests after disturbances probably helped reduce the effects of the observer. Embryo mortality from chilling or overheating was avoided by not flushing adults on cold mornings or when temperatures in the nest were high.

Laying order was recorded by numbering each egg with a felt tip pen containing permanent ink. A sample of 80 eggs was collected from eight subcolonies for shell thickness measurements and pesticide analysis. An additional 100 eggs were collected from ten subcolonies for further shell thickness measurements. Nests from which eggs were taken were evenly distributed along the transects of marked nests.

Eggs collected for pesticide analysis and shell thickness measurements were selected at random from complete clutches. Eggs collected for thickness measurements only were the second egg laid, when it could be identified, as laying order can affect shell thickness (Capen 1977b).

Eggs were washed in warm tap water and detergent, air dried, and weighed. Volume was measured by water displacement. Eggs were then cut around the equator with disecting scissors, and emptied. Empty shells were washed in warm water and air dried. A micrometer was used to make six measurements of shell thickness, to the nearest 0.01 mm. Measurements were spaced evenly around the equator of each shell. Six measurements were judged by Capen (1977b) to be sufficient to obtain a precision of 95 percent. Statistical tests were carried out with the original measurements as well as measurements corrected for thinning during incubation.

Contents of eggs for pesticide analysis were placed in clean glass jars that had been rinsed in acetone and hexane. Jars were then capped with aluminum foil and plastic lids, frozen and shipped to Raltech Scientific Services in Madison, Wisconsin, for analysis. The methodology of the pesticide analysis is described in the Appendix.

Pesticide concentrations on a wet weight basis were used for all analyses. Peakall and Gilman (1979) found that the lipid weight varied from 143 to 298 percent during the course of incubation while wet weight varied only 23 to 26 percent. Thus pesticide residues on a wet weight basis are less affected by length of incubation than those on a lipid weight basis.

Pesticides expressed on a wet weight basis are still somewhat affected by incubation (Stickel et al. 1973). Consequently, both the actual levels found and levels corrected for weight loss during incubation were used in statistical tests.

RESULTS AND DISCUSSION

Pesticides and Reproduction

Pesticides

Thirteen different organochlorine compounds were found in the 80 eggs analyzed (Table 3). The most prevalent was DDE which was found in all eggs and had the highest geometric mean (1.25 ppm) and maximum (23.6 ppm) concentration. DDE levels in eggs may have decreased since 1975 when Capen (1977a) reported a geometric mean of 1.50 ppm for 36 eggs.

Shell thickness

Average thickness of eggshells in 1979 (0.313 mm) was greater than thickness in 1975 (0.307 mm, $t = 1.89$, $p<0.05$), but was still below pre-1945 thickness (0.327 mm, $t = 7.51$, $p<0.01$) that is assumed to have been unaffected by pesticides (Table 4).

Correlation coefficients indicate that shell thinning may be related to residues of DDE, DDT, dieldrin, and heptachlor epoxide (Table 5). Coefficients in Table 5 were calculated from two different nonparametric tests: Spearman's and Kendall's. Spearman's coefficient (r) corresponds more closely to the standard product-moment correlation coefficient while Kendall's r is often lower in absolute value, but gives more reliable results when there are many ties in rank (Hollander and Wolfe 1973, Nie et al. 1975). Heptachlor epoxide, oxychlordane, beta BHC and DDD were not detected in many cases yielding numerous ties in rank.

Table 3. Organochlorine compounds found in 80 white-faced ibis eggs from northern Utah, the number of eggs in which they were found, geometric mean, 95 percent confidence limits, and range of concentrations on a wet weight basis.

Organochlorine	# of eggs containing compound	Geometric mean (ppm)	95% confidence limits (ppm)	Range ppm
DDE	80	1.25	1.04-1.62	0.08-23.6
PCB as aroclor 1254	68	0.25	0.11-0.41	N.D.*-1.15
DDT	48	0.14	0.09-0.19	N.D.-1.68
Dieldrin	42	0.12	0.06-0.18	N.D.-2.94
Heptachlor epoxide	27			N.D.-0.94
Oxychlordane	27			N.D.-0.19
Beta BHC	27			N.D.-0.56
DDD	25			N.D.-0.65
Endrin	12			N.D.-0.15
Nona chlordane	7			N.D.-0.14
HCB	5			N.D.-0.11
Alpha BHC	3			N.D.-0.07
Mirex	1			0.06

*Not detected.

Table 4. Mean thickness of white-faced ibis eggshells from northern Utah collected during 1968 to 1979 and of museum eggs collected before 1945.

Collection	Number of eggs	Mean thickness (mm)	Comparison with pre-1945 eggs
Pre-1945 Museum[1]	374	0.327	
1968[1]	18	0.286	$t = 8.56$, $p < 0.01$
1969[1]	80	0.271	$t = 24.68$, $p < 0.01$
1971[1]	40	0.292	$t = 11.03$, $p < 0.01$
1974[1]	56	0.324	Not significant
1975[1]	86	0.307	$t = 8.38$, $p < 0.01$
1976[1]	99	0.311	$t = 5.33$, $p < 0.01$
1979	176	0.313	$t = 7.51$, $p < 0.01$

[1] Data from Capen (1977a).

Table 5. Correlation coefficients between organochlorine concentrations and shell thickness measurements of 80 white-faced ibis eggs from northern Utah, 1979.

Organochlorine	Correlation with: Measured shell thickness	Corrected shell thickness
DDT[1]	-0.51*	-0.43*
DDE[1]	-0.33*	-0.27*
Dieldrin[1]	-0.22*	-0.19*
Heptachlor epoxide[2]	-0.19*	-0.13
Beta BHC[2]	-0.08	-0.09
PCB as arochlor 1254[1]	0.08	0.11
Oxychlordane[2]	0.03	0.11
DDD[2]	0.01	0.01

*Significant ($p < 0.05$).

[1] Spearman's correlation coefficient.

[2] Kendall's correlation coefficient.

Correlation coefficients between organochlorines and corrected shell thickness also appear in Table 5. Eggshells become thinner during incubation because developing embryos remove calcium from the shells. To eliminate this bias, measured shell thicknesses were corrected using a model which is based on a 4.3 percent decrease in white-faced ibis eggshell thickness during 11 days of incubation (Capen 1977a). Because laying date was often estimated from embryo size or hatching date, corrected thicknesses are not necessarily more accurate than uncorrected values. In Table 5, when the correlation with measured thickness was significant, the correlation with corrected thickness was lower. Thus the correction model added more variation than was caused by different amounts of incubation of the collected eggs.

The four residues significantly correlated with shell thickness, DDE, DDT, dieldrin, and heptachlor epoxide, were all significantly correlated with each other (Table 6). Therefore only one residue may be related to shell thinning and other correlations with thickness may be due to correlations between pesticides.

I believe that DDT and DDE were responsible for the observed thinning. DDT was closely correlated with DDE, probably came from the same source, and has the same effect. Longcore et al. (1971), Risebrough and Anderson (1975), and Kolaja and Hinton (1978) found that feeding DDE and DDT to ducks caused thinning of eggshells. In this study the highest correlation coefficients with thickness were with DDT and DDE. Other workers who identified several organochlorine residues in eggs of wading birds concluded that DDE or DDT

Table 6. Kendall correlation coefficients between eight organochlorines found in white-faced ibis eggs in northern Utah, 1979.

	DDE	DDT	DDD	PCB	Dieldrin	Heptachlor epoxide	Oxychlordane	Beta BHC
DDE		.58**	.16*	.15*	.24**	.33**	.21**	.37**
DDT			.16*	.01	.25**	.47**	.33**	.47**
DDD				-.07	.24**	.31**	.29**	.25**
PCB					.01	.06	.03	-.01
Dieldrin						.41**	.32**	.36**
Heptachlor epoxide							.61**	.51**
Oxychlordane								.46**

*Significant $p < 0.05$.

**Highly significant $p < 0.01$.

were primarily responsible for shell thinning (Capen 1977a, Ohlendorf et al. 1978a, 1978b).

It is unlikely that dieldrin or heptachlor epoxide caused shell thinning. Dieldrin and heptachlor epoxide were weakly correlated with thickness and were found not to cause thinning in other studies. Fowler et al. (1971) found no correlation between dieldrin levels and eggshell thickness of common and purple gallinules (*Gallinula chloropus* and *Poryphyrula martinica*). Similarly, Blus et al. (1979) reported that heptachlor epoxide was not correlated with thickness of Canada goose (*Branta canadensis*) eggshells.

The correlation coefficient between shell thickness and DDE residues (-0.33) implies that the effect of this compound was not very strong. This value is low in absolute value compared to correlation coefficients found in other studies (Table 7). Log transformation of DDE data, which is common in the literature (Blus et al. 1972, 1974b, Capen 1977a), resulted in a slightly higher coefficient ($r = -0.43$). Apparently, at the levels of DDE found in 1979, other sources of variation in shell thickness were relatively more important, causing r values to be low.

Log transformation of the original data, which was positively skewed, also made it resemble more closely the normal distribution assumed for regression. A regression of thickness on the log of DDE (Figure 1) was highly significant ($p<0.001$), but did not have a very steep slope ($b = -0.017$). Thus, white-faced ibis eggshells were not highly sensitive to the levels of DDE found in 1979.

Table 7. Correlation coefficients between DDE residues and shell thickness for wading birds. All residues were measured on a wet weight basis.

Species	Correlation	Coefficient (r)	Source
White-faced ibis	thickness & log DDE	-0.61	Capen 1977a
White-faced ibis	thickness & DDE	-0.39	Capen 1977a
White-faced ibis	thickness & DDE or ΣDDT	-0.64	King et al. 1978
Wood stork	thickness & DDE	-0.42*	Ohlendorf et al. 1978b
Reddish egret	thickness & DDE or ΣDDT	-0.74	King et al. 1978
Black-crowned night heron	thinning & DDE	0.43	Ohlendorf et al. 1978a
Great blue heron	thickness & DDE or ΣDDT	-0.66	King et al. 1978
Anhinga	thickness & DDE	-0.32*	Ohlendorf et al. 1978b
Brown pelican	thinning & log DDE	0.37	Blus et al. 1975
Brown pelican	% of normal & log DDE	-0.96	Blus et al. 1974b
Brown pelican	thickness & DDE	-0.52	Blus et al. 1971
Brown pelican	% of normal & log DDE	-0.80	Blus et al. 1972
Brown pelican	thickness & DDE or ΣDDT	-0.61	King et al. 1978
White pelican	thickness & DDE	-0.48	Knopf and Street 1974

*Spearman Correlation Coefficient.

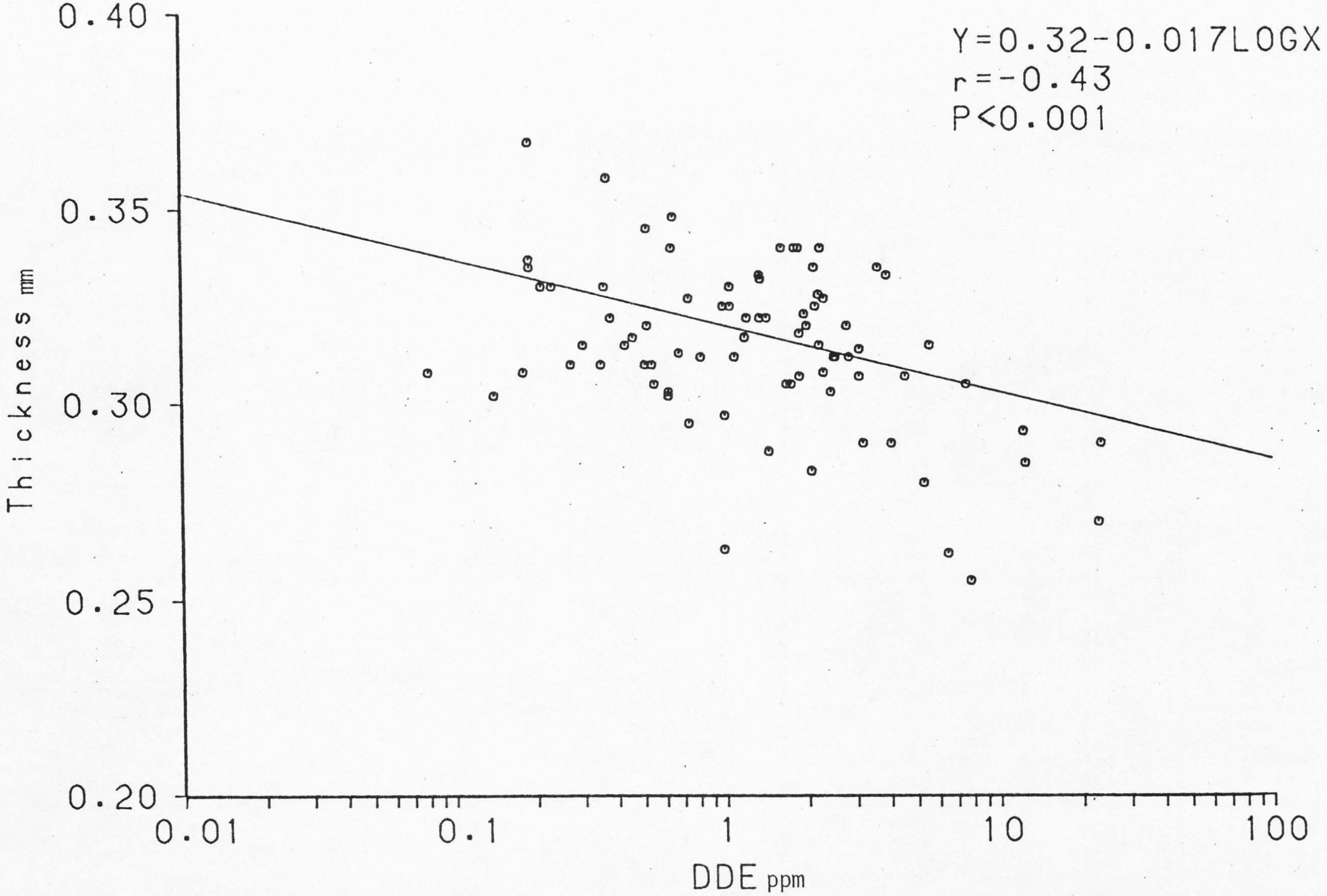

Figure 1. Regression of white-faced ibis eggshell thickness with DDE concentration in eggs collected in 1979.

Nest initiation date

Significant but weak negative correlations were found between two pesticides, DDT and dieldrin, and nest initiation date ($r = -0.30$, $p<0.01$ and $r = -0.24$, $p<0.01$). This is the reverse of what one would expect. Several workers (Jefferies 1967, Haegele and Hudson 1973, Richie and Peterle 1979) found that pesticides delayed ovulation or breeding. In this study, adults with higher levels of pesticides, as indicated by levels in their eggs (Smith et al. 1970), nested earlier in the season. Apparently, current levels of pesticides did not cause a delay in breeding.

The observed decrease in DDT during the breeding season may be due to changes in fat storage in the adult birds. DDT is lipid soluble, hence when lipids are used during starvation, the total amount of lipid in the bird decreases and concentration of DDT in blood and tissue increases (Ecobichon and Saschenbrecker 1969, Findlay and deFreitas 1971). Capen and Leiker (1979) found that as fat reserves in the white-faced ibises decreased, DDE levels in blood increased. If white-faced ibises that nest earlier have smaller fat reserves, the DDT concentration in their eggs should be higher. There are several reasons why birds nesting earlier might have less stored fat, but, as the nutritional status of adult females is unknown, this explanation of the observed changes in DDT and dieldrin must be regarded as speculative.

An alternative explanation for higher pesticide concentrations occurring in earlier eggs is that adults that nested earlier encountered more pesticides as a group. This idea was used by Knopf and Street (1974) to explain an increase in DDE and dieldrin in eggs of white pelicans (Pelicanus erythrorhynchos) as the breeding season progressed.

Reproductive success

Correlations of DDE, DDT, and heptachlor epoxide levels with clutch size and chick per nest (Table 8) are weak but significant. The coefficients may be low because, at 1979 pesticide levels, natural variation in reproductive success was relatively more important. Also the coefficients are from Kendall's test which produces values of r that are lower in absolute values than those from the standard product-moment test (Nie et al. 1975).

Although residues of DDT, DDE and heptachlor epoxide are all correlated with smaller clutches, I feel that the smaller clutches were most likely caused by DDT and DDE. DDT and DDE have been shown to affect clutch size in experimental studies (Hickey 1969, Haegele and Hudson 1973, Stickel 1973). Heptachlor epoxide was present in only 27 of 80 eggs and is correlated with both DDE and DDT (Table 6).

The decrease in number of chicks per nest associated with pesticide residues was the result of a reduction in clutch size rather than a decrease in hatching success. Hatching success was not correlated with any residue, although clutch size was correlated with DDE, DDT, and heptachlor epoxide. Thus, shell thinning in 1979 was not sufficient to cause a significant number of cracked eggs or poor hatching success.

If thin shelled eggs cracked and were discarded before clutch size was measured, then hatching failure due to shell thinning might

Table 8. Kendall correlation coefficients between organochlorine concentrations in white-faced ibis eggs and reproduction in the nests from which they were taken.

Organochlorine	Chicks per nest	Clutch size	Hatching success	Initiation date
DDT	-0.22**	-0.30**	-0.07	-0.30**
Heptachlor epoxide	-0.19*	-0.18*	-0.08	
DDE	-0.15*	-0.26**	-0.02	0.09
Dieldrin	-0.14	-0.04	-0.14	-0.24**
PCB as aroclor 1254	-0.06	-0.09	-0.05	-0.07
Oxychlordane	-0.003	-0.09	0.08	

*Significant ($p < 0.05$).

**Highly significant ($p < 0.01$).

have been recorded as a reduction in clutch size. I do not believe that this error occurred in this study because nests were visited frequently during laying and searches were made for shell fragments.

In contrast to what has been reported in the literature, dieldrin levels in this study were not correlated with reproductive success (Table 8). Dieldrin has been associated with lowered reproductive success in shags (Phalacrocorax aristotelis, Potts 1968), pheasants (Phasianus colchicus, Baxter et al. 1969), and other birds (Stickel 1973). DDT and DDE encountered by the white-faced ibis may obscure the effects of dieldrin on reproduction.

The negative correlation ($r = -0.22$, $p<0.05$) between shell thickness and dieldrin (Table 5) also contradicts what others have found. Fowler et al. (1971) found no significant correlation between dieldrin and thickness of purple and common gallinule eggs. In the present study, the weak but significant correlation may be due to the correlation between dieldrin and other pesticides (Table 6).

Eggs lose moisture through their shells and become lighter during incubation. Consequently, organochlorine concentrations measured on a wet weight basis are likely to be higher in older eggs than in freshly laid ones (Stickel et al. 1973). Shells of eggs also become thinner during incubation so one would expect a correlation between pesticide levels and shell thickness if eggs were collected after different periods of incubation. Although most eggs in this study were collected within six days of laying, the laying date was not known for 12 eggs. To correct for weight loss due to incubation, Stickel et al. (1973) suggest a density of 1.0 g/ml to estimate the unincubated weight from the volume. In this study, volume of each egg was divided by measured weight to obtain a correction factor which was then multiplied by each pesticide level. Correlation coefficients were then recalculated for corrected pesticide levels (Table 9), with only slight changes occurring in the coefficients. Thus the eggs in this study were fresh enough when collected to eliminate bias caused by weight loss.

Cracked eggs

Out of a total of 5231 nests, 76 (1.5 percent) were found to have one or more cracked eggs in 1979. This low incidence compared to other years (Figure 2) might suggest that there was no effect on reproductive success from pesticides. Correlations between pesticide levels and reproductive success suggest a weak but significant effect which points out that the incidence of cracked eggs is a poor indicator of the impact of pesticides. There are four reasons why incidence of cracked eggs can misrepresent a loss of reproductive success.

First, cracks may not be related to thin shells. Cracks that appeared in collected eggs were not associated with thin shells even though they were associated with DDE levels. A nonparametric "Rand test" (Green 1977) showed that the mean thickness of nine eggs from nests with cracked eggs was not significantly different from a subsample of 16 noncracked eggs. Cracked eggs did have higher levels of DDE than noncracked eggs ($p<0.01$). Thus, if the cracks are caused by pesticides they may occur without thinning the entire shell.

Table 9. Comparison between Kendall correlation coefficients calculated from measured and corrected concentrations of organochlorines and reproductive success of white-faced ibis.

Correlation	Measured organochlorine	Corrected organochlorine
DDE with clutch size	-0.26**	-0.27**
DDE with chicks/nest	-0.15*	-0.16*
DDE with hatching success	-0.02	-0.03
DDT with clutch size	-0.30**	-0.31**
DDT with chicks/nest	-0.22**	-0.22**
DDT with hatching success	-0.08	-0.08
Dieldrin with clutch size	-0.04	-0.05
Dieldrin with chicks/nest	-0.14	-0.15
Dieldrin with hatching success	-0.14	-0.14

*Significant ($p < 0.05$).

**Highly significant ($p < 0.01$)

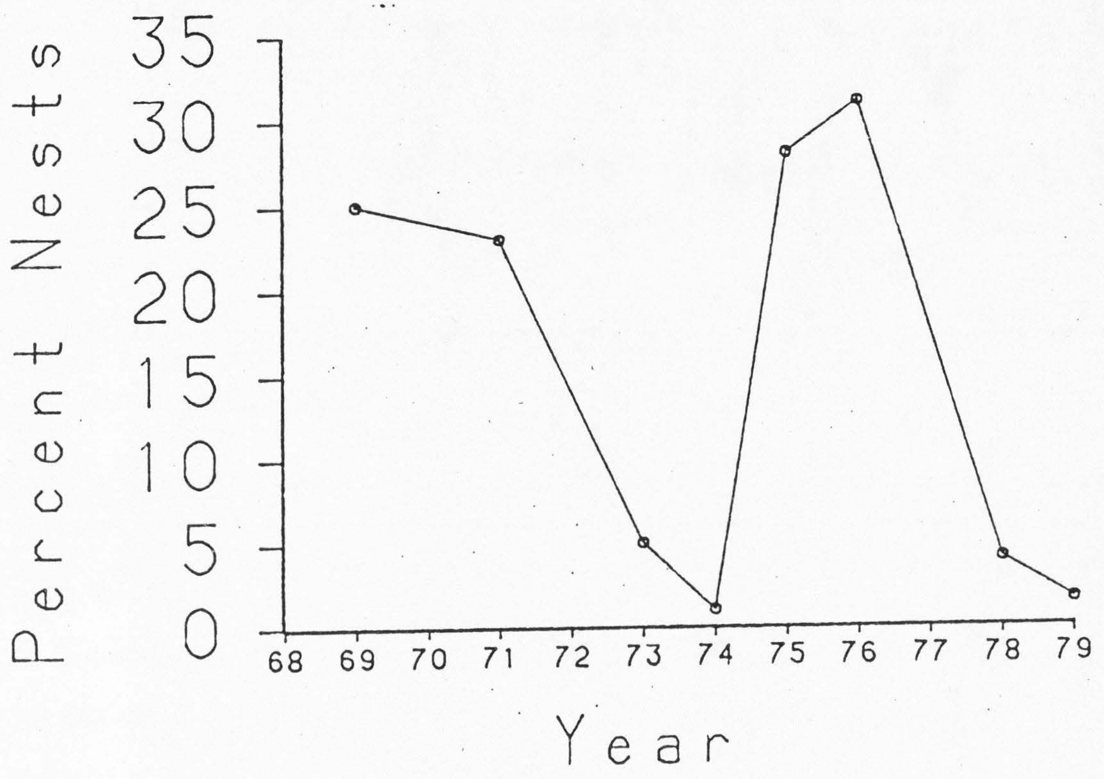

Figure 2. Percent of white-faced ibis nests that had one or more cracked eggs from 1969 to 1979. Data for 1969 to 1976 from Capen (1977a).

Second, the real incidence of cracked eggs can be underestimated. Eggs that break in the nest may be discarded by the adults and not be seen by the observer. Also thin shells may develop cracks after the nest is checked. These biases caused Capen (1977a, c) to judge the incidence of cracked eggs unacceptable as a measure of the effects of pesticides.

Third, different observers may define a cracked egg differently. Several eggs were observed to have creases or lines on them where the shells were thin but no actual fracture occurred. I observed seven creased eggs that did not break and hatched a viable chick. Creased eggs occurred in 0.7 percent of the nests in 1979 in addition to the 1.5 percent with cracked eggs. The total of 2.2 percent that had either creased or cracked eggs must still be below abnormal nests in 1975 and 1976. However, different definitions of cracks in eggs may explain some of the variation in Figure 2.

Fourth, the occurrence of cracked eggs may not indicate a loss in reproductive success. Some cracked eggs might occur in a population unimpacted by pesticides. In fact, reproduction (clutch size, hatching success, and chicks per nest) was not significantly different between nests with at least one cracked egg and normal nests.

Effects on population

It is difficult to assess the effects of the observed levels of pesticides on recruitment into the white-faced ibis population and their effects on total population levels.

The observed mean shell thickness of 0.313 mm, a 4.3 percent decrease from the pre-1945 thickness of 0.327 mm, may not represent a problem. Others (King et al. 1978, Kiff et al. 1979) have assumed that a decrease in thickness as low as this will not affect reproduction. Longcore et al. (1971) found that a 17 percent thinning of mallard (*Anas platyrhynchos*) eggs led to a 10 percent cracking incidence.

A more severe effect on white-faced ibis is the reduction in clutch size associated with DDE and DDT. Despite the fact that clutch size is not a continuous variable and thus violates an assumption of regression, a regression was done between clutch size and log DDE (Figure 3). Violation of the assumption detracts from the validity of the regression; however, it may be useful as an approximation of the effects of DDE. The mean 1979 clutch size of 3.20 is a 13.5 percent reduction from the mean clutch (3.70) of the 20 nests lowest in DDE ($t = 2.81$, $p<0.005$). Although 3.70 is not necessarily an unimpacted clutch size, the magnitude of the reduction in clutch size suggests that there could be an effect on population levels.

Although chick survival was not measured in this study, it has been shown to be affected by DDE in other species (Longcore et al. 1971, Haegele and Hudson 1973, Stickel 1973). Thus, the impact on white-faced ibis recruitment may be even more than is implied by the observed decrease in clutch size.

Colony Characteristics and Reproduction

Mean values of clutch size, hatching success and chicks per nest were calculated for each subcolony (Table 10). Because many colony characteristics are related to predator avoidance strategies, two

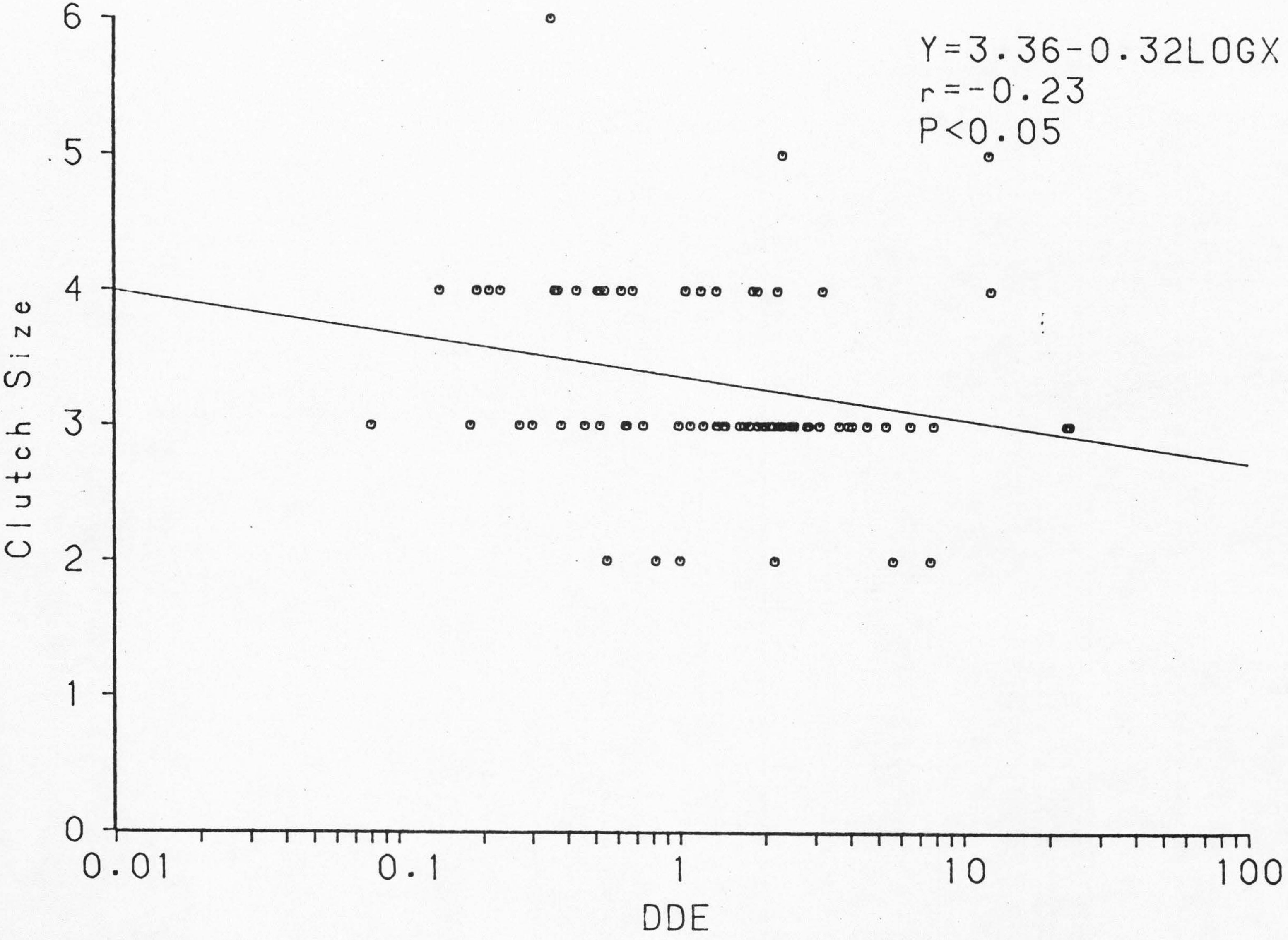

Figure 3. Regression of DDE concentration in white-faced ibis eggs with clutch size in the nests from which they were taken.

Table 10. Five characteristics of reproduction for 22 subcolonies of white-faced ibis in northern Utah. All data are from 1979 except BRC-S which is from 1978.

Colony	Sub-colony	Clutch size	Hatching success	Chicks/nest	Percent predation	Percent unsuccessful nests
BRR-5	1	3.06	75.7	2.31	25.7	14.3
"	2	2.83	65.9	2.31	20.0	26.7
"	3	3.19	29.1	0.93	40.7	59.3
"	4	3.23	69.1	2.23	13.3	13.3
BRR-1A		3.50	64.7	2.27	0	16.7
BRR-2		3.04	3.3	0.10	4.3	91.3
Knudson's		3.35	81.7	2.73	0	11.5
BRC-E[a]		2.92	67.1	1.96	21.9	31.3
BRC-W		3.12	85.1	2.65	4.7	7.0
BRC-M	1	3.00	76.3	2.29	10.3	17.9
"	2	3.23	80.0	2.58	0	9.7
"	3	3.00	66.7	2.00	6.5	22.6
"	4	3.09	86.5	2.67	1.4	10.1
"	5	3.03	75.2	2.41	9.1	10.3
"	6	2.74	83.9	2.29	2.9	11.8
"	7	3.00	77.8	2.33	9.1	12.1
"	8	3.03	84.5	2.56	0	5.9
GSL	1	3.27	58.4	1.91	10.6	20.9
"	2	3.00	58.3	1.75	16.7	16.7
Cutler	1	2.97	-	-	25.0	64.5
"	2	2.97	23.2	0.71	48.4	96.8
BRC-S		2.80	44.0	1.27	43.8	31.0

[a] Located where BRC-S was in 1978.

measures of predation were also calculated: the percentage of nests in which predation was actually identified and the percentage of nests that were unsuccessful for any reason. The first measure is an underestimate of the actual amount of predation, while the second is an overestimate.

Comparisons in terms of reproductive success were made between large and small colonies, large and small subcolonies, early and late subcolonies, more or less synchronous subcolonies, and colonies in two vegetation types and two avian nesting associations. Each subcolony was classified as early or late, large or small, or more or less synchronous based on the median value of these variables (Table 2). Similarly, each entire colony was classified as large or small. Within each one of these classifications, means for each of the reproductive parameters in Table 7 (clutch size, hatching success, chicks per nest, synchrony, percent predation, and percent unsuccessful nests) were calculated (Table 11). Similar means were calculated for both vegetation types (hardstem bulrush/cattail and alkali bulrush) and both avian nesting associations (heron/egret and gull).

The means in Table 11 were calculated directly from the measures of reproduction in each subcolony (Table 10) with the exception of the comparison between large and small colonies which was based on the weighted mean reproduction for each entire colony. Weighted mean reproduction for a colony was calculated from reproduction in each subcolony of that colony weighted by the number of nests in that subcolony.

Table 11. Mean values of measures of reproductive success, predation, and synchrony for six classifications of subcolonies or colonies of white-faced ibis in northern Utah from 1978 and 1979.

	Measures of Reproductive Success					
Comparison	Clutch size	Hatching success	Chicks/ nest	Synchrony[e]	Percent predation	Percent unsuccessful nests
Date						
Early	3.13	61.4	1.97	2.68	14.8	26.7
(subcolonies)						
Late	3.02[f]	68.0	2.06	2.50	12.7	22.3
Size						
Large	3.02	71.6	2.17	2.70	17.4	21.5
(colonies)						
Small	3.25	58.5	2.47	2.94	2.3[f]	31.6
Size						
Large	3.06	71.4	2.20	2.36	14.4	19.8
(subcolonies)						
Small	3.11	62.3	1.98	2.68	10.6	27.7
Avian spp.						
Herons[a]	3.08	60.3	1.89	2.29	16.3	31.5
(subcolonies)						
Gulls[b]	3.08	63.7	2.01	2.95	16.9	23.0

Table 11. Continued.

	Measures of Reproductive Success					
Comparison	Clutch size	Hatching success	Chicks/ nest	Synchrony[e]	Percent predation	Percent unsuccessful nests
Vegetation						
Cattail[c] (subcolonies)	3.05	65.3	2.02	2.41	13.2	30.1
Alkali[d]	3.08	63.5	2.00	2.87	16.7	22.5
Synchrony[e]						
More (subcolonies)	3.01	61.9	1.87		11.6	27.7
Less	3.10	67.6	2.14		13.0	19.3

[a] Snowy egrets and black-crowned night herons.

[b] Franklin's gulls.

[c] Cattail and hardstem bulrush.

[d] Alkali bulrush.

[e] Standard deviation of initiation dates of nests in a smple. Larger number indicated less synchrony.

[f] Significant, $p < 0.05$.

$$M_a = \frac{m_1x_1 + m_2x_2 + \ldots + m_ix_i}{x_1 + x_2 + \ldots + x_i}$$

M_a = mean reproduction for the entire colony a

m_i = mean reproduction for subcolony i of colony a

x_i = number of nests in subcolony i of colony a

The most noticable result in Table 11 is that out of 35 comparisons, only two were shown to be significantly different using a t test. T tests were recalculated without the Cutler colony to see whether apparently abnormal success in this colony was hiding significant differences. Similarly, the subcolony from 1978 was eliminated from the tests to avoid the potential effects of between year variation. No additional sigificant differences were found in either of these changes.

The lack of significant differences in reproduction between types of subcolonies may be because there were no real differences or because the data were insufficient to detect differences. Below, I present reasons why there might be differences.

Initiation date

Classifying subcoloines as "early" or "late" on the basis of the median nest initation date is somewhat artificial because we do not know what is early or late in terms of the factors affecting ibises. For example, all nests may have been early. The median date was used as a dividing point because of the lack of a better way to distinguish early from late.

Despite this artificial classification into early and late subcolonies, earlier colonies were found to have significantly larger clutches. Alford (1978) also found this to be true of white-faced ibises nesting at Farmington Bay on the Great Salt Lake. He reported a highly significant regression ($r = -0.23$) between laying date and clutch size. A decrease in clutch size during the nesting season has also been found in gull-billed terns (*Gelochelidon nilotica*, Sears 1978), ring-billed gulls (*Larus delawarensis*, Ryder 1976), black-legged kittiwakes (Coulson and White 1958), and brown pelicans (*Pelicanus occidentalis*, Blus and Keahey 1978).

I believe, as did Alford (1978), that the appearance of larger clutches earlier in the season was the result of older, more experienced ibises returning first. Older birds, capable of finding food for a larger brood, often lay larger clutches (Lack 1968). Older or more experienced adults nested earlier in black-legged kittiwakes (Coulson and White 1958), ring-billed gulls (Ryder 1975), and brown pelicans (Blus and Keahey 1978). Ryder (1975) presumed that younger birds nested later because of delayed maturation of testes and behavioral differences.

There was no difference between late and early subcolonies in terms of hatching success or chicks per nest, although differences have been reported in the literature for other species. Birds in early nests had better hatching success in razor bills (*Alca torda*, Lloyd 1979) and ring-billed gulls (Ryder 1975). More chicks were produced per nest in early nests of Cassin's auklets (*Ptychoramphus aleutica*, Manuwal 1979), black-legged kittiwakes (Coulson and White

1958), brown pelicans (Blus and Keahey 1978), and white-faced ibises (Alford 1978). In two of these studies (Alford 1978, Blus and Keahey 1978) late nesters either chose or were left with nest sites that were flooded. The reason that the data in this study did not show poorer hatching success in later nests may have been that the environmental conditions that would harm poorer sites did not occur in 1979.

Colony or subcolony size

There are two reasons why one might expect larger groups of birds to have better success. First, if one area of habitat is intrinsically better in terms of reproductive success, one would expect more birds to nest there. Second, a larger group of birds might increase the advantages of living colonially.

Data from this study did not show significantly higher reproductive success in either larger colonies or larger subcolonies, in contrast to what others have found. Langham (1974) observed better hatching success in larger colonies (between years) and larger subcolonies (within one year) for sandwich terns. Second broods of red-wing blackbirds also produced more young in larger colonies (Smith 1943).

Predation was found to be significantly higher in larger colonies (but not in larger subcolonies). Because they cover a greater area, larger colonies have a greater chance of being found by predators. If the predators exhibit surplus killing, that is, if they do not stop destroying nests when they are satiated, then larger colonies should suffer greater predation. Thus, the advantage, from predator satiation, of nesting in a large colony is lost. Two of the larger colonies in the present study showed signs of being "found" by a predator. In these instances, large sections of the colonies had all nests destroyed by predators. Puncture marks in eggs and on the heads of chicks suggested that the predation was caused by a mustelid such as mink (*Mustela vison*) or striped skunk (*Mephitis mephitis*). Striped skunk was the only predator observed in these colonies.

Other avian species

Many colonial birds, especially wading birds and seabirds, nest in association with other species. In some instances, different species may simply be using the same nesting resource. In other instances, there may be benefits to one or several species. It was expected that white-faced ibises would benefit more from nesting with Franklin's gulls than from nesting with snowy egrets and black-crowned night herons. Egrets and herons are not aggressive nest defenders, whereas Franklin's gulls tend to circle, alarm calling and diving at an intruder. This behavior may be effective in repelling some predators and thus convey advantage on ibises that nest in the same colony. Sears (1979) has reported an instance in which colonial defense by larids repelled predators. Several others (Larson 1960, Evans 1970, Langham 1974, Gochfeld 1977) have speculated that birds nesting with larids suffer less predation. Clark and Robertson (1979) found less predation on yellow warbler nests that occurred within the response range of the more aggressive gray catbird (*Dumetella carolinensis*).

White-faced ibises may also benefit by nesting in a colony that consists of many more Franklin's gull nests than ibis nests. Sears (1978) suggested that predators develop a search image for nests of the most common species and avoid the scarcer nests. Ibis nests in a Franklin's gull colony are also more dispersed than those in other colonies which may retard development of a search image for ibis nests.

Data from this study showed no significant difference in success or predation between the two species associations. In fact, reproductive measurements and percent predation were almost equal. Possibly, protection from other predators was balanced by gull predation on eggs and chicks. Although I saw no predation that could be identified as from Franklin's gulls, this possibility cannot be eliminated. An alternate explanation is that the benefit of nesting with gulls may only occur in some years and not in others.

Vegetation type

Vegetation type also had no detectable effect on reproductive success or predation. This contrasts with Alford's (1978) study in which a late high water period flooded the nests in the cattails and did not affect the higher nests in the hardstem bulrush. The present study made no distinction between nests in these two plant species as they were often intermixed. However, if flooding had occurred, one would expect it to affect the lower nests in alkali bulrush.

Synchrony

More synchronous subcolonies were expected to have better success for two reasons. First, greater synchrony might lead to less predation because of predator satiation. Second, if more experienced birds were better at synchronizing and at producing offspring, then colonies of more experienced birds would have higher synchrony and better reproductive success than colonies of less experienced birds. Patterson (1965) found a correlation between synchronization and breeding success for black-headed gulls (*Larus ridibundus*) and suggested that the synchronization reduced predation. Similarly, Clark and Robertson (1979) found a lower incidence of predation in synchronous nests of yellow warblers. Data from this study, however, showed no significant difference in either reproductive success or predation between more or less synchronous subcolonies. In order for synchronized nesting to reduce predation, predators must stop killing when they are satiated. This apparently did not occur in 1979 as two instances of excess killing in colonies were observed.

I also expected that if older, more experienced birds were present in certain types of subcolonies, that synchrony would be greater in these subcolonies. Smith (1943) found a higher degree of synchronization in larger colonies of red-winged blackbirds. This study, however, showed no significant differences in synchrony between groups of subcolonies.

Summary

In general, very few differences in reproductive success, predation, or synchrony were observed between groups of colonies or subcolonies. Thus, if there are adaptive advantages of certain types of associations, they are either slight and difficult to document given normal variation in reproductive success, or they are only evident in certain years when environmental conditions are such that some types of colonies do poorly. In the latter case one would need several years of data to identify the advantages of certain types of colonies.

Another reason for differences not to be evident is that selection pressures that determined colony selection were important before the impact of human development. Human interference may have changed the factors that lead to better reproduction in certain areas. For example, maintenance of water level in managed marshes may have eliminated the disadvantage of nesting in areas prone to drying out in mid summer.

In some cases, advantages of certain types of subcolonies may be counteracted by disadvantages due to some other cause. It could be argued that all colony characteristics had an effect, but most colonies have some good and some bad characteristics, obscuring differences due to a single factor. Comparing groups of colonies that have only one characteristic that is different would show if this was important.

I believe that three factors, vegetation type, avian species association, and synchrony did not affect reproductive success in

1979. The differences in success between subcolonies in different vegetation types or avian species associations were very slight. Variations in synchrony were probably too small to show a relationship to reproductive success. The remaining two colony characteristics, size and initiation date, were analyzed separately. That is, large-early subcolonies were compared with large-late subcolonies, small-early with small-late, large-early with small-early, and large-late with small-late. None of these showed any significant differences in reproductive success measures. Apparently, the effect of one of these factors on reproductive success was not obscuring the effect of the other.

SUMMARY AND RECOMMENDATIONS

Current levels of organochlorine pesticides are adversely affecting reproductive success of the white-faced ibis, but the effects of colony characteristics are slight or nonexistent.

Pesticides

White-faced ibises are accumulating pesticide residues at levels that are potentially harmful. Thirteen residues were identified, the most prevalent of which was DDE which occurred in all 80 egg samples.

Shell thinning is occurring, apparently because of DDE residues. Shells are 4 percent thinner than pre-1945 shells. However, this decrease did not cause many nests to have cracked eggs (1.5 percent) or many eggs to be lost during incubation. If pesticides caused egg loss during incubation, hatching success would have been correlated with pesticide residues. No correlation was found.

A significant decrease in clutch size was associated with DDE levels. The current mean clutch size (3.20) is 13.5 percent lower than the mean of 20 clutches (3.70) from nests that had the lowest DDE levels. The effect of this decrease on recruitment is not known, although given other constraints on white-faced ibis populations, such as habitat destruction, it is potentially harmful.

In order to evaluate the effects of a decreased clutch size on population levels, one would need to know juvenile and adult mortality. Monitoring of population levels would identify severe effects on populations. Censuses would have to cover large areas as ibises tend to move their colonies from year to year.

Colony Characteristics

Subcolonies that were initiated earlier in the season had larger clutches than later subcolonies, but otherwise, reproduction was similar between early and late subcolonies.

No differences were found in reproductive success between large and small colonies or subcolonies. Associated avian species, vegetation type or degree of nesting synchrony also did not affect reproductive success. Predation was significantly higher in large colonies. This result, which contradicts what one would predict from the literature, can be explained by the fact that predators on ibis exhibited surplus killing so that the benefits in large colonies due to predator satiation were not realized. Large colonies had a greater chance of being discovered by predators and therefore suffered more predation.

In general, there are no apparent selective pressures for white-faced ibises to nest in certain nesting associations. Data collected over several years under a variety of different environmental conditions might demonstrate some adaptive advantages.

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APPENDIX

Method of Organochlorine Residue Analysis

Limit of Detection: 0.05 ppm for chlorinated insecticides
0.10 ppm for PCB

Storage: All samples were stored in a deep freeze prior to analysis.

Extraction: A weighed portion of the sample (approximately 10 g) was placed into a 150-mL beaker and allowed to air dry in the hood for 24 hours. The sample was then mixed with anhydrous sodium sulfate and allowed to air dry in the hood for another 24 hours. The contents of the beaker were transferred to a Whatman extraction thimble (pre-rinsed with dichloromethane), plugged with glass wool, and placed in a dessicator overnight. The thimble was removed from the dessicator and placed on a Soxhlet extractor and extracted with 250 mL of 50:50 ethyl ether: petroleum ether for 8 hours. The resulting solution was concentrated on a steam bath to 5-10 mL and brought to 25 mL with petroleum ether.

Cleanup: A 5-mL aliquot of the extract was placed on previously standardized Florisil and eluted with 150 mL of 3% ethyl ether in petroleum ether, followed by 250 mL of 15% ethyl ether in petroleum ether. The resulting solutions were concentrated to approximately 5 mL and brought to 25 mL with petroleum ether. Samples of 10 microliters or less of each elution were injected into a gas chromatograph for quantitation.

Silicic Acid: For those samples requiring further clean-up, a 10 mL aliquot of the first elution from Florisil was transferred to a pre-standardized Silicar CC-4 column and eluted with 80 mL of petroleum ether, followed by 350 mL of petroleum ether, and then by a 150 mL mixture of 1% acetronitrile, 9% hexane, and 80% methylene chloride. The resulting solutions were concentrated on a flash evaporator and brought to 10 mL with petroleum ether. Samples of 10 microliters or less of each elution was injected into a gas chromatograph for quantitation.

Lipid Determination: A 5-mL aliquot of the original extract was transferred to a tared 2-drum vial. The solvent was removed and the vial was placed in a 40°C oven for 24 hours. The vial was removed, dessicated, reweighed, and the amount of lipid was calculated.

Gas Chromatography: Instrument: Hewlett Packard Model 5710A equipped with a linerized Ni^{63} detector, automatic injector, and 3352C data system.

Column #1: For all chlorinated insecticides and PCB except chlordane isomers.
Packing: 1.5% SP-2250 & 1.95% SP-2401 on 80/100 supelcoport
Column: 6 ft x 4 mmID glass
Temperatures: Column 208°C
Injector, 250°C
Detector, 300°C
Carrier gas: 95% argon, 5% methane
Flow: 35 mL/min or adjusted to give DDE retention time of approximately 10.0 min

Column #2: For chlordane isomers
Packing: 3% OV-1 on 80/100 mesh Supelcoport
Column: 6 ft x 4 mm ID glass
Temperatures: Column, 200°C
Injector, 250°C
Detector: 300°C
Carrier gas: 95% argon, 5% methane
Flow: 33 mL/min