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The Impact of Pesticides on the White-Faced Ibis

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THE IMPACT OF PESTICIDES ON THE WHITE-FACED IBIS

by

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Approved:

Major Professor	Committee Member
Committee Member	Committee Member
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ABSTRACT

The Impact of Pesticides on

the White-faced Ibis

by

David E. Capen, Doctor of Philosophy

Utah State University, 1977

Major Professor: Dr. David R. Anderson
Department: Wildlife Science

The white-faced ibis (Plegadis chihi) which nested in northern Utah was assessed as a species with a relatively low reproductive potential. Ibises normally laid either three or four eggs in a clutch and did not renest persistently, nor with good success, if initial nesting attempts failed. Evidence indicated that the birds did not breed until at least 2 years old. Competition for food, exposure to severe weather, and predation were conspicuous sources of nestling mortality. White-faced ibises usually fed in irrigated agricultural areas, where they came into direct contact with insecticides, such as DDT which was used routinely in northern Utah until 1971. The most frequent food items of the ibises were insect larvae and earthworms, hence the birds were subject to food-chain concentrations of pesticide residues.

White-faced ibises commonly laid eggs with cracked or broken shells from 1968 through 1971, but the incidence of aberrant eggs decreased after 1971. By 1974, no significant difference was found between the current mean eggshell thickness and the thickness of eggshells collected

before 1940 and preserved in museums. Also, in 1974, less than 1 percent of nests surveyed contained cracked eggs. White-faced ibises in Utah again laid thin-shelled eggs in 1975 and 1976. Cracked eggs were found in about 30 percent of nests examined during both of these years, and the means of eggshell thickness were significantly less than in 1974. A high incidence of cracked eggs was associated with less than 10 percent thinning of eggshells.

Eggshell thickness of white-faced ibis eggs collected in 1975 was significantly related, linearly and negatively, to the logarithms of DDE residues of the eggs. The comparison of this relationship to those of other species indicated that the white-faced ibis is especially sensitive to eggshell thinning.

DDE residues were found in samples of blood serum, breast muscle, and subcutaneous fat of white-faced ibises collected in 1974 and 1975. The logarithm of DDE in blood serum was positively correlated with ln DDE in fat and with ln DDE in muscle. DDE levels in blood serum were related to lipid mobilization and varied by season and between sexes.

(85 pages)

INTRODUCTION

The white-faced ibis (Plegadis chihi) is a common breeding-season inhabitant of marshes in western North America. Isolated nesting colonies have been reported in Mexico, and in wetlands from Kansas to Oregon. The largest known nesting populations are traditionally found along the coast of Texas and Louisiana and in the marshes of the Great Salt Lake Valley of northern Utah. White-faced ibis colonies of northern Utah are probably the most reliable in North America (Ryder 1967).

Apparently the population of the white-faced ibis in North America has decreased markedly in recent years. The species now nests in fewer known sites than a decade ago, and population declines have been reported in all major nesting areas in the United States (Ryder 1967, Capen et al. in prep.).

There was concern, in the late 1960's, that the white-faced ibis was being adversely affected by organochlorine pesticides. Until 1971, DDT was widely used in northern Utah in and around the marshes where the ibis nests and in adjacent farmland where the bird feeds. Ibises feed primarily on invertebrates so they are susceptible to pesticide residues which concentrate in food items.

Pesticide residues may cause birds to die (Hickey and Hunt 1960, Keith 1966), but persistent organochlorine insecticides more commonly contribute to a reduction in reproductive success. The most widely recognized pesticide-related problem is that of unusually thin eggshells

(Stickel and Rhodes 1970). Pesticides are also believed to cause decreased egg production (Haegele and Hudson 1973), delayed ovulation (Jefferies 1967), reduced hatchability due to embryo mortality (Enderson and Berger 1970, Blus et al. 1974b), and lowered fledging success (Stickel 1973). Pesticide-induced reproductive losses have caused or contributed to population declines in a number of avian species (Hickey 1969, Blus et al. 1975).

Nesting colonies of white-faced ibises in northern Utah were initially studied from 1968 through 1971. A high incidence of abnormal eggshells, conspicuous nestling mortality, and a sharp decline in the number of nesting pairs were reported (Smith, unpublished reports 1968, 1969, 1970; King and Friend, unpublished report 1971, Denver Wildlife Research Center). The investigators also documented organochlorine pesticide residues in adult ibises and their eggs. These preliminary findings provided the stimulus for the design of the present study.

The initial objective of my study was to evaluate selected parameters of the reproductive biology of the white-faced ibis as potential indicators of the effects of pesticides on the species. A second objective was to determine the relationship between pesticides and the reproductive success of the white-faced ibis. The final objective was to sample organochlorine residues in tissues of white-faced ibises and determine the feasibility of estimating annual or seasonal changes in body burdens of pesticides in the ibises.

Field work for this study was conducted during the nesting seasons from 1973-1976. Earlier studies by U.S. Fish and Wildlife Service biologists are often referred to and many of their data were incorporated with those of the present study to provide a long-term perspective.

SELECTED ASPECTS OF THE ECOLOGY OF THE WHITE-FACED IBIS IN NORTHERN UTAH

Introduction

The white-faced ibis has been the subject of little scientific study. Most published accounts of the species have reported sightings or locations of breeding colonies, e.g., Brewster (1886), Peabody (1896), Lamb (1910), Barnes (1943), Giles and Marshall (1954). Much of the ecological information concerning the ibis was summarized by Ryder (1967). Three studies of the natural history of the white-faced ibis have been conducted (Belknap 1957, Kotter 1970, Kaneko 1972), but each was limited to one nesting colony for a single season. Additional study of the natural history and ecology of the ibis was necessary, therefore, to evaluate the effects of pesticides.

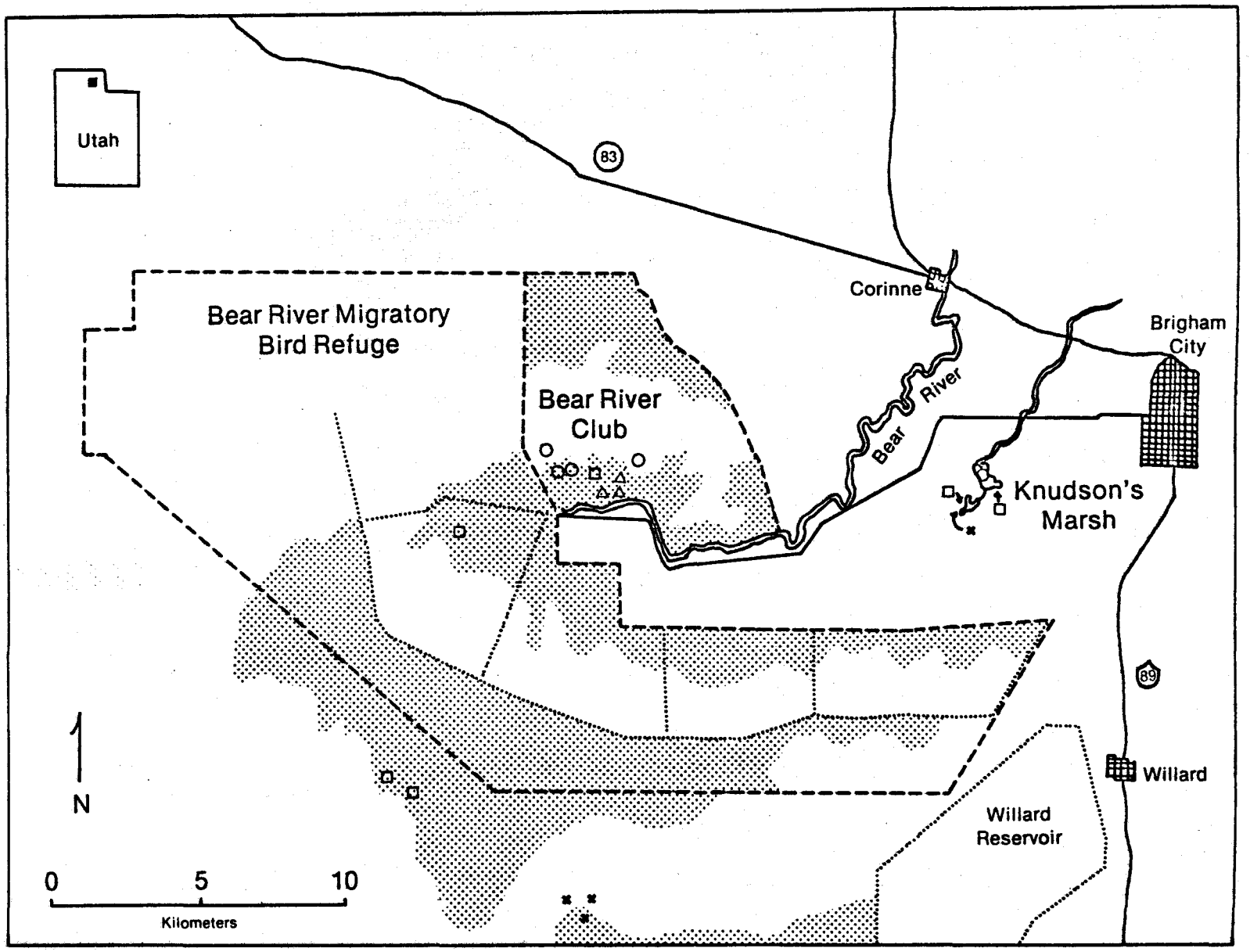
After preliminary study of several northern Utah ibis colonies in 1973, I selected five parameters of the reproductive biology of the white-faced ibis for additional study: eggshell thickness, eggshell condition, clutch size, hatching success, and fledging success. These parameters were thought to be influenced by pesticides, either in the white-faced ibis or other species. The estimation of each parameter was evaluated by testing the following hypothesis: "A suitable estimate of the parameter can be obtained with adequate precision to indicate potential differences attributed to pesticides." A suitable estimate was, most importantly, one which was not inconsistently biased. Suitability also implied representative sampling and the use of field

procedures which were not overly time-consuming, unreasonably expensive, nor detrimental to the nesting success of the ibises. Rejection of the hypothesis was possible by identifying an inconsistent bias which could not be feasibly measured nor eliminated, and/or by determining that estimates of a desired precision were not feasible.

Study Areas

The delta of the Bear River in northern Utah is located where the Bear River flows into the northeastern corner of the Great Salt Lake. Marshes of this delta provide some of the most outstanding habitat in North America for shore birds, wading birds, and waterfowl. The marshes are isolated between the Wasatch mountain range to the east and an extensive desert to the west. Irrigated agricultural land surrounds the marshes on the north and the east; alkali or mud flats are found on the south and west borders of the marsh areas.

In recent years, most white-faced ibis colonies in northern Utah have been located in three areas: the Bear River Migratory Bird Refuge, the Bear River Club marsh, and Knudson's marsh, all in Box Elder County (Fig. 1). The Bear River Refuge contains 26,276 ha and is fed by waters of the Bear River. The Bear River Club marsh covers more than 4050 ha and is part of the Bear River delta, but is fed primarily by the Malad River. Knudson's marsh is an 81-ha area in the Bear River delta supplied by water from the mountains east of Brigham City and springs west of the city.


Utah
83
Corinne
Brigham City
Bear River Migratory Bird Refuge
Bear River Club
Bear River
Knudson's Marsh
89
Willard
Willard Reservoir
N
0
5
10
Kilometers

Methods

Breeding populations of white-faced ibises in the Bear River marshes were censused by aerial and ground counts. I conducted weekly aerial surveys in May and June, 1973-1976, when the nesting colonies were being established, and made either bi-weekly or monthly flights during the remainder of the season.

Data on migration, wintering areas, philopatry, and age of first breeding were obtained by banding and color-marking nestlings. The young birds were easily captured in nests at about 4 days of age and banded with U.S. Fish and Wildlife Service bands. Most nestlings were also banded with yellow plastic bandettes (National Band and Tag Co., Newport, Ky.). The two types of bands were attached to either the right or left legs in different combinations for different years, to allow for age determination if a color-marked bird was observed.

Eggs for shell thickness measurements were collected from active nests. By design, the eggs were collected from different clutch sizes, different laying sequences, and different stages of incubation (Capen 1977).

Many of the data necessary to evaluate the estimation of reproductive parameters were obtained by visiting nests periodically and recording the status of the eggs or the nestlings. In 1973, I selected a sample of nests in each colony, marked the nests, and collected data from only the marked nests. During the following seasons, I usually collected nesting data by censusing an entire colony and recording the desired information from all nests. Time-lapse cameras were used to

automatically record the activities of ibises in the nests (Capen, in press).

Food items were collected from 55 nestlings by forcing the birds to regurgitate. Young birds which had recently been fed showed a bulging throat region. Samples were collected by forcing the food in the throat back into the buccal cavity, then into a collecting jar. Food items were preserved in 5 percent formalin until they were cleaned, counted, and identified (Korschgen 1971). Feeding habits were also studied by observations of habitat preferences, available food supplies, and feeding behavior.

Results and Discussion

Location and size of nesting colonies

Large fluctuations in the numbers of nesting white-faced ibises and changes in the locations of nesting colonies in the Bear River marshes were documented from 1968 through 1976 (Table 1, Fig. 1). Small colonies of ibises nested in other marshes of northern Utah: Farmington Bay and Ogden Bay Waterfowl Management Areas and Utah Lake. These colonies, in total, accounted for only 100 to 450 nesting pairs per year.

Each of the three study areas supported the largest nesting colony at some time during the study. The Bear River Club marsh was the most important nesting site until 1975 and 1976, when the water levels were kept low early in the season. Local observers and marsh managers informed me that ibises formerly nested most consistently and in the greatest numbers in Knudson's marsh, and that the 1970 season was one of the few in this century when a large colony of white-faced ibises

Table 1. Estimated number of nesting pairs of white-faced ibises in the Bear River delta marshes, 1968-1976.

Years[a]	Colony locations			Total nesting pairs
	Knudson's marsh	Bear River club	Bear River refuge	
1968	100	3000	0	3100
1969	540	350	10	900
1970	0	350	100	450
1971	200	2850	0	3050
1973	30	2890	80	3000
1974	10	1500	100	1610
1975	810	120	760	1690
1976	120	0	2560	2680

[a]Data for 1968-1970 were from Smith (unpublished reports 1968, 1969, 1970, Denver Wildlife Research Center); ibises were censused by aerial counts. Data for 1971 were from King and Friend (unpublished report 1971, Denver Wildlife Research Center); ibises were censused by ground counts. Data for 1973-1976 were collected during the present study; ibises were censused by complete nest counts.

had not nested there. Knudson's marsh had been poorly maintained since 1970, however, and was nearly dry in some seasons. The white-faced ibises of northern Utah traditionally returned to the same general area to nest each year, but were clearly flexible in the selection of specific locations for their nesting colonies.

Nesting ecology

Chronology of the nesting season

White-faced ibises spent 6 to 7 months in northern Utah; their activities during this period are summarized in Table 2. Timing of the activities varied, of course, from year to year. The ibises in some years did not arrive until mid-April, nor begin nesting until mid-May, whereby subsequent events were delayed accordingly. The birds spent the first weeks after arrival feeding, usually in flooded hay fields throughout several northern Utah counties. They concentrated in the vicinity of the Bear River marshes shortly before selecting locations for nesting. When nesting activities were completed, the adults and juveniles segregated. Juveniles fed actively throughout the remainder of the season, but adults, during a period of molt, retreated to the large expanses of shallow, open marsh and mudflats on the Bear River Refuge and areas near Willard reservoir. The molting adults were reluctant to fly, though never flightless, and they frequented areas where disturbances were rare.

Nesting habitat

White-faced ibises built nests in dense stands of the four most common emergent plants in the Bear River marshes: cattail (Typha

Table 2. Chronology of white-faced ibis activities in northern Utah.

Activities	Approximate dates of initiation	Approximate duration (days)
Arrival and feeding	1 April	30
Nest building, Egg laying	7 May	10
Incubating	10 May	20
Hatching	1 June	--
Feeding nestlings	2 June	30
Juveniles fledging	1 July	--
Adults molting	20 July	30
Juveniles feeding	15 July	60
Leaving Utah	20 Sept	--

latifolia), hardstem bulrush (Scirpus acutus), alkali bulrush (S. paludosus), and Olney's bulrush (S. olneyi). The birds showed no obvious preference for any vegetation type. Water depth beneath the nesting cover ranged from 5 to 80 cm when nests were established. Water levels in the Bear River marshes usually dropped from mid-May throughout the summer, but it was not common for the stands of vegetation in which the birds nested to become dry before the young fledged.

The height of nests above the water varied greatly. Nests built in hardstem bulrush or cattail were commonly 1.5 m or more high, yet many nests in alkali or Olney's bulrush were constructed so the eggs were only 5 to 15 cm from the water. Spacing among nests followed no apparent pattern, and the distance between nests varied from 0.5 m to many meters.

Natality

Age of first breeding. The age at which the white-faced ibis or the congeneric glossy ibis (Plegadis falcinellus) first breeds is not known. The closely related white ibis (Eudocimus albus) does not obtain full adult plumage, in the wild, nor breed, in captivity, until 2 years of age (Palmer 1962). Evidence also indicates that the white-faced ibis does not breed until 2 years old. K. A. King (pers. comm.) observed that captive white-faced ibises did not obtain the definitive alternate (breeding) plumage, red legs, nor red eyes until their second spring. My banding and color-marking data suggested that individuals did not breed when 1 year old, and documented that at least some nested at 2 years of age (Table 3). I observed only four marked birds: two males on nests, and two females before nesting began. Leg bands indicated that all four ibises were 2 years old.

Table 3. Numbers of white-faced ibises banded as nestlings in northern Utah and records of birds observed in the following years.

Years	Number of nestlings banded	Observations of adults during the breeding season	
		Unbanded[a]	Banded (age)
1973	1265	--	--
1974	1235	773	0
1975	300	428	0
1976	0	867	4 (2 yrs)
Total	2800	2068	4

[a]Birds identified as having no leg bands.

Clutch size. The white-faced ibis is a determinate egg-layer (Kotter 1970) and normally produces a clutch of either three or four eggs. The mean clutch size for 281 nests was 3.5 eggs, and there was little variation in mean clutch size among different colonies (Table 4). The extreme deviation of the mean for any of the five colonies (Table 4) from the overall mean, was only 8.6 percent.

The number of eggs in a clutch is determined not only by the eggs laid, but by those lost. In many instances, I found crushed or broken eggs, presumably because of thin eggshells, which were discarded from nests during the egg-laying period. The observed clutch sizes, then,

Table 4. Number of eggs per clutch in five white-faced ibis colonies on the Bear River Club marsh in 1973 and 1974.

Colony and year	Complete clutches[a]		All clutches	
	Nests sampled	Mean ± SE	Nests sampled	Mean ± SE
BRC-B 1973	19	3.8 ± 0.096	25	3.3 ± 0.189
BRC-C 1973	24	3.5 ± 0.104	25	3.4 ± 0.141
BRC-D 1973	21	3.6 ± 0.109	25	3.3 ± 0.170
BRC-E 1973	38	3.3 ± 0.078	40	3.3 ± 0.088
BRC 1974	179	3.5 ± 0.040	189	3.4 ± 0.045
Total	281		304	
Mean		3.5 ± 0.031		3.4 ± 0.038

[a]Only those clutches with three or more eggs.

were less than the number of eggs laid in the nests. I believed that clutches of less than three eggs resulted from egg losses, or nest abandonment. There were clearly more one-egg and two-egg clutches in colonies with a high incidence of cracked eggs (Table 5).

Egg laying, incubation, hatching. Eggs were laid in the morning, most frequently at intervals of 2 days (Table 6). Thus, 5 days were usually required to complete a three-egg clutch and 7 days for four eggs. Bent (1926) and Kotter (1970) reported that the incubation period was usually 20-22 days; my data were consistent with their findings. Incubation began when the first egg was laid and both sexes shared the incubation duties, rarely leaving eggs unattended. Hatching was asynchronous within a clutch, but the hatching interval was less than the laying interval (Table 6).

The initiation of egg-laying was usually quite synchronous within a nesting colony. Often the first egg was deposited in every nest on the same day, hence all subsequent events were equally synchronous. The largest colonies and the earliest to nest usually exhibited the greatest synchrony of activities. Sometimes an island of vegetation would contain two distinctly different groups of nesting birds, each group having initiated egg-laying on different dates.

Hatching success. The proportion of nests in which eggs hatched varied tremendously, ranging from 4 to 85 percent among six colonies (Table 7). Most of this variation was due to natural factors, such as predation and predation-related abandonment (e.g., colony BRC-B, Table 7). However, I believed that my presence contributed to, or entirely caused, a reduction in hatching success in one colony, BRC-C.

Table 5. Comparison of proportions of one-egg or two-egg clutches between white-faced ibis colonies with contrasting occurrences of cracked eggs.

Colony and year	No. of nests sampled	Incidence of cracked eggs (%)	Proportion of 1- or 2-egg clutches (%)
	Colonies with low incidence of cracked eggs		
BRC-C 1973	25	4.0	4.0
BRC-E 1973	40	5.0	5.0
BRC 1974	189	1.0	5.3
	Colonies with high incidence of cracked eggs		
Middle Willard 1976	67	30.6	11.9
Late Willard 1976	70	28.4	11.4
Promontory 1976	183	41.0	9.8

Table 6. Laying and hatching intervals within clutches of white-faced ibises in northern Utah.

	Laying interval (days)				
	1	2	3	>3	Total
This study					
Number	5	73	3	0	81
Percent	6.2	91.0	3.7	0	100.0
Kotter (1970)					
Number	10	88	11	4	113
Percent	8.8	77.9	9.7	3.6	100.0

Interval between	Hatching interval (days)					
	0	1	2	3	>3	Total
1st and 2nd eggs						
Number	15	22	4	0	2	43
Percent	34.9	51.2	9.3	0	4.6	100.0
2nd and 3rd eggs						
Number	0	15	19	2	0	36
Percent	0	41.7	52.8	5.5	0	100.0
3rd and 4th eggs						
Number	0	5	16	5	2	28
Percent	0	17.9	57.1	17.9	7.1	100.0
Totals						
This study						
Number	15	42	39	7	4	107
Percent	14.0	39.3	36.5	6.5	3.7	100.0
Kotter (1970)						
Number	9	54	35	12	0	110
Percent	8.2	49.1	31.8	10.9	0	100.0

Table 7. The fate of white-faced ibis nests in six colonies on the Bear River Club marsh in 1973 and 1974.

Colony and year	No. of nests	Nests sampled	Fate of sampled nests (%)			
			Unknown	Abandoned	Destroyed	Hatched[a]
BRC-A 1973	600	25	0	84.0[b]	12.0	4.0
BRC-B 1973	85	25	0	56.0[b]	25.0	20.0
BRC-C 1973	225	25	0	64.0[c]	8.0	28.0
BRC-D 1973	220	25	4.0	4.0	12.0	80.0
BRC-E 1973	430	40	12.5	2.5	0	85.0
BRC 1974	1200	202	0	1.5	37.1	61.4

[a]One or more eggs hatched.

[b]Abandonment occurred at the same time other nests were destroyed.

[c]Only 12 percent were actually abandoned, 52 percent failed to hatch, then were abandoned.

The ibises did not abandon their nests because of the disturbance I created. Instead, the hatching failure in this colony was probably due to excessive exposure of eggs to the sun, thus embryo mortality from overheating.

Renesting. There is only circumstantial evidence that the white-faced ibis renests. On several occasions I noted widespread predation of ibis eggs, and new nesting colonies were established several days after the nests were destroyed. These later nesting attempts were characterized by extended nest-building periods, asynchronous egg deposition, more nest desertion, and in general, lower nesting success. I observed numerous instances of apparent renesting, and almost all resulted in poor success which led me to believe that the renesting ability or tendency of the white-faced ibis did not adequately compensate for the loss of original clutches.

Nestling mortality

White-faced ibis nestlings have died from residues of organochlorine pesticides (Flickinger and Meeker 1972). In 1968, dead nestlings were common in the white-faced ibis colonies of the Bear River marshes, but the cause of death was unknown (Smith, unpublished report, 1968, Denver Wildlife Research Center). I studied natural processes of pre-fledging mortality before attempting to evaluate pesticide-related mortality.

Exposure. Cool, rainy weather was one of the most obvious agents of nestling mortality. When the youngest nestlings reached 4 or 5 days of age, the adults commonly left the nests unattended while they searched for food. Curiously, this behavior did not change with weather

conditions, as evidenced by my time-lapse photography records. In one instance, in 1974, a time-lapse camera was recording the activities of two adjacent nests during a rainstorm. No adult birds returned to the nests during the storm. The five nestlings from the two nests huddled together in one nest, and all died of apparent exposure. Dead nestlings were common throughout the colony following the storm. Again in 1975, a severe rainstorm occurred when many nests in a large colony contained young of the critical age. The day after the storm, 13 of 43 nests, which I was inspecting on alternate days, contained dead nestlings.

Predation. Predation upon eggs or nestlings was usually not a serious mortality factor in the ibis colonies of the Bear River marshes. White-faced ibises and Franklin's gulls (Larus pipixcan) frequently nested together, but I never observed Franklin's gulls preying upon ibis eggs, though some ibis eggs in these mixed colonies were destroyed by avian species. Kotter (1970), however, reported that Franklin's gulls destroyed 21.8 percent of the ibis eggs in the colony which he studied. I have, on occasion, observed widespread predation which seriously affected the reproductive success of white-faced ibis colonies. In 1973, a mammalian predator, thought to be a mink (Mustela vison), destroyed the eggs in 25-30 nests and killed at least seven adult ibises. When eggs began to hatch in the same colony, which contained over 600 nests, avian predators destroyed the eggs and nestlings in all but 11 nests. Much of this destruction was malicious because most of the egg contents were not consumed. I attributed the above predation to California gulls (Larus californicus) because I observed some adult ibises being viciously harassed by individuals of this species within hours after the eggs were destroyed.

Competition for food. I observed many instances of adults feeding their nestlings. The young competed vigorously for food, and it appeared to me that the smallest nestlings, resulting from the asynchronous hatch, suffered high mortality as a result of the competition. I tested this hypothesis by selecting 45 nests, marking the nestlings in these nests so their hatching order was known, and determining the survival of each nestling through 7 days of age. In some nests all the nestlings died at once (because of a rainstorm and nest destruction by cattle). These deaths were excluded from the analysis, leaving what I termed "competitive mortalities" (Table 8). The nestlings which hatched third and fourth in their clutches suffered significantly higher mortality than the first two nestlings hatched (X^2=34.45, df=1,P<0.01).

Reproductive parameters as potential indicators of pesticide effects

Eggshell thickness

Two natural factors, laying sequence and incubation, were found to contribute to shell thickness variability (Capen 1977), hence they might bias samples of shell thickness measurements. Both of these biases, however, could be eliminated from samples of eggshells by collecting fresh eggs and ignoring the order of egg deposition, i.e., by not collecting only the first eggs laid in each nest (or second eggs laid, etc.). A third consideration was shell thickness differences among colonies. This factor was evaluated by collecting eggs from five major nesting colonies in 1976 and testing for differences in mean shell thickness. No significant differences were found (F=1.00,df=4,94,P> 0.25). However, in 1975, I observed that the proportion of nests containing cracked or broken eggs increased as colonies were initiated

Table 8. The relationship between hatch order and mortality, 0-7 days, for nestling white-faced ibises in northern Utah, 1975.

Hatch order in clutch	Number hatched	Competitive mortalities[a]		
		Expected number[b]	Observed number	Observed percent ± SD
1	45	8.8	1	2.2 ± 2.1
2	43	8.4	2	4.6 ± 3.2
3	40	7.8	12	30.0 ± 7.2
4	25	4.9	15	60.0 ± 9.8
5[c]	(1)	--	(1)	(100.0)
Total	153	29.9	30	19.6

[a]There were additional mortalities, of a catastrophic nature, which resulted in death for all nestlings in a nest.

[b]Expected if mortality was independent of the order of hatching.

[c]Excluded from calculations.

later in the season (range: 9.4 - 44.9 percent), suggesting that mean eggshell thickness was also different. Among-colony differences in shell thickness are certainly possible, and a representative sample should include eggs from all major colonies. When eggshells were collected without regard to the order of laying and from different colonies, sample variability increased. Nevertheless, natural variability in eggshell thickness of the white-faced ibis is reasonably low and fewer than 40 eggs may be sufficient to show significant differences of 5 percent between shell thickness means (Capen 1977).

Eggshell condition

Eggs were examined in nests and classified as either normal or cracked. An obvious problem in measuring this variable was that a normal egg one day might be cracked the next, thus the highest incidence of cracked eggs would theoretically occur at the end of the incubation period. However, badly crushed eggs usually were discarded from nests and often could not be found. These were sampling problems which could not be overcome. If a colony truly contained a high proportion of cracked eggs, the parameter was underestimated. Hypothetically, the greater the proportion of cracked eggs, the more severe the underestimate (Fig. 2). The actual incidence of cracked eggs also was underestimated if the eggs were examined early in the incubation period. The effect of broken eggs discarded from nests was most important, however, and I believed that it was better to sample within 4 or 5 days after the clutches were complete. Eggshell condition was probably measured with bias, except when the true occurrence of cracked eggs

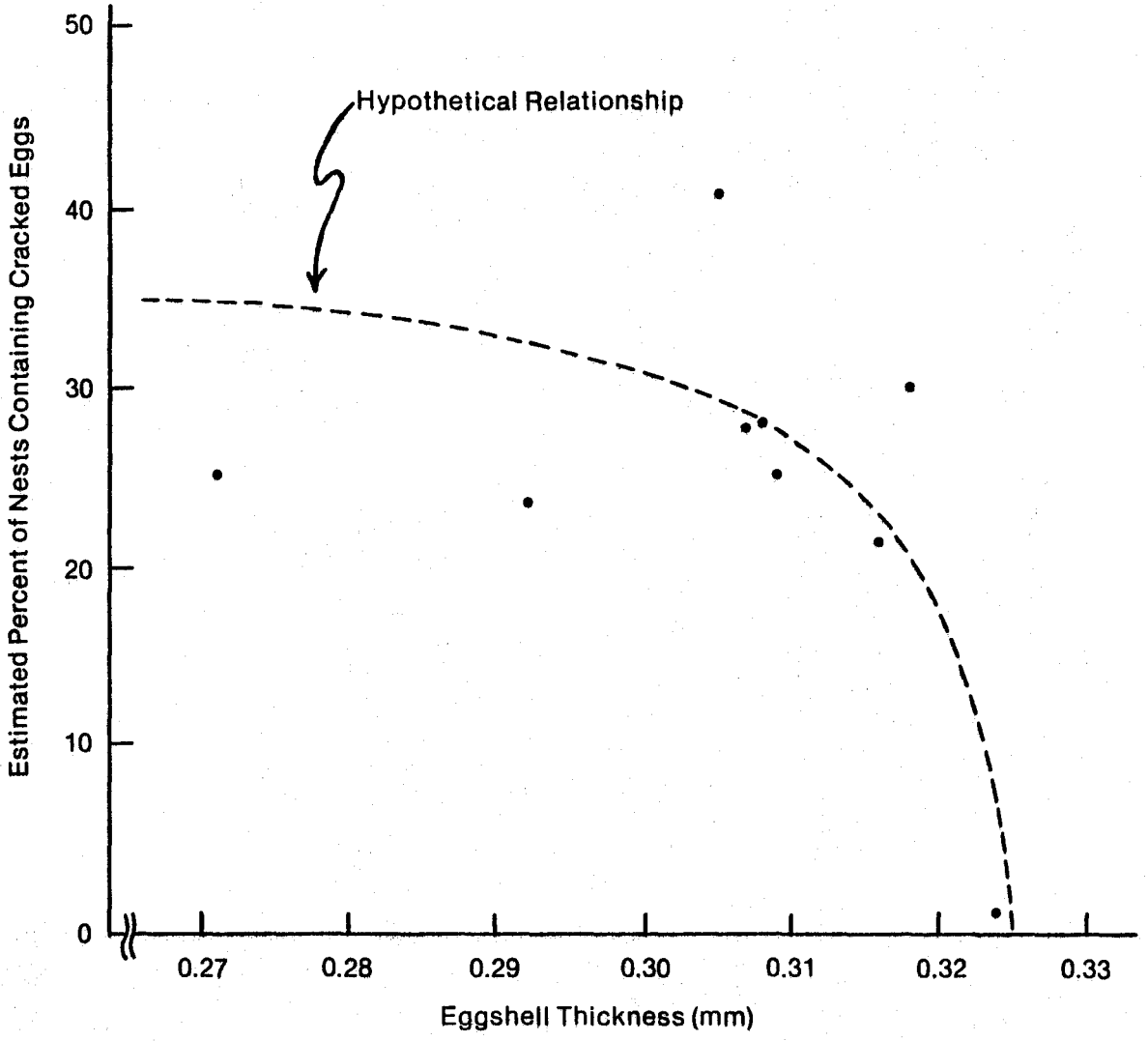


Figure 2. The relationship between mean eggshell thickness and eggshell condition for nine white-faced ibis colonies in northern Utah, 1968-1976. Sample sizes for eggshell thickness ranged from 18 to 80; for incidence of cracked eggs, 100+ in all cases.

was low. Nevertheless, I considered the variable of value because the observed incidence of cracked eggs in a colony provided a reasonable minimum statistic.

Clutch size

The most convenient procedure for estimating clutch size was to visit nests only once, when it appeared that egg-laying had ceased, and record the apparent clutch size. Because the observed clutch size may be underestimated due to egg loss, a better technique for estimating clutch size involved visiting nests and counting eggs each afternoon during the egg-laying period. This procedure prevented a bias due to egg loss, unless eggs were lost shortly after they were laid.

Data for five white-faced ibis colonies (Table 4) indicated that clutch size was a variable which could be precisely estimated. Using the combined data for 281 clutches, and a formula for estimating sample size (Sokal and Rohlf 1969:246), I calculated that clutch size counts from about 50 nests would be necessary to show a deviation of 10 percent from the mean (α=0.05).

Hatching success

Field studies of hatching success were subject to the disturbance caused by the investigator. In 1973, I selected a sample of nests in each colony, marked and numbered each nest, and collected nesting data from the marked nests. Because the study nests were not selected in a dense cluster, but instead were spread throughout the colony, sometimes it was difficult to locate marked nests. Thus, too much time was spent looking for marked nests, and birds were prevented from returning to their eggs. Incubating ibises remained on or returned to their nests

if I was only 8 to 10 meters away, so the problem of keeping the birds from their eggs would have been worse if the marked nests had been clustered.

To effectively eliminate this problem, I favored a scheme where a greater number of nests were checked but were not numbered and marked, thus the same nests did not have to be located on each visit. This method required more time to sample a colony, but the nesting birds were disturbed less because I was not in one vicinity of the colony for long.

Hatching success was highly variable (Table 7), largely due to natural processes. It was not feasible to compare hatching success among colonies and test for differences which might be due to pesticides, because the natural factors could not be held constant. Even if these intrinsic factors, e.g., abandonment, were estimated and accounted for, an analysis of hatching success could be biased because the estimation of the variables might not be independent of pesticide effects.

Fledging success

Nestling white-faced ibises began to leave the nests and wandered for short distances when only 5 to 10 days old, and for considerable distances when 14 to 28 days of age. It was impossible, then, to estimate the numbers of pre-fledging survivors because the birds could not be located and counted. Most pre-fledging mortality probably occurred during the first week after hatching, thus it seemed reasonable to restrict the definition of fledging success to include only survival through 7 days of age. Even with this restriction, there were difficulties because nestlings of only 5 days old would sometimes leave nests and hide in dense vegetation. This tendency varied with nest

height and water depth and was a factor which had to be evaluated for each colony.

The accurate estimation of fledging success was complicated by natural mortality factors which were difficult to identify and estimate, such as the mortality attributed to competition among nestlings. There was little doubt that natural mortality of nestlings varied among colonies and among years. I concluded that it was not feasible to isolate pesticide-induced nestling mortality from other sources of mortality.

Summary of evaluations

Results of the evaluations of the hypothesis stated earlier are summarized in Table 9. The estimation of five parameters was evaluated, but only two, eggshell thickness and clutch size, were acceptable as potential indicators of the effects of pesticides. The relationships between eggshell thickness and pesticides were investigated, but the effects of pesticides on clutch size were not studied.

Feeding ecology

Feeding habitat

When the white-faced ibises arrived in northern Utah each spring, they were frequently observed feeding in uncultivated farmland or hayfields which were partially inundated from run-off or high water from nearby streams or rivers. The ibises continued to feed in habitat of this type and in shallow marsh areas until nesting was well under way. By late May, much of the farmland to the north and east of the Bear River marshes was being irrigated by gravity-flow canal systems which periodically flooded fields with several centimeters of water. The

Table 9. Summary of assessments of the hypothesis that "A suitable estimate of each parameter can be obtained with adequate precision to indicate potential differences attributed to pesticides."

Parameter	Suitability	Precision	Hypothesis
Eggshell thickness	Suitable estimate with proper sampling	Adequate for efficient sampling	Accept
Eggshell condition	Biases cannot be eliminated	Not evaluated	Reject
Clutch size	Suitable estimate with time-consuming field procedures	Adequate for efficient sampling	Accept
Hatching success	Suitable estimate with proper field procedures	Inadequate for efficient sampling	Reject
Fledging success	Sampling problems cannot always be eliminated	Inadequate for efficient sampling	Reject

ibises showed an obvious preference for irrigated alfalfa hayfields and frequented these habitats almost exclusively during the nesting and brood-rearing periods. When the fledglings left the marshes, they also utilized irrigated fields, and by late summer when adults were molting, large flocks of predominantly juveniles were observed in these fields.

Feeding behavior, food items

From late-May through August, the ibises left the marshes soon after daylight each day and flew in long strings towards irrigated farmlands. The birds located fields with standing irrigation water and concentrated in these fields to feed. Ibises fed in one location for only a few hours, until the irrigation water was cut off and the field began to dry. Then they located and fed in other fields which were still flooded. When feeding in agricultural farmland, the ibises usually did not probe the soil for food items, but moved about rapidly and snatched food from the surface. I frequently examined fields where ibises fed, and observed an abundance of invertebrates, particularly earthworms, on the surface of the flooded soil.

Most of the food of the white-faced ibis is invertebrate matter, typical of birds with long, decurved bills. Peterson (1953, cited by Ryder 1967) collected 209 white-faced ibises in northern Utah and identified the contents of their stomachs. Insects, probably larval forms, and earthworms were the two most frequent food items, respectively. I collected food samples from white-faced ibis nestlings, 1-12 days old. The identification of these food items provided data (Table 10) which were similar to Peterson's findings.

Table 10. Food items collected from 55 white-faced ibis nestlings in northern Utah, 1974.

Food item	Numbers	Occurrence in 55 samples	
		Frequency	Percent
Insects, Insecta[a]			
Diptera (larvae)	1761	31	56.4
Stratiomyidae	1188	27	49.1
Tabanidae	262	20	36.4
Tipulidae	175	5	9.0
Chironomidae	136	4	7.2
Coleoptera (larvae and adults)	225	37	67.3
Hydrophilidae	190	14	25.4
Dytiscidae	25	15	27.2
Carabidae	9	4	7.2
Staphylinidae	1	1	1.8
Odonata (nymphs and adults)	149	19	34.5
Libellulidae	73	11	20.0
Lestidae	75	14	25.4
Aeshnidae	1	1	1.8
Lepidoptera (larvae)			
Noctuidae	9	2	3.6
Hemiptera			
Corixidae	1	1	1.8
Earthworms, Oligochaeta	373	29	52.7
Spiders, Arachnida	20	12	21.8
Snails, Gastropoda	14	9	16.3
Leeches, Hirudinea	16	4	7.2
Plant material		26	47.2

[a]Taxonomy is consistent with Borror et al. (1976).

Migration and wintering areas

Ryder (1967) summarized band recoveries and field observations and suggested that when white-faced ibises left northern Utah, the largest concentrations migrated down the Colorado Valley in western Arizona. Smaller numbers apparently moved through the Phoenix-Tucson area, while still others may have migrated into New Mexico, then down the Rio Grande River. Despite the migration route, Ryder (1967) reported that virtually all white-faced ibises produced in Utah wintered in Mexico, as evidenced by 102 band recoveries.

I analyzed 39 recoveries from ibises banded in Utah since 1968 and concluded that the wintering areas were essentially the same as Ryder (1967) reported (Fig. 3). White-faced ibises banded in Utah obviously wandered or moved frequently as groups from one area to another, as indicated by the geographical variation in direct (first-year) recoveries of birds banded in the Bear River marshes. For instance, three nestlings from the same colony banded in June 1973 were each recovered in December 1973, one in Sinaloa, one in Nayarit, and the third in Michoacan (Appendix A).

Figure 3. Locations of band recoveries and sightings of white-faced ibises banded or color-marked in the Bear River marshes since 1968. Solid symbols=direct recoveries, open symbols= indirect recoveries, ● =fall-winter 73-74, ▲ =74-75, ■ =75-76, ◬ =sightings of color-marked birds. (Note: symbols do not represent recovery locations within states.)

PESTICIDES, EGGSHELL THINNING, AND REPRODUCTIVE SUCCESS

Introduction

The association of pesticides with eggshell thinning was initially reported in Great Britain by Ratcliffe (1967), then in North America by Hickey and Anderson (1968). These investigators studied raptor eggs in museum collections and determined that eggshell thickness decreased noticeably in the late 1940's, coincident with the widespread use of DDT on both continents. Anderson and Hickey (1972) further demonstrated the usefulness and validity of examining museum eggs to record shell thickness changes over time. Shell thinning has been demonstrated in at least 54 species of birds of 10 orders (Stickel 1975), and numerous studies have provided correlative evidence that thin eggshells are associated with organochlorine pesticide residues (Cooke 1973, Stickel 1973). DDE, the environmentally stable metabolite of DDT, is the chemical which correlates best with thin eggshells (Blus et al. 1971, Faber and Hickey 1973).

Experimental studies have shown that DDE causes eggshell thinning (Heath et al. 1969, Longcore et al. 1971, Davison and Sell 1974); and that no other chemicals tested at realistic doses produced important shell thinning (Haegele and Tucker 1974). DDE is particularly important because it is persistent and may cause thin-shelled eggs many months after exposure (Haegele and Hudson 1974, Peakall et al. 1975).

Experiments have also dealt with the physiological explanation of eggshell thinning induced by pesticides. The probable mechanism is

that DDE works through the thyroid and the parathyroid to interfere with calcium ATPase and the formation of calcium carbonate in the shell gland (Jefferies 1973, Haseltine et al. 1974, Miller et al. 1975).

The purpose of this portion of my study was to determine the association between pesticides and the reproductive success of the white-faced ibis. My earlier findings indicated that eggshell thickness was the reproductive parameter which could best be estimated, thus it was logical to investigate the eggshell thickness-pesticide relationship in the white-faced ibis. Two null hypotheses were tested: (1) The means of shell thickness of white-faced ibis eggs collected periodically from 1968 through 1976 were no different than the pre-DDT mean eggshell thickness; (2) The shell thickness of eggs collected in this study was independent of pesticide residues in the eggs. Implicit in the second hypothesis is the assumption that pesticide residues in eggs are representative of pesticides in laying females, a relationship which is reasonably well supported (Cummings et al. 1966, 1967, Smith et al. 1970).

Methods

Normal eggshell thickness

White-faced ibis eggs collected in the pre-DDT era were measured to establish a "normal" mean eggshell thickness, which was individually compared with means of shell thickness of eggs collected in six recent years. Eggs in museums were measured by A. G. Smith and J. O. Keith, who allowed me to analyze the raw data. White-faced ibis eggs were examined in four museum collections: the Museum of Vertebrate Zoology, University of California at Berkeley; the California Academy of Sciences,

San Francisco; the Western Foundation of Vertebrate Zoology, Los Angeles; and the Museum of Natural History, Brigham Young University. The eggs measured included 679 collected in California and Utah between 1893 and 1935.

Shell thickness of museum eggs was measured to the nearest 0.01 mm with a Starrett No. 1010 dial micrometer adapted to fit through a small hole in the eggshell. Four measurements were taken of each eggshell and averaged. The procedures and the suitability of museum eggs for these measurements were described by Anderson and Hickey (1970, 1972). The length, breadth, and weight of each eggshell were measured, and a shell thickness index was calculated (Ratcliffe 1967).

Eggshell thickness, 1968-1976

Eggs were collected each year from 1968-1976, except 1970, 1972, and 1973. The number of eggs collected and the sampling procedures differed among years (Table 11), but I selected samples that were reasonably representative of the entire nesting population and were not biased towards either normal or aberrant eggs. In 1968, eggs were sampled from only one of two colonies, but aberrant eggs were present in similar proportions in the second colony, so the sample was included in the shell thickness comparisons. Usually, only one egg was taken from a nest, disregarding the order in which the eggs were laid, but in 1969, 50 eggs represented 15 entire clutches.

The best procedure for collecting eggs for shell thickness comparisons was the systematic sample used in 1976. Eggs were collected when total nest counts were conducted in each major nesting colony. Before censusing a colony, I estimated the number of nests,

Table 11. Summary of procedures for sampling white-faced ibis eggs in northern Utah, 1968-1976.

Year	No. eggs collected	Sampling scheme	Sample representative of all nesting colonies?
1968	18	Non-random	No: eggs collected from one of two large colonies
1969	80	Non-random	Yes: eggs collected from both large colonies
1971	40	Non-random	Yes: eggs collected from the one large colony
1974	56	Random	Yes: eggs collected from the one large colony
1975	86	Stratified non-random	Yes: eggs collected from three large colonies
1976	99	Systematic	Yes: eggs collected from five large colonies

then decided to collect an egg from every 5th, 10th, or nth nest so the sample, of pre-determined size, was properly stratified throughout the colony. The mean eggshell thickness for each colony was then weighted by the size of the colony.

Procedures for measuring the eggshells were described by Capen (1977). The means for six measurements of each eggshell, expressed to 0.001 mm, were used in the analyses. Only four measurements were taken of each eggshell collected from 1968-1971 and means were rounded to the nearest 0.01 mm.

Eggshells are known to become thinner during incubation as the growing embryo obtains calcium from the eggshell (Simkiss 1967,

Kreitzer 1972). For this reason, the shell thickness of all eggs containing embryos of greater than 6 days development was adjusted upward. Based on the results of an earlier study (Capen 1977), white-faced ibis eggshells are thinned an average of 4.3 percent between 6 and 18 days incubation. I divided this 12-day interval into four 3-day periods, assumed that the decrease in thickness was linear, estimated the age of the developed embryos, and adjusted the measured shell thickness (e.g., if an egg contained an embryo which was estimated to be 16-18 days old, 0.014 mm, 4.3 percent of normal shell thickness, was added to the measured thickness). Most eggs collected from 1968-1976 were taken during early stages of incubation; many were collected the day they were laid. About 20 percent of the eggs, however, did contain embryos of more than 6 days development, so the adjustment factor was considered important.

Incidence of cracked eggs

In 1969, 1971, and 1973, the incidence of cracked eggs was estimated by inspecting eggs in a sample of marked nests in each colony. In 1974, 1975, and 1976, I examined eggs in most or all nests in a colony. In large colonies, I sometimes inspected the eggs in every second or third nest counted. If one or more eggs in a clutch was cracked, the nest was counted as one with cracked eggs. The eggs were usually examined for cracks shortly after clutches were completed, and sometimes during mid-incubation.

Pesticide analysis

The contents of 132 eggs, collected in 1974 and 1975, were analyzed individually for residues of chlorinated hydrocarbon pesticides. Chemical analyses were conducted at the Denver Wildlife Research Center using the procedures of Peterson et al.(1976), with minor modifications. Eggs were first homogenized with a blender, then a 10-g sample was mixed with 50 g of anhydrous sodium sulfate, frozen, and blended again. The sample was extracted with 20 percent acetone in isooctane. The liquid-liquid partition was omitted. Organochlorine compounds were identified and quantified on a Tracor MT-220 gas chromatograph with ^{63}nickel electron-capture detectors. Two columns, a 3 percent OV-1 on 80/100 mesh Chromosorb W and a 5 percent QF-1 on 100/120 mesh Chromosorb W, were used for qualitative confirmation. The lower limits of sensitivity for pesticides and PCB's were 0.1 ppm and 0.5 ppm, respectively.

Adjustment for moisture loss. Comparisons of pesticide residues in eggs, expressed on a wet weight basis, may be biased if moisture is lost from the egg contents (Stickel et al. 1973). I attempted to eliminate such a bias by collecting eggs that were relative fresh, thereby having similar moisture content. Most of the 132 eggs were taken during early incubation; only 15 eggs were more than 6 days old. To evaluate the possible bias of the few mid-incubation eggs, the weight loss of white-faced ibis eggs during incubation was estimated (Appendix B). I concluded that a bias towards high pesticide levels, attributed to lost weight, was 5 percent maximum in the eggs sampled but averaged only 1 percent for the entire sample. Hence, no adjustments for moisture loss were made.

Lipid weight. Lipid weight equivalents were determined by the method of Peterson et al. (1976). Lipids comprised, by weight, 5.66 percent (SE=0.083) of the egg contents. Romanoff (1932) reported that one-third of the lipid content of the hen's egg was utilized by the developing embryo. Blus et al. (1974a), however, found that the percentage lipid remained constant until the last third of incubation. In my samples, no significant difference ($t=1.31, df=74, P>0.20$) was found in the mean lipid weight between fresh eggs and mid-incubation eggs. Because lipids did not vary significantly, pesticide residues are expressed on a fresh wet weight basis.

Results and Discussion

Normal eggshell thickness

Shell thickness measurements were obtained from 374 of 679 museum eggs (Table 12). A mean shell thickness of 0.327 mm (SE=0.001) was calculated and considered to represent the "normal" mean eggshell thickness for the white-faced ibis. Shell thicknesses of museum eggs were compared for five years, to obtain an appreciation for natural variability among nesting seasons (Table 13). The samples selected were those where a reasonable number of eggs, 20 or more, were measured. No significant differences among years were detected ($F=0.58, df=4,250, P>0.50$). Other authors (Blus et al. 1974a) tested their pre-1945 eggshell thickness data from brown pelicans (Pelecanus occidentalis) for variation among decades, and found no significant differences ($P>0.05$).

Actual shell thickness of museum eggs often cannot be measured, due to small blow-holes, and Ratcliffe's thickness index is used as a

Table 12. Eggshell thickness measurements and thickness indexes for white-faced ibis eggs in museum collections.

Location	Shell thickness (mm)		Thickness index	
	No. eggs	Mean ± SE	No. eggs	Mean ± SE
California	327	0.327[a] ± 0.001	476	1.485[b] ± 0.005
Utah	47	0.326[a] ± 0.002	203	1.533[b] ± 0.008
Total	374		679	
Mean		0.327 ± 0.001		1.500 ± 0.004

[a]No significant differences found between means, t=0.34,df=372,P>0.50.
[b]Means significantly different, t=5.52,df=677,P<0.01.

Table 13. Eggshell thickness measurements for five years of pre-DDT white-faced ibis eggs in museum collections.

Year	No. eggs	Shell thickness Mean ± SE
1908	86	0.327[a] ± 0.002
1913	24	0.325[a] ± 0.004
1917	100	0.327[a] ± 0.002
1919	22	0.324[a] ± 0.005
1925	23	0.321[a] ± 0.002
Total	255	
Mean		0.326 ± 0.001

[a]No significant differences found among means, F=0.58,df=4,250,P>0.50.

substitute variable (Anderson and Hickey 1972). I calculated the index for 679 eggs and evaluated its suitability as an indicator of eggshell thickness in the white-faced ibis. The index was significantly correlated ($r=0.74, P<0.001$) with shell thickness for 326 museum eggs, but was significantly different between the Utah and California samples ($t=5.52, df=677, P<0.01$, Table 12). No significant differences were detected between the actual shell thicknesses ($t=0.34$, $df=372, P>0.50$, testing a smaller sample), suggesting that the thickness index was not a suitable substitute for actual shell thickness measurements of white-faced ibis eggs. Hence, no comparisons in this study utilized the thickness index.

Eggshell thickness, 1968-1976

Results of eggshell thickness comparisons from 1968-1976 are summarized in Table 14 and illustrated in Figure 4. The hypothesis that mean shell thickness was no different than normal was rejected for each of the 6 years except 1974. In that year the mean shell thickness was not found to be significantly different than normal ($t=1.08, df=428, P>0.10$). The other comparisons, however, showed significant deviations from normal ($P<0.01$ in all cases). Thinnest eggshells were collected in years when DDT was used in Utah, 1968 and 1969, and in 1971, only 1 year after the use of DDT ceased. Eggshell thickness increased 4 to 6 years after DDT was last used. Means for the early samples, 1968, 1969, and 1971, were significantly less than means of 1974, 1975, and 1976 ($F=21.74, df=5,373, P<0.01$, Scheffe's multiple comparison test, Winer 1971). Even though eggshells were of normal thickness in 1974, they were again significantly below normal

Table 14. Comparisons of shell thickness for white-faced ibis eggs collected in northern Utah, 1968-1976, and museum eggs collected in Utah and California before 1945.

Source	Sample size	Mean thickness (mm)	95 percent conf. int.	Deviation from museum eggs (%)	Significance of deviation
Museum eggs	374	0.327	0.325 - 0.329	--	
1968 eggs	18	0.286	0.266 - 0.306	-12.5	t= 8.56,df=390,P<0.01
1969 eggs	80	0.271	0.266 - 0.276	-17.1	t=24.68,df=452,P<0.01
1971 eggs	40	0.292	0.283 - 0.300	-10.7	t=11.03,df=412,P<0.01
1974 eggs	56	0.324	0.318 - 0.330	- 0.9	t= 1.08,df=428,P>0.10
1975 eggs	86	0.307	0.302 - 0.312	- 6.1	t= 8.38,df=458,P<0.01
1976 eggs	99	0.311[a]	0.305 - 0.317	- 4.9	t= 5.33,df=471,P<0.01

[a]Mean and variance of the mean weighted by size of the colony.

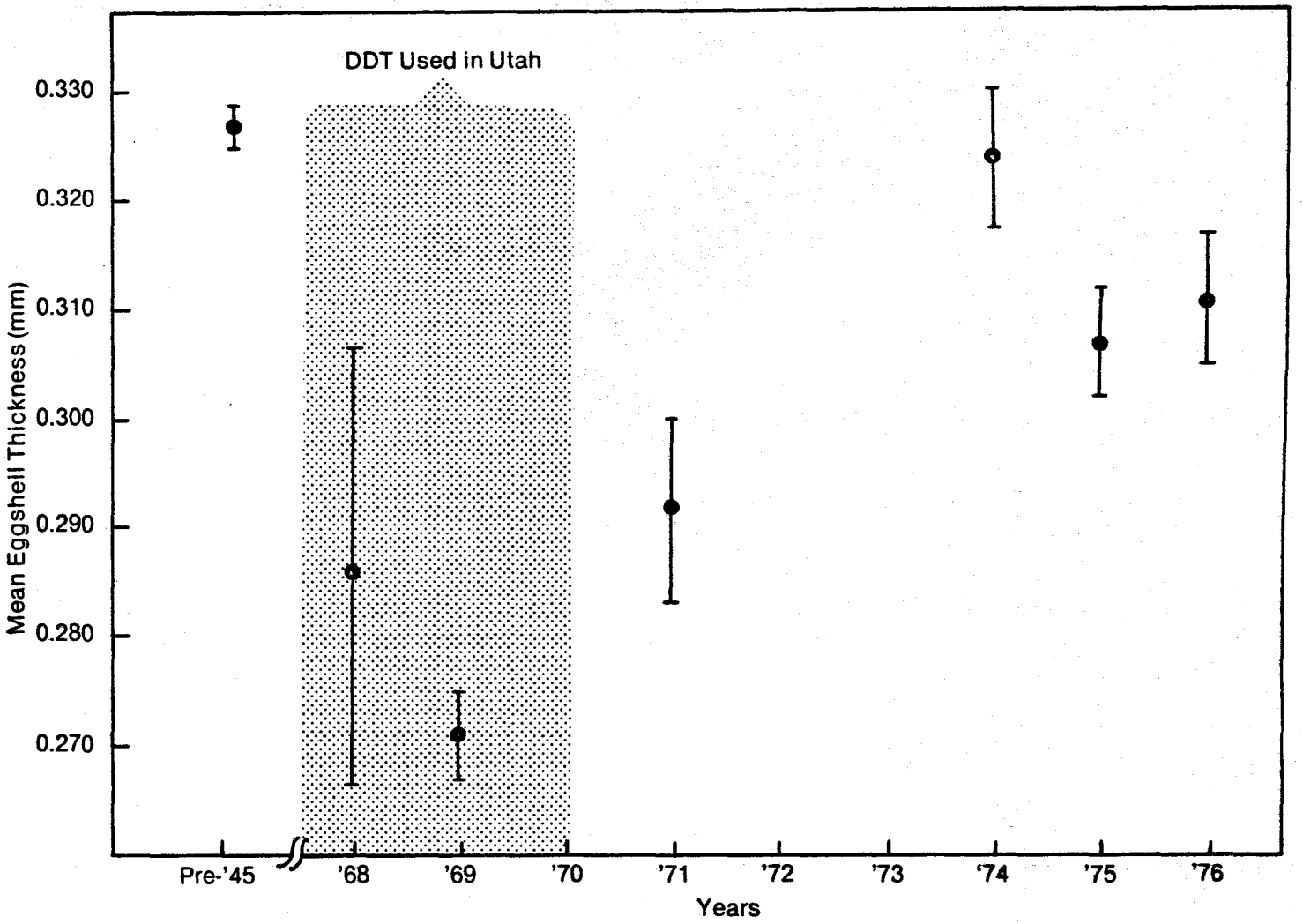


Figure 4. Comparisons of shell thickness for white-faced ibis eggs collected in Utah (data from Table 14). Solid dots indicate means; vertical lines represent 95 percent confidence intervals.

in 1975 and 1976 ($F=7.50, df=2,240, P<0.01$, Scheffe's test). I considered the differences in the last 3 years of the study particularly meaningful because egg samples were carefully selected to represent the entire nesting population of the Bear River marshes.

Incidence of cracked eggs

In 1969, the year of the lowest mean eggshell thickness, 25 percent of nests contained cracked eggs (Fig. 5). The results were similar in 1971. Less than 1 percent of nests contained cracked eggs in 1974, when the mean eggshell thickness was normal. Eggshell thickness again decreased in 1975 and 1976, and the incidence of nests with cracked eggs increased to 28 percent and 31 percent, respectively. Serious egg losses occurred in 1975 and 1976, despite the evidence that mean eggshell thickness was only 5 to 6 percent below normal. This is contrary to studies which indicate or assume that more than 10 percent reduction in eggshell thickness is necessary before eggs are lost because of crushed shells (Anderson and Hickey 1972, Keith and Gruchy 1972). Faber and Hickey (1973) even stated, "Certainly, widespread eggshell breakage does not occur with changes below this magnitude [10 percent]."

There is an apparent discrepancy between the relationship of eggshell thickness and the incidence of cracked eggs (Fig. 5). Data did not indicate a greater incidence of cracked eggs in 1969 and 1971, than in 1975 and 1976, despite thinner eggshells in the early years. This illustrates the bias discussed earlier, that the occurrence of cracked eggs increases quickly to a certain point, as eggshells become thin, but may reach an asymptotic level because entire clutches

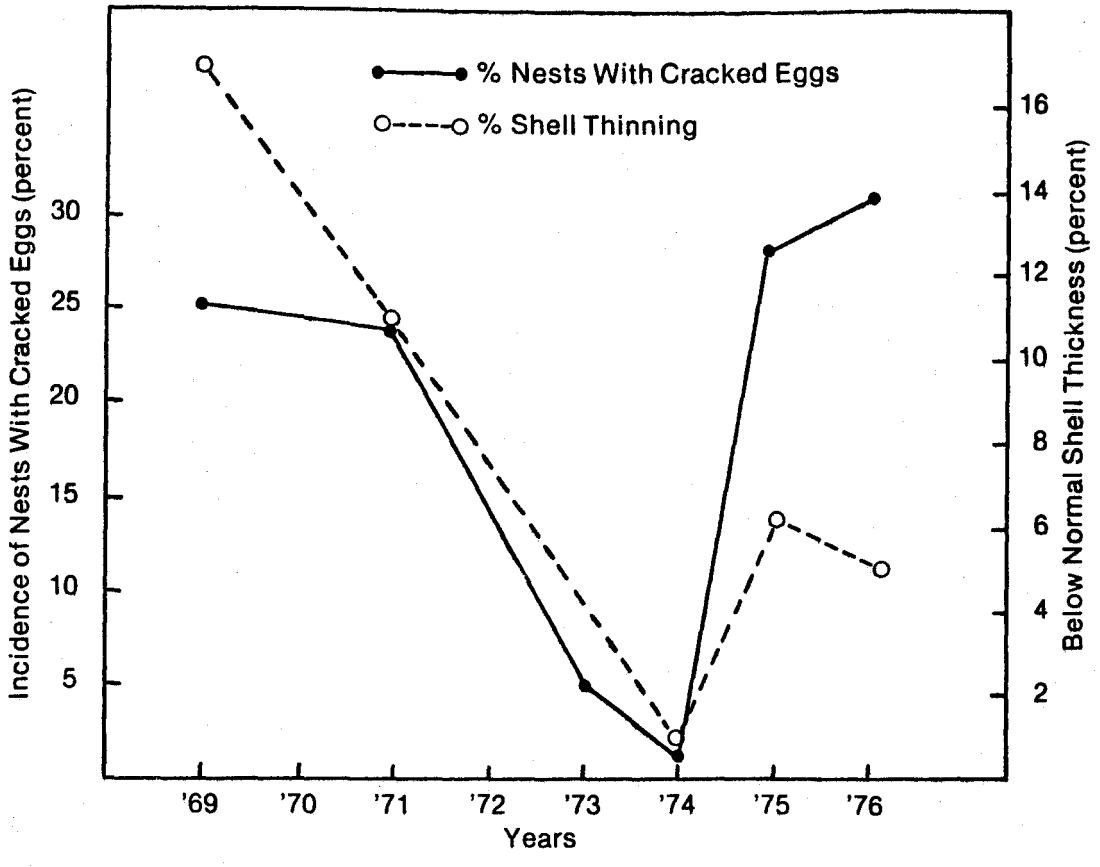


Figure 5. Relationship between the incidence of cracked eggs in white-faced ibis nests in northern Utah and the degree of eggshell thinning.

of cracked eggs were discarded from nests.

Pesticides and eggshell thickness

The contents of eggs were analyzed for p,p'DDE, p,p'DDT, p,p'DDD, dieldrin, endrin, lindane, helptachlor epoxide, and the PCB's Aroclor 1254 and Aroclor 1260. All egg samples contained measurable amounts of DDE, but this was the only chemical which occurred consistently. DDD, DDT, dieldrin, and Aroclor 1254 were detected, but were not found consistently nor in more than trace amounts, usually less than 0.2 ppm.

Eggshell thickness-DDE data for 1974 and 1975 samples were analyzed separately. One egg in the 1974 sample contained over 30 ppm DDE, five times more than the second highest concentration, and was eliminated from the analysis. The correlation between eggshell thickness and DDE residues for the 1974 data was significant ($r=-0.39$, $df=53, P<0.001$, Fig. 6), but fairly weak ($r^2=0.15$). The relationship between shell thickness and DDE levels was better presented by the 1975 data because greater ranges of shell thickness and DDE levels were represented (Fig. 7). The regression between shell thickness and ln DDE was significant ($r=-0.61, df=74, P<0.001$) and the correlation coefficient (r) is comparable to those of other studies where individual sets of eggs were analyzed (Table 15). The logarithmic relationship of DDE residues to eggshell thickness indicates that eggshell thinning, per ppm of DDE, varied for different levels of DDE in the egg. For instance, I calculated, on the basis of the regression equation $Y = 0.306 - 0.014 \ln X$ that shell thinning per ppm of DDE was 6.3 percent at 1 ppm, 1.6 percent at 10 ppm, and 0.97 percent at

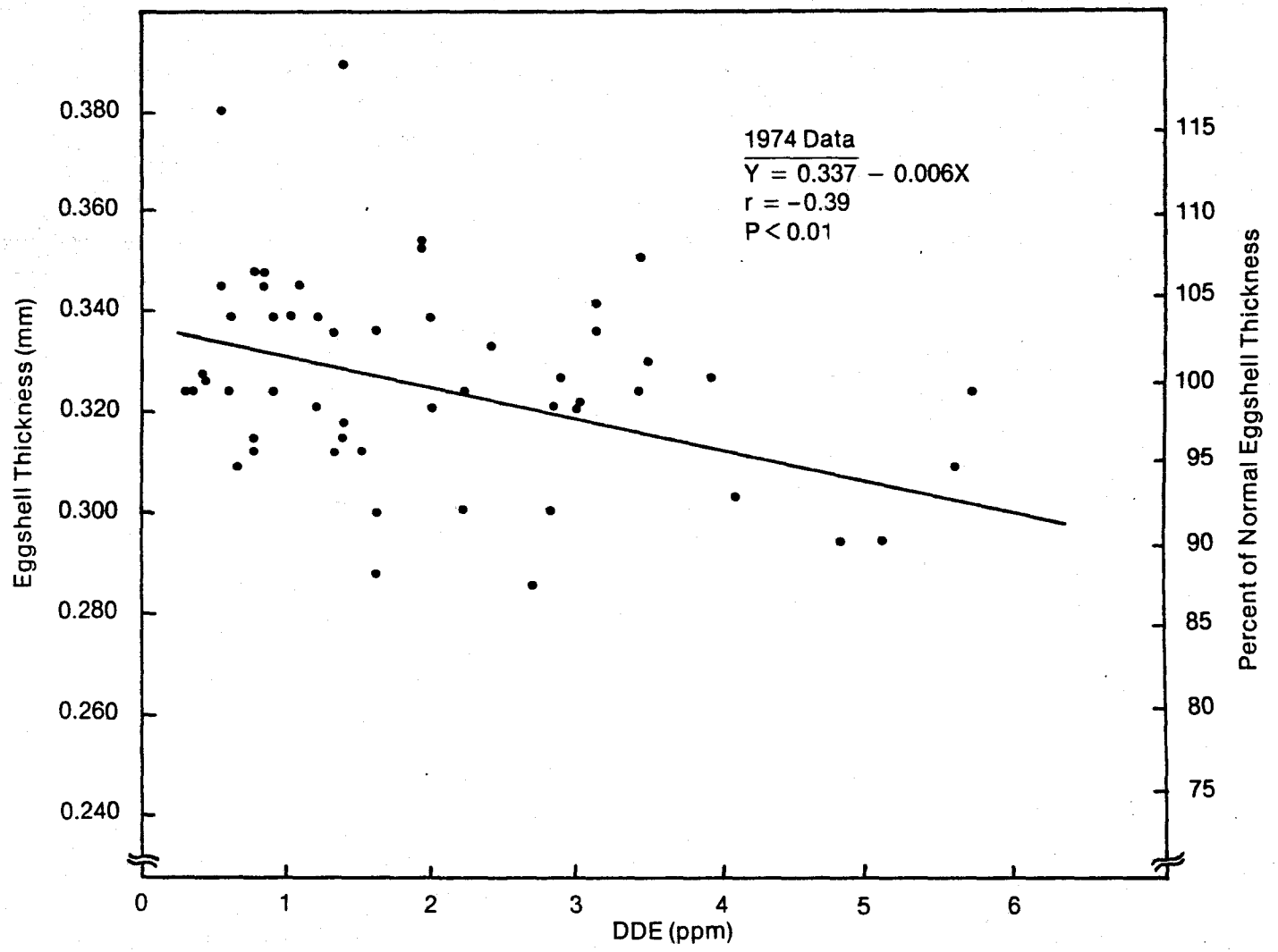


Figure 6. Relationship of DDE residues and eggshell thickness in 55 white-faced ibis eggs from northern Utah, 1974.

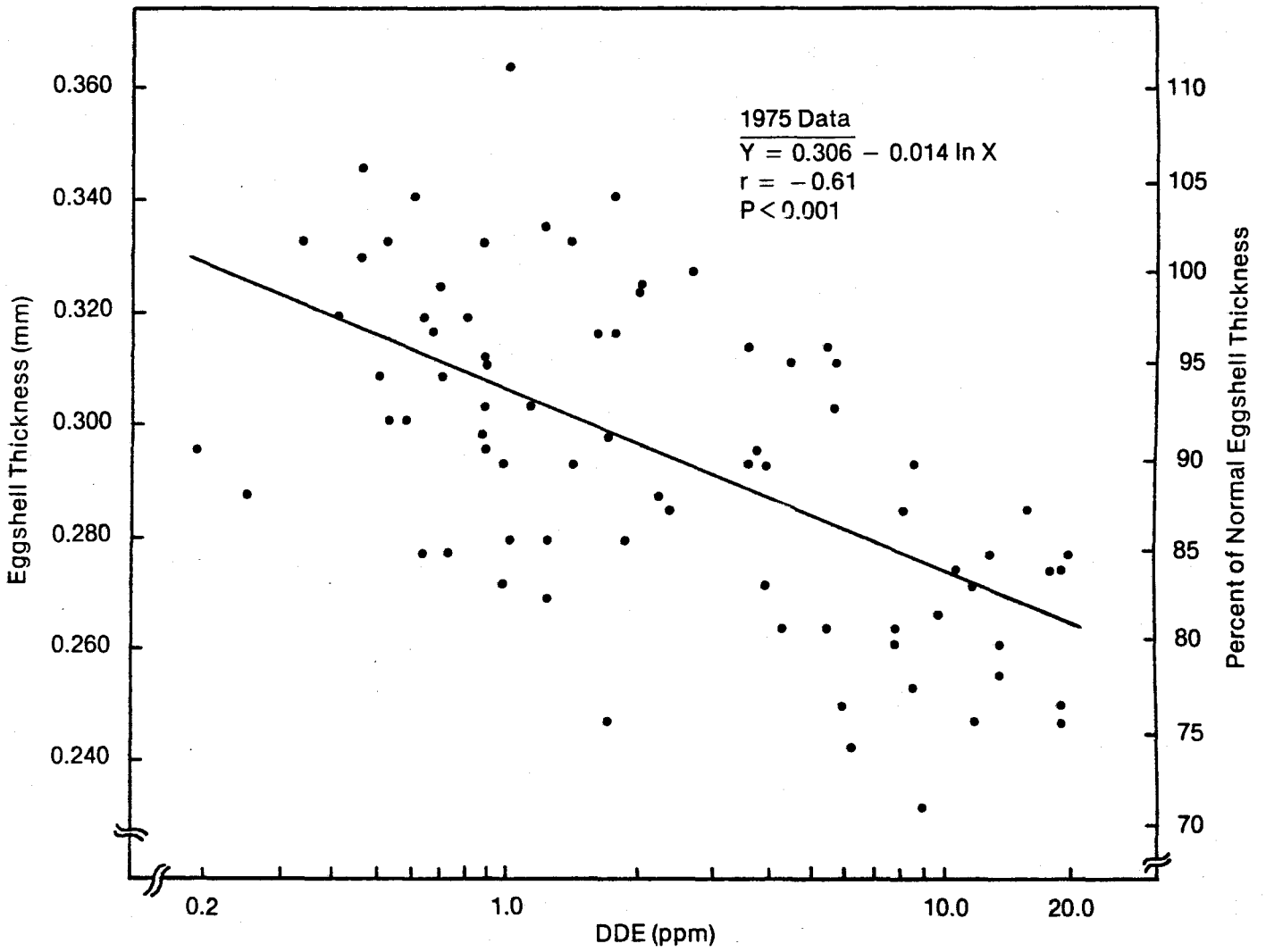


Figure 7. Relationship of DDE residues and eggshell thickness in 76 white-faced ibis eggs from northern Utah, 1975.

Table 15. The dependence of eggshell thickness on DDE residues in eggs: a comparison of correlative evidence.

Species Location	Variables	Correlation coefficient[a]	Sample size	Source
		Eggs pooled by colonies		
Herring gull RI,ME,MI,MN,WI	Shell thickness DDE (wet)	-0.99	5	Hickey and Anderson (1968)
Double-crested cormorant Prairies	Shell thickness DDE (wet)	-0.99	9	Anderson et al. (1969)
Brown pelican FL,SC,CA	Shell thickness Log DDE (wet)	-0.92	12	Blus et al. (1974a)
		Individual eggs from different colonies		
Brown pelican FL,SC,CA	Shell thickness Log DDE (wet)	-0.80	80	Blus et al. (1972a)
Great blue heron Alberta	Shell thickness Log DDE (lipid)	-0.69	40	Vermeer and Risebrough (1972)
Double-crested cormorant Prairies	Shell thickness DDE (wet)	-0.80	29	Anderson et al. (1969)
Mixed heron spp. Lake states, LA	Thickness index Log DDE (lipid)	-0.58	49	Faber and Hickey (1973)
		Individual eggs from one population		
Peregrine falcon Alaska	Thickness index Log DDE (lipid)	-0.74	43	Cade et al. (1971)
Prairie falcon Colorado	Shell thickness Log DDE (wet)	-0.72	40	Enderson and Wrege (1973)
White-faced ibis Utah	Shell thickness Log DDE (wet)	-0.61	76	This study

[a]All correlations were significant ($P<0.01$).

20 ppm.

The estimated relationship of DDE to eggshell thickness for the white-faced ibis was compared to that of the brown pelican (Blus et al. 1972a). The brown pelican is known for serious problems with thin eggshells (Keith et al. 1970); it is a species which has been extensively studied (Jehl 1973, Blus et al. 1974a, 1975, Anderson et al. 1975); and the DDE-eggshell thickness relationship is well documented (Blus et al. 1971, 1972a, 1972b). A comparison of the regression equations for the two species is illustrated in Figure 8. The slope of the regression line for the white-faced ibis was significantly different ($t=2.17, df=152, P<0.05$, Sokal and Rohlf 1969:455) from that of the brown pelican, but the regression coefficients were obviously similar. Enderson and Wrege (1973) reported that the DDE-eggshell thickness relationships for the prairie falcon (Falco mexicanus) and the peregrine falcon (F. peregrinus) (Cade et al. 1971) were not statistically different than for the brown pelican. Falcons and pelicans are notably sensitive to DDE residues (Keith and Gruchy 1972), hence, from the standpoint of eggshell thinning, the white-faced ibis must be considered among the most sensitive avian species.

The relationship between DDE and eggshell thickness apparently follows a similar pattern in several species, thus differences in extent of shell thinning depend on mean levels of DDE in the eggs. DDE levels in eggs vary widely among species and geographical locations (Stickel 1973). The geometric mean DDE residues in 36 white-faced ibis eggs, collected in 1975 and considered representative of the entire nesting population, was 1.50 ppm. The expected shell thickness for these eggs was 0.301 mm, only slightly different than the

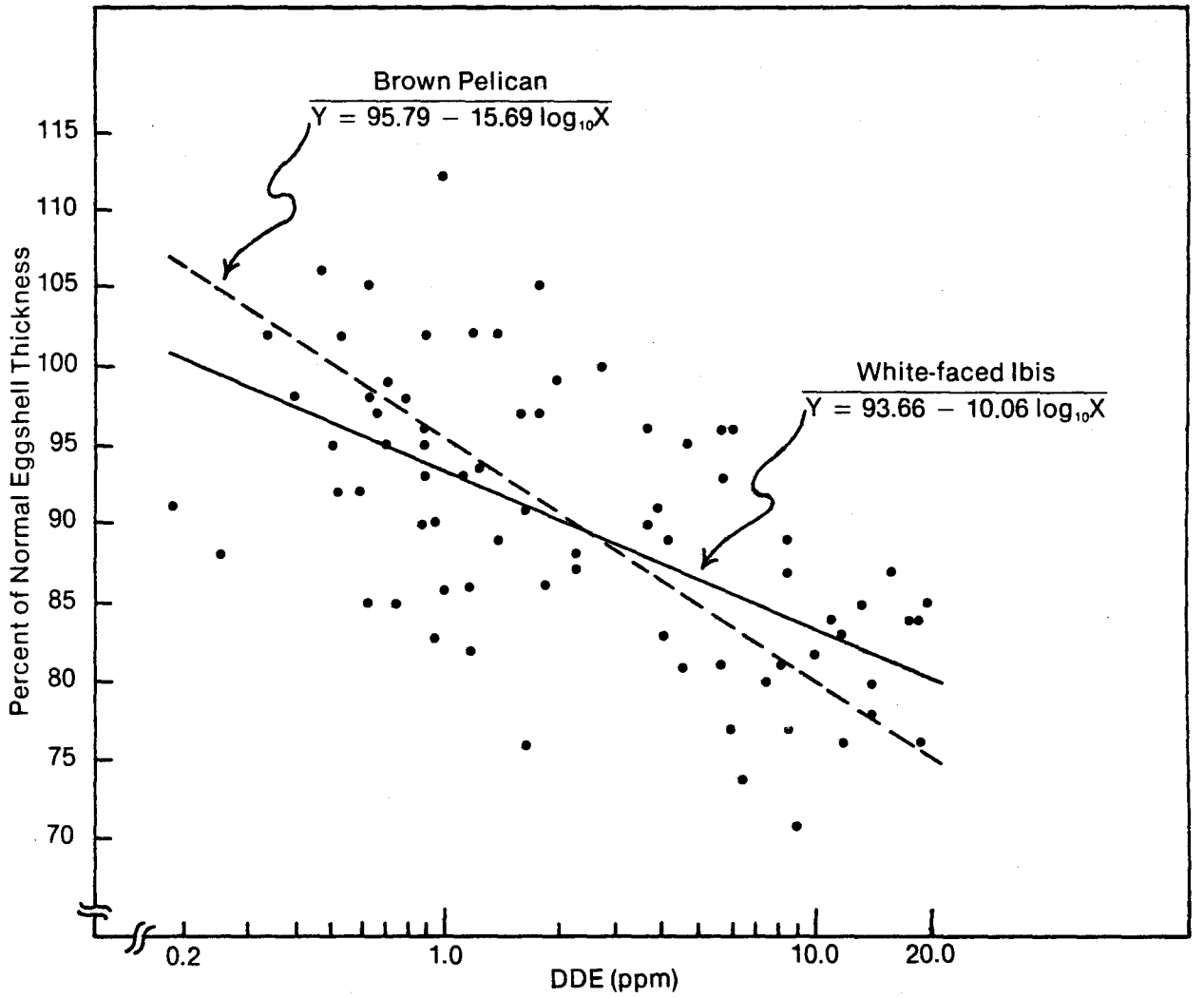


Figure 8. Comparative logarithmic relationship of DDE and eggshell thickness for the white-faced ibis and the brown pelican (Blus et al. 1972a). Plotted data points are for the white-faced ibis.

observed 0.307 mm, 6.1 percent below normal (Table 14).

Additional evidence relating white-faced ibis egg losses to DDE was obtained by comparing variables of eggs which appeared either normal or cracked when collected in the field (Table 16). The cracked eggs had thinner shells and higher DDE residues than did the normal-appearing eggs.

Reproductive success

Several studies have objectively related eggshell thinning to reduced reproductive success and subsequent population declines (e.g., Fyfe et al. 1969, Cade et al. 1971, Jehl 1973). Findings of this nature depend on long-term studies with precise survey methods, precipitous population declines, or detailed nesting studies of species

Table 16. Comparisons of normal and cracked white-faced ibis eggs collected in northern Utah, 1975.

Variable	Normal eggs		Cracked eggs		Significance of difference
	Mean[a]	n	Mean[a]	n	
Eggshell thickness (mm)	0.310	75	0.288	58	t=5.3,df=131,P<0.01
DDE	1.16	41	5.18	35	t=6.5,df=74,P<0.01

[a]Means are arithmetic for eggshell thickness, geometric for DDE.

for which population processes are previously understood. None of these advantages were realized in my study of the white-faced ibis. It is clear that data do not exist to allow an analysis of the population dynamics of the white-faced ibis to assess changes in the population.

Collective evidence indicates that reproductive success of the white-faced ibis is adversely affected by DDE. Most importantly, a high incidence of nests with cracked eggs has been documented and related to DDE. Pesticide residues have been found to be similar in eggs of the same clutch (Vermeer and Reynolds 1970, Blus et al. 1974b). It follows, then, that the occurrence of one cracked egg in a nest suggests that an entire clutch of eggs may have thin shells. Thus, egg losses resulting from thin shells are more likely to affect whole clutches than only one or two eggs per nest. The white-faced ibis does not persistently renest to compensate for lost clutches. Therefore, eggs which do not hatch because of cracked shells almost certainly represent a loss in recruitment to the population.

PESTICIDE RESIDUES IN TISSUES OF WHITE-FACED IBISES

Introduction

Given the relationship between the reproductive success of the white-faced ibis and DDE, I sought to determine if significant changes in DDE residues in the ibises could be measured from one season to another. Tissue samples were collected and analyzed for DDE so that variability of residues in tissues would indicate the potential for determining changes in body burdens of pesticides. Previous studies, e.g., Keith (1970) and Anderson and Hickey (1976) indicated that pesticide residues in bird populations are highly variable, hence large samples are necessary to show significant differences between populations, seasons, etc. For this reason, I endeavored to evaluate the suitability of sampling pesticide residues in blood samples which could be collected without sacrificing adult ibises. Blood samples can be collected at any season, from different age and sex groups, and may provide a direct index to body burdens of pesticides. Eggs also provide a useful index to pesticide levels, but only to residues in adult females during the nesting season.

Studies of various organisms, mostly mammals, have related pesticide levels in blood to dosage (Schager 1972), and a few investigators have examined the correlation of pesticide levels in blood and in adipose tissue (Laben et al. 1965, Robinson and Hunter 1966). But even in humans, the subject of most of this research, data are insufficient to conclude that pesticide residues in blood are reliable

indicators of body burdens of pesticides (Schafer 1972). Very little research of this nature has been conducted with birds. Friend et al. (in prep.) found a high correlation ($r=0.93, df=108$) between DDE in blood sera and in adipose tissue samples in male mallards (Anas platyrhynchos) raised in captivity, but there have been no similar studies of birds in the wild. Thus, one objective of this study was to determine the relationship between DDE in blood sera and in adipose tissue in adult white-faced ibises collected at different times during the breeding season.

Methods

Collection of birds and tissue samples

Sixty-one adult white-faced ibises were collected from 19-27 May, 3-12 July, and 23 August-4 September 1974 and 16-24 June 1975. Birds were shot as they flew to or from nesting colonies in the Bear River marshes, except in August-September (referred to as the August collection). The May 1974 and June 1975 collections were taken during incubation; the July sampling period was at the time when the young fledged; and the August sample followed the molt.

When a bird was shot, a 5-ml blood sample was taken from the heart, transferred to a centrifuge tube, and stored in an ice chest. The bird was wrapped in aluminum foil and also kept near ice. Specimens were taken to the laboratory within 4 hr, fat and muscle samples were removed from the birds, and blood samples were centrifuged 15 min at 2000 rpm. Blood samples were refrigerated overnight, then serum was removed and frozen. Subcutaneous fat samples, 1-5 g, were taken from the lower neck region of 42 ibises with sufficient fat deposits.

A 10-g sample of breast muscle also was removed from each carcass.

Pesticide analysis

Pesticide analysis and lipid determination followed the procedures described earlier. Fat samples were prepared by the methods of Peterson et al. (1976). Extraction procedures for blood serum were simplified, however, by merely mixing 8 g of granular sodium sulfate with 1 ml of blood serum, adding 5 ml of extraction solvent, and vibrating the mixture in an ultra-sonic glassware cleaner for 15 min. After centrifuging, a sub-sample of the supernate was removed for gas chromatography. Breast muscle samples were extracted like fat samples except that ethyl acetate was used as an extraction solvent, and cleanup was by a GPC Autoprep 1001 gel permeation unit. The lower limit of sensitivity for pesticides and PCB's was 0.1 ppm for fat samples and 0.01 ppm for blood sera and breast muscle samples.

Chemical residue measurements were determined by wet weight of tissues, and data for fat and breast muscle samples are expressed as µg pesticide/g lipid. Because the residue data were positively skewed, they were transformed to natural logarithms prior to statistical testing.

Results and Discussion

DDE residues: blood--fat--muscle relationships

Chemical residues other than DDE did not occur consistently and are not reported. DDE residues were detected in all 42 paired blood and fat samples. Statistical analysis indicated that ln DDE in blood was significantly correlated with ln DDE in fat ($r=0.82, df=40, P<0.001$,

Fig. 9). A similar positive relationship existed between DDE in blood and DDE in breast muscle lipids ($r=0.90, df=21, P<0.001$, Fig. 10). In fact, the regression equations for these two relationships were essentially identical.

Seasonal differences. Ibises collected in May 1974 and June 1975 appeared to be in good condition and had ample deposits of subcutaneous fat. Both subcutaneous and abdominal fat were noticeably absent in the birds collected in July and in three birds taken in August. The other four birds collected in August were quite fat, more so than the birds taken in May and June.

Organochlorine pesticides are lipophilic, so DDE residues in different tissues may change during periods of lipid mobilization or storage (Donaldson et al. 1968, Ecobichon and Saschenbrecker 1969, Findlay and deFreitas 1971). Because both fat depletion and storage were obviously occurring during the May-August sampling interval, I compared the residues in blood, fat, and muscle samples from different dates of collection (Table 17), and tested, by analysis of variance, for differences among means for sampling periods (Fig. 11).

DDE levels in blood and breast muscle increased between the May and June sampling periods (Figs. 11a,c). This interval corresponded with a time when adult ibises were feeding nestlings, and subcutaneous fat depots in the 20 adults examined had been depleted. Between July and August, when fat was again being deposited in some of the birds sampled, DDE in blood and muscle returned to approximately the same mean levels as in the May samples. Increased DDE, or DDT, in blood of chickens during periods of starvation and subsequent fat depletion has been reported by Donaldson et al. (1968) and Ecobichon and

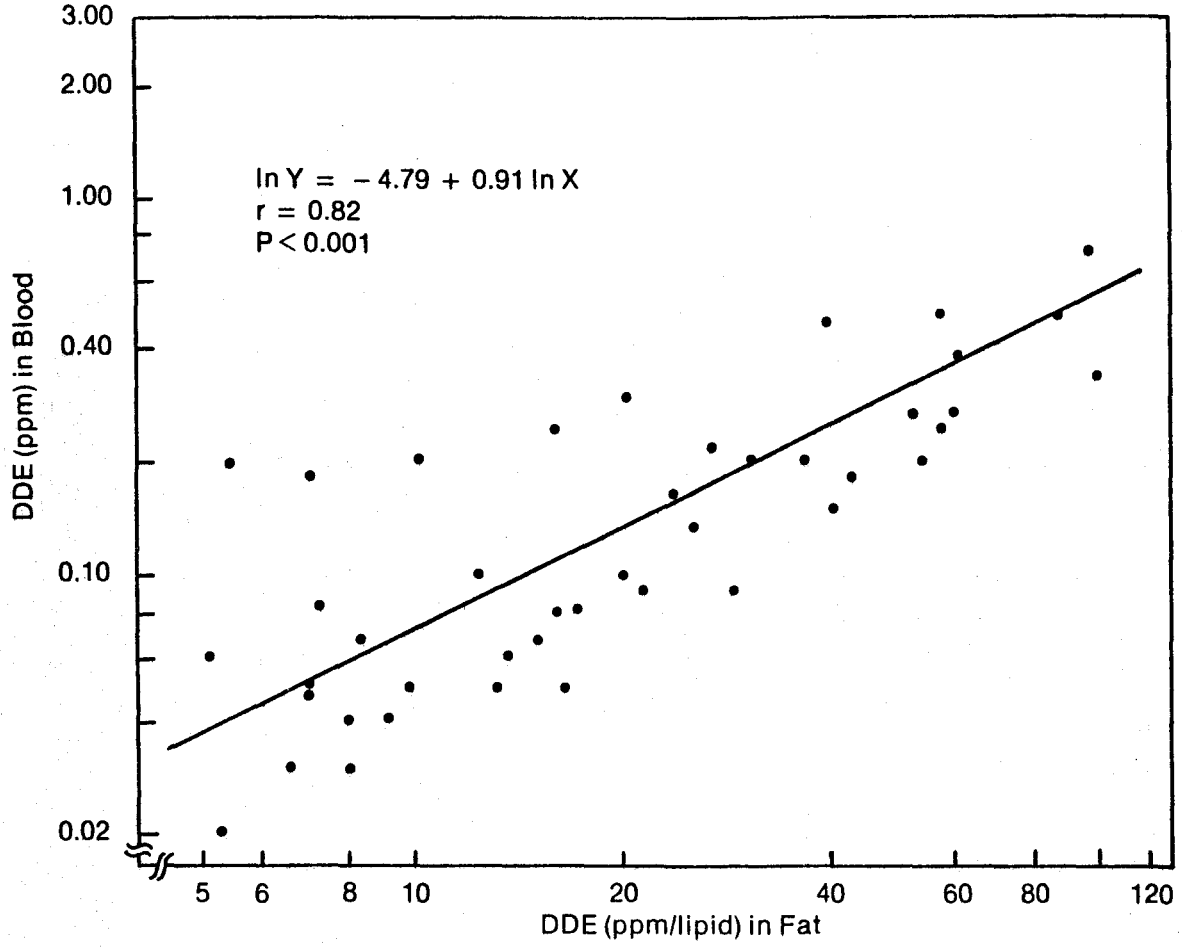


Figure 9. The relationship of DDE in blood serum and subcutaneous fat from white-faced ibises collected in northern Utah, 1974 and 1975.

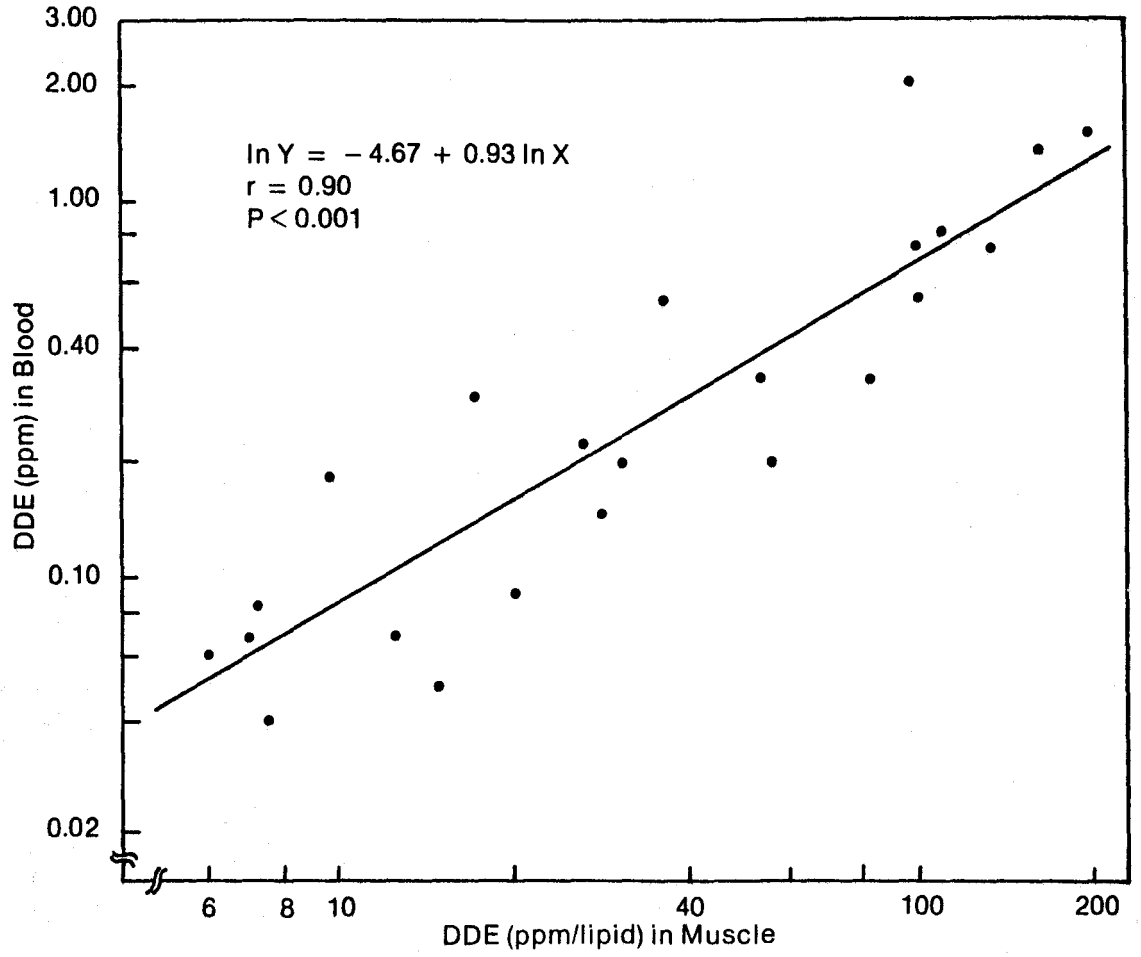


Figure 10. The relationship of DDE in blood serum and breast muscle from white-faced ibises collected in northern Utah, 1974.

Table 17. DDE residues in blood sera, subcutaneous fat, and breast muscle from adult white-faced ibises collected in northern Utah, 1974 and 1975.

Sample	Dates of collection			
	May 1974	July 1974	Aug 1974	June 1975
Blood sera (DDE,ppm)				
Geometric mean	0.201	0.405	0.206	0.113
95% conf. int.	0.109-0.369	0.258-0.635	0.070-0.603	0.066-0.194
Range	0.04-2.0	0.05-1.7	0.06-1.5	0.02-2.5
Sample size	14	20	7	20
Subcutaneous fat (DDE, ppm/lipid)				
Geometric mean	26.7	37.9	6.9	20.1
95% conf. int.	15.7-45.4	12.2-117	5.15-9.22	13.0-31.2
Range	5.5-110	17-98	5.2-8.5	5.2-110
Sample size	14	4	4	20
Breast muscle (DDE, ppm/lipid)				
Geometric mean	28.6	65.6	19.8	--
95% conf. int.	13.7-59.8	32.1-134	6.05-64.8	--
Range	7.7-100	15-160	6.1-190	--
Sample size	8	8	7	

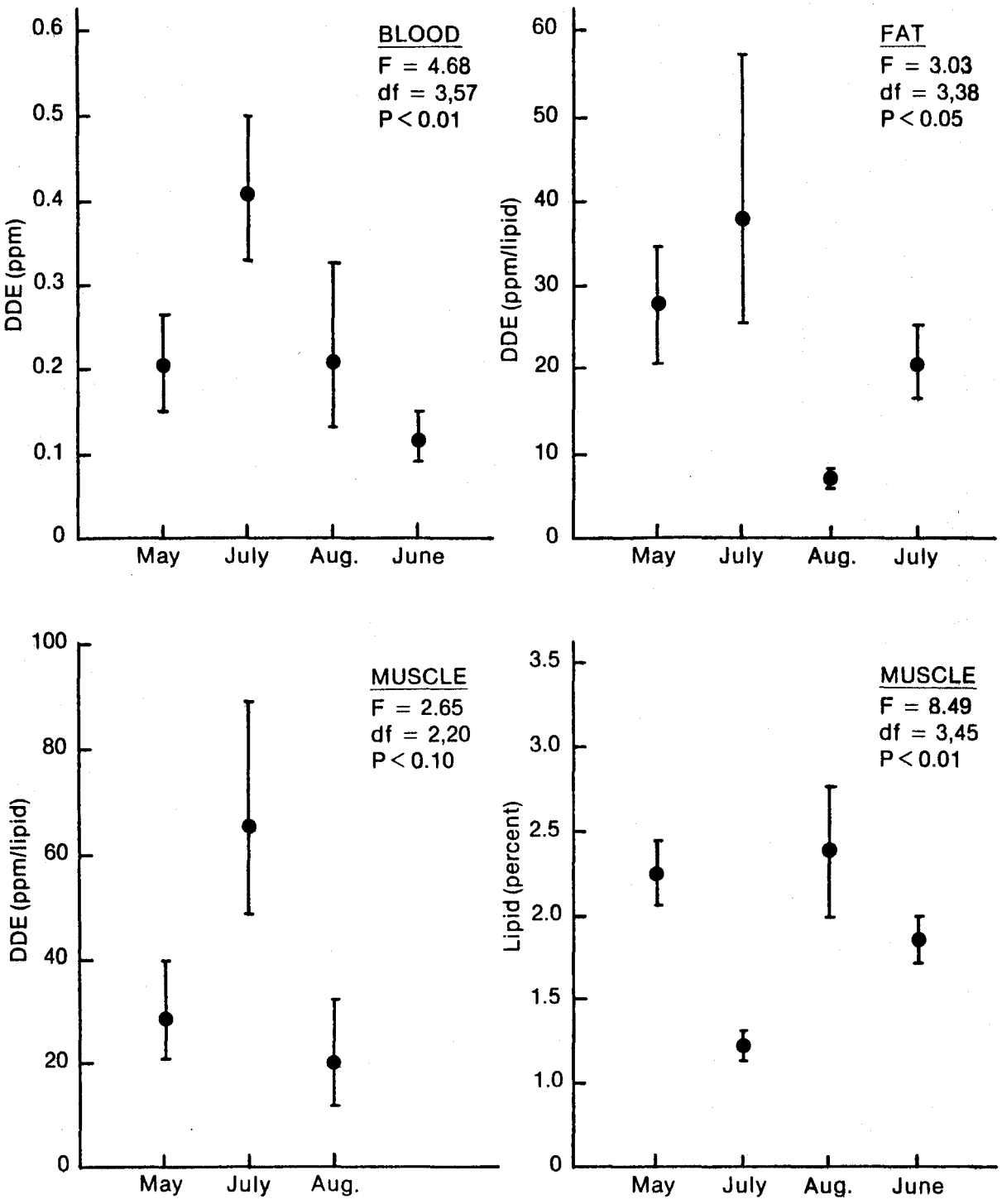


Figure 11. Comparisons of DDE residues in blood, fat, and muscle, and lipid content of muscle in white-faced ibises collected in northern Utah during May, July, August 1974, and June 1975. Solid circles represent geometric (a,b,c) and arithmetic means (d); vertical lines indicate standards errors.

Saschenbrecker (1969). The latter authors documented a similar response for DDT in breast muscle, as did Findlay and deFreitas (1971) in pigeons which were stressed by starvation and cold temperatures.

DDE in subcutaneous fat was less in the ibises collected in August than in those collected in May and June (Fig. 11b). Although only four birds with fat were sampled in August, all had low levels of DDE in the adipose tissue. These data suggest that body burdens of DDE were reduced as a result of a 3-month cycle of lipid mobilization and storage. This phenomenon was demonstrated in the laboratory by Wesley et al. (1969) and with wild birds by Harvey (1967).

Concurrent with the loss of fat between May and July, and the increase of DDE in blood and breast muscle, the lipid content of the breast muscle decreased significantly (Fig. 11d). When compared with the data presented by Ecobichon and Saschenbrecker (1969) and Findlay and deFreitas (1971), this decrease in breast muscle lipids suggests that the ibises utilized 70 percent or more of their fat stores.

I examined the correlation between DDE levels in blood and lipid content of breast muscle, because the data (Fig. 11) suggested that lipids in breast muscle reflected changes in total body lipids. When data from all sampling periods were combined, a significant, but weak, correlation existed ($r=-0.49, df=47, P<0.001$). If only the data from May and June were analyzed, no significant correlation was found ($r=-0.02, df=26, P>0.40$, Fig. 12a); these data represented ibises which were fat. However, when only July data, from ibises with little subcutaneous fat and low lipids in breast muscle, were analyzed, a strong correlation existed ($r=-0.93, df=12, P<0.001$, Fig. 12b). These analyses support the hypothesis that the elevated levels of DDE in

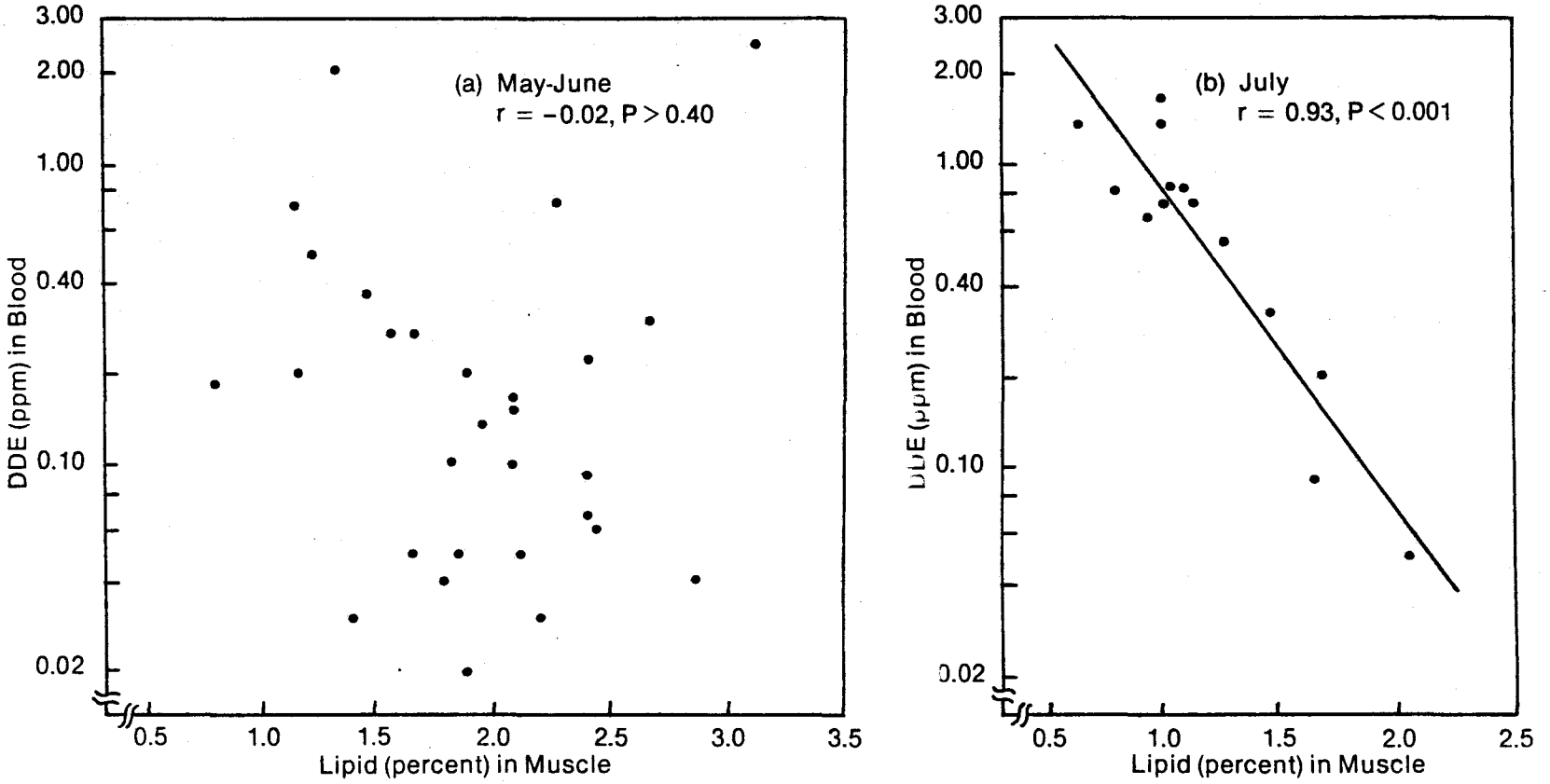


Figure 12. The relationship of DDE in blood serum and the lipid content of breast muscle from white-faced ibises collected in northern Utah in (a) May 1974 and June 1975, and (b) July 1974.

blood and breast muscle for the July samples resulted from lipid mobilization.

Differences between sexes. Males apparently utilized a greater proportion of their fat stores than did females during the interval between incubation (May-June samples) and when the young fledged (July-August samples). In Table 18, the differences by sex between DDE residues and lipid content of muscle are summarized for both early-season and late-season samples. Males showed higher levels of DDE in the blood and lower lipid content of the breast muscle for the combined July-August samples than did females. The differences by sex for these same variables were not found to be significant in the combined May-June samples. No significant differences were found between sexes for DDE residues in fat and breast muscle for either the early or late-season samples.

Variability and sampling

Blood samples of white-faced ibises appear to be suitable for assessing changes in body burdens of DDE, because DDE residues in blood may be used to predict DDE levels in subcutaneous fat and breast muscle. Before collecting blood to detect differences in DDE residues, however, the variability of the residue data should be considered. Variation in blood DDE levels is related to both seasonal differences, due to lipid mobilization, and differences by sex. Intuitively, the most efficient sampling scheme would be to eliminate these sources of variation. Hence it would be best to sample at the same chronological state, e.g., during incubation, or at least at times when body fat deposits are stable. Additional variation might be

Table 18. DDE residues and breast muscle lipid content: differences between sexes of white-faced ibises collected in northern Utah, 1974 and 1975.

Variables	May-June samples n	May-June samples mean[a]	May-June samples t-test	July-August samples n	July-August samples mean	July-August samples t-test
Blood sera (DDE, ppm)						
Male	13	0.102	t=-1.39,P>0.10	16	0.515	t= 2.79,P<0.02
Female	21	0.177		11	0.186	
Lipid in breast muscle (%)						
Male	11	1.87	t=-0.70,P>0.10	15	1.30	t=-2.70,P<0.02
Female	17	2.01		6	2.30	
Subcutaneous fat (DDE, ppm/lipid)						
Male	13	20.7	t=-0.42,P>0.10	3	20.5	t= 0.46,P>0.10
Female	21	23.9		5	14.0	
Breast muscle (DDE, ppm/lipid)						
Male	2	28.4	t=-0.01,P>0.10	9	54.7	t= 1.52,P>0.10
Female	6	28.7		6	21.3	

[a]Means are geometric for residue data, arithmetic for lipid content.

eliminated by only sampling individuals of one sex, or by sampling both sexes and partitioning the variance to account for differences by sex.

I attempted to estimate the number of blood samples necessary to show whether DDE residues in incubating ibises changed from one season to the next. The formula for estimating sample sizes (Sokal and Rohlf 1969) is sensitive to the estimate of the mean and the difference from the mean that one wishes to detect. With these data for DDE residues, it was not clear how much difference in the mean represented a biologically significant change, although a two-fold or greater change in the mean was not unreasonable (Table 17). Nevertheless, I could not objectively estimate sample size using the formula. The previous mean comparison tests (Fig. 11), however, indicated that 25 to 50 blood serum samples will provide adequate data to test hypotheses concerning changes in DDE residues.

CONCLUSIONS AND RECOMMENDATIONS

The white-faced ibises which nest in northern Utah probably represent the most important breeding population of the species in North America, yet the size of the population has declined during the past two decades (Ryder 1967). Other nesting populations of this species in the western United States have also declined, and some may no longer exist. Loss of habitat may have contributed to the reduction of many nesting colonies, but wetland habitat in northern Utah has been preserved and improved in recent decades. The use of DDT in Utah may have contributed to the decline of white-faced ibises in the Bear River delta.

Pesticide Relationships

Numerous agricultural pesticides have been used in Box Elder County, Utah, because most farms are small, family-operated enterprises, and a variety of crops is cultivated. The most widespread use of pesticides in the county, however, has been for mosquito and fly control. The Mosquito and Fly Abatement Commission used DDT regularly through 1970, and was the last county in Utah to officially suspend the use of this chemical. Mosquito and fly abatement was still active in Box Elder County in 1976, but all insecticides used were phosphorous compounds (L. Nielsen, pers. comm.). The Bear River Migratory Bird Refuge and the Bear River Club prohibited the use of pesticides, but chemicals were sprayed in and around Knudson's marsh. Irrigation canals and areas of shallow water also were sprayed fre-

quently with insecticides.

The conclusion that the white-faced ibis is one of the most sensitive species to adverse effects of DDE is interesting because other avian species which are notably sensitive to DDE are predators which feed on fish and other birds. Although the ibis may not be subject to as much biological concentration of pesticides (Woodwell et al. 1967) as higher-order predators, the feeding habits of the species bring it into direct contact with pesticides. Hazards of pesticide contamination are increased because the birds feed in irrigated croplands and because persistent pesticides concentrate in soil invertebrates (Thompson 1973), the common food of the ibises.

By 1974, four nesting seasons after the last routine use of DDT in Box Elder County, eggshell thickness and the condition of eggshells appeared normal. This response to an apparent decrease of persistent DDE residues in the environment was surprisingly rapid. Anderson et al. (1975) reported a similar response during the same years in brown pelicans and the bird's principal food source, northern anchovies (Engraulis mordax).

The significant decrease in eggshell thickness and poor condition of eggshells in 1975 and 1976 was not expected and appeared unrelated to pesticide use in northern Utah. It seems reasonable to assume that the white-faced ibis is being exposed to pesticides in Mexico, where the use of DDT is not prohibited, but it is not clear why exposure to this pesticide may have increased since 1974. One possible reason, of course, might be an increased use of DDT in Mexico; another possibility could be that ibises have wintered recently in areas where DDT is used more extensively.

Population Movements

Speculation on the possible source of DDE contamination is limited by an inadequate understanding of the composition and movements of white-faced ibis populations. The fact that I observed so few banded and color-marked ibises during the nesting season suggests some problems in interpreting population movements. Assuming that bands were not lost and that I was able to properly identify a bird as either banded or not, the small number of observed banded ibises suggest (a) an inconceivably high mortality of banded birds, (b) that most white-faced ibises do not breed until 4 years old, (c) that there is an extremely large population of white-faced ibises in North America, or (d) that ibises do not return to natal marshes to nest. None of these suggestions seems plausible when only information on white-faced ibis populations in the western United States is considered. If white-faced ibises do not breed until 4 years old, there would be larger populations of non-breeding birds. Such concentrations do not occur in areas where ibises nest, nor are they found in other areas of the West (R. A. Ryder, pers. comm.). It is possible that large populations may remain in Mexico during the nesting season, but this is not thought to occur (R. A. Ryder, pers. comm.), and there are no band recoveries from Mexico during summer months.

A better understanding of the segregation and movements of white-faced ibis populations would aid studies of nesting ecology as well as pesticide investigations. For example, I cannot explain why ibises nested in one large colony in 1974, but five colonies in 1976, which were initiated at different times. Did these different groups of birds winter and migrate together, or segregate on the breeding areas?

Such segregation may indeed be related to pesticides. Delayed breeding in birds has been attributed to pesticides (Jefferies 1967). Knopf and Street (1974) reported that DDE residues in eggs of white pelicans (Pelecanus erythrorhynchos) in Utah changed significantly between early and late-nesting groups of birds. I presented evidence that later-nesting white-faced ibises produced more thin-shelled eggs. This phenomenon for either species may be due to delayed breeding caused by pesticides, or to a temporal separation of different groups of birds which may have allowed later-nesting individuals to accumulate higher levels of pesticides, as suggested by Knopf and Street (1974).

Research Recommendations

A large-scale banding and color-marking effort coordinated with seasonal surveys of white-faced ibis populations in Mexico is recommended. If most ibises leave Mexico to nest in the United States, as is thought, this should be documented. Large populations of non-breeding ibises should be located if they exist. The extent of exposure of white-faced ibises to pesticides in Mexico should also be investigated, and the reproductive success of the ibis in northern Utah, as it relates to pesticides, merits further evaluation.

Management Recommendations

The white-faced ibis should be given careful consideration when formulating and implementing management plans for marsh areas where this species may nest. In several instances, in the Bear River marshes and marshes of the Carson Lake area of Nevada (L. C. Howard, pers. comm.), nesting populations of white-faced ibises have apparent-

ly been displaced when water levels were low early in the nesting season. The extensive Bear River marshes provide alternate locations for nesting, but this is not the case in the Carson Lake marshes where ibises displaced by poor habitat conditions may fail to nest successfully.

The white-faced ibis has undoubtedly benefited from regulations restricting the use of DDT and other persistent organochlorine insecticides in the United States. Similar regulations may be necessary in Mexico, however, before the species consistently lays normal eggs. Special permits for use of persistent pesticides in the United States are still available; the location of white-faced ibis populations should influence decisions to issue such permits.

SUMMARY

In the late 1960's, there was concern that white-faced ibises nesting in northern Utah were being adversely affected by organochlorine insecticides. My study was conducted in the Bear River marshes of Utah from 1973-1976 to assess the impact of pesticides on the white-faced ibis. Objectives of the research were (a) to evaluate selected parameters of the reproductive biology of the white-faced ibis as potential indicators of the effects of pesticides on the species; (b) to determine the relationship between pesticides and the reproductive success of the white-faced ibis; and (c) to sample organochlorine residues in tissues of white-faced ibises and determine the feasibility of estimating annual or seasonal changes in body burdens of pesticides in the ibises. Findings of this study, which included information from previous investigations, 1968-1971, are summarized as follows:

1. The total estimated number of nesting pairs of white-faced ibises in the marshes of the Bear River delta ranged from a low of 450 to a maximum of 3100 from 1968-1976.

2. The biotic potential of the white-faced ibis is moderately low. Evidence indicated that the species does not breed until at least 2 years old. The ibises usually laid either three or four eggs in a clutch, and did not renest very successfully if the first clutch was destroyed. Major mortality factors of nestlings appeared to be

competition for food, exposure to severe weather, and predation.

3. Five reproductive parameters of the white-faced ibis were evaluated as potential indicators of the effects of pesticides: eggshell thickness, eggshell condition, clutch size, hatching success, and fledging success. Only two, eggshell thickness, and clutch size, could be estimated suitably and with adequate precision.

4. During the nesting season, white-faced ibises most commonly fed in irrigated farmland. Insect larvae and earthworms were the most frequent food items.

5. Band recoveries indicated that white-faced ibises produced in Utah migrated to Mexico for the winter.

6. Means of shell thickness of white-faced ibis eggs collected in northern Utah from 1968-1976 were compared to the mean shell thickness of 374 eggs collected before 1945 and preserved in museums. Eggshells collected in five of six years were significantly thinner than museum eggshells.

7. During four of six nesting seasons, cracked or broken eggs were found in over 20 percent of nests surveyed. A high incidence of cracked eggs was associated with less than a 10 percent decrease in eggshell thickness.

8. DDE was the only chemical residue consistently detected in eggs of the white-faced ibis. A negative relationship of ln DDE residues and eggshell thickness was found. This relationship was similar to those of falcons and pelicans which are notably sensitive to DDE.

9. Eggs which failed to hatch because of broken shells probably represented a substantial loss in recruitment to the population of white-faced ibises.

10. Samples of blood serum, breast muscle, and subcutaneous fat were analyzed for DDE residues. The logarithm of DDE in blood serum was positively correlated with ln DDE in fat and with ln DDE in muscle.

11. Blood samples of white-faced ibises appeared to be suitable for assessing changes in body burdens of DDE. However, changes in blood DDE levels were related to lipid mobilization which varied by season and between sexes.

12. DDT was last used routinely in northern Utah in 1971, and by 1974 white-faced ibises were laying eggs which appeared normal. In 1975 and 1976, however, thin-shelled and broken eggs were prevalent. I concluded that pesticide use in northern Utah was not related to the most recent problems of thin eggshells, but that white-faced ibises were probably being exposed to pesticides in Mexico during the winter.

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APPENDIXES

Appendix A

Band recoveries and sightings of white-faced ibises banded or color-marked as nestlings in the Bear River marshes, 1968-1975.

Band number or color-mark	Date banded or marked	Date recovered or sighted	Location of recovery or sighting
		Direct recoveries	
826-10851	06-06-73	02-74	Guanajuanto
10748	06-06-73	01-74*	Jalisco
10953	06-11-73	01-74*	Durango
15506	06-12-73	01-74	Guerrero
15522	06-12-73	01-74	Michoacan
15729	06-15-73	12-73	Nayarit
15794	06-15-73	01-74	Michoacan
15861	06-15-73	03-74	Sinaloa
15927	06-19-73	01-74	Guerrero
16050	06-19-73	11-73	Guanajuanto
16000	06-19-73	02-74	Guanajuanto
16025	06-19-73	04-74*	Jalisco
16115	06-20-73	04-74	Arizona
16161	06-20-73	12-73	Sinaloa
16094	06-20-73	12-73	Michoacan
16285	05-26-74	03-75*	Sinaloa
16480	05-28-74	03-75	Sinaloa
16581	05-28-74	12-74*	Guerrero
16525	05-28-74	11-74*	Jalisco
16702	05-28-74	02-75	Sinaloa
16500	05-28-74	01-75	California
16628	05-28-74	04-75	Guanajuanto
16804	05-29-74	02-75	Jalisco
16990	05-31-74	12-74	Jalisco
16988	05-31-74	11-74	Michoacan
16941	05-31-74	10-74	Michoacan
16915	05-31-74	01-75*	Michoacan
99692	06-01-74	10-74	Sinaloa
99800	06-06-74	12-74	Sinaloa
99789	06-06-74	05-75*	Guerrero
99923	06-11-74	04-75	Michoacan
55606	06-16-75	10-75	Nayarit
55636	06-23-75	12-75*	Michoacan

Appendix A (continued)

Band number or color-mark	Date banded or marked	Date recovered or sighted	Location of recovery or sighting
		Indirect recoveries	
646-16533	06-26-68	05-74*	Nayarit
826-15678	06-12-73	09-74*	Guanajuanto
15782	06-15-73	01-75*	Guerrero
16142	06-20-73	02-75	Nayarit
15675	06-12-73	12-75	Jalisco
		Sightings	
Yellow wing-tag	06-26-73[a]	09-73	California
Yellow leg-band	06- -73[a]	08-74	New Mexico
Yellow leg-band	06- -74	08-76	Colorado

[a]May have been banded 06-74, but unlikely. Observer did not record which leg the color-band was on.

*Month of recovery is uncertain; dates indicate postmarks of letters reporting the band recoveries.

Appendix B

Estimation of weight loss from white-faced ibis eggs during incubation

Variable	Fresh eggs	Incubated eggs (19-20 days)
Sample size	36	36
Egg volume (ml) mean ± SE	35.1 ± 0.48	34.9 ± 0.39
Egg weight (g) (less shell weight) mean ± SE	33.64 ± 0.46	30.18 ± 0.44
Weight:volume ratio mean ± SE	0.958 ± 0.004	0.864 ± 0.008
Difference between weight:volume ratios	0.094 (9.8%)	
Significance	t=10.7,df=70,P<0.01	

VITA

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