STUDIES OF THE BROWN PELICAN

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I. STATUS OF BROWN PELICAN POPULATIONS IN THE UNITED STATES.

THE American Ornithologists' Union Check-list of North American Birds (1957: 29) records the following distribution for *Pelecanus occidentalis*, the Brown Pelican:

> "From southern British Columbia south along the Pacific coast to Chiloe Island, southern Chile, casually to Tierra del Fuego, including the Pearl Islands, in the Gulf of Panama, and the Galapagos Islands, and from North Carolina and the Gulf coast of the United States southward through the West Indies including the Netherlands West Indies, to British Guiana, casually to extreme northern Brasil."

Since the mid-1950's the Brown Pelican population has declined in much of its northern range. In Louisiana no pelicans bred between 1961 and 1970; in 1971 several semi-captive birds introduced from Florida to Grand Terre Island, Louisiana nested there successfully (Evenden, 1968, 1969; Joanen and Neal, 1971). In Texas the breeding population is reduced to a few pairs (H. Hildebrand, in litt.); in California and northwestern Baja California, Mexico, a sizable population persists but breeding has been largely unsuccessful since 1968 (Schreiber and DeLong, 1969; Jehl, 1969; Gress, 1970; Risebrough, Sibley, and Kirven, 1971).

This paper briefly discusses the past and present status of the Brown Pelican in the United States. It must be emphasized that there are few data concerning the status of the species throughout the country at any time in this century. Documentation of population declines is therefore difficult. The available information, however, provides a useful background for interpretation of the present status of the species and for formulation of a conservation policy.

There is now considerable evidence linking reproductive failures of fish-eating birds to chemical pollutants in the environment. As yet no monitoring programs have been devised to measure the rates of accumulation of the known persistent pollutants in coastal waters, or to determine whether steady state concentrations have been established, with input from all sources balanced by degradation and deposition in sediments. Continued accumulation would clearly pose a threat to the remaining populations of Brown Pelicans; moreover, the long term effects of current levels of pollution are unknown.

NORTH CAROLINA

In North Carolina the first nesting record of Brown Pelicans was in 1929, when Birsch found 14 pairs breeding on Royal Shoal (Wray and Davis, 1959). Wind and tide destroyed the shoal the next year and North Carolina nesting was not reported again until 1947 when Wolff found 30 nests and 33 young on Shell Castle Island, Ocracoke Inlet (Wray and Davis, op. cit.). This is the northernmost breeding record for the Brown Pelican on the East coast. The maximum number of young recorded at Shell Castle Island was in 1959, when H. T. Davis banded 116 nestlings. Between 1960 and 1967 the number of young banded fluctuated between 11 in 1966 and 100 in 1965 (Davis, pers. comm.). No detailed observations were made in 1968 and 1969, but R. H. Steiner visited the island in July 1970 and counted 31 nestlings and 9 nests with eggs (Steiner, in litt.). No young remained on the island on 19 August and fewer than 30 young may have fledged in 1970 (Steiner, in litt.).

SOUTH CAROLINA

In South Carolina, there are few data and those available are in need of close scrutiny. Apparently, three colonies have existed in recent years. In the 1940's, a small colony was present on Egg Bank, Beaufort County (Mason, 1945); the other colonies are in the Cape Romain National Wildlife Refuge and on Deveaux Bank south of Charleston.

At the Cape Romain National Wildlife Refuge information on Brown Pelicans has varied with the assigned priorities and individual interests of refuge managers. The available data are therefore not sufficient to determine population trends. Mr. Travis McDanial, Refuge Manager at Cape Romain NWR from 1968 through 1970, has kindly provided us with the following information: since the establishment of the refuge in 1932 the pelican colony has been on at least five different islands, including Bird Bank, Bulls Bay, noted as an egg collection site in Anderson and Hickey (1970: 26). Exact numbers are not available, but distinct yearly fluctuations in productivity are indicated. In 1949 to 1953, 500 to 900 young fledged each year. In 1954–56 only 250 to 500 young fledged per year. In 1957–60 the breeding population increased and from 1,200 to 1,500 young fledged each year. The estimated population remained stable in 1961 but productivity was higher and 1,800 young fledged. In 1962 the population declined and only 500 young fledged that year and in 1963. In 1964, 800 young fledged; production reached its highest level on record in 1965 when 2,000 young fledged. Approximately 500 young fledged in 1966 and 1967.

Accurate records are available for 1968–70. McDanial estimated that 500 young fledged in 1968. In April 1969 he counted 1,016 nests. After periodic visits to the colony through the summer he estimated that 900 young fledged.

In May 1970, McDanial counted 627 nests and estimated that 500 to 600 young fledged (McDanial, pers. comm.). Although total production was lower in 1970 than in 1969, it is essentially the same as that reported for 1962–1964 and 1966–1968. Since historical population fluctuations are apparent at Cape Romain, it would seem worthwhile documenting future population trends in detail.

On the Deveaux Bank, T. A. Beckett III believes that the breeding population has undergone an apparent 90 per cent decline in the last decade. Beckett (1966: 94) reported 5,000 breeding pairs in unspecified "former years" and in the early 1960's 7,000 to 10,000 young fledged per year (1966: 99). In 1964 Beckett (op. cit.) noted high nestling mortality and in 1965 estimated only 600 breeding pairs. In 1970 Beckett counted 485 nests (in litt.). The reasons for the decline are not documented but Beckett notes (pers. comm.) that almost three-fourths of the Deveaux Bank has washed away in the last 10 years.

GEORGIA

Although in 1898 T. D. Perry collected pelican eggs "on beach" in Chatham Co., Georgia, Burleigh (1958) states that Brown Pelicans are not known to have nested in the state. Explanation of this apparent discrepancy at this time is impossible.

GULF STATES

In 1918 T. Gilbert Pearson (1918) estimated the adult pelican population between Corpus Christi, Texas and Key West, Florida as 65,000 birds. This same region in 1971 has fewer than 5,500 nests and probably not more than 12,000 birds (Hildebrand, in litt.; Joanen and Neal, 1971; Fogarty, in litt.).

In Alabama, Imhoff (1962) noted that Brown Pelicans possibly bred prior to 1900 but none have done so there since. He listed the species as "abundant throughout the year" but notes that in 1956–57 the local non-breeding population declined sharply. No recovery has occurred to date (Imhoff, pers. comm.).

LOUISIANA

The state bird of Louisiana is the Brown Pelican, yet no wild birds have bred there since 1961. Bailey and Wright (1931) indicate that thousands of birds nested on the mud lump islands at the mouth of the Mississippi River and in 1918 Bailey (in Bailey and Wright, op. cit.) estimated 1,200 pairs nesting on Grand Gosier Island. Oberholser (1938) listed Brown Pelicans as an abundant permanent resident in Louisiana, and during a survey of the coast in June 1933 estimated at least 5,500 nests with young and a population of at least 14,000 adults. He found no breeding on Grand Gosier Island in 1933

(p. 35). McIhenny (1943) did not mention Brown Pelicans in a paper on major changes in the bird life of southern Louisiana. Lowery (1960) makes no mention of a decrease in numbers of pelicans in the state and notes that he "once" found approximately 5,000 adults with eggs and young on East Timbalier Island (p. 113), where Oberholser found none in 1933. These shifts of breeding locations exemplify the problems encountered in documenting an historical account of pelican nesting populations.

Brown Pelicans were not mentioned in the nesting season reports from the Central Southern Region of *Audubon Field Notes* between 1950 and 1955. However, in 1956 several observers noted large numbers of dead adults washed up on beaches and Imhoff believed a severe mid-June storm may have caused high mortality among young birds in the large colony on North Island of the Chandeleurs (Newman, 1956). On 27 June 1957, Hurricane Audrey had disastrous effects on many nesting species of birds in Louisiana, but no mention was made of Brown Pelicans (Newman, 1957). In 1957–1958 wintering Brown Pelicans were "alarmingly" scarce along the entire northern Gulf, and were entirely absent in many areas (Newman, 1958*a*). On 7 July 1958 "thousands" of adults and young of all ages were present on North Island (Newman, 1958*b*). Again, few birds were seen during the fall and winter, and the first speculation as to what happened to the species appeared in *Audubon Field Notes* (Newman, 1959*a*, 1959*b*). Between 1956 and 1960 the total coastal Christmas Bird Count estimates of Brown Pelicans decreased from 995 to 366, to 41, to 14, to four individuals. On North Island in 1960 only about 200 pairs were reported nesting (Imhoff, 1960). On 21 June 1961, van Tets (1965; in litt.) observed ca. 200 pairs and 100 chicks with white down and developing primaries on North Island. In June 1962 no nests were present on the island and during a survey of the area only six adults were observed (Stewart, 1962).

A propagation program was begun in the state in 1968 and over 170 nestlings were imported from Florida during 1968, 1969, and 1970. In March 1971 some of the 1968 imports nested on a shell island in Barataria Bay near Grand Terre (Joanen and Neal, 1971). Few wild pelicans occur elsewhere in Louisiana or the northern Gulf region.

TEXAS

In Texas fewer than ten pairs of Brown Pelicans nested in 1969 or 1970 (Hildebrand, in litt.). Pearson (1921) estimated the total Texas Brown Pelican population at approximately 5,000 birds. Little information is available about the dramatic decline in nesting, but reports in *Audubon Field Notes* for the South Texas Region between 1950 and 1963 reveal some interesting observations. "Brown Pelicans that had a somewhat-below-normal nesting season last year had a repeat this year with hundreds of adults having been killed by the freeze" of 29 January–3 February, 1951 (Goldman, 1951). In 1952 "Brown Pelicans which decreased in numbers at the time of the freeze early in 1951, had a much improved season this year" (Goldman and Watson, 1952). Between 1953 and 1959 pelicans are not mentioned, but in 1960 pelicans "made a comeback at Galveston" (Webster, 1960). This last comment apparently refers to the effects of Hurricane Audrey in June 1957, or to other unidentified factors. For 1961 and 1962 no mention appears of Brown Pelicans, but in 1963 only 18 young were produced in Texas (Webster, 1963).

In 1967 four pairs are known to have produced four young in Corpus Christi Bay and Hildebrand believes a few pairs bred in Texas each year from 1964–1966 as well (Hildebrand, in litt.). In 1968, four young fledged from two nests on Carroll Island in the Second-chain of Islands. In 1969 the only observed nesting was reported on an unnamed spoil island on Long Reef in Aransas Bay, five nests produced seven young (Hildebrand, in litt.).

In 1970 Emily Payne recorded observations on the few remaining pelicans in Texas and Hildebrand supplied the following information (in litt.): one or two birds overwintered along the coast and numbers increased in March to a peak in mid-June of 105 Brown Pelicans concentrating in Corpus Christi Bay. Only eight "subadults" were seen. Three pairs and at least ten eggs were noted on Carroll Island but the birds abandoned the site between 3 April and the end of the month. The cause of the desertion was apparently not human molestation. Several pairs nested in May on "Pelican Island" in Corpus Christi Bay (the same island used in 1969) and in early July four nests contained 9 healthy young.

The status of the Brown Pelican in eastern Mexico, the Caribbean, or Central America, past or present, is essentially unrecorded. Pelicans are reported to have nested and apparently still nest in scattered colonies in the Mexican states of Veracruz, Yucatan, and Quintana Roo; nesting also occurs in Panama, British Honduras, Colombia, Venezuela, Trinidad, Tobago, the Lesser and Greater Antilles, and the Bahamas (A.O.U., 1957; Murphy, 1936; Wetmore, 1945, 1965; Hildebrand, pers. comm.). Probably none of the colonies contain more than a few hundred pairs. The precise locations of most colonies is unknown and the ranges of the subspecies are uncertain (Palmer, 1962; Voous, 1957). The need for more information on the Brown Pelicans in these areas is obvious.

CALIFORNIA

Historic breeding records for Brown Pelicans in California were summarized by Schreiber and DeLong (1969) who noted that no nesting occurred in the state in 1968, except on Anacapa Island, where sites active in early April had been abandoned by mid-May. In the early 1900's, colonies of up to a few hundred pairs existed in at least five locations and several thousand pairs were present on Los Coronados, Baja California, Mexico, and on Anacapa Island. In 1958, large numbers were still present on Los Coronados. On Anacapa in 1964 perhaps 1,000 pairs bred successfully. In 1969 Anacapa was visited by Risebrough et al. (1971) who summarized the nesting attempts for the summer and noted that a minimum of 1,272 nests were built, more than 75 per cent received eggs, and no more than four young fledged. Gress (1970) working on Anacapa Island in 1970 found from over 500 nests constructed, only one young fledged. Schreiber and Gress (unpubl. observ.) noted aberrant nesting behavior in the Anacapa pelicans in 1970 and Risebrough et al. (in prep.) present data on shell thickness and chemical residue analyses.

The status of the Brown Pelican in the Gulf of California of western Mexico is poorly understood but the Section of Pesticide-Wildlife Ecology, Bureau of Sport Fisheries and Wildlife, Denver, Colorado is presently carrying on extensive investigations of the biology of the pelicans in the Gulf. Information on the pelicans in Peru is available but is beyond the scope of this discussion.

FLORIDA

In Florida the available historical information on the Brown Pelican status was summarized by Howell (1932). Little accurate information on the total population is available, but the species has been abundant in the state since the first bird observations were recorded. Williams and Martin (1968; 1970) present data based on aerial surveys and visits to colonies in 1968, 1969, and 1970 indicating that the Florida breeding population has remained essentially stable with 6,705, 6,133, and 7,690 nests counted in those years respectively. The conclusion by Blus (1970) that the Florida east coast population was declining based on data supplied in 1969 by Williams (pers. comm. to Blus) appears to have been premature in light of the 1970 survey by Williams and Martin (1970).

II. STUDIES OF THE BROWN PELICAN IN FLORIDA.

In summarizing the available information on the natural history of Brown Pelicans, Palmer (1962) indicates the dearth of knowledge about their biology. One of us (R.W.S.) began a detailed study of Brown Pelicans in Florida in January 1969 with efforts being concentrated in the largest colony in the state, on Tarpon Key in Boca Ciega Bay, St. Petersburg, at the mouth of Tampa Bay.

The pelicans nest on Tarpon Key from two to 25 feet above the high tide

TABLE 1

BROWN PELICAN HATCHING SUCCESS, TARPON KEY, BOCA CIEGA BAY, ST. PETERSBURG, FLORIDA, 1969 AND 1970

		1969		1970	
		Nests checked weekly	Nests checked more frequently	Nests checked weekly	Nests checked more frequently
No. Nests Observed		13	63	25	37
Eggs Laid		37	142	64	77
Eggs/Nest		2.85	2.25	2.56	2.08
Eggs Hatched	no.	31	80	45	22
	%	84	56	70	29
Eggs Destroyed	no.	3	45	8	50
	%	8	32	13	65
Eggs Addled	no.	3	17	10	2
	%	8	12	16	3
Eggs Crushed	no.	0	0	1	3
	%			2	4

line in black mangrove (*Avicennia nitida*) primarily surrounding the central lagoon of the key. The colony is subdivided into distinct areas relatively isolated from each other and one "subcolony" could be surveyed without disturbing others. In 1969 13 nests were checked weekly and 63 nests were checked more frequently, as often as thrice weekly in March, April, and May.

In 1970, over 100 nests were selected for study. However, while Schreiber was on Anacapa Island in California during the last week of April, the colony was disturbed at least once. We are unable to explain otherwise the egg loss from certain areas of the colony and thus have limited analysis to 25 nests checked weekly and 37 nests checked more frequently from 19 March till mid-August. Nest building and laying began in early March and continued through mid-May in both years and nest checks began when the first nest was found. Most nests were found and marked before egg deposition began and were checked periodically thereafter.

CLUTCH SIZE

In 1969 the 13 nests checked only weekly contained slightly larger clutches than the 63 more frequently checked nests; in 1970, the same pattern emerged (Table 1). The lowered clutch size in the nests which were more frequently checked may reflect reduced laying by disturbed birds. On 30 April 1969 Schreiber surveyed 250 nests which had never been disturbed and counted 728 eggs and/or small nestlings, or 2.91 eggs per nest. A similar survey of 193 nests on 6 May 1970 showed 537 eggs and/or small nestlings, or 2.73

eggs per nest. Three eggs per clutch was the maximum found. Bent (1922: 297) states that three or often two eggs constitute a full clutch of the Brown Pelican. He also found four or five eggs in a set but believed these were from two different females. Anderson and Hickey (1970) analyzed 236 sets in oological collections and found the mean clutch size was 2.95 eggs.

HATCHING SUCCESS

Hatching success in both years was higher in nests checked less frequently (Table 1). Total hatching success was lower in 1970 than in 1969 (Table 1). In nests checked weekly, 84 and 70 per cent of the eggs laid hatched in 1969 and 1970 respectively. In nests checked more frequently, 56 and 29 per cent of the eggs laid hatched in 1969 and 1970 respectively.

Causes for failure to hatch were assigned to three categories: 1) "addled"—eggs remaining in nests after other eggs of the clutch had hatched. These either were infertile or contained a dead embryo. In 1969, 20 of 179 eggs laid (11 per cent) were addled; in 1970, 12 of 141 eggs laid (9 per cent) were found addled. 2) "destroyed"—eggs noted as laid but missing on subsequent nest checks. Some of these eggs were found broken below nests; others just disappeared between visits. In both years the more frequently disturbed nests suffered distinctly higher egg loss and many more eggs were destroyed in 1970 than in 1969 (Table 1). 3) "crushed"—eggs obviously thin shelled and crushed in the nest. In 1969, no crushed eggs were found among the 179 eggs laid in marked nests. During 1970, 4 (3 per cent) of 141 eggs laid in marked nests were crushed.

In both 1969 and 1970 the two major known causes of "destroyed" eggs were egg breakage by flushing adult pelicans and egg breakage by predators. Pelicans incubate with their totipalmate feet surrounding the clutch. When its flight distance is "trespassed" by a human intruder an incubating adult will flush and the force exerted to become airborne is often sufficient to break the egg shell. To avoid this cause of egg destruction, nesting pelicans must be approached slowly and in full view so they can step off the eggs before flying.

Fish Crow (*Corvus ossifragus*) predation was the most serious known cause of egg loss. When undisturbed, one partner of a pair of pelicans remains on the nest throughout incubation, and crows do not molest the nest. However, when disturbed, pelicans leave their nests and either circle overhead or land on the water nearby. During March, April, and May, as many as 50 Fish Crows spend the daylight hours on Tarpon Key. Frequently within seconds after pelicans were disturbed, crows would land on nests, peck holes in the eggs, and eat the contents.

Because of the high level of mortality in pelican colonies accompanying

TABLE 2
BROWN PELICAN EGGSHELL THICKNESS FROM FLORIDA IN 1969 AND 1970

Colony	Date	No.	Mean thickness ± 95% confidence limit range	Per cent change*
Tarpon Key				
Boca Ciega Bay				
St. Petersburg	1969	14	0.506 ± 0.022 (0.55–0.42)	9
	1970	21	0.509 ± 0.024 (0.58–0.39)	9
Hemp Key				
Charlotte Harbor	1970	20	0.518 ± 0.024 (0.61–0.43)	7
Hall Island				
Cocoa Beach	1970	22	0.501 ± 0.013 (0.56–0.46)	10
Rio Del Mar				
Vero Beach	1970	10	0.502 ± 0.018 (0.53–0.46)	10
All Florida		87	0.508 ± 0.009 (0.61–0.39)	9

* Pre-1943 Florida eggs: 0.557 ± 0.004 mm, n = 172 (Anderson and Hickey, 1970).

human visitation from accidental breakage of eggs, predation on eggs and young by other birds, temperature stress on eggs and naked nestlings (Bartholomew and Dawson, 1954; Schreiber, unpubl. observ.), and possible disruption of adult nesting behavior, we strongly recommend that human visits to pelican colonies be curtailed.

EGGSHELL THICKNESS AND CHEMICAL RESIDUE ANALYSES

In 1969 and 1970, R. W. S. collected eggs from four colonies in Florida for chlorinated hydrocarbon residue analyses. From Tarpon Key in 1969, 17 eggs were collected: one egg each from 11 three-egg clutches in April and May, one three-egg clutch on 15 April, and one three-egg clutch on 31 May. In 1970, 20 eggs from this colony were collected: one egg each from 20 three-egg clutches, two on 30 March, 16 on 5 April, and 2 on 19 April. Fifty-three eggs were collected from other colonies in 1970: ten from the Rio Mar Island colony in Vero Beach on 27 March; twenty from Hemp Key, Charlotte Harbor on 16 April; and two from the Fort Pierce colony and 18 from the Cocoa Beach Colony on 21 April. All these eggs were one of three in a clutch and almost all were fresh or in early stages of incubation.

To prevent contamination, eggs were wrapped with aluminum foil in the

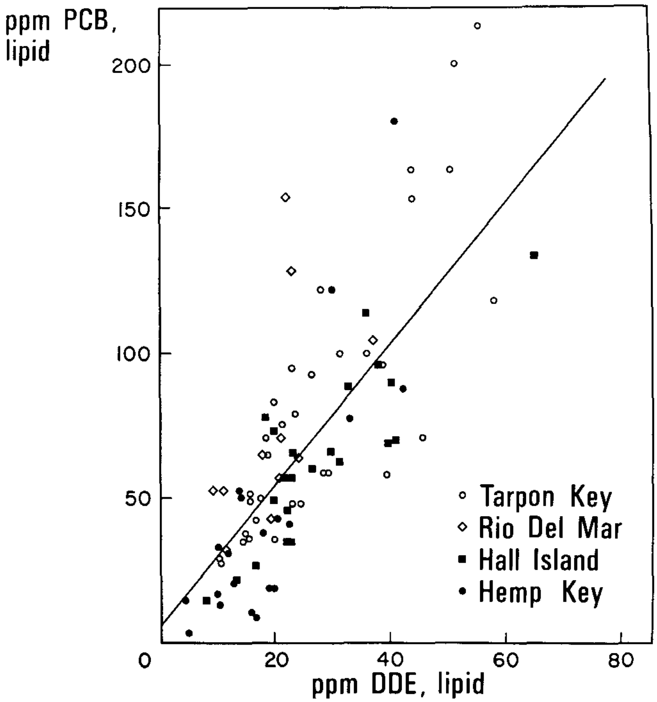

FIG. 1. Relationship between concentration of DDE and PCB in eggs of Florida Brown Pelicans obtained in 1969 and 1970 ($r = 0.701$, $p < 0.01$).

field and frozen within six hours after collection. Eggs remained frozen during air shipment to the Laboratory of the Institute of Marine Resources, University of California, Berkeley. The analytical techniques employed for measuring chlorinated hydrocarbons, including the polychlorinated biphenyls, have been described by Risebrough, Florant, and Berger (1970) and Risebrough (in press). Eggshells were measured by D. W. Anderson as described in Anderson and Hickey (1970).

Eggshell thickness.—No statistical differences were apparent between the thickness means for four colonies (Table 2). The 87 eggs collected in Florida in 1969 and 1970 averaged 9 per cent thinner than 172 eggs collected prior to 1943 (Anderson and Hickey, 1970). It must be pointed out that the thickness data presented for 1970 from the Tarpon Key colony, and undoubtedly from all colonies as well, represent a maximum thickness for the colony. Eggs were collected from three-egg clutches, which evidently had not lost eggs due to shell collapse. There is therefore a greater probability that one- and two-egg clutches, which were not sampled, have lost eggs due to excessive thinning.

TABLE 3

DDT COMPOUNDS AND POLYCHLORINATED BIPHENYLS IN BROWN PELICAN EGGS, FLORIDA 1969 AND 1970.

Concentrations in ppm of the yolk lipid and wet weight contents. Mean values with 95% confidence limits.

	Tarpon Key Boca Ciega Bay St. Petersburg 1969	1970	Hemp Key Charlotte Hbr. 1970	Hall Island Cocoa Beach 1970	Rio Del Mar Vero Beach 1970	All Florida
Number of eggs	14	21	20	22	10	87
p,p′-DDE lipid	37.2± 21.5	26.4± 12.0	18.3± 8.6	27.8± 12.3	20.6± 14.1	26.0± 5.6
p,p′-DDD lipid	12.8± 7.4	6.6± 3.0	4.5± 2.1	2.9± 1.3	4.0± 2.9	5.9± 1.3
p,p′-DDT lipid	6.0± 3.5	3.2± 1.5	1.1± 0.5	1.4± 0.6	1.0± 0.7	2.5± 0.5
Total DDT lipid	56.0± 32.3	36.2± 16.5	23.9± 11.2	32.1± 14.2	25.7± 18.4	34.3± 7.4
wet	2.90± 0.83	1.68± 0.38	1.19± 0.35	1.45± 0.24	1.42± 0.42	1.67± 0.22
PCB lipid	120.0± 69.3	68.9± 31.4	44.6± 20.9	63.8± 28.3	77.4± 55.4	71.2± 15.3
wet	6.21± 2.62	3.69± 0.38	2.20± 1.03	2.88± 0.53	4.20± 1.34	3.61± 1.99

Remaining eggs in those clutches were more likely thinner shelled than the average. On 16 May 1970 a shell-less egg composed of only membrane and albumen was found. None of the four thin shelled and crushed eggs found in the 62 nests on the Tarpon Key colony (see Table 1) were included in this analysis. These results regarding eggshell thinning are essentially the same as described by Blus (1970).

Chlorinated Hydrocarbon Residues.—Concentrations of the DDT compounds, p,p′-DDE, p,p′-DDD (TDE), and p,p′-DDT, and of the polychlorinated biphenyls (PCB) in the 87 Florida Brown Pelican eggs are presented in Table 3. Pollutant concentrations in eggs may be expressed as parts per million (ppm) of the wet weight, including the shell; as ppm of the wet weight of the contents (consisting of the yolk, albumen, and embryo); or as ppm of the yolk lipid. In Table 3 concentrations are expressed as both ppm of the wet contents and of the yolk lipid. In order to compare wet weight concentrations among eggs which may have lost moisture it is necessary to apply correction factors (Mulhern and Reichel, 1970). As wet weight of the contents was determined by subtracting the weight of the dried shell from the weight of the fresh egg measured at the time of collection, a correction factor was not necessary.

Chlorinated hydrocarbons are associated with the lipids in the yolk rather than with albumen or shell. The lipid content of the 87 Florida Brown Pelican eggs averages 4.4 g per egg or 5.0 per cent of the wet weight contents. The percentage of lipid in eggs of the White Pelican (*Pelecanus erythrorhynchos*) and the Double-crested Cormorant (*Phalacrocorax auritus*) are on the order of 4.2 and 4.4 per cent respectively (Anderson et al., 1969) and average 6.5 per cent in the egg contents of American Kestrels (*Falco sparverius*) (Wiemeyer and Porter, 1970). Fresh eggs of the Common Murre (*Uria aalge*) from California contained 13.7 per cent lipid (Gress et al., 1971). Concentrations of chlorinated hydrocarbons expressed on a wet weight basis only might appear to be higher in eggs of species such as the Common Murre, with greater amounts of lipid than in eggs of other species with lower amounts of lipid. Concentrations in tissue such as breast muscle and brain should always be expressed as ppm of both wet weight and lipid weight.

Yolk materials laid down in ova are derived from lipids and other components of the blood. Presumably chlorinated hydrocarbons codeposited with the yolk lipid are in physiological equilibrium with the chlorinated hydrocarbons associated with the blood lipids and these in turn are in physiological equilibrium with the chlorinated hydrocarbons at sites such as the membranes of the shell gland where the egg shell is deposited. Although many different physiological and biochemical factors can be expected to modify these relationships somewhat, the model appears to represent adequately the sequence of events in the deposition of chlorinated hydrocarbons in the egg. Therefore, we prefer to relate parameters such as eggshell changes to chlorinated hydrocarbon concentrations in the yolk lipid, rather than in whole yolk, albumen, or total egg contents.

In the Florida Brown Pelican eggs, as in most environmental samples, p,p′-DDE is the most abundant of the DDT compounds. PCB, a class of compounds with varying chlorine content, is about twice as abundant as the DDT compounds (Table 3). The eggs obtained in 1969 from Tarpon Key were also analyzed for dieldrin and endrin. Mean concentrations of dieldrin in yolk lipid was 4.17 ppm with a range from 8.1 to 0.38 ppm. Mean concentrations of endrin in the yolk lipid was 0.12 ppm with a range from 0.37 to 0.02 ppm.

DDT concentrations in Florida pelican eggs, with an arithmetic mean of

34 ppm in yolk lipid, are higher than those in pelican eggs from Jamaica ($\bar{x}$ = 5.5, n = 4), Panama ($\bar{x}$ = 11.7, n = 6), Venezuela ($\bar{x}$ = 1.0, n = 4) and Peru ($\bar{x}$ = 9.1, n = 5); but are much lower than in eggs of California Brown Pelicans. The arithmetic mean of DDT concentration in the yolk lipid of 65 eggs, the majority of them thin shelled and crushed, from Anacapa Island, California, was 1,223 ppm. The excessively high residues in California eggs are believed to derive from the effluent of a DDT manufacturing plant in Los Angeles (Risebrough et al., in prep.).

PCB concentrations are also higher in Florida than in the Caribbean and lower than in the coastal waters of California (Risebrough et al., in prep.).

There is a highly significant linear correlation ($r = 0.701$, $p < 0.01$) between the concentration of PCB and concentration of DDE in the yolk lipid of the Florida eggs (Figure 1). Thus, birds with high PCB also tend to have high DDE. A similar correlation exists between PCB and DDE in California Brown Pelicans but in the west coast ecosystems DDE is more abundant than is PCB. We interpret this to mean that these compounds move in similar ways through marine food chains. The sources of DDT compounds in Florida coastal waters include aerial fallout from global sources (Tarrant and Tatton, 1968; Risebrough et al., 1968), aerial fallout from local application, and local runoff in water. The relative importance of each source has not been determined. A study of the effects upon south Florida wildlife of the "eradication program" for the mosquito *Aedes aegypti* concluded that "there was little reason to suspect immediate and widespread damage to wildlife" from the DDT spraying. Although many songbirds were analyzed for DDT residues in this study, possible accumulation in marine food webs was not considered (Lehner et al., 1967).

Since several pollutants may occur together in environmental samples, it is frequently difficult to determine which is causing an effect such as a reduction in eggshell thickness. The correlation between DDE concentration and shell thinning of the Florida Brown Pelicans is highly significant ($r = -0.579$, $p < 0.01$). However, as PCB is also highly correlated with DDE, the correlation between thickness and PCB is also significant ($r = -0.499$, $p < 0.01$). Experimental studies have shown that DDE induces shell thinning in Mallard Ducks (*Anas platyrhynchos*) (Heath et al., 1969), American Kestrels (Wiemeyer and Porter, 1970), Japanese Quail (*Coturnix coturnix*) (Stickel and Rhodes, 1970), and Ring Doves (*Streptopelia risoria*) (Peakall, 1970), but PCB does not affect shell thickness in Mallard Ducks (Heath et al., in press), Bobwhite Quail (*Colinus virginianus*), and Ring Doves (Peakall, 1971). The relative contributions of the various pollutants to shell thinning in the Brown Pelican is further discussed by Risebrough et al. (in prep.).

Very low concentrations of DDE are correlated with significant thinning of eggshells of the Brown Pelican and the relationship is linear from zero concentrations of DDE (Risebrough et al., in prep.). Physiological mechanisms proposed to explain the effect of DDE on egg shell thickness must take this into account. Our data are inconsistent with the theory that inhibition of soluble carbonic anhydrase in the shell gland is responsible for shell thinning. In all systems examined thus far, carbonic anhydrase is present in excess of physiological needs (Dvorchik et al., 1971). Inhibition of a small fraction of the soluble enzyme by low concentrations of DDE would not be expected to produce a physiological effect, whereas our observations indicate that small amounts of DDE are associated with a reduction of shell thickness.

Our data are consistent with a theory that postulates inhibition of a finite number of sites in the shell gland membrane associated with transport of calcium ions or diffusion of bicarbonate ions. The enzyme inhibited could be an ATP-ase associated with calcium transport or a membrane-bound carbonic anhydrase (Risebrough, Davis, and Anderson, 1970).

Thinning of Brown Pelican eggshells below about 0.45 mm (20 per cent reduction) usually causes them to break during incubation (Risebrough et al., in prep.). The mean reduction of 9 per cent in the Florida eggs has not yet been observed to have an effect on population stability. Moreover, there is no clear evidence to indicate that thinning of this magnitude interferes with water retention or gas exchange. It may, however, increase the probability of accidental breakage. The data in Table 1 show that a substantial number of eggs are lost during incubation. Mysterious disappearance of eggs of the Peregrine Falcon (*Falco peregrinus*) (Ratcliffe, 1970) and of American Kestrels (Porter and Wiemeyer, 1969) coincided with shell thinning in those species. In evolutionary terms, any significant deviation from normality might be considered a selective disadvantage lowering the reproductive capacity and affecting the long term population stability. In areas such as California and perhaps also Louisiana and Texas where levels of environmental pollution are higher than in Florida, effects on Brown Pelican productivity have been both rapid and dramatic. The species, however, is long-lived and exhibits deferred maturity; effects on the reproductive capacity associated with the present level of shell thinning in Florida will not be evident for many years.

SUMMARY

This paper summarizes the historical status of the Brown Pelican in the United States through 1970; presents data on the effects of human disturbance on clutch size and hatching success for a colony on Tarpon Key, St. Petersburg, Florida in 1969 and 1970; and presents data on eggshell thickness and chlorinated hydrocarbon residues, including polychlorinated biphenyls, for 87 eggs collected from four colonies in Florida in 1969 and 1970. Methods of reporting pollutant residues are reviewed and the relationship

between PCB's and DDE in samples is noted. The significance of these levels of contamination and attendant eggshell thinning to the Florida Brown Pelican population is discussed.

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