STUDIES OF A DECLINING POPULATION OF BROWN PELICANS IN NORTHWESTERN BAJA CALIFORNIA

JOSEPH R. JEHL, JR.

Natural History Museum
P.O. Box 1390
San Diego, California 92112

The effect of chlorinated hydrocarbon pesticides, principally DDT and its metabolites, in causing reproductive failure in certain species of birds is widely documented. In raptorial and fish-eating birds reproductive failures are manifested primarily by the production of thin-shelled eggs (Hickey and Anderson 1968). The mechanism of shell-thinning is not fully known but may involve (1) inhibition of carbonic anhydrase or membrane ATPase activity by p,p′-DDE and p,p′-DDT (Peakall 1970a; Bitman et al. 1970); (2) the deposition of medullary bone (Ostreicher et al. 1971); as well as (3) other possible mechanisms (discussed by Risebrough et al. 1970a).

In 1969 shell-thinning was found to have affected the Brown Pelican (*Pelecanus occidentalis*) colony at Anacapa Island, California, the only nesting site for pelicans in the state and the northernmost colony on the West Coast. In mid-March the colony was found littered with eggs that had collapsed under the weight of the incubating adults. Shells of these eggs averaged 53% thinner than those collected before 1943 (Risebrough et al. 1971), and a maximum of five young hatched from 1272 nesting attempts in 1969 (Risebrough et al. 1970a).

To determine the status of pelican colonies immediately to the south as well as the geographic extent of the reproductive failure, L. C. Binford and I made a preliminary survey of coastal islands from the Mexican border south to Natividad Island (fig. 1) in mid-April 1969. Colonies were found on South Coronado Island, San Martín Island, and East San Benito Island. These are the only extant colonies north of Punta Eugenio, except for a small colony on Cedros Island, discovered in 1971, and a possible small colony on Natividad Island. In each colony we found some degree of reproductive failure, though nesting success increased to the south (Jehl 1970).

As time and opportunity permitted, the Los Coronados, San Martín, and San Benito colonies were studied in 1970 and 1971. These studies indicated that the impaired reproduction in 1969 was not an isolated event and that the survival of some colonies is still threatened. However, the patterns of nesting success varied markedly in the 3 years and included an encouraging resurgence of breeding success in 1971, so that the factors affecting pelican survival now appear more complicated than they had previously. By documenting in detail annual changes in these colonies, it is hoped that factors influencing their success will come into clearer focus.

HISTORY OF THE BAJA CALIFORNIA COLONIES

At one time or another, pelicans have nested on most of the islands on Baja California's west coast, with the exception of Guadalupe, a truly oceanic island some 160 miles offshore. Despite the long-standing interest of biologists in these islands, relatively little has been published on the breeding status of pelicans or other sea birds, and the scattered data that do exist are often vague or anecdotal. Nevertheless, they do provide some basis of comparison for the current situation.

Los Coronados. Pelicans have nested on Los Coronados for many decades. Early reports (Anthony 1889; Grinnell and Daggett 1903; Osburn 1909; Wright 1909; Huey [1913] *in* Anderson and Hickey 1970; Howell 1917; Stephens 1921; Cookman 1923; L. M. Huey, unpubl. field notes 1923, 1924; L. W. Walker, pers. comm.) suggest that from the late 1880s until about 1920 the colony consisted of 500 to 1000 pairs, most nesting on North Island. The colony reached maximum abundance in the 1930s, with 5000 birds nesting on North Island, 100 on Middle Island, and a few on South Island (L. W. Walker, pers. comm.) and remained at several thousand pairs into the 1940s (Walker *in* Schreiber and DeLong 1969). A sizeable colony nested on South Island at least into the 1950s (Carl L. Hubbs, pers. comm.) at which time the North Island colony was declining. T. R. Howell (pers. comm.) found 200–300 pairs on North Island in May 1956, but in late May 1963 he found only two or three eggs, and pelicans deserted the island after that season. Pelicans were not found nesting at Los Coronados in 1968

The Condor 75:69–79, 1973

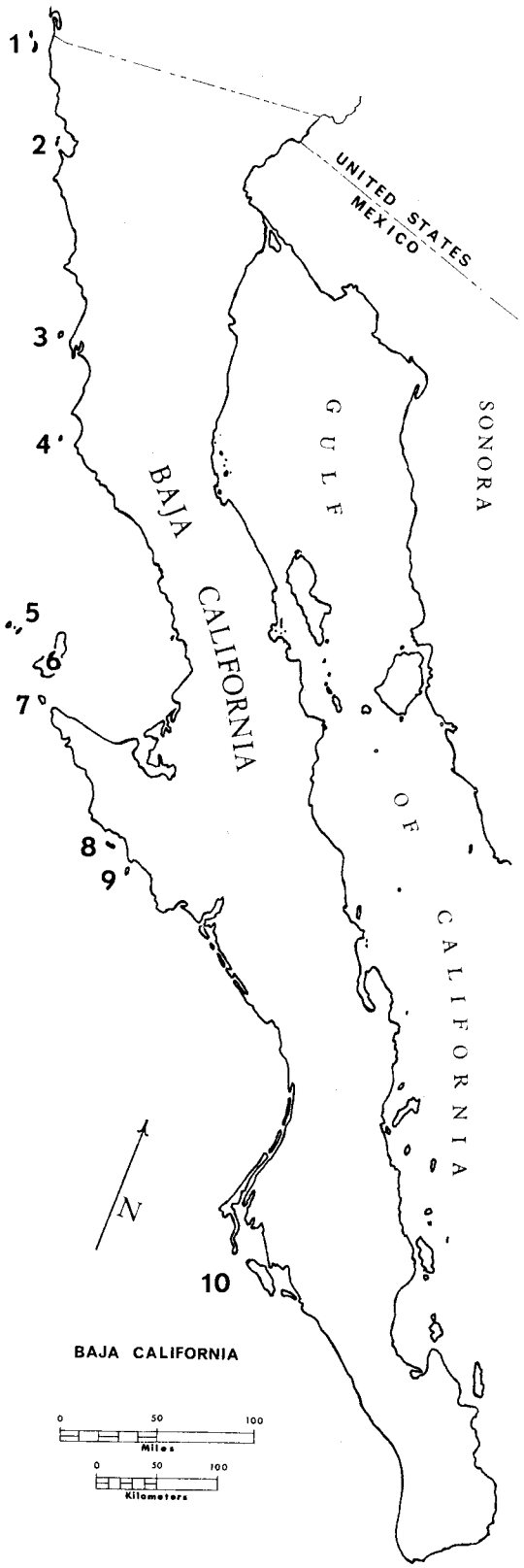

FIGURE 1. Baja California, showing location of islands and pelican colonies mentioned in the text. 1. Los Coronados; 2. Todos Santos Islands; 3. San Martín Island; 4. San Geronimo Island; 5. San Benito Islands; 6. Cedros Island; 7. Natividad Island; 8. San Roque Island; 9. Asunción Island; 10. Santa Margarita Island, Magdalena Bay.

(Schreiber and DeLong 1969) although they nested on South Island in 1969 (see below). Possibly they had experienced nesting failure and deserted the area by the time of the 1968 survey.

Todos Santos Islands. Approximately 200 pairs of pelicans nested on these two small islands in the 1920s (Van Denburgh 1924; see also Anthony 1889; Howell 1912), but disappeared soon thereafter. Ospreys also left the islands at that time and Kenyon (1947) attributed their departure to human disturbance. Pelicans were not nesting on South Island in April and June 1969, and the lack of old nests indicated that they had not done so for a long time.

San Martín Island. Data are scanty, but pelicans have presumably nested on this island in large numbers for hundreds of years (Anthony 1889; Wright 1913; A. S. Loukashkin 1961, unpubl. field notes, photographs). The remains of nests of pelicans and Double-crested Cormorants (*Phalacrocorax auritus*) may be found at the base of virtually every bush on the western half of the island, from sea level nearly to the crest. A few fishermen camp on the east side of the island in winter but usually depart before the start of the nesting season. The current status of the colony is discussed below

San Geronimo Island. There are no records of pelicans ever having nested on this tiny, almost barren island (Anthony 1889; Willett 1913; R. C. Banks 1963, unpubl. field notes; Jehl 1969, unpubl. field notes). There is a permanent fishing camp on this island, but the northern half is a sanctuary for a huge colony of Brandt's Cormorants (*Phalacrocorax penicillatus*). Thus, the absence of pelicans presumably reflects factors other than human disturbance.

Cedros Island. There are no published records of pelicans nesting on Cedros Island, and Willett (1913) specifically indicated their absence. They were not nesting on the south or east sides of the island in April 1969. In May 1971, I located an inconspicuous and inaccessible colony high in an arroyo on the northwestern corner of the island. From the sea I could not determine its size, but local fishermen guessed that it might hold 50 to 100 pairs.

San Benito Islands. These three desert islands lie approximately 15 miles W of Cedros.

East Benito and Middle Benito are uninhabited; a small group of fishermen reside on West Benito in winter and a few remain through the summer in some years. Pelicans have nested on East Benito, though not on the other islands, for many years. Historical data are imprecise (Hanna 1925; Bancroft 1932). R. C. Banks (1963, unpubl. field notes) found pelicans abundant there on 17 April 1963 and noted that the colony contained a number of birds that could barely fly. This colony is discussed below.

Natividad Island. There is no evidence that pelicans have nested on Natividad. Lamb (1927) reported old nests, as did DeLong and Crossin (unpubl. data) in 1968, but confusion with nests of Double-crested Cormorants is possible. DeLong and Crossin obtained no evidence of nesting in April and June 1968, when eggs or young would have been expected. Neither Hanna (1925), Banks (1963, unpubl. field notes), M. N. Kirven (April 1971, pers. comm.), nor Binford and I (April 1969, unpubl. data) found pelicans nesting there. We did not explore the northern end of the island but from the sea we saw no evidence of pelicans there and a colony—if one exists—is quite small. Feral cats now abound on Natividad and kill many nesting shearwaters (*Puffinus puffinus*). Their possible effect on other sea birds is unknown.

Other colonies. Pelicans have also been reported nesting on San Roque and Asunción Islands (Anthony 1925). Although Hanna and Anthony (1923:93) stated that ". . . pelicans nest here by the thousands," Hanna (1925) later stated that only a few pairs nested on Asunción in 1922. Huey (1927) found a large colony there, but none on San Roque in April 1927. In April 1971 the lighthouse keeper at Asunción told M. Kirven that a few pelicans still nest there. Kirven saw hundreds on San Roque in April 1971 but was unable to land or to determine if they were nesting.

At the close of the last century a large colony nested on Santa Margarita Island, Magdalena Bay (Bryant 1889; see also Anthony 1925). According to local fishermen the colony still exists (M. N. Kirven, pers. comm.) but no details are available.

Because historical data are poor, the former pelican population of northwestern Baja California cannot be estimated with any great degree of confidence. The desertion of colonies (e.g., Todos Santos), the failure of birds to breed at large colonies in some years (e.g., San Martín, see below; Anacapa, see Gress 1970), and the possibility of shifting between islands (e.g., Asunción and San Roque) further complicate any attempt at analysis. I would suggest that the total population in the area north of Natividad Island early in this century averaged about 2000 pairs (range 1250–2750) with the following distribution: Los Coronados 500–1000; Todos Santos Island 200–250; San Martín 300–1000; Cedros Island 50–100; San Benitos 200–400. The population may have exceeded 3000 pairs in the 1930s, when the Los Coronados colony reached a maximum.

CURRENT STUDIES, 1969–71

Observations at pelican colonies during this study, particularly at San Martín and the San Benitos, were impeded by Western Gulls, which nest in vast numbers on the islands and which destroy eggs of pelicans or cormorant nests the moment they are left unattended. Most observations in the early part of the nesting season were brief and were made from steep slopes overlooking the colonies, from which the contents of some nests could be noted. This procedure precluded thorough censusing but minimized losses to gulls. However, despite extreme caution, it was not possible to avoid some loss each time the colonies were approached. Later, after the eggs had hatched, broken, or disappeared, colonies were entered for short periods with no apparent adverse effects.

LOS CORONADOS

1969. In the winter 1968–69, 2000 Brown Pelicans, including 40 immatures, roosted at North Island. On 8 March the roost was deserted and 30 birds had appeared at the South Island colony; from sea level I could not observe any evidence of nesting. On 9 April the colony contained approximately 300 nests, most of which were empty or contained only fragments of broken, thin-shelled eggs (fig. 2). Crushed eggs lay under nests throughout the colony. Of 194 nests counted, only 19 contained intact eggs; 15 contained one, 4 contained two, and no nest contained the normal complement of three eggs. A few birds were carrying nesting material and 30% of the nests were freshly lined. At many nests birds appeared to be incubating normally, but the nests were empty. By 2 May this site was deserted, except for two pairs, each with a single egg. One hundred birds had formed a new colony a short distance to the north, but only 20 pairs appeared to be nesting. Some birds were carrying nest material and single eggs were present in four nests. On 7 June I

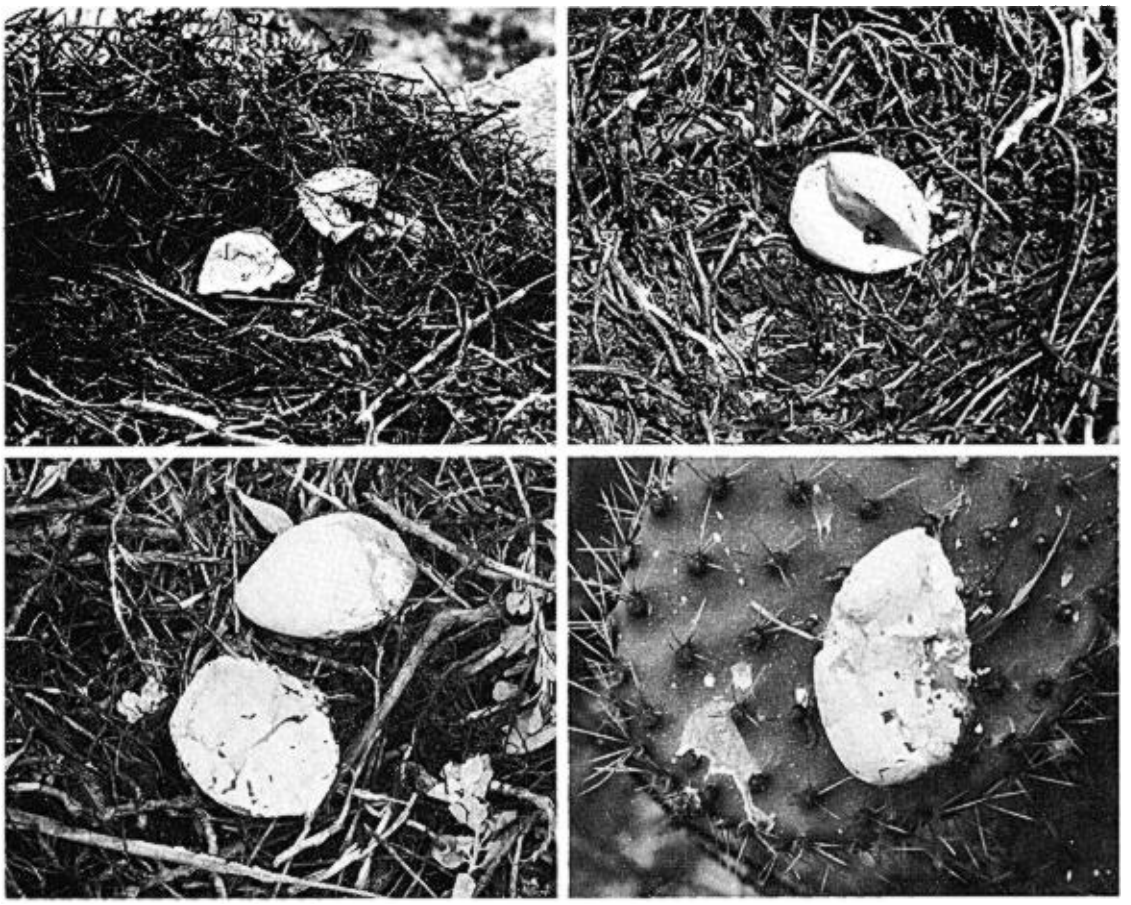

FIGURE 2. Thin-shelled and sometimes shell-less Brown Pelican eggs from colonies in northwestern Baja California collapse and rupture under the weight of incubating adults.

gathered the remains of 14 eggs from this colony and saw fragments of 10 more that I could not retrieve. Twenty birds stood near nests, but only five one-egg clutches were found. No birds were carrying nesting material and no nest was freshly lined. On 19 June the colony was deserted, after total reproductive failure, and by 5 August only a few birds remained in the vicinity of the islands.

1970. Only 500 birds, of which more than 95% were adult, wintered at Los Coronados in 1969–70. Fewer than 100 remained near the roost on 3 March, but nesting was not initiated for another month. On 11 April, 75 birds were present in the South Island colony, and one was carrying nesting material. On 22 April approximately 50 nests showed signs of occupancy, and eggs were found in 11 nests (clutch sizes: C/1–10, C/3–1). However, many eggs were thin-shelled, and others had already been broken and been discarded. On 1 June Suzanne I. Bond observed 350–400 adult pelicans and 150 nests in the colony, although only a few nests contained eggs and were still being attended (C/2–5, C/3–1). However, two nestlings approximately 2 weeks old and one month-old chick were present. Despite the late date, a few additional young may have hatched.

1971. In the winter of 1970–71, 600 pelicans roosted on North Island. On 9 April about 100 pairs had established a new colony there. From sea level I noted several birds sitting on nests and others carrying nesting material. On 2 May I estimated 100 nests in the colony. The contents of those that could be examined without disturbing the colony included: C/O–51, C/1–5, C/2–2, C/3–3. In addition, there were two week-old chicks and one half-grown young. Except for one subadult carrying nesting material there was no evidence of recent nesting activity. Linings of most nests were old and dried, and only a few had been added within the previous week. Thin-shelled eggs were seen under several nests.

On 2 June the remains of thin-shelled eggs were widespread in the colony. Yet, there were 16 nonflying young, representing all stages from newly hatched to three-quarters

grown, and eggs were found in 30 nests (C/1–15, C/2–15). Some of these were thin-shelled and one collapsed of its own weight as I lifted it from the nest. Others had relatively thick shells and almost certainly hatched. I estimate that 30–40 young fledged here in 1971. Also in the colony were approximately 25 flying young. Since nesting probably did not begin in this colony until early March, and since the interval between laying and fledging is approximately 4 months (D. W. Anderson, pers. comm.), these birds must have been produced elsewhere, presumably in colonies in the Gulf of California.

SAN MARTÍN ISLAND

On 11 April 1969, 800 pairs of Brown Pelicans were nesting near the southwestern corner of this island. Because of the vast numbers of Western Gulls, we made no attempt to survey the colony fully. Eggs were present in only 13 of 100 nests examined (C/1–10, C/2–2, C/3–1), but many nests were freshly lined and nesting may have begun only recently. Some eggs had noticeably thin or flaking shells, and crushed eggs were found under several nests. On 11 June the colony contained 80–100 young, most were 3 to 4 weeks old, although older and much younger chicks were present. We saw no eggs, incubating adults, or freshly lined nests.

In 1970 Brown Pelicans deserted San Martín. A wintering population of 1500–2000 birds (95% adults) on 6 February dwindled to 300 on 6 April and to eight on 4 June. There was no evidence of nesting or courtship behavior in this colony at any time.

Pelicans returned to San Martín in 1971. In weekly visits from early January through early March we found 500–1000 birds (2–3% immatures) roosting there. There was no sign of nesting on 4 March, but by 19 March a colony had been established about one-quarter mile N of the 1969 colony. Many birds were carrying nesting material and eggs had been laid in perhaps 50 nests. I estimated 900 birds there and 150 additional adults in the vicinity of the island, and a breeding population of approximately 500 pairs seemed reasonable.

On 28 May the pelican colony had been encompassed by several hundred nests of Double-crested Cormorants, so that it was impossible to determine pelican productivity without seriously impairing that of the cormorants. Three hundred and fifty adult pelicans remained in the colony, but their behavior suggested that they were attending empty nests. Only three half-grown young were seen. Near the island's crest I found 10 more empty nests with adults in attendance. I estimate that a maximum of 10 young were produced on San Martín in 1971.

SAN BENITO ISLANDS

On 14 April 1969, 130 pairs of pelicans were nesting in arroyos on the northeastern corner of East Benito Island. Although some nests were still under construction, most had been completed recently and contained fresh lining or eggs. However, one nest contained a pipped egg and therefore some birds had begun nesting by early March. By surveying the colony through binoculars, it was possible to observe the following nest contents: C/0–35, C/1–11, C/2–16, C/3–11. Most eggs we examined appeared to be superficially normal, unlike those in more northern colonies. Yet, several thin-shelled eggs were present, including one shell-less egg that broke as I attempted to collect it. This colony was not revisited in 1969. Because shell thicknesses were greater and chlorinated hydrocarbon levels lower (see below) than in other colonies, nesting success should have been improved. Previously (Jehl 1970), I estimated that perhaps 50 young may have fledged, but in light of the success enjoyed by the colony in 1971 a minimum figure of 100 seems more likely.

Apparently, few pelicans wintered at the San Benitos in 1969–70. None were observed at West Benito or Central Benito on 5 February and only a few were seen near East Benito. On 20 April I found two isolated nests on East Benito: one contained a single chick 6–10 days old; the other held a clutch of three eggs that was later destroyed by gulls. Toward the northeast corner of the island 50 nests, none with fresh linings or eggs, had been started in an arroyo one-quarter mile N of the 1969 colony; only 20 adults were in the area. In view of the late date and lack of nesting behavior, I doubt that pelicans raised young there. The northwestern corner of the island was not thoroughly surveyed, but so few adult pelicans were near the island that it seems unlikely that any significant number of nesting birds was overlooked. Probably the single chick represented the entire reproductive effort of the San Benito colony in 1970.

Weekly observations at the San Benitos from late December 1970 through early March 1971 revealed no more than 50 pelicans in the area. The hundreds of pelicans seen at that time in Scammon's Lagoon (maximum 800, 21 January), where pelicans do not nest, may have originated in colonies on Cedros and the San Benitos. When East Benito Island was

surveyed on 25 May, I counted 270 nests, all in arroyos on the northern half of the island. The contents of 109 nests could not be determined. A total of 102 eggs were found in 76 nests (C/0–28, C/1–16, C/2–10, C/3–22) and 159 young were found in the vicinity of 85 nests. Brood sizes ranged from one to three (B/1–13, B/2–32, B/3–24). (Larger chicks tend to congregate in small groups and data on brood sizes are approximations.) Thin-shelled eggs were found under 12% of the nests, and others were certainly overlooked.

Within each section of the colony nesting was fairly well synchronized. Evidently, nesting had begun on the north side of the island in early April, as most nests there contained large young, some were three-quarters grown. Later-nesting pairs tended to occupy peripheral areas, particularly on the northeastern corner of the island; many nests in that area contained full clutches (C/3) or small young. There was no obvious pattern to nesting in arroyos on the western side of the island. However, most of the broken thin-shelled eggs were found in that area. Further, small clutches were commoner there than elsewhere on the island (14 of the 16 C/1's observed). Because the linings of these nests were old and dried, I infer that they contained replacement clutches for eggs lost earlier in the season. In colonies where laying is just beginning, the linings of nests containing C/1's are fresh and green.[1]

The productivity of this colony can only be approximated. Inasmuch as 102 eggs were present on 25 May and the contents of 109 nests—many of which were in areas of high nesting success—could not be ascertained, I estimate that a minimum of 100 chicks hatched after the survey, for a total of 256 young.

PRODUCTIVITY

Productivity from 1969 through 1971 is summarized in table 1. In 1969 perhaps 200 young were hatched from 1300–1400 nests. In 1970 many birds failed to nest, and only four young are known to have hatched from 200–250 nests. Breeding success improved in 1971, with 300 young being produced by 900 pairs, but still averaged far below normal in all colonies. These figures do not include the Cedros Island colony, discovered late in 1971, which contained an estimated 100 pairs and whose productivity is likely equivalent to the San Benito colony.

TABLE 1. Reproductive success of Brown Pelicans in northwestern Baja California, 1969–71.

Colony	Year	Nests	Young produced
Los Coronados	1969	350–400	None
	1970	150–200	3–5
	1971	100–120	30–40
San Martín	1969	800	80–100
	1970	None	None
	1971	500	10
San Benito Is.	1969	130	50–100
	1970	50	1
	1971	270	260

SHELL-THINNING

Thin-shelled eggs that had collapsed and broken during incubation were found in each colony. Few eggs on Los Coronados seemed normal; nearly all showed signs of flaking and some had areas where no shell at all had been deposited on the egg membrane. On San Martín and on the San Benitos most eggs were superficially normal, though even on the remote San Benitos we found eggs with virtually no shell.

Shell thicknesses were determined using the techniques of Anderson and Hickey (1970). Shells averaged thinnest on Los Coronados and thickness increased southward (table 2). Because samples were taken at different stages of the nesting cycle in the several colonies and included varying numbers of eggs collected intact, eggs broken by gulls, or eggs that had collapsed during incubation, mean thicknesses are only approximations of conditions prevailing in the colonies. Note, however, that not one of the eggs collected on Los Coronados or on San Martín had a shell as thick as those collected prior to 1943 (mean thickness of eggs collected before 1943 is 0.57 mm; Anderson and Hickey 1970), and

TABLE 2. Shell thickness of Brown Pelican eggs from northwestern Baja California.

Colony	Year	No.	Thickness, range, and mean in mm
Los Coronados	1969	48	0.17–0.44 (0.308)
	1970	17	0.18–0.44 (0.303)
	1971	16	0.23–0.45 (0.340)
San Martín	1969	19	0.28–0.54 (0.421)
San Benitos	1969–70	12	0.27–0.59 (0.468)
	1971	8	0.23–0.57 (0.456)

[1] There are no unequivocal data that Brown Pelicans lay replacement clutches, but this circumstantial evidence suggests that they do. Furthermore, in colonies where shell breakage was high (Anacapa, see Gress 1970; Los Coronados) the frequency of one-egg clutches was high; at the San Benitos, where breakage was relatively low, three-egg clutches were common in 1969 and 1971 at the same time that one- and two-egg clutches predominated on Los Coronados. This indicates that replacement clutches of one egg (occasionally two?) may be laid if the original clutch is lost early in incubation. The alternate explanation—that pelicans carrying high loads of pesticides lay small clutches—cannot be ruled out, however (see Stickel and Rhodes 1970, for pertinent data on *Coturnix*).

that the thickest-shelled eggs in those colonies showed reductions of 22 and 5%, respectively. Of the 120 eggs and egg fragments examined in this study, only four from the San Benitos were as thick as those collected before 1943. The use of comparative material collected prior to 1943 is not without occasional problems, for early oologists sometimes "cleaned" their eggs with sandpaper (see Anthony 1889: 84).

I estimate that shells whose thickness is 20–25% below normal break almost immediately after laying. Of the 27 intact eggs examined in this study (mean thickness 0.43 mm), only nine had thicknesses under 0.42 mm (minimum 0.32 mm); most could not have survived the stress of incubation. The shell of a hatching chick on Los Coronados in 1971 measured 0.43 mm; Risebrough et al. (1971) reported that a chick hatched from a 0.45 mm egg on Anacapa in 1969.

CHLORINATED HYDROCARBONS

In 1969, a few intact eggs were collected in each colony though not more than one egg was taken from any nest. As many thin-shelled and collapsed eggs as possible were salvaged during each visit; some of these retained significant amounts of dried yolk. Yolk lipids were analyzed for the presence of DDT compounds, dieldrin, endrin, and polychlorinated biphenyls (PCB's), using methods described by Risebrough et al. (1970b).

Pesticide levels were highest at Los Coronados and decreased to the south (table 3), which suggests that the source of these contaminants is the polluted waters of southern California. In fact, it seems virtually certain that a major source of the DDT is effluent from the Montrose Chemical Corporation plant that empties into the Los Angeles County sewer system (Burnett 1971). Birds may acquire significant pesticide loads during their postbreeding wanderings in areas far from their nesting colony (Anderson et al. 1969); this may account for the anomalously high levels found in a single San Benitos egg.

The decreased levels found at Los Coronados in 1970 are thought to result from sampling error. They do not indicate reduced levels of environmental contamination because shell thicknesses (table 2) are similar to those of 1969. In 1969, eggs and egg fragments were collected regularly and throughout the laying period, whereas in 1970 the colony was visited infrequently and the few samples were collected a week or more after laying. Thus, extremely thin-shelled and freshly broken eggs, which were present in 1969, were not available, having been discarded by adults and eaten by gulls; only relatively thick-shelled eggs remained.

Inverse correlations between concentrations of DDT compounds and eggshell thickness have been demonstrated for a wide variety of fish-eating and raptorial birds (Hickey and Anderson 1968; Anderson et al. 1969). A similar relationship is found in Brown Pelicans. Data for Baja California colonies are

TABLE 3. Pesticide residues in eggs of Brown Pelicans from northwestern Baja California.

	LOS CORONADOS, 1969			LOS CORONADOS, 1970		
	No.	Range and mean	S.D.	No.	Range and mean	S.D.
DDE	21	335–2610 (1310)	594	7	98–1035 (503)	297
p,p′ DDT	21	1.0–36.6 (22.0)	10.6	7	1.6–16.4 (7.31)	4.5
p,p′ DDD	21	3.8–79.2 (37.6)	22.0	7	4.0–29.8 (12.9)	7.7
PCB's	21	77–1620 (361)	356	7	40–481 (190)	132
DIELDRIN	3	11.0, 14.0, 35.0			Not analyzed	
ENDRIN	3	0.0			Not analyzed	
	SAN MARTIN ISLAND, 1969			SAN BENITO ISLANDS		
	No.	Range and mean	S.D.	No.	Range and mean	S.D.
DDE	5	58–384 (150)	118	9 (1)	17–247 (63.4) (636)[a]	68
p,p′ DDT	5	0–7.1 (3.6)	2.6	9 (1)	1–4.1 (1.8) (17.9)[a]	1.0
p,p′ DDD	5	2.2–58. (4.1)	1.4	9 (1)	0.9–4.6 (1.71) (25.4)[a]	1.1
PCB's	5	27.6–73.3 (47.6)	20.0	9 (1)	6.7–39.0 (17.1) (234)[a]	11.0
DIELDRIN	4	2.7–8.6 (5.0)		3	0, 0, 2.6	
ENDRIN	4	1.1–2.5 (1.7)		3	0.0	

[a] One highly contaminated egg given separately. Figures are in parts per million of lipid wt.

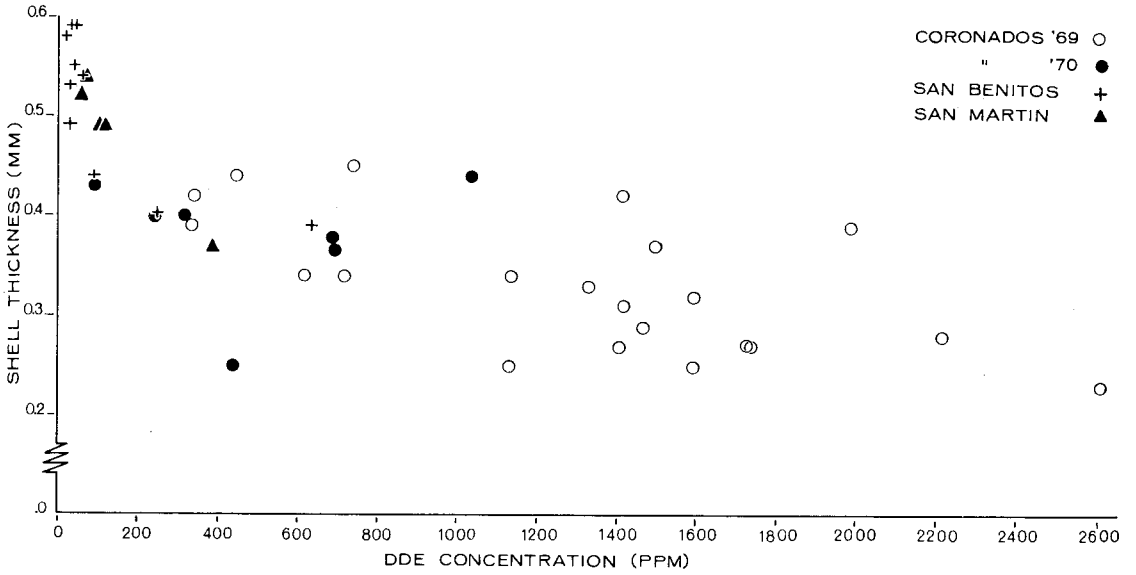

FIGURE 3. Relationship between DDE concentration and shell thickness in Brown Pelican eggs from northwestern Baja California.

graphed in figure 1. Additional data will be presented elsewhere (R. W. Risebrough, in prep.). PCB's appear to have only a limited role in shell-thinning (Peakall 1971).

There are few data on the effects of chlorinated hydrocarbons on developing pelican embryos. Living 20-day embryos were found in eggs whose yolk lipid contained 64 and 450 ppm DDE, 2-day embryos in eggs with 103 and 340 ppm DDE.

Possible indirect or sublethal effects of these contaminants, either alone or in combination, remain to be determined. In cage birds and possibly in wild populations of Double-crested Cormorants (Risebrough et al. 1970a), p,p'-DDT has been shown to inhibit ovulation and to delay reproduction (Jeffries 1967; Peakall 1970b), and dieldrin and PCB's may have an even greater retarding effect (Peakall 1970a; Peakall and Lincer 1971). Historical data are inadequate to test whether pelicans are nesting later now than in past decades.

Gress (1970) suggested that the erratic behavior (e.g., extreme wariness, tendency to leave nest unattended) of pelicans on Anacapa might be due to the "presence of large amounts of chlorinated hydrocarbon residues." On the San Benitos in 1971, birds attending replacement clutches were very wary, and would leave their nests when I was some distance away; adjacent pairs in the same arroyo and attending full clutches permitted close approach and showed defensive behavior at the nest. A relationship between behavioral changes and residue levels will be difficult to prove but demands further research.

DISCUSSION

The breeding failure of 1969 can be ascribed largely to shell-thinning. Nesting success was poorest at Los Coronados but improved southward as shell thickness increased and chlorinated hydrocarbon levels decreased. However, this clinal variation in breeding success was not fully realized in 1970 or 1971, as might have been expected, and factors other than shell-thinning must have contributed to the poor productivity in those years. Because it was not possible to monitor the colonies continuously, these factors can only be surmised.

In 1970, nesting success remained low on Los Coronados, but pelicans failed to nest at all on San Martín and they were virtually absent from the San Benitos. Local food shortages might have led to the temporary desertion of those colonies. This explanation is consistent with observations at San Martín of progressively declining pelican numbers, the apparent absence of any nesting behavior, and the decline of the Double-crested Cormorant colony to 20% of its 1969 size (Jehl, unpubl. data). Anchovies (*Engraulis mordax*) are the major prey species for pelicans in this area.

In 1971, productivity improved at Los Coronados, although colony size decreased. Possibly the shift to North Island, which is uninhabited, resulted in less disturbance and improved nesting conditions. At the San Benitos colony size increased, as did hatching success; contributing factors are unknown. In sharp contrast was the situation at San Martín. Because productivity was far lower

there than at colonies both north and south, local conditions again would seem to have been involved. Food shortage seems unlikely, however, because pelicans attempted to nest and cormorants of two species did so in great numbers. I believe that disturbance by humans was the major factor affecting productivity at this colony in 1971. Fishermen at San Martín have told me that gull and cormorant eggs are harvested there each year for human consumption. Further, San Martín possesses a sheltered harbor that attracts hundreds of pleasure boats annually. Hundreds of visitors, including exploring naturalists, land on the island during the breeding season and, usually inadvertently, disturb the colonies, causing high egg losses through gull predation. These activities are sufficient to lower productivity at San Martín, and their persistence poses a serious threat to the colony.

Disturbance by yachtsmen is probably minimal at the San Benitos, but there is evidence that gull (and pelican?) eggs are sometimes harvested there for local consumption. Many people visit Los Coronados each year, and although the rugged topography prevents most from climbing to the colonies, some disturbance is unavoidable. The shooting of birds from fishing boats and the buzzing of colonies by low-flying aircraft cause panic flights among nesting birds. The extent to which these activities impair reproductive activities is not known, but certainly is not insignificant.

Populations of pelicans and other long-lived birds may forego breeding in some years without suffering any long-term effects, but no species can maintain a stable population in the face of prolonged nesting failures. Shell-thinning occurred on Anacapa Island, California, as early as 1962 (Anderson and Hickey 1970); some young were produced in 1964 (Banks 1966:179), but by 1969 nesting failed completely (Risebrough et al. 1971). Presumably, colonies in northwestern Baja California were affected at the same time and by now—barring recruitment from other colonies—one would expect a decrease in their size as a result of normal adult mortality plus the virtual lack of production of young. Indeed, from 1969–71, the number of breeding pairs on Los Coronados dropped from a maximum of 400 to 120, and on San Martín, from 800 to 500. Observations of postbreeding birds along the entire West Coast of the United States also indicate a marked decline (Ralph 1969; Crowell and Nehls 1970:97; Baldridge et al. 1970:89; McCaskie 1970:97).

Pelican populations on the West Coast have reached a critical stage. Unless the results of the 1971 season herald a return toward improved productivity, the colonies on Anacapa, Los Coronados, and San Martín may disappear within a decade. Studies currently in progress indicate that shell-thinning is affecting a wide variety of other sea birds as well [e.g., Common Murre (*Uria aalge*) Gress et al. 1971; Ashy Petrel (*Oceanodroma homochroa*) Coulter and Risebrough, 1973; Double-crested Cormorant, Gress et al., unpubl. data].

The survival of these species depends on a clean and protected marine environment as well as on freedom from human disturbance. By declaring nesting islands as sanctuaries for the peak of the breeding season (March through June) and by prohibiting access to all but a few qualified observers, the Mexican and United States governments could improve the birds' chances for survival.

SUMMARY

From 1969 through 1971, the reproductive success of Brown Pelicans was studied at Los Coronados, San Martín Island, and the San Benito Islands. These are the only pelican colonies in northwestern Baja California north of Natividad Island, with the exception of a small colony on Cedros Island discovered in 1971. Large-scale reproductive failure was found in all colonies. In 1969, 1300–1400 pairs produced 200 young; in 1970, 200–250 pairs produced four young; in 1971, 900 pairs produced 300 young. Thin-shelled eggs that collapse and break during incubation are the major factor contributing to nesting failure, although human disturbance is important particularly at San Martín. Shell-thinning is inversely related to concentrations of DDT compounds, principally DDE, in the egg yolk. It is most pronounced at Los Coronados, but to the south, where chlorinated hydrocarbon levels average lower, shell thickness increases.

The pelican population of this area has declined from an estimated 2000 pairs in the early years of the century to 1000 pairs in 1971. The long-term survival of colonies at San Martín and Los Coronados is in doubt but may be enhanced by declaring nesting islands as sanctuaries during the breeding season.

ACKNOWLEDGMENTS

This study represents the combined generosity and cooperation of many people. Richard F. Dwyer supported the preliminary survey in April 1969. John S. Bradshaw and the Bradshaw Foundation provided transportation to Los Coronados on many occasions in 1969 and 1970. Carl L. Hubbs arranged for

transportation to the southern colonies in 1970 and 1971 through Scripps Institution of Oceanography. Studies on San Martín Island were supported, in part, by Richard P. Phillips and by a National Audubon Society grant to Robert W. Risebrough. Chlorinated hydrocarbon analyses were carried out by R. W. Risebrough, Institute of Marine Resources, University of California, Berkeley, through grants (GB 6362, GB 11649) to H. S. Olcott, principal investigator. Egg shell thicknesses were determined, in part, by Daniel W. Anderson. S. I. Bond, L. C. Binford, and D. Power provided important assistance in the field. For help in various ways I am indebted to G. Cox, J. E. Fitch, A. R. Longhurst, M. N. Kirven, R. Spring, W. Booth, and the late L. W. Walker. The cooperation of the Mexican government, through Dr. Rodolfo Hernandez Corzo, in granting permission for these studies, is gratefully acknowledged.

D. W. Anderson, R. W. Risebrough, and B. J. LeBoeuf commented on an earlier draft of the manuscript.

LITERATURE CITED

ANDERSON, D. W., AND J. J. HICKEY. 1970. Oological data on egg and breeding characteristics of Brown Pelicans. Wilson Bull. 82:14–28.

ANDERSON, D. W., J. J. HICKEY, R. W. RISEBROUGH, D. F. HUGHES, AND R. E. CHRISTENSEN. 1969. Significance of chlorinated hydrocarbon residues to breeding pelicans and cormorants. Can. Field Natur. 83:91–112.

ANTHONY, A. W. 1889. Nesting habits of the California Brown Pelican (*Pelecanus californicus*). Proc. Calif. Acad. Sci. 2:83–85.

ANTHONY, A. W. 1925. Expedition to Guadalupe Island, México, in 1922. The birds and mammals. Proc. Calif. Acad. Sci. 14:277–320.

BALDRIDGE, A., T. CHANDIK, AND D. DESANTE. 1970. Middle Pacific Coast Region. Audubon Field Notes 24(1):88–95.

BANCROFT, G. 1932. The flight of the Least Petrel. G. P. Putnam's Sons, New York and London, 403 p.

BANKS, R. C. 1966. Terrestrial vertebrates of Anacapa Island, California. Trans. San Diego Soc. Natur. Hist. 14(14):173–188.

BITMAN, J., H. C. CECIL, AND G. F. FRIES. 1970. DDT-induced inhibition of avian shell gland carbonic anhydrase: a mechanism in thin eggshells. Science 168:594–596.

BURNETT, R. 1971. DDT residues: distribution of concentrations in *Emerita analoga* (Stimpson) along coastal California. Science 174:606–608.

BRYANT, W. E. 1889. A catalogue of the birds of Lower California, México. Proc. Calif. Acad. Sci., Ser. 2, 2:237–320.

COOKMAN, A. 1923. Recent expedition to Los Coronado Islands, México. Oologist 40:176–178.

COULTER, M. C., AND R. W. RISEBROUGH. 1973. Shell thinning of eggs of the Ashy Petrel *Oceanodroma homochroa*. Condor, in press.

CROWELL, J. B., JR., AND H. B. NEHLS. 1970. Northern Pacific Coast Region. Audubon Field Notes 24(1):82–88.

GRESS, F. 1970. Reproductive status of the California Brown Pelican in 1970, with notes on breeding biology and natural history. State of California, Wildlife Manage. Branch Admin. Rep. No. 70–6 (July 1970).

GRESS, F., R. W. RISEBROUGH, AND F. C. SIBLEY. 1971. Shell thinning in eggs of the Common Murre, *Uria aalge*, from the Farallon Islands, California. Condor 73:368–369.

GRINNELL, J., AND F. S. DAGGETT. 1903. An ornithological visit to Los Coronados Island, Lower California. Auk 20:27–37.

HANNA, G DALLAS. 1925. Expedition to Guadalupe Island, México in 1922. General Report. Proc. Calif. Acad. Sci. 14:217–275.

HANNA, G DALLAS, AND A. W. ANTHONY. 1923. A cruise among desert islands. Nat. Geogr. Mag. 44:71–99.

HICKEY, J. J., AND D. W. ANDERSON. 1968. Chlorinated hydrocarbons and eggshell changes in raptorial and fish-eating birds. Science 162:271–273.

HOWELL, A. B. 1912. Notes from Todos Santos Islands. Condor 14:187–191.

HOWELL, A. B. 1917. Birds of the islands off the coast of Southern California. Pacific Coast Avifauna 12, 127 p.

HUEY, L. M. 1927. Northernmost breeding station of the Heerman Gull on the Pacific Ocean, and other notes from San Roque Island, Lower California. Condor 29:205–206.

JEFFRIES, D. J. 1967. The delay in ovulation produced by pp'-DDT and its possible significance in the field. Ibis 109:266–271.

JEHL, J. R., JR. 1970. Is thirty million years long enough? Pacific Discovery 23:16–23.

KENYON, K. W. 1947. Breeding populations of the Osprey in Lower California. Condor 49:152–158.

LAMB, C. C. 1927. The birds of Natividad Island, Lower California. Condor 29:67–69.

MCCASKIE, R. G. 1970. Southern Pacific Coast Region. Audubon Field Notes 24(1):96–100.

OSTREICHER, M. I., D. H. SCHUMAN, AND C. F. WURSTER. 1971. DDE reduces medullary bone formation in birds. Nature 229:571.

OSBURN, P. I. 1909. Notes on the birds of Los Coronados Islands, Lower California. Condor 11:134–138.

PEAKALL, D. B. 1970a. Pesticides and the reproduction of birds. Sci. Amer. 222(4):72–78.

PEAKALL, D. B. 1970b. p,p'-DDT: Effect on calcium metabolism and concentration of estradiol in the blood. Science 168:592–594.

PEAKALL, D. B. 1971. Effect of polychlorinated biphenyls (PCB's) on the eggshells of Ring Doves. Bull. Environ. Contam. Toxicol. 6(2): 100–101.

PEAKALL, D. B., AND J. L. LINCER. 1970. Polychlorinated biphenyls. BioScience 20(17):958–964.

RALPH, C. J. 1969. An analysis of offshore migration. Point Reyes Bird Observatory Bull. 12: 12–15.

RISEBROUGH, R. W., J. DAVIS, AND D. W. ANDERSON. 1970a. Effects of various chlorinated hydrocarbons, p. 40–50. *In* J. W. Gillett [ed.], The biological impact of pesticides in the environment. Oregon State Univ. Press, Corvallis.

RISEBROUGH, R. W., G. L. FLORANT, AND D. D. BERGER. 1970b. Organochloride pollutants in Peregrines and Merlins migrating through Wisconsin. Can. Field Natur. 84:247–253.

RISEBROUGH, R. W., F. C. SIBLEY, AND M. N. KIRVEN. 1971. Reproductive failure of the Brown Pelican on Anacapa Island in 1969. Amer. Birds 25(1):8–9.

SCHREIBER, R. W., AND R. L. DELONG. 1969. Brown Pelican status in California. Audubon Field Notes 23:57–59.

STEPHENS, F. W. 1921. Early spring notes on birds of Coronado Islands, México. Condor 23:96–97.

STICKEL, L. F., AND L. I. RHODES. 1970. The thin eggshell problem, p. 31–35. *In* J. W. Gillett [ed.] The biological impact of pesticides in the environment. Environmental Health Science Series, No. 1. Oregon State Univ. Press, Corvallis.

VAN DENBURGH, J. 1923. The birds of the Todos Santos Islands. Condor 26:67–71.

WILLETT, G. 1913. Bird notes from the coast of northern Lower California. Condor 15:19–24.

WRIGHT, H. W. 1909. An ornithological trip to Los Coronados Islands, México. Condor 11: 96–100.

WRIGHT, H. W. 1913. The birds of San Martín Island, Lower California. Condor 15:207–210.

Accepted for publication 14 February 1972.