REPRODUCTIVE FAILURES OF DOUBLE-CRESTED CORMORANTS IN SOUTHERN CALIFORNIA AND BAJA CALIFORNIA

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DOUBLE-CRESTED Cormorants (*Phalacrocorax auritus*) have been considered a common resident of the Channel Islands of southern California and the islands of western Baja California (Grinnell, 1928; Grinnell and Miller, 1944; Howell, 1917). Because the breeding colonies are frequently on inaccessible terrain, data on the numbers of breeding birds and of breeding biology in general are few. The largest breeding colonies of the Channel Islands apparently were on Prince Island (an islet near San Miguel Island) (Willett, 1910), Anacapa Island (Howell, 1917; Banks, 1966) and Santa Barbara Island (Howell, 1917; Wright and Snyder, 1913). Along the west coast of Baja California, Grinnell (1928) reported that breeding colonies of Double-crested Cormorants were present on virtually every island from Los Coronados south to Santa Margarita. The largest colony, on San Martín Island, was estimated at 350,00 pairs (Wright, 1913), an estimate that is likely exaggerated. Bent (1922) considered this to be the largest colony of Double-crested Cormorants ever recorded. The species was also abundant on Los Coronados early in this century (Howell, 1917; Wright, 1909), but there are no published estimates of colony size. L. M. Huey (unpublished field notes) estimated the Los Coronados colony at "fully a thousand pairs" in 1916. By 1920 he noted a great decrease, which he attributed to disturbance by tourists during the nesting season. By 1924 he estimated the colony at 200 pairs; in 1926 he found only "a few" pairs still nesting on North Island.

Double-crested Cormorants in southern California and northwestern Mexico typically nest on steep rocky slopes or hillsides among Brown Pelicans (*Pelecanus occidentalis*). The nests are bulky structures constructed primarily of sticks and resemble those of pelicans. The cormorants generally breed from late April through June, although nesting activities may continue as late as August in some years (Willett, 1933). The clutch usually consists of three or four eggs, but may number up to seven (Bent, 1922). Cormorants, like pelicans, may suffer heavy losses of eggs to gull predation (Howell, 1917).

Breeding failures of Brown Pelicans in several west coast colonies was first observed in 1969, following several suggestions of abnormal reproduction of fish-eating birds in southern California. Virually no young pelicans were fledged on either Anacapa or Los Coronados in 1969 and 1970, and hatching success was reduced in the colonies at San Martín Island and San Benitos Islands. All Brown Pelican colonies in the United States and northwestern Mexico produced thin-shelled eggs in 1969 and 1970. Eggshell thickness in the Florida colonies averaged 9 percent thinner than that of eggs laid before 1945. On the West Coast shell thinning was considerably more severe. Decrease in shell thickness averaged as much as 50 percent in some west coast colonies, and, as a result, most eggs broke during incubation. The degree of shell thinning was shown to be closely dependent upon the concentrations of the DDT metabolite DDE in the lipid of the yolks, but was not influenced by polychlorinated biphenyls (PCB) (Gress, 1970; Jehl, 1973; Risebrough, 1972; Risebrough, Sibley, and Kirven, 1971; Schreiber and Risebrough, 1972).

During visits to the west coast pelican colonies in 1969, we found that the Double-crested Cormorants had also experienced reproductive failures caused by excessive thinning of the eggshells. On the west islet of Anacapa Island there were 76 nesting attempts in two colonies in 1969. Neither colony produced young. The pattern of reproductive failures and nest abandonment was similar to that observed in the pelican colony. Thin-shelled eggs, which had been crushed and discarded from the nests, were strewn about the colony site. Ten of these crushed shells and seven intact eggs were collected on 13 May (L.F.K.). The colony on South Los Coronados Island, too, was littered with crushed, thin-shelled eggs and fragments; 32 active nests produced only one young in 1969. Six intact eggs and 17 broken shells were collected on 6 June (J.R.J.). The cormorant colony on San Martín Island numbered approximately 5000 in 1969 and appeared to be having no reproductive problems. Seven intact eggs from individual clutches were collected on 12 June by J.R.J.

METHODS

The eggshells collected were classified as either "intact" or "crushed." Intact eggs were those which were whole when collected; crushed eggs had been broken during incubation. The intact eggs were measured for shell weight, length, breadth, and thickness using methods described by Anderson and Hickey (1970). An index of shell thickness (Ratcliffe, 1967) was calculated by dividing ten times the weight of the shell (in grams) by the length times the breadth (in cm^2). Thickness of the shell at the girth was the only measurement possible of the crushed eggs. These data were then compared with those of museum specimens originally collected from the coastal islands of southern California and northwestern Baja California prior to 1946 and now preserved in the Museum of Vertebrate Zoology, University of California, Berkeley, and the Western Foundation of Vertebrate Zoology, Los Angeles. The parameters examined, length, breadth, weight, and thickness, showed no significant geographical variation between

TABLE 1

COMPARISON OF MEANS (WITH 95 PERCENT CONFIDENCE LIMITS) OF SHELL MEASUREMENTS BETWEEN INTACT EGGS COLLECTED IN 1969 AND PRE-1946 MUSEUM SPECIMENS

	N	Shell weight (g)	Length (mm)	Breadth (mm)	Thickness (mm)	Thickness index[1]
Museum specimens	134	4.70 ±0.08	60.12 ±0.54	37.56 ±0.23	0.43[2] ±0.01	2.08 ±0.03
Anacapa	7	3.77 ±0.34	58.84 ±2.23	39.87 ±0.56	0.38 ±0.02	1.60 ±0.10
Los Coronados	6	2.97 ±0.44	58.58 ±3.31	37.33 ±2.54	0.30 ±0.03	1.35 ±0.12
San Martín	7	4.90 ±0.59	58.50 ±1.96	38.29 ±1.36	0.44 ±0.02	2.19 ±0.21
All colonies	20	3.93 ±0.44	58.65 ±1.13	38.56 ±0.87	0.38 ±0.03	1.73 ±0.18

[1] weight (g) × 10/length (cm) × breadth (cm)
[2] n = 29 (museum thickness measurements)

the colonies in southern California and those in northwestern Baja California. These data were therefore pooled for comparison with recent eggs.

The 20 intact cormorant eggs collected in 1969 were analyzed for chlorinated hydrocarbon residues. The yolks were ground with anhydrous sodium sulphate to a dry, homogeneous mixture from which the lipids were extracted with a 2:1 hexane-acetone mixture refluxing in a Soxhlet apparatus for eight hours. The average amount of lipid extracted from each egg was 1.58 ± 0.17 (95 percent C.L.) or 4.24 percent of the total wet-weight contents. This value is in close agreement with the lipid content of 4.26 percent in the eggs of Double-crested Cormorants from interior North America (Anderson, et al., 1969). A sub-sample of lipid was analyzed using the methodology of Risebrough, Florant, and Berger (1970).

Anderson, et al. (1969) studied the relationships between chlorinated hydrocarbons and shell thinning of populations of Double-crested Cormorants in interior North America. The cormorants breeding in Wisconsin were among the first fish-eating species to show regional population declines (Anderson and Hamerstrom, 1967). A comparison of the residue levels and shell thickness among 11 midwestern colonies showed that thinner shelled eggs contained higher concentrations of both DDE and PCB. To compare the relationship found between shell thinning and residue levels in the fresh-water colonies of the Midwest with those in the west coast marine environment, we have reanalyzed the data from the midwestern colonies studied by Anderson, et al. (1969). Analysis of variance was used to determine the significance of the regression of thickness on DDE. Some of these samples had consisted of pools of two or three eggs. The variance of both DDE and thickness measurements of the group of pooled samples was not significantly different ($p > 0.05$) from those of the group of individual egg samples. Pooled and individual samples were therefore considered together in the consideration of the regression of thickness on DDE among eggs from the Midwest.

TABLE 2

THICKNESS OF CRUSHED EGGSHELLS AND OF SHELLS OF INTACT EGGS FROM ANACAPA AND LOS CORONADOS (1969), WITH PERCENTAGE DECREASE FROM PRE-1946 SPECIMENS

	N	Mean thickness (mm) (± 95% C.L.)	Percentage decrease
		Anacapa	
intact	7	0.383 ± 0.024	–10.5
crushed	10	0.251 ± 0.029	–41.4
combined	17	0.305 ± 0.039	–28.8
		Los Coronados	
intact	6	0.298 ± 0.032	–30.4
crushed	17	0.252 ± 0.017	–41.2
combined	23	0.264 ± 0.016	–38.3

RESULTS AND DISCUSSION

Mean values of measurements of the intact eggs collected in 1969 from each colony and the average of the combined samples, together with museum measurements, are summarized in Table 1. The Anacapa eggs have significantly lowered shell weights and shell-thickness indices and significantly thinner shells than the museum specimens ($p < 0.05$). The length of the Anacapa shells shows no significant differences from the mean length of museum specimens. The recent eggs, however, show a greater breadth, which we attribute to sampling error. The eggs from Los Coronados also have reduced thickness indices and shell weight, and thinner shells ($p < 0.05$). Neither the breadth nor the length of the 1969 Los Coronados eggs are different from those collected prior to 1946. The San Martín eggshells show no significant differences of any of the parameters from the museum specimens.

Mean thickness of both crushed and intact eggs and of the combined samples collected on Los Coronados and Anacapa are given in Table 2. No crushed eggs were found on San Martín. The mean shell thicknesses of crushed eggs collected on both Anacapa and Los Coronados are significantly lower than the thickness of the intact eggs collected from these colonies ($p < 0.05$). The eggshells collected from both islands in 1969 ($N = 40$) show a combined decrease in mean thickness of 34.2 percent from museum eggs taken prior to 1946.

The arithmetic mean and concentration range of values of the DDT compounds and PCB found in the lipids of yolks from eggs of each colony are

TABLE 3

MEAN CONCENTRATIONS OF DDT COMPOUNDS AND PCB IN PARTS PER MILLION IN YOLK LIPIDS OF DOUBLE-CRESTED CORMORANT EGGS COLLECTED IN 1969
(THE RANGE OF CONCENTRATIONS IS LISTED IN PARENTHESES.)

Colony	N	p,p'-DDE	PCB	p,p'-DDD	p,p'-DDT
Anacapa	7	754 (510–1,000)	87 (55–130)	2.1 (0.66–6.8)	7.0 (0.0–11)
Los Coronados	6	574 (180–1,300)	422 (66–1,100)	13.8 (3.6–36)	5.5 (0.0–12)
San Martín	7	41.4 (24–63)	17.6 (12–25)	not detected	0.28 (0.14–0.41)

listed in Table 3. The mean DDE concentrations in the Anacapa and Los Coronados eggs, 754 ppm and 574 ppm respectively on a lipid basis, or about 32 ppm and 24 ppm on a wet-weight basis assuming 4.2 percent lipid, is considerably higher than in the eggs from San Martín where no reproductive failure nor obvious shell thinning was observed. These levels were also much higher than those of eggs of midwest Double-crested Cormorants where the mean DDE concentration from 11 colonies was 10.4 ppm (wet-weight) associated with an 8.3 percent reduction in shell thickness (Anderson, et al., 1969). Other studies of the relationship between organochlorine residues and cormorant reproductive success have reported no apparent reproductive impairment associated with relatively low levels of DDE (Kury, 1969; Potts, 1968). Potts (op. cit.) found a range of 1 to 9 ppm DDE (wet-weight) in eggs of the Shag (*Phalacrocorax aristotelis*) from Great Britain and found no correlation between these levels and embryonic mortality, egg breakage, or fledging success. Kury (op. cit.) reported that a mean level of 6.2 ppm (wet-weight) in Double-crested Cormorant eggs had not apparently reduced breeding success in Maine. These authors, however, did not examine eggs for shell thinning. The comparatively low levels of DDE reported suggest that the degree of thinning, if present, would not be sufficiently great to affect reproductive success.

DDE concentrations in the cormorant eggs of this study show decreasing levels from the Anacapa-Los Coronados colonies southward to San Martín Island. A north-south gradient of DDE concentrations along the West Coast has also been observed in northern anchovies (*Engraulis mordax*) (Risebrough, et al., in press), in sand crabs (*Emerita analoga*) (Burnett, 1971), in the Brown Pelican (*Pelecanus occidentalis*) (Risebrough, 1972), and in the California mussel (*Mytilus californianus*) (Southern California Coastal

Water Research Project, 1973). This gradient, which peaks in the Los Angeles area, is attributed to the effluent of a DDT manufacturing company in Los Angeles (Burnett, 1971; Risebrough, et al., in press; Schmidt, et al., 1971).

Analysis for dieldrin and endrin yielded no concentrations greater than 1 ppm (lipid-basis) for dieldrin and only trace amounts of endrin.

The Spearman rank correlation coefficient (r_s) between increasing DDE concentrations and decreasing thickness in the combined sample of Anacapa, Los Coronados, and San Martín eggs was 0.615 ($p < 0.01$). In these populations, therefore, the thinner shelled eggs also have higher concentrations of DDE. PCB, however, is highly correlated with DDE in these samples ($r_s = 0.804$; $p < 0.01$). Thus eggs that are heavily contaminated with DDE also have high concentrations of PCB and decreasing thickness is also correlated with PCB ($r_s = 0.749$; $p < 0.01$). Because of this close relationship between DDE and PCB, we cannot conclude, as we have done in a study of a much larger sample of eggs of Brown Pelicans breeding in the same areas (Risebrough, 1972), that no relationship exists between PCB and shell thinning. Experimental studies have shown that PCB has no effect on shell thickness of Ring Doves (*Streptopelia risoria*) (Peakall, 1971) or Mallard Ducks (*Anas platyrhynchos*) (Heath, et al., in press). Moreover, PCB does not enhance the thinning induced by DDE in Mallards (Risebrough, 1972).

Measurements of 350 museum eggs from interior North America obtained before 1945 yield a mean thickness of $0.430 \pm .003$ mm (95 percent C.L.) (Anderson and Hickey, in press). The normal eggshell thickness of the west coast marine populations (Table 1) was therefore identical to that of the fresh-water populations in the interior. We have found that the relationship between thickness and DDE is equivalent in both fresh-water and marine groups. The regression coefficient of thickness of the interior eggs versus ln DDE is –.030 (SE $= 0.005$; $F = 31.8$, df $= 1,27$; $p < 0.001$). The west coast eggs show a regression coefficient of –.029 of thickness versus ln DDE (SE $= 0.008$; $F = 14.4$, df $= 1,18$; $p < 0.001$). In both groups more than 80 percent of the variation of thickness from the normal can be explained by the regression on the natural log of DDE. As stated above, however, DDE is closely correlated with PCB in the marine samples as well as in those from the Midwest (Anderson, et al., 1969).

CHARACTERISTICS OF THIN-SHELLED CORMORANT EGGS

Normal eggs of Double-crested Cormorants, like those of other pelecaniforms except the Phaethontidae, are unpigmented and possess a "cover" of variable thickness which surrounds the true shell (in the terminology of Tyler, 1965). The cover is white and is chalky in consistency. It may

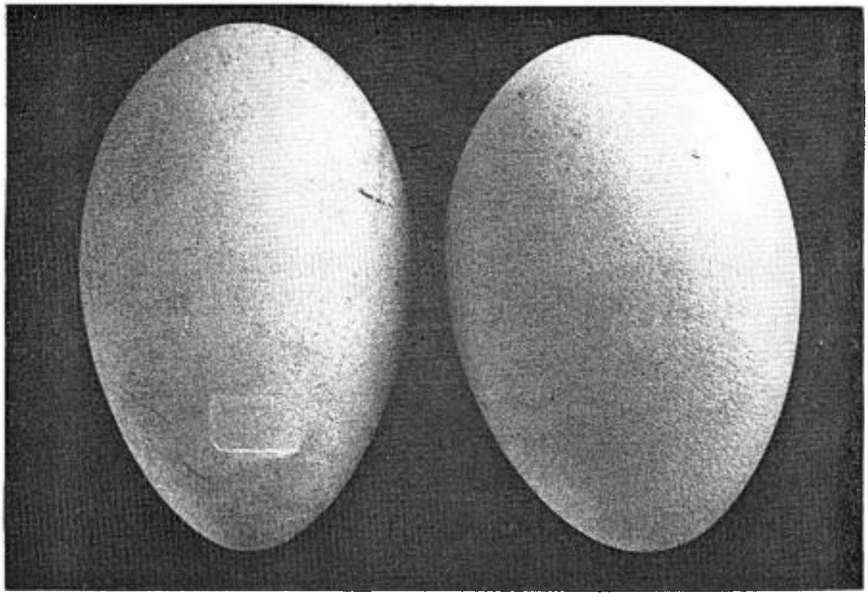

FIG. 1. Comparison of a Double-crested Cormorant egg collected on Anacapa Island, California, prior to 1940 (left) with one collected in 1969 (right). The 1969 egg, appearing bluish in color, lacks a chalky "cover" that normally surrounds the true shell. A portion of the cover has been scraped away on the earlier eggshell (left), exposing the true shell beneath. Photo by Clark Sumida.

easily be scraped away with a needle or fingernail to expose the underlying true shell which is pale blue in color (Fig. 1). According to Tyler (1969*a*) the cover of cormorant eggs consists of organic matter in which small crystals of calcite are imbedded.

Examination of a series of over 300 pre-1940 Double-crested Cormorant eggs in the collection of the Western Foundation of Vertebrate Zoology showed that all possess a cover, except for a few specimens from which this layer had been removed by the original collector. Typical eggs of the species are creamy-white in color and most shells bear brownish nest stains on their surfaces. In contrast, all Double-crested Cormorant eggs and shell fragments found on Anacapa in 1969 and 1971 and Los Coronados in 1969 were bluish in appearance and nearly all were found to be completely lacking the normal chalky cover (Fig. 1).

In experimental tests on egg strength, Tyler (1969*b*) demonstrated that the eggshell cover of *Pelecanus* sp. was of major importance in protecting the shell when subjected to impact. Thus, it is probable that the absence of a cover on the abnormal cormorant eggs contributed to greater breakage of

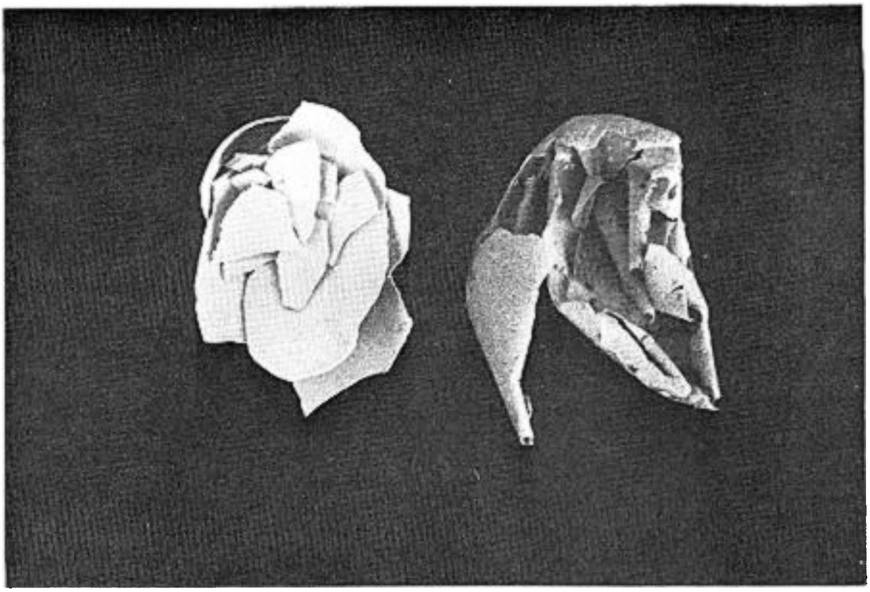

FIG. 2. A broken cormorant eggshell of normal thickness (left) compared with a fragment of an abnormally thin-shelled egg (right). Photo by Clark Sumida.

the eggs by incubating birds. In addition, Tyler (1969*a*) found that the pore channels in the true shell of pelecaniform eggs do not penetrate the cover. Presumably the cover functions to reduce evaporative water loss through the pores and at the same time inhibits the entrance of bacteria into the egg. Eggs lacking the normal cover are therefore not only more likely to break but probably are also more vulnerable to dehydration than normal eggs.

Collapsed eggs and eggshell fragments collected on Anacapa and Los Coronados in 1969 and 1971 could readily be distinguished from broken cormorant eggs of normal thickness by their curled edges. This appears to be due to a crinkling of the shell membranes as they dry out, with the abnormally thin shells conforming to the resulting membrane shapes. Eggshells of normal thickness, whether broken by hand or in normal hatching processes, produce fragments with sharp, jagged edges which do not curl (Fig. 2). In addition, the shell membranes, when attached, conform to the shape of the shell in fragments of normal thickness.

FURTHER OBSERVATIONS ON THE STATUS OF WEST COAST COLONIES

The decline of reproductive success continued on Los Coronados in 1970 and 1971. About 30 pairs of cormorants nesting with pelicans were observed on South Island of Los Coronados in 1970. On 1 June only five nests were still active; no young were observed. Thin-shelled eggs were found around abandoned nests. On 1 June 1971, only five pairs were observed nesting in a deserted colony on South Island; five additional pairs were nesting with pelicans on North Island. No young were observed on either island on that day.

The San Martín colony declined markedly to no more than 1,000 pairs in 1970, presumably because of diminished food resources. Brown Pelicans failed to breed at all on San Martín that year (Jehl, 1973). In 1971, however, the estimated number of breeding cormorants was again at approximately 5,000 pairs. No thin-shelled eggs were observed and all indications were that breeding was normal.

In 1970 observations were made on Anacapa from February to July in the course of a study of Brown Pelicans (Gress, 1970). Of 50 nesting attempts only one was successful, producing three young. To avoid disturbance of the birds the colony area was not entered; thus no egg samples were obtained in 1970. As in 1969, however, the eggs, with the exception of the one nest, did not survive incubation.

In 1971 the Anacapa colony of Double-crested Cormorants was observed monthly between March and August. A total of 48 nests was under observation. To our knowledge there was no human disturbance in the colony until 12 June, when a research group from the Western Foundation of Vertebrate Zoology observed a portion of the colony area at close range. They observed 18 occupied nests of which only one contained intact eggs, a clutch of five. On 29 July only several birds lingered in the colony area at the time of our assessment of reproductive success of both Brown Pelicans and cormorants. Eight occupied nests were observed; three of these contained intact eggs. The clutches consisted of 1, 3, and 4 eggs, all addled. Fragments of 19 crushed eggs, similar to those observed in 1969 and described above, were collected. Mean thickness of these egg fragments was 0.242 ± 0.043 (95 percent C.L.), a reduction of 44 percent from the normal. No young Double-crested Cormorants were therefore fledged on Anacapa in 1971.

In 1972 reproductive success on Anacapa improved. A colony consisting of at least 14 nests was observed by boat on 26 April but was abandoned when the area was surveyed again in May. To our knowledge the birds had not been disturbed by human intruders; moreover, the area was closed to travel by the National Park Service at that time. A second colony was first observed on 29 June. Observations, as on previous occasions, were from a boat. On 15 August, however, the colony area was entered. Eleven recently active nests were counted. Of these, two nests contained two downy young each and a third, one young, the latter about to fledge. Moreover, four young of the year were observed on offshore rocks in the company of adults. Approximately 60 adults were counted along the shores of Anacapa. In spite of the lateness of the season, a majority of them had bright orange gular pouches.

Brown Pelicans breeding in southern California also showed an increase in productivity in 1972. Whereas the pelican colony on Anacapa produced 2 to 4 young from 1272 known nesting attempts in 1969 (Risebrough, Sibley, and Kirven, 1971), one young in 552 nesting attempts in 1970 (Gress, 1970), and 7 young in approximately 540 nesting attempts in 1971 (F.G., D.W.A.), 57 young were produced in 1972 in 260 nesting attempts between two colonies, one on Anacapa and the other on Scorpion Rock near Santa Cruz Island (D.W.A., F.G., R.W.R.).

In April 1970, the DDT manufacturing company in Los Angeles began to dispose of its liquid wastes in a sanitary landfill rather than discharging them into the sewage systems of the Los Angeles County Sanitation Districts. Input of DDT residues into the sea from this sewage system has declined sharply since that time (Carry and Redner, 1970; Redner and Payne, 1971; Risebrough, et al., in press). In anticipating the results of studies now underway, we suggest that the improved reproductive success of both Double-crested Cormorants and Brown Pelicans observed in 1972 is an indication of a decrease of DDE levels in the southern California coastal marine ecosystem.

SUMMARY

Double-crested Cormorants have experienced reproductive failures in colonies on Anacapa Island in southern California and Los Coronados Islands of northwestern Baja California. These failures were characterized by eggs with thin shells that collapsed in the nest during incubation. The pattern of reproductive failures was the same as that observed in Brown Pelicans breeding in the same areas. Shell thinning was not found on San Martín Island, and reproductive success of the cormorant colony there apparently was not affected.

Data are given for eggshell measurements and chlorinated hydrocarbon residues for eggs collected from these colonies in 1969. The eggshells from Anacapa and Los Coronados show a 34 percent decrease in thickness from pre-1946 museum eggs. DDE levels in the yolk lipids show a concentration gradient decreasing southward from Anacapa to San Martín. The values of r_s (Spearman rank correlation coefficient) between decreasing shell thickness and increasing concentrations of both DDE and PCB are highly significant. PCB levels parallel those of DDE; it was not possible therefore to separate the effects of PCB and DDE on eggshell thinning in this study. The relationship between DDE and shell thickness of these eggs, however, was equivalent to that of midwest fresh-water cormorant colonies.

The eggshells from Anacapa and Los Coronados were found to be lacking a chalky cover characteristic of normal eggs, possibly contributing to a greater fragility of the shells.

Further field observations indicate an apparent increase of productivity on Anacapa in 1972. No young were observed on Los Coronados in 1970 and 1971. The San Martín colony suffered a decline in 1970, presumably from lack of food resources, but returned to normal numbers in 1971.

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