EFFECTS OF TOXIC POLLUTANTS ON PRODUCTIVITY IN COLONIAL WATERBIRDS

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This paper is a review of reported effects of toxic pollutants on productivity, or reproductive success, in colonial waterbirds. It is necessarily brief and somewhat speculative, because in fact we know very little about these effects. One problem is that it is very difficult to measure productivity in colonial waterbirds without reducing it by disturbance; there are surprisingly few precise and reliable measurements of reproductive success in the literature on colonial waterbirds or on other sensitive species. Most of the published reports of toxic effects either describe spectacular effects such as total reproductive failure and heavy chick mortality, or report measurements of something else, such as eggshell thinning, egg breakage, or embryonic mortality. Even if the scope of the review is broadened to include all effects on reproductive performance, we still know very little about the effects that may be taking place at the present time. Over much of North America and Western Europe, where most studies of these effects have been carried out, the levels of the two pollutants of greatest concern—DDE and dieldrin—have decreased markedly in the last five or 10 years. As a consequence, the reproductive performance of many affected species has returned almost to normal. One subject of this paper is the precise meaning of this phrase "almost to normal."

For the purposes of this review, I have divided the reported effects into four categories, listed in diminishing order of severity. I also include discussion of two more speculative categories of effects, which are the subject of recent and current research.

Acute Poisoning of Breeding Adults or of Nestlings

There are remarkably few published reports that fall into this category. Most of them date from the 1960s and involve poisoning with cyclodiene insecticides.

1. The most spectacular incidents of this kind were reported in The Netherlands in the period 1962–1965 (Koeman, 1972). They were traced to residues of telodrin (and to a lesser extent, dieldrin) that were discharged in effluents from a manufacturing plant and accumulated in fish and shellfish. The species most severely affected was the Sandwich Tern (*Sterna sandvicensis*)—large numbers of adults and chicks were killed and the breeding population in The Netherlands was reduced by 97–98 percent (Koeman *et al.*, 1972; Rooth and Jonkers, 1972). Other species affected were the Common Eider (*Somateria mollissima*) (Swennen, 1972), and probably the Least Tern (*Sterna albifrons*), the Common Tern (*S. hirundo*), and the Spoonbill (*Platalea leucorodia*) (Rooth and Jonkers, 1972).

2. Severe mortality of waterbirds resulting from the use of aldrin-treated rice seed was observed in Texas and Missouri in the period 1967–74 (Flickinger and King, 1972; Flickinger and Meeker, 1972; Flickinger, 1979; Babcock and Flickinger, 1977). The species most severely affected were the White-faced Ibis (*Plegadis chihi*), in which large numbers of nestlings were poisoned by contaminated invertebrates fed to them by their parents, and the Fulvous Whistling-Duck (*Dendrocygna bicolor*)

and the Snow Goose (*Chen caerulescens*), in which large numbers of adults were killed.

3. Other reported effects on colonial waterbirds have been documented less conclusively. There is strong circumstantial evidence that the population crash and disappearance of Brown Pelicans (*Pelecanus occidentalis*) from the Louisiana coast in the early 1960s were related to the pollution of the Mississippi River with endrin (King *et al.*, 1977; Blus *et al.*, 1979a). Following the re-introduction of Brown Pelicans to Louisiana, a number were killed in 1975, apparently by poisoning with endrin and/or other cyclodienes (Blus *et al.*, 1979a). Poisonings and major population declines of the Bald Ibis (*Geronticus eremita*) in Turkey and of the Japanese Crested Ibis (*Nipponia nippon*) in Japan in the period 1956–1968 were also attributed to unspecified pesticides (Hirsch, 1977; Yamashima, 1977).

I have not found any documented accounts of mass poisonings of colonial waterbirds attributable to use of DDT (*cf.* Rudd and Genelly, 1956). Abrupt population declines have been reported mainly since 1956 and appear to be attributable primarily to cyclodiene insecticides.

Delayed Lethal Effects

A number of incidents have been reported in which lethal poisoning of colonial waterbirds has been attributable to accumulation of persistent chemicals in the birds' tissues, followed by release of the chemicals into the bloodstream as a result of subsequent stress. There is some overlap between incidents in this category and the direct poisonings listed in the previous section.

1. One of the best documented cases is that of the Common Eider in The Netherlands, referred to above. Female Common Eiders accumulated telodrin and dieldrin in their tissues from feeding on contaminated shellfish, and were subsequently poisoned as they mobilized their fat reserves while fasting during incubation. In the period 1962–65 up to 60% of the breeding females died each year. After 1965 the mortality rate declined in parallel with the decline in cyclodiene residues; most deaths in the period 1966–68 were attributed to the combination of an otherwise nonlethal pollutant load with otherwise nonlethal infection with intestinal parasites (*Polymorphus botulus*) (Koeman, 1971; Swennen, 1972).

2. In the summers of 1969 and 1973, more than 100 Ring-billed Gulls (*Larus delawarensis*) were found dead in southern Ontario. On the basis of residue levels in the brain, their deaths were attributed to poisoning with PCBs, probably in combination with DDE and dieldrin (Sileo *et al.*, 1976).

3. The deaths of a number of Great Cormorants (*Phalacrocorax carbo*) in The Netherlands in the spring of 1970 were attributable to poisoning with PCBs, on the basis of residue levels in tissues (Koeman *et al.*, 1972, 1973).

4. In 1967, 1971, and 1972, unusual mortality of nesting female Snow Geese took place in a colony at McConnell River, Northwest Territories, Canada. The circumstances of the mortality were similar to those of the Common Eiders referred to above. The mortality followed poisonings of Snow Geese from the same population in Texas prior to spring migration, and dead birds had dieldrin residues in their brains (Flickinger, 1979).

5. Although the Bald Eagle (*Haliaeetus leucocephalus*) is not a colonial waterbird, it is pertinent that up to 15% of the eagles found dead in various parts of the United States since 1963 have had lethal residue levels of one or more chlorinated hydrocarbon pollutants in their tissues. Most of these deaths are attributable to poisoning with dieldrin, but a few birds have contained lethal or near-lethal residue concentrations of DDE, PCBs, and endrin; in some cases residue levels of heptachlor epoxide and oxychlordane were sufficiently high to have contributed to the lethal toxic effects (Reichel *et al.*, 1969; Mulhern *et al.*, 1970; Belisle *et al.*, 1972; Cromartie *et al.*, 1975; Prouty *et al.*, 1977; and unpublished data from the U.S. Department of the Interior).

6. Other miscellaneous reports in this category include deaths of Western Grebes (*Aechmophorus occidentalis*) in California attributable to poisoning with DDD (Hunt and

Bischoff, 1960), of Great Egrets (*Casmerodius albus*) in California attributable to poisoning with dieldrin (Faber *et al.*, 1972), of a Great Blue Heron (*Ardea herodias*) in South Dakota attributable to poisoning with DDE (Call *et al.*, 1976), and of a Glaucous Gull (*Larus hyperboreus*) at Bear Island attributable to poisoning with PCBs (Bourne and Bogan, 1972). The last report is especially noteworthy because it referred to a site remote from any likely point of discharge. Young *et al.* (1979) have recently shown that fish caught off southern California contain enough DDE to kill gulls and cormorants after prolonged feeding.

A noteworthy feature of the reports cited in this section is that they have involved a variety of different organochlorine compounds, including several of relatively low toxicity, such as DDD, DDE, and PCBs.

Effects on Reproductive Performance in the Absence of Overt Mortality

The principal reported effects that fall into this category are hatching failure and eggshell thinning. These two effects are closely related, although each can occur in the absence of the other (Ratcliffe, 1972; Blus *et al.*, 1974; Fox, 1976; Fyfe *et al.*, 1976). The examples listed below are the best documented cases in which reductions in productivity have been associated with residue levels of toxic pollutants.

1. *Brown Pelican.* Productivity in Brown Pelicans was severely reduced in both Atlantic and Pacific coast colonies during the 1960s, in association with high residue levels of organochlorine compounds (Anderson *et al.*, 1975; Blus *et al.*, 1972a, b, 1974, 1977, 1979b; Jehl, 1973; Keith *et al.*, 1970; Risebrough *et al.*, 1970). In California, almost complete hatching failure was associated with egg breakage and extreme eggshell thinning, which in turn were associated with residues of DDE (Risebrough *et al.*, 1970; Anderson *et al.*, 1975). In South Carolina, the degree of eggshell thinning was lower than in California and direct embryotoxic effects may have been more important. Nest failure was associated primarily with residues of DDE, although effects of dieldrin could not be excluded (Blus *et al.*, 1972a, b, 1974, 1977, 1979b). In both California and South Carolina, productivity increased rapidly as residues of DDE (and dieldrin) declined after 1972 (Anderson *et al.*, 1975; Blus *et al.*, 1979b).

2. *Common Tern.* Very low productivity in Common Terns nesting in Alberta in 1972 was attributed primarily to egg breakage and to embryonic mortality. The degree of eggshell thinning was comparatively minor in this population, and the effects were traced in part to disruption of eggshell structure, which reduced the oxygen supply to the embryo. Behavioral abnormalities were detected in chicks hatching from affected eggs. All these effects were statistically associated with DDE residues in the eggs (Fox, 1976). The circumstances are noteworthy because levels of DDE and other toxic pollutants were extemely low in the terns' local food supply: the residues responsible for the effects were probably acquired in Mexico during spring migration (Fox, 1976). Hatching success of Common Terns has also been unusually low at colonies in Lakes Erie and Ontario in the period 1972–77, in association with high residues of DDE, PCBs, and other toxic pollutants, but productivity has not been clearly affected since 1972 (Gilbertson, 1974b; Morris *et al.*, 1976; Courtney and Blokpoel, 1979). A small number of abnormal chicks was noted in 1971–73 (Gilbertson *et al.*, 1976). Low productivity of Common Terns was also reported at Clay Lake, in western Ontario, in 1971, and was attributed tentatively to severe local contamination with mercury (Vermeer *et al.*, 1973), but the evidence for this was only circumstantial.

3. *Herring Gull.* Reproductive failure of Herring Gulls (*Larus argentatus*) at a colony in Lake Michigan in 1964 was associated with flaking of eggshells, embryonic mortality, and high levels of DDE (Keith, 1966). Since 1971, productivity of Herring Gulls at colonies in Lake Ontario has been very low relative to that of other colonies on the Great Lakes (Gilman *et al.*, 1977). Reproductive failures are characterized by disappearance of eggs and nests, death of embryos during incubation, and death

of chicks around the time of hatching; parental behavior also appears to be abnormal (Gilbertson and Hale, 1974a, b; Gilbertson and Fox, 1977; Gilman *et al.*, 1977; Fox *et al.*, 1978). The effects are associated with elevated levels of DDE, PCBs, and Mirex, but a causal association has not been demonstrated (Gilbertson, 1974a; Gilbertson and Fox, 1977; Gilman *et al.*, 1977, 1978).

4. *Black-crowned Night Heron.* Productivity of Black-crowned Night Herons (*Nycticorax nycticorax*) on Pigeon Island, Lake Ontario, in the period 1972–76 was very low due to a combination of low hatchability of eggs and poor survival of young. The low hatching success was associated with egg breakage, eggshell thinning, and high residues of DDE, PCBs, and dieldrin (Price 1977). In an extensive study in the eastern United States and Canada, eggshell thinning in this species was more closely related to levels of DDE than to other pollutants, but evidence for effects on productivity was only circumstantial (Ohlendorf *et al.*, 1977).

5. *Great Blue Heron.* Reproductive failure of Great Blue Herons at Red Rock Reservoir, Iowa, in 1970–72 was associated with near-lethal levels of DDE and dieldrin in the tissues of newly hatched chicks (Konermann *et al.*, 1977). In other studies of Great Blue Herons, high levels of DDE and dieldrin have been associated with eggshell thinning and adult mortality, respectively, but not clearly with reduced productivity (Vermeer and Reynolds, 1970; Faber *et al.*, 1972).

6. *Great Egret.* Reduced reproductive success of Great Egrets as a colony in California in 1967–70 was associated with high levels of dieldrin in adults (Faber *et al.*, 1972).

7. *Gannet.* A decline in the breeding population of Gannets (*Morus bassanus*) at Bonaventure Island, Quebec, between 1969 and 1973 was associated with low hatching and fledging success during the 1960s, which in turn were associated with eggshell thinning and high levels of DDE (Pearce *et al.*, 1973; Nettleship, 1975). In Scotland, eggshell thinning in Gannets was statistically associated with residues of DDE, but a significant effect on productivity has not been shown (Parslow and Jefferies, 1977).

8. *Double-crested Cormorant.* Double-crested Cormorants (*Phalacrocorax auritus*) nesting off southern California and in the Great Lakes experienced almost total reproductive failure in the period 1969–71, associated with crushed eggs, thin and defective eggshells, and high levels of DDE, PCBs, and dieldrin (Gress *et al.*, 1973; Postupalsky, 1971). Eggshell thinning in this species is statistically associated with residues of DDE (Gress *et al.*, 1973; Anderson *et al.*, 1969). Reproductive success has increased in both areas since 1972 (R. W. Risebrough and S. Postupalsky, unpublished data). In a population of this species in coastal Maine, egg residues of DDE were only modest during the 1960s, but reproductive success was nevertheless unusually low (Kury, 1969).

9. *Cahow.* Reduced productivity in the Cahows (*Pterodroma cahow*) of Bermuda in the period 1966–70 was associated with high residues of DDT and its metabolites in eggs (Wurster and Wingate, 1968). Since 1972 residues of DDE have decreased in Cahow eggs, and eggshell thickness and productivity have increased (D. B. Wingate, personal communication).

Effects on Reproductive Performance Which do not Lead to Reduction in Productivity in the Absence of Other Stress Factors

The outstanding effect in this category is eggshell thinning, which has been recorded in at least 30 species of colonial waterbirds in North America or Western Europe (Anderson and Hickey, 1972; Ratcliffe, 1970; Faber and Hickey, 1973; Koeman *et al.*, 1972; King *et al.*, 1978; Ohlendorf *et al.*, 1978; and other papers cited above). Indeed, it seems likely that most colonial waterbird species suffered from eggshell thinning in at least some areas in the 1950s and 1960s. In all cases where statistical analysis has been carried out, eggshell thinning is closely associated with residue levels of DDE, and there is no evidence that other pollutants make any contribution to eggshell

thinning in wild birds (see references cited above, and Cooke, 1973; Peakall, 1975). According to a tabulation by Peakall (1975), Pelecaniformes and Ciconiiformes are highly sensitive to DDE-induced eggshell thinning, and Charadriiformes (Laridae) are moderately sensitive.

Although broken and cracked eggs have been noted in colonies of Common Terns and White-faced Ibises with only 3–4% eggshell thinning (Fox, 1976; King *et al.*, 1978), in most species egg breakage does not become significant until the degree of shell thinning exceeds 10%, and productivity is not usually reduced significantly until shell thinning exceeds 15–20% (Ratcliffe, 1970, 1972; Anderson and Hickey, 1972). Except for the nine species listed above, most of the reported instances of eggshell thinning in colonial waterbirds appear to have been below the threshold for significant adverse effects on productivity. However, it should be stressed that productivity is not often measured, and the few reported cases are not likely to represent the full range of populations affected.

In addition to eggshell thinning, a few other effects of toxic pollutants on reproduction have been reported, which were apparently insufficient to cause significant reductions in productivity.

1. In Grey Herons (*Ardea cinerea*) in Great Britain, the principal cause of egg loss was deliberate breaking and ejecting of eggs by the parents. Although more than half the pairs under study broke their eggs in some years, overall productivity of the colony was not markedly reduced, because most pairs repeatedly produced a new clutch (Milstein *et al.*, 1970). Egg breakage was associated with high levels of DDE and dieldrin in eggs (Cooke *et al.*, 1976), whereas eggshell thinning in this species is related primarily to DDE (Koeman *et al.*, 1972).

2. Deliberate egg breaking has also been reported in Great Blue Herons in Iowa, in association with high levels of dieldrin (Konermann *et al.*, 1977). In Alberta and California, productivity of Great Blue Herons was not clearly reduced in spite of eggshell thinning (Faber *et al.*, 1972; Vermeer and Reynolds, 1970).

3. Egg breakage in Shags (*Phalacrocorax aristotelis*) was apparently related both to social factors and to high levels of dieldrin, but only a few birds were affected (Potts, 1968).

4. In my studies of Common Terns in Massachusetts, I have found associations between failure of eggs to hatch, reduced porosity of eggshells, and residue levels of PCBs and/or DDE. However, hatching failures are rare (only 1–8% of eggs laid) and productivity is not measurably affected. I have also recorded behavioral abnormalities in chicks from the most contaminated colony, but preliminary data suggest that post-fledging survival is not affected. These effects are similar to those recorded by Fox (1976), but appear to represent only marginal effects on reproductive performance.

Although only a few effects of this kind have been described, they would be difficult to detect without detailed observation and measurement. The lack of baseline data on behavior, physiology, and breeding performance in colonial waterbirds in the pre-pesticide era makes it very difficult to establish the existence of subtle effects of this kind. Nevertheless, the pervasive occurrence of eggshell thinning (an effect for which it was possible to reconstruct baseline data from museum specimens) demonstrates that many colonial waterbird populations do show measurable sub-threshold effects of environmental pollutants. The occurrence of other physiological and behavioral effects is therefore likely. Even when such effects are below the threshold for causing significant reductions in productivity, they are potentially important because they may interact with other stress factors.

Effects in Search of a Cause

A number of other effects on reproductive performance in colonial waterbirds have been described. Although they have been reported primarily in highly contaminated populations, their relation to these contaminants is more speculative. In addition to the apparent behavioral anomalies in Herring Gulls, Common Terns, and Grey Herons referred to above, these effects include the following:

1. Abnormal feather loss and congenital anomalies in Common Terns and other species (Hays and Risebrough, 1972; Gilbertson *et al.*, 1976).

2. Reduced clutch size in Black-crowned Night Herons and Common Terns (Ohlendorf *et al.*, 1977; Fox, 1976).

3. Female-female pairing in Western Gulls (*Larus occidentalis*) (Hunt and Hunt, 1977) and Ring-billed Gulls (Ryder and Somppi, 1979).

The supposed relationships of these effects to toxic contaminants need further investigation.

Causes in Search of an Effect

In addition to the effects recorded in the field which can be associated more or less conclusively with residues of toxic pollutants, there are a number of other effects of toxic chemicals on reproduction in birds which have been detected in laboratory experiments, but which have not yet been matched by corresponding field observations. A short list of these effects includes the following:

1. Effects of petroleum hydrocarbons on egg hatchability (Albers, 1978; Coon *et al.*, 1979).

2. Effects of DDE and other toxic chemicals on behavior of chicks (Heinz, 1976).

3. Two-generation effects of dieldrin on reproductive performance and behavior (Baxter *et al.*, 1969).

4. Teratogenic and chromosomal effects of PCBs (Tumasonis *et al.*, 1973; Peakall *et al.*, 1972).

5. Effects of PCBs on incubation behavior (Peakall and Peakall, 1973).

6. Effects of methylmercury on reproductive success (Scott *et al.*, 1975).

Although all these effects have at least potential parallels in phenomena already observed in the field, much more detailed work is required to determine whether or not they are significant under field conditions.

Summary and Conclusions

Adverse effects of toxic pollutants on reproductive performance have been reported for at least 35 species of colonial waterbirds in North America or Western Europe. For about half the species, the reported effects included significant reductions in productivity; for the other half the principal effect reported was eggshell thinning, without measurable reduction in productivity.

Although eggshell thinning took place in some species before 1951, most of the more striking effects (mass mortality of adults or nestlings, or population crashes), did not occur until the period 1956–73. The latter effects are attributable primarily to dieldrin and/or other cyclodiene insecticides, whereas eggshell thinning and other effects on reproduction are attributable primarily to DDE. Combined effects of DDE and dieldrin may have been important in several cases.

There is little direct evidence that PCBs have had significant effects on reproductive performance in colonial waterbirds. Apart from one inconclusive case involving mercury, there are no reports implicating toxic pollutants other than chlorinated hydrocarbons as having significant effects on productivity.

With the general reduction in environmental levels of DDE and dieldrin in North America and Western Europe, the reproductive performance of several affected species has at least partially recovered. Most of the remaining effects of toxic pollutants are likely to be effects on eggshell thickness or structure, or on aspects of reproductive physiology or behavior that are difficult to measure without intensive study. However, such effects are important to study: (a) because they may affect productivity when acting in conjunction with other environmental stresses; (b) because they complicate interpretation of field data. *Without detailed study of potential sub-lethal toxic effects, no colonial waterbird species can be assumed to be normal in its reproductive performance, physiology, or behavior.*

Since DDT and dieldrin are still being used fairly widely in "Third World" countries, it is reasonable to assume that major effects on colonial waterbirds are still taking place there. However, almost no studies have been reported.

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Comments

Schreiber: Ian, I would like to emphasize a point that you started out with: the effect of investigator bias on measuring reproductive success. I have been working with Brown Pelicans and Laughing Gulls and am finding it almost impossible to compare results between years, and certainly between investigators, because everyone is looking at the colony and checking nests on different cycles. The figures for productivity are not comparable between studies. It is something that behooves all of us, as students of colonial birds, to be very concerned about the "paper figure and population reality," as Joe Hickey called it in 1955. We need to look very carefully at the numbers we are publishing in our tables because other people use them without looking at our methodologies.

Nisbet: I didn't say so, but I agree with you very strongly. It is a major obstacle to measuring productivity and to comparing productivity. I believe we can do certain comparisons, however. There are certain species for which investigator bias doesn't affect clutch size very much, or doesn't affect hatching success very much even though it may affect chick survival.

Ohlendorf: Could you give PCB and DDE residue concentrations for the tern eggs that you mentioned?

Nisbet: The PCB concentrations which were associated with differences in eggshell structure and hatching success, and also chick behavior, were on the order of 20–30 parts per million in the whole egg. In the other colony the only significant difference I found was in DDE levels—a difference between 1.5 and 0.5 parts per million in the whole egg.

Ohlendorf: Those are wet weight?

Nisbet: Wet weight.

Gallegos: Do you have any knowledge at all of lead poisoning from environmental contaminants? I am asking this because in New Jersey we have a lead-shot ban during the waterfowl hunting season. It has been my belief that the lead-shot problem may not originate from just lead-shot deposition during the hunting season; it may also be from environmental contaminants.

Nisbet: In preparing for this talk I read a lot of papers on lead poisoning, and I did not find a single one on a colonial waterbird species. That is not to say it does not occur, but as far as I know it has not been documented.

Unidentified: Could you expand a little bit on your differences in your two tern colonies that were 50 km apart, which by our standards is very close, to show differences in residue levels? Can you explain the particular situation that allows the birds from the two different colonies to have different residue levels?

Nisbet: One is in Buzzards Bay, Mass., which is highly polluted with PCB's from a local point source. The other is on the outer part of Cape Cod, Mass., which is in the Labrador Current and has exceptionally clean water.

Bourne: I am rather worried about our situation at home with regard to the maintenance of

routine monitoring. We had a good deal of trouble in the 60s and our Nature Conservancy, as it then was, was pretty militant in drawing attention to this; and steps were taken to deal with it. The people who are now doing the monitoring are at the Ministry of Agriculture. They are efficient and do apply pressure to the manufacturers, but they maintain a very low profile and don't make their results known on the same scale as previously. We no longer have the same level of public awareness and control. If this isn't happening in Western Europe, one very much wonders what level of monitoring is being maintained in the developing nations. While the effects of all these compounds are debatable, the information which is absolutely vital and which we need for the future is the way in which the levels are changing. We need fairly adequate samples so that if at some stage in the future we wish to look back and see what happened we do have a record. Personally, I am becoming increasingly worried about this and would hope that steps can be taken to maintain a better world record.

Nisbet: Monitoring is very important for a number of reasons. One global monitoring scheme which is being promoted by people in the United States is the Mussel Watch, which I think will have some value. But the theme of my paper was that the effect of toxic chemicals on reproduction in birds is primarily a research problem and is a good deal more difficult than it was 10 years ago when levels were higher and the effects were more overt. I don't think routine monitoring is going to help us very much with that research. To solve questions we will have to focus primarily on the individual bird, the individual colony, the individual egg, or the individual fish. If we are going to answer the difficult questions which I have raised here, we need a lot more precise measurement at that level.