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# SURVIVAL AND REPRODUCTIVE SUCCESS OF BLACK DUCKS FED METHYL MERCURY

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*ABSTRACT*

*A diet containing* 3 *ppm mercury was fed to black ducks* (Anas rubripes) *for periods of* 28 *weeks during two consecutive breeding seasons. Clutch size, egg production, number of eggs incubated, hatchability and survival of ducklings were lower during both years in hens fed mercury. Reduced hatchability and poor duckling survival were the most harmful effects. During* 2 *years,* 13 *pairs of breeders fed mercury produced only* 16 *ducklings that survived* 1 *week compared with* 73 *ducklings from* 13 *pairs of controls. Mercury residues in eggs, embryos and ducklings averaged about* 30% *lower during the second breeding season compared with first year results. Third eggs laid by treated hens contained a mean of* 6·14 *and* 3·86 *ppm mercury during the first and second years. Whole embryos that failed to hatch contained means of* 9·62 *and* 6·08 *ppm mercury during the first and second years. Brains of dead ducklings contained between* 3·25 *and* 6·98 *ppm mercury and exhibited lesions characteristic of mercury poisoning. Relative tissue mercury levels for treated adult breeders were: feathers > liver > kidney > breast muscle > brain. Mercury levels in males and females did not differ.*

## INTRODUCTION

The highly toxic and persistent alkyl mercury compounds have caused severe pollution problems in both terrestrial and aquatic habitats. With the decline in usage of mercurials for seed treatment, the greatest potential hazard to birds from mercury contamination seems to be with species occupying higher trophic levels in aquatic food chains. Several reports have assessed mercury residues in tissues and eggs of a variety of wild birds in different localities (Borg *et al.*, 1969; Vermeer, 1971; Dustman *et al.*, 1972; Fimreite, 1974; Baskett, 1975). Laboratory studies of mercury

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kinetics and toxicity have contributed to the interpretation of mercury levels carrie by wild birds (Miller *et al.*, 1970; Gardiner, 1972; Hough & Zabik, 1972; Wright *al.*, 1974).

Experimental studies have shown that low dietary concentrations of mercury ca lower reproductive success in certain birds. Ethyl mercury fed in the diet reduced eg production and embryo survival in pheasants (*Phasianus colchicus*) (Spann *et al* 1972). Sublethal doses of methyl mercury reduced hatchability and caused chic mortality in chickens (Wright *et al.*, 1974). Reproductive failure occurred i pheasants (Borg *et al.*, 1969; Fimreite, 1971) and in mallard ducks (*Ana platyrhynchos*) when fed low dietary levels of methyl mercury (Heinz, 1975). In thes studies mercury treatment had little adverse effect on the health of adults, bu enough mercury transferred into eggs to lower hatchability and cause embryoni mortality.

The population of North American black ducks (*Anas rubripes*) in the easter United States has shown a continuous decline during the past 20 years (Bellrose 1976). This decline cannot be explained solely by hunting pressure, habita destruction, or genetic swamping due to hybridisation with mallards (Heusmann 1974). Sufficient data are not available to interpret levels of environmenta pollutants and possible harmful effects on waterfowl reproduction. A survey o mercury residues in eggs of several species of dabbling and diving ducks in the Canadian prairie indicated that mercury contamination occurred on the breeding ground (Vermeer, 1971). A monitoring survey revealed that mercury residues were highest in the wings of adult black ducks from the Atlantic Flyway (Heath & Hill, 1974). The present study was designed to determine the effects of a low dietary level of methyl mercury on survival and reproduction of captive black ducks through two successive breeding seasons. Concentrations of mercury were determined in tissues of young and adult birds.

## MATERIALS AND METHODS

One-year-old black ducks from a captive colony were randomly paired and assigned to 4·6 × 9·1 m outdoor pens in December 1972. Each pen was equipped with a 908 litre water trough, nest box and feeder. One group of 13 pairs received *ad libitum* commercial duck breeder mash containing 3 ppm mercury (as 2·2 % methyl mercury dicyandiamide in Morsodren). Another group of 13 pairs served as controls. Feed was prepared by dissolving Morsodren in propylene glycol equivalent to 2 % (w/w) of the total diet and mixing into the mash. Only propylene glycol was mixed into the control diet. Samples of feed from each mixing were saved for mercury analysis.

Breeders were placed on mercury-treated feed in January 1973, approximately 3 months before laying. Birds were weighed in late January and at monthly intervals beginning in July after the reproductive season. Reproductive success of all birds

was followed throughout the breeding season. At the onset of laying, nest boxes were checked daily. Eggs were marked and examined for cracks. The third egg from each hen was collected for residue analysis and eggshell measurements. Females that abandoned their first clutch of eggs were allowed to renest. The contents of all eggs which failed to hatch and ducklings that died were saved for residue analysis. Drakes were removed from the breeding pens and placed on untreated feed 1 week before eggs were scheduled to hatch. Ducklings were brooded by hens and fed starter mash containing 3 ppm mercury. Hens were taken off treated feed in July at the conclusion of the 1973 breeding season; the duration of mercury ingestion was 28 weeks. Offspring from hens fed mercury remained on the treated diet.

These procedures were continued through the second breeding season. In August 1973, 1 control hen died of unknown causes and was replaced by a hen of the same age and background. Breeders were again placed on treated feed in January 1974 and reproductive success followed for a period of 28 weeks. During the second year, the diets of ducklings were supplemented with amprolium-ethopabate (0·013 %) to control coccidiosis. At the conclusion of the 1974 breeding season all 26 pairs of breeders and ducklings of hens fed mercury were sacrificed and tissues saved for histopathological examination and mercury analysis.

During both breeding seasons ducklings that exhibited signs of tremors and loss of co-ordination were saved for histological examination. Ducklings subjected to necropsy were either collected immediately after death or sacrificed in a moribund condition. Kidney, heart, liver and half of the brain were fixed in 10 % formalin. Tissues were embedded in paraffin, sectioned and stained by either haematoxylin and eosin, Luxol's blue or Ziehl-Neelson acid fast.

Samples of primary feathers, liver, kidney, breast muscle and brain from adults and ducklings were analysed for mercury. Brain, yolk sac and remaining carcass were analysed from advanced embryos that failed to hatch. Samples were frozen and shipped to WARF Institute, Inc., Madison, Wisconsin, for mercury analysis by cold vapour atomic absorption. Samples of whole brains and kidneys, 3 g of muscle or diced liver and vaned portions of the primary feathers from right wings were analysed. Yolk sacs and 10 g aliquots of duckling carcasses were analysed. Egg contents were homogenised and a 10 g aliquot analysed. A 3 g aliquot of feed was analysed. All samples were homogenised and digested by refluxing with sulphuric and nitric acid. A mixture of hydroxylamine hydrochloride, stannous chloride and sulphuric acid was added to the digest to reduce ionic mercury to elemental mercury. Samples were aerated and mercury measured in the air stream passing through a gas cell by atomic absorption. Residues in tissues are reported as ppm wet weight with limits of sensitivity of 0·05 ppm. Feed residues are given as ppm dry weight with limits of sensitivity of 0·05 ppm. Mercury recovery on the analytical method was conducted using duplicate and spiked samples. Recovery ranged from 90 to 112 %. Data were not corrected for recovery.

Reproductive data were tested by analysis of variance with arcsin transformations

applied to percentages before analysis. The non-parametric technique of Fisher' exact probability test was used to test certain reproductive parameters (Siegel, 1956) Regression analysis was used to examine the correlation between mercury levels ir various tissues of adult breeders. Significance was tested at the 0·05 level unless otherwise stated.

## RESULTS

### *Reproduction and survival*

No mortality occurred in adult breeders fed 3 ppm mercury for periods of 28 weeks during each of two breeding seasons. One control hen died of unknown causes following the 1973 nesting season. Body weights of breeders taken at 12 intervals during the study revealed no significant difference between controls and treated ducks. Tissue lesions usually associated with mercury poisoning were not found.

The reproductive performance of breeders fed mercury was considerably lower for all parameters measured compared with controls during the 1973 and 1974 nesting seasons (Table 1). Most of the data collected from the earlier stages of the reproductive season were not significantly different when control and treated groups were compared. More control hens laid and incubated their eggs during both nesting seasons compared with hens fed mercury. The hens that laid in 1973 also laid in

TABLE 1

REPRODUCTIVE SUCCESS OF BLACK DUCKS FED A DIET CONTAINING 3 PPM MERCURY OR CLEAN FEED DURING TWO CONSECUTIVE SEASONS[a]

| | 1973 | | 1974 | |
|---|---|---|---|---|
| | *Control* | *Mercury* | *Control* | *Mercury* |
| Pairs of breeders | 13 | 13 | 13 | 13 |
| No. hens laying | 10 | 8 | 12 | 10 |
| Mean date for first egg | 15 April | 17 April | 10 April | 22 April |
| No. hens incubating | 10 | 5[c] | 10 | 7 |
| No. eggs laid[b] | 98 | 60 | 92 | 63 |
| Mean clutch size | 9·8 | 7·5 | 7·7 | 6·3 |
| Eggs incubated | 88 | 45 | 74 | 48 |
| No. eggs hatched | 62 | 19 | 43 | 26 |
| Mean hatchability (%) | 72 | 44[c] | 57 | 52 |
| No. ducklings surviving | | | | |
| 1 week | 39 | 5[d] | 34 | 11[d] |
| 4 weeks | 31 | 3[d] | 33 | 7[d] |
| per laying hen | 3·1 | 0·4[d] | 2·8 | 0·7[d] |
| per breeding pair | 2·4 | 0·2[d] | 2·5 | 0·5[d] |

[a] Reproductive performance is based on the second clutch when hens renested.
[b] Includes eggs removed for mercury analysis: 10 and 11 eggs from control hens in 1973 and 1974; 7 and 8 eggs from mercury-treated hens in 1973 and 1974.
[c] Significantly different from controls for that year, $p < 0·10$.
[d] Significantly different from controls for that year, $p < 0·025$.

1974; 2 additional hens from each treatment group laid during the second year. Nine of the control hens that incubated eggs in 1973 incubated again in 1974. The 5 mercury-treated hens that incubated in 1973 incubated again in 1974. Clutch size, egg production, number of eggs incubated and hatchability were lower during both years in hens fed mercury.

The most harmful effects of the mercury diet in 1973 involved hatchability and duckling survival (Table 1). Of 10 control hens incubating, 9 produced a total of 62 ducklings. In the group fed mercury, only 19 ducklings were hatched by 3 of the 5 hens incubating. Only 3 of these ducklings survived to 3 weeks of age. The highest embryo mortality occurred during the last week of incubation and most of the ducklings died during the first week after hatching. Ducklings found dying of suspected mercury poisoning exhibited obvious tremors and loss of co-ordination. The difference in duckling survival between treated and control groups in 1973 would have been even greater had it not been for 24 control ducklings from 3 broods dying from coccidiosis during the first 2 weeks after hatching. Careful examination of dead ducklings failed to identify coccidiosis in any other broods in 1973 or 1974.

Although hatchability decreased in the control group and increased in the mercury-treated hens in 1974 compared with the 1973 results (Table 1), differences were not significant. Control hens incubated fewer eggs in 1974 and only 7 of 10 hens that incubated successfully hatched ducklings. The number of control ducklings that survived was similar for both seasons. However, about twice as many ducklings from hens fed mercury survived to 4 weeks of age compared with the first year of reproduction. A significantly greater number of ducklings was produced per laying hen in the control group compared with hens fed mercury during 1974.

During the two breeding seasons, 8 ducklings from parents fed mercury and 3 randomly selected control ducklings were examined histologically. Brains of control ducklings revealed no abnormalities. Kidney, heart and liver specimens showed no lesions suggesting infectious disease (excluding control ducklings killed by coccidiosis in 1973). All brains of ducklings from parents fed mercury had focal areas of demyelination, neuron shrinkage and extensive necrosis. These lesions were most prominent in the cerebellum and optic lobes. Extensive haemorrhages were found in the cerebellar meninges and in the cerebellar folia.

Egg weight and shell measurements did not differ significantly between the control and mercury-treated groups for either year. However, shell thickness measurements taken at the egg equator, cap and apex averaged 7·4, 9·3 and 11·9 % less in eggs laid by hens fed mercury during the first breeding season. These differences were considerably less in eggs measured during the second year on mercury. Few eggs were cracked or broken by incubating hens from either treatment group.

*Mercury residues*

Mercury residues in feed, eggs and tissues of advanced embryos and ducklings that died during the 1973 and 1974 breeding seasons are given in Table 2. All control

TABLE 2

MERCURY RESIDUES (PPM) IN FEED, EGGS AND TISSUES OF DEAD EMBRYOS AND DUCKLINGS FROM BREEDERS FED 3 PPM MERCURY OR CLEAN FEED DURING TWO BREEDING SEASONS. MEANS ± SE, SAMPLE NUMBER IN PARENTHESES

| | *Control diet* | | *Mercury diet* | |
|---|---|---|---|---|
| | 1973 | 1974 | 1973 | 1974 |
| Feed | <0·05 (3) | <0·05 (3) | 2·92 ± 0·11 (3) | 3·41 ± 0·16 (3) |
| Eggs (third/clutch) | <0·05 (10) | 0·07 ± 0·01 (11) | 6·14 ± 0·43 (7) | 3·86 ± 0·22 (8)[a] |
| Eggs (complete clutch)[b] | | | 5·53 ± 0·14 (9) | 4·70 ± 0·29 (8)[d] |
| Advanced embryos:[b] | | | | |
| Brain | | | 5·78 ± 0·38 (6) | 4·61 ± 0·73 (6) |
| Yolk | | | 8·61 ± 1·06 (6) | 4·24 ± 0·64 (6)[c] |
| Remainder | | | 9·91 ± 0·78 (6) | 6·56 ± 0·63 (6)[c] |
| Whole embryo | | | 9·62 ± 0·76 (6) | 6·08 ± 0·60 (6)[c] |
| Ducklings: | | | | |
| Brain | <0·05 (2) | 0·13 ± 0·04 (3) | 5·22 ± 0·47 (8) | 4·24 ± 0·39 (8) |
| Liver | <0·05 (2) | 0·20 ± 0·08 (3) | 14·46 ± 1·11 (8) | 10·23 ± 1·22 (8)[d] |
| Muscle | <0·05 (2) | 0·12 ± 0·01 (3) | 6·19 ± 0·60 (8) | 5·40 ± 0·74 (8) |
| Feathers | <0·05 (2) | 0·47 ± 0·21 (3) | 65·64 ± 4·78 (5) | 40·84 ± 3·05 (8)[c] |

[a] Significantly different from 1973 residue levels, Student's $t$ test ([c] = $p < 0·01$; [d] = $p < 0·05$).
[b] Not determined for controls.

feed samples contained less than 0·05 ppm mercury. The 1973 control eggs and duckling tissues contained levels of mercury below the limits of detection. In 1974, the third egg from 1 control hen contained 0·17 ppm mercury; all other eggs contained levels below 0·09 ppm. Tissues of 3 control ducklings that died during the first week after hatching in 1974 contained low levels of mercury.

Eggs, embryos and ducklings from hens fed mercury contained about 30% lower mercury residues during the second breeding season compared with results in the first year (Table 2). Most of these differences were significant. Third eggs laid by hens fed 3 ppm mercury contained mean mercury levels of 6·14 and 3·86 ppm during 1973 and 1974. Mercury levels in individual eggs within a clutch did not vary appreciably in either of the 2 clutches analysed during the 2 years. When comparing third eggs from each of the 7 hens that laid during both seasons, mercury levels were twice as high in 1973 as in 1974 ($p < 0·01$). This reduction in mercury residues during the second breeding season was also evident in yolks and carcasses of advanced embryos that failed to hatch. Brain residues were lower in the 1974 embryos but did not differ significantly from 1973 levels. Mercury residues in livers and feathers of ducklings that died within 11 days of hatching were significantly lower in 1974 than in 1973. Brain and muscle residues were also lower in 1974 ducklings but did not differ significantly from the 1973 levels. Mercury levels were not related to weight or age of the ducklings for any of the tissues analysed during either year.

Table 3 shows levels of mercury in the third egg, embryos and ducklings from the same hen fed mercury during both breeding seasons. From a total of 18 eggs incubated during both years, most of the embryos failed to hatch and only 1 duckling survived for more than 10 days. The lower levels of mercury in the 1974

TABLE 3
MERCURY RESIDUES (PPM) IN EGGS, EMBRYOS AND DUCKLINGS FROM A BLACK DUCK HEN FED 3 PPM MERCURY DURING TWO REPRODUCTIVE SEASONS. MEAN ± SE

| *Sample* | *Mercury residues* 1973 | 1974 |
|---|---|---|
| Third egg | 7·56 | 4·47 |
| Embryos (3)[a] | | |
| Brain | 4·95 ± 0·12 | 3·56 ± 0·61 |
| Yolk | 8·65 ± 0·40 | 3·57 ± 1·11[b] |
| Remainder | 9·58 ± 0·58 | 7·21 ± 1·23 |
| Whole embryo | 9·30 ± 0·45 | 6·69 ± 1·18 |
| Ducklings (3) | | |
| Brain | 6·25 ± 0·68 | 3·72 ± 0·44[b] |
| Liver | 16·23 ± 0·87 | 9·44 ± 1·84[b] |
| Muscle | 6·89 ± 1·21 | 4·96 ± 0·42 |

[a] Sample number.
[b] Significantly different from 1973 residue levels, Student's $t$ test ($p < 0·05$).

eggs shown in Tables 2 and 3 are reflected by the mercury levels in tissues of embryos and ducklings. Mercury residues in second-year embryos and ducklings taken from the same clutch of eggs confirm the reduction of mercury levels during the second reproductive season.

Levels of mercury in tissues of adult breeders and surviving ducklings are given in Table 4. Two control males contained 0·24 and 0·10 ppm mercury in their livers. Excluding feathers, tissues of control breeders contained low to non-detectable levels of mercury. In breeders fed mercury, residues in tissues of females did not differ from those found in males. Mercury levels were highest in feathers followed by livers, kidneys, breast muscle and brains. Other than feathers, little variation occurred in residues in a particular organ or tissue. No lesions characteristic of methyl mercury poisoning were found in any tissues of control or mercury-treated adults.

Positive correlations ($p < 0·01$) were found between the levels of mercury in breast muscle and brains, livers and kidneys, and livers and brains of adult breeders fed mercury (Fig. 1). Mercury levels in livers were not significantly correlated with levels in breast muscle. A positive correlation occurred between levels of mercury in livers of hens and the third egg laid during 1974 (Fig. 2). Mean ratios of mercury levels in tissues of adult breeders were: breast muscle/brain = 1·3; liver/kidney = 1·5; liver/brain = 6·2; liver/muscle = 5·2 and liver/egg = 5·1.

Residues in ducklings that survived the mercury treatment during 1973 and 1974 are also shown in Table 4. One of the 3 ducklings that survived from the first year died after 8 months. This male contained 3–4 times more mercury in soft tissues than adults or the two 1973 ducklings that were sacrificed. This bird exhibited signs of mercury poisoning for several months prior to death and necropsy revealed lesions

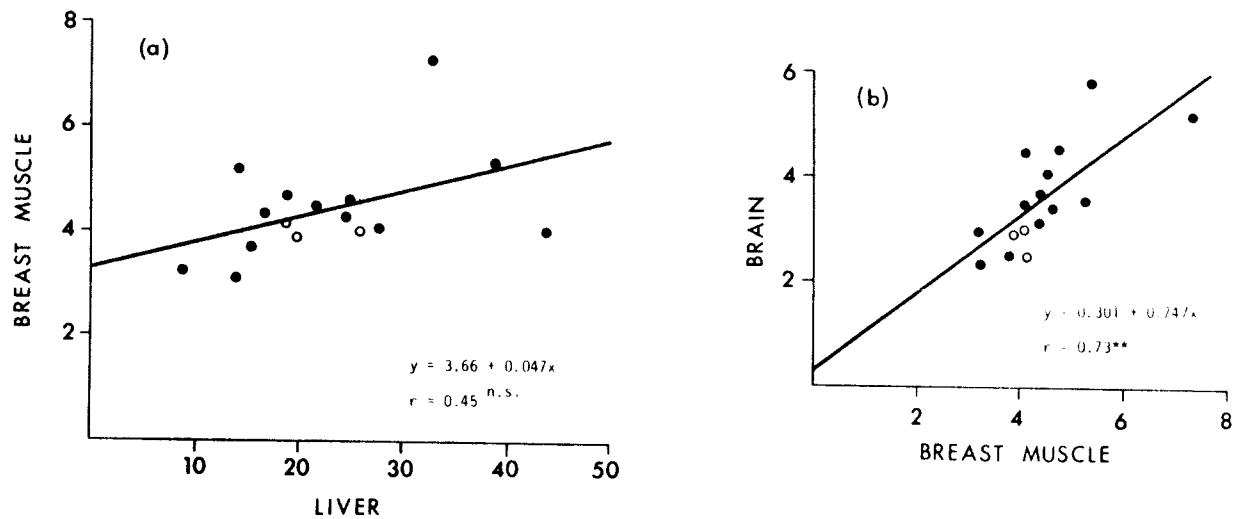


Fig. 1. Correlations between mercury levels (ppm) in various tissue combinations for adult black ducks fed 3 ppm mercury. Open circles = 3 males and solid circles = 13 females (** = $p < 0{\cdot}01$).

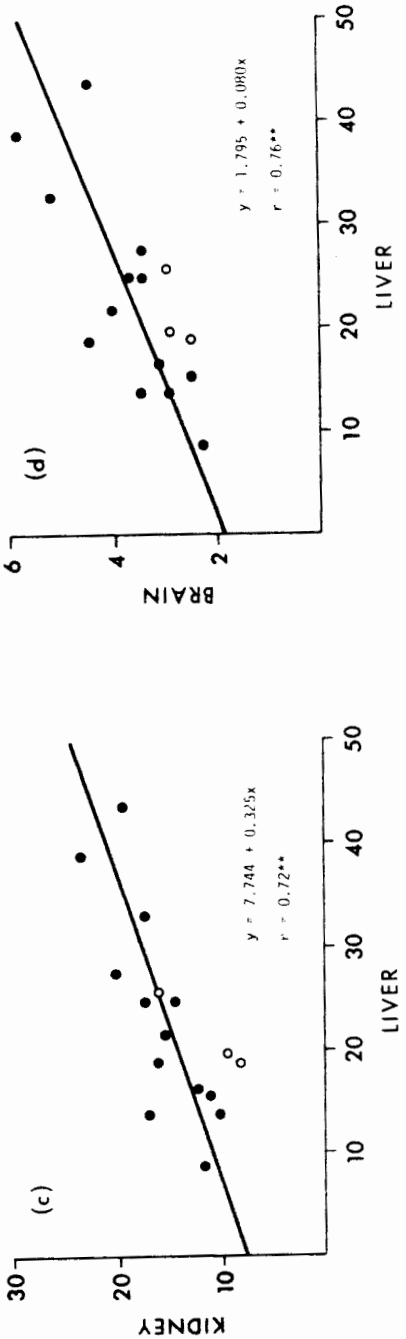
(c)
KIDNEY
30
20
10
LIVER
10
20
30
40
50
y = 7.744 + 0.325x
r = 0.72**
(d)
BRAIN
6
4
2
LIVER
10
20
30
40
50
y = 1.795 + 0.080x
r = 0.76**

Fig. 1 *contd.*

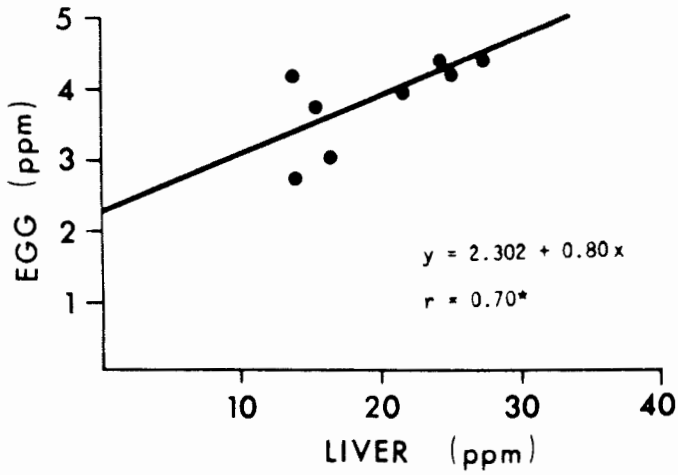


Fig. 2. Correlation between mercury levels (ppm) in livers and third eggs of hens fed 3 ppm mercury ($n = 8$, * = $p < 0{\cdot}05$).

in the nervous system characteristic of methyl mercury poisoning; the brain of this bird contained 12·2 ppm mercury. Histological examination of the two 1973 ducklings that were sacrificed at the end of the study revealed no lesions associated with mercury ingestion. In 1974 offspring, liver and kidney residues averaged 2·97 and 4·35 ppm in 4-week-old ducklings; this compared with 5·69 and 5·44 ppm in 8-week-old ducklings. This increase in mercury residues in 8-week-old compared with 4-week-old ducklings did not occur in breast muscle and brain tissues. Histological examination of these second-year ducklings revealed no lesions or abnormalities related to mercury treatment.

TABLE 4

MERCURY (PPM W/W) IN TISSUES OF ADULT AND YOUNG BLACK DUCKS FED 3 PPM MERCURY *ad libitum* DURING TWO REPRODUCTIVE SEASONS. MEAN ± SE

| | *No.* | *Liver* | *Kidney* | *Muscle* | *Brain* | *Feathers* |
|---|---|---|---|---|---|---|
| Controls | | | | | | |
| Male | 3 | 0·13 ± 0·06 | 0·06 ± 0·01 | <0·05 | <0·05 | 0·47 ± 0·26 |
| Female | 3 | <0·05 | <0·05 | <0·05 | <0·05 | 0·12 ± 0·03 |
| 3 ppm mercury | | | | | | |
| Male | 3 | 21·33 ± 2·20 | 11·16 ± 2·45 | 4·03 ± 0·10 | 2·83 ± 0·13 | 65·70 ± 7·25 |
| Female | 13 | 23·07 ± 2·88 | 16·05 ± 1·06 | 4·51 ± 0·29 | 3·79 ± 0·28 | 56·12 ± 6·13 |
| 1973 ducklings | | | | | | |
| Male | 1[a] | 75·90 | 59·40 | 16·00 | 12·20 | 40·30 |
| | 1 | 25·80 | 28·90 | 7·84 | 5·96 | 38·50 |
| Female | 1 | 16·40 | 19·20 | 6·33 | 4·38 | 42·00 |
| 1974 ducklings | | | | | | |
| 4-weeks | 3 | 2·97 ± 0·34 | 4·35 ± 0·15 | 2·82 ± 0·08 | 2·05 ± 0·22 | 48·23 ± 5·07 |
| 8-weeks | 3 | 5·69 ± 0·55 | 5·44 ± 0·40 | 2·07 ± 0·17 | 1·59 ± 0·09 | 37·43 ± 4·50 |

[a] Died at 8 months of age.

## DISCUSSION

Adult black ducks were in good health after ingesting dietary levels of 3 ppm mercury as methyl mercury for 28 weeks during each of two consecutive breeding seasons. However, reproduction was significantly lower in mercury-treated breeders than in controls during both nesting seasons. The most harmful effects of the mercury diet were reduced hatchability and high duckling mortality. During the two-year study, only 16 ducklings from mercury-treated hens survived to 1 week of age compared with 73 ducklings from breeders fed untreated diets. In reproductive studies with mallards, 3 ppm mercury reduced egg production, lowered hatchability and caused high duckling mortality (Heinz, 1974). Other experimental studies report reproductive impairment in chickens (Tejning, 1967) and pheasants (Fimreite, 1971).

In our study, the effect of mercury on reproductive success was more severe during the first year. Even though few ducklings survived the 3 ppm mercury treatment during either season, about twice as many ducklings survived during the second year. In a two-year study with mallards, egg production, hatching success and duckling survival were lower during the first breeding season in hens fed diets containing 3 ppm methyl mercury (Heinz, 1975). This improvement in reproductive success in mallards during the second year of mercury treatment was associated with about 0·5 to 1 ppm less mercury in the eggs.

The slight improvement in reproduction during the second year may be related to an increased capability of the hens to metabolise the mercury. Residues in eggs, embryos and ducklings averaged 30 to 50 % lower during the second year. The form of the mercury in these tissues was not determined. The possibility that the black duck hens were capable of partial demethylation of the mercury during the second breeding season could explain the lower residues and subsequent improved reproduction. Extensive biotransformation of organic to inorganic mercury has been demonstrated in the rat (Norseth & Clarkson, 1970) and in guinea pigs (Iverson & Hierlihy, 1974).

Our results agree with a number of experimental studies showing that mercury does not cause significant eggshell thinning (Peakall & Lincer, 1972; Spann *et al.*, 1972; Haegele *et al.*, 1974). Eggshells of mallards were not significantly thinned after receiving diets containing 0·5 and 3 ppm methyl mercury through two laying seasons (Heinz, 1976). Since the small amount of thinning that occurred in eggshells of black ducks fed mercury during the first laying season was not significant and was not repeated during the second year, mercury cannot be related as a causative factor of eggshell thinning.

Mercury in the eggs laid by treated hens is thought to have been the major cause of embryo and duckling mortality in this study. Mean mercury levels of 6·14 and 3·86 ppm in eggs during 1973 and 1974 were high enough to kill the young. Brains of 16 dead ducklings that hatched from these eggs contained between 3·25 and 6·98 ppm mercury. All ducklings that were examined contained brain lesions

characteristic of mercury poisoning. Our data indicated that about 4 ppm mercury in the brain, based on wet weight, is sufficient to cause embryo and duckling mortality in black ducks.

Mercury from the treated feed given to all hatchlings was not considered an important factor causing mortality. Heinz & Locke (1976) reported that mallard ducklings did not die when fed diets of 3 ppm methyl mercury, whereas ducklings whose parents were fed 3 ppm mercury died within 3–6 days when fed a clean diet. Eggs from these mallard hens contained an average of 7·18 and 5·46 ppm mercury during two successive years. Brains of dead ducklings contained 6·17 and 5·19 ppm mercury during these 2 years and exhibited mercury-induced lesions.

Residues of mercury in tissues of adult black ducks fed 3 ppm methyl mercury were similar in males and females. Levels of mercury as high as 23, 16, 4·5 and 3·8, on a wet weight basis, in liver, kidney, breast muscle and brain tissues, respectively, were not lethal in adults. However, the behaviour of breeders fed mercury appeared somewhat abnormal during the second year of treatment. Several adults appeared hyperactive, suggesting possible mercury poisoning. The weights of these birds were normal and histological examination failed to reveal any neurological lesions. The 3 surviving ducklings from the first reproductive season also exhibited hyperactive responses. One of these ducklings died after 8 months and contained 2–3 times more mercury in all soft tissues than adult breeders. The brain of this first-year offspring contained 12·2 ppm mercury and necropsy revealed definitive mercury-induced lesions in the central nervous system. The remaining 2 ducklings were sacrificed at 1 year and revealed no brain lesions. Mercury levels in livers of these 2 ducklings were similar to those of adult breeders; kidney, muscle and brain residues were slightly higher. Adult black ducks may tolerate up to 20 ppm mercury in the liver and up to 6 ppm in the brain.

Heinz (1976) reported levels of 11·1, 14·7, 5·0 and 4·6 ppm mercury in livers, kidneys, breast muscle and brains of mallard hens fed 3 ppm methyl mercury for 18 months; males averaged 19·3 ppm mercury in the liver after only 4 months of mercury treatment. These mallard breeders were considered in excellent health when necropsied. These mercury levels are similar to those reported here for black ducks except for the lower liver residues in mallard hens. In the mallard study, eggs were collected daily from hens for 14 weeks during mercury treatment. Laying for such an extended period would facilitate elimination of mercury through the eggs. In our study, 3 non-laying hens contained 38·4 ppm mercury in the liver while the 10 hens that laid contained only 18·5 ppm mercury in their livers. There was no demonstrable relationship between the number of eggs laid in a clutch and the concentration of mercury in the liver.

Several investigators have examined the relationships between residues of mercury in various soft tissues. Significant correlations were found between mercury concentrations in muscle–liver, muscle–kidney and liver–kidney tissue combinations for 5 species of birds (Hesse *et al.*, 1975). Similar correlations were

reported by Vermeer & Armstrong (1972*a*) between levels of mercury in wing muscles and breast muscles in each of 5 species of field-collected ducks. Significant correlations were also found between breast muscle and livers of ducks (Vermeer & Armstrong, 1972*b*). Krapu *et al.* (1973) reported a positive correlation between mercury residues in liver tissue and albumen of eggs taken from the oviduct of wild pintail ducks. Approximate mercury levels can be predicted in muscle, liver and kidneys of several species of duck when the level is known in any one tissue. When all combinations of tissues from black duck breeders were examined, significant positive correlations ($p < 0{\cdot}01$) were found for liver–kidney, liver–brain and breast muscle–brain combinations. Approximate mercury levels appear predictable in these tissues if the level of mercury in one is known. This relationship was also found between mercury levels in egg contents and livers of hens fed mercury.

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