Effects of Dietary Methylmercury on Ring-necked Pheasants

by Norvald Fimreite

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With Special Reference to Reproduction

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Canadian Wildlife Service
Department of the Environment

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Abstract

The effects of methylmercury-treated grain (methylmercury dicyandiamide) on penned pheasants (*Phasianus colchicus*) were studied in a two-way factorial experiment, the factors involved being mercury levels (100, 50 and 25 per cent treated grain in the grain ration) and the length of the experimental feeding period (2, 4 and 12 weeks). An additional three groups served as controls.

No weight reduction in the adult birds could be ascribed to the mercury compound. Compared to the controls, mortality was lower than average in the groups that received a mercury-contaminated diet throughout the experiment, suggesting a possible therapeutic effect of mercury. Food consumption was affected only in the group that received the largest amounts of mercury. Some of the hens receiving the greatest amounts of mercury exhibited extensive demyelination of the spinal cord.

Strong adverse effects on reproduction were found: the most important indication was reduced hatchability, followed by a reduced egg production and a large number of shell-less eggs. Chick survival was comparatively less affected. Egg weight was reduced significantly in most of the experimental groups, especially during the last weeks of the experiment, and the highest mercury levels produced a large number of eggs with abnormal colour.

The relevance of these findings to mercury poisoning among wild bird populations is discussed, and it is concluded that hatchability at least might be adversely affected to an extent that is significant where mercury seed-dressings are used extensively.

Résumé

La présente expérience visait à étudier les effets du grain traité au méthylmercure (dicyanodiamide de méthylmercure) sur les faisans à collier (*Phasianus colchicus*) en fonction de deux facteurs: la teneur en mercure (ration alimentaire contenant 25, 50 et 100 p. 100 de grain traité) et la durée du régime expérimental (2, 4 et 12 semaines). Trois autres groupes témoins ont été utilisés aux fins de vérification.

Dans le cas des oiseaux adultes, aucune perte de poids n'a pu être imputée au composé au mercure. Le taux de mortalité des groupes soumis à un régime au mercure pendant toute la durée de l'expérience, a été plus bas que la moyenne obtenue pour les groupes témoins. Cela donne à penser que le mercure aurait peut-être un effet thérapeutique.

C'est seulement dans le groupe ayant absorbé les plus fortes doses de mercure que furent observées une variation dans la consommation de nourriture et, chez quelques femelles, une démyélinisation avancée de la moelle épinière.

L'expérience a permis de déceler les effets néfastes sur la reproduction, le plus sérieux étant surtout une production réduite d'œufs viables, suivie d'une diminution de la ponte et de la présence d'un grand nombre d'œufs sans coquille. Le taux de survie des poussins a subi un fléchissement de moindre importance. En plus de la diminution du poids des œufs observés chez tous les sujets soumis à l'expérience, surtout pendant les dernières semaines, un grand nombre des œufs provenant du groupe ayant absorbé les plus fortes doses de mercure étaient de couleur anormale.

Après avoir discuté de la valeur de ces résultats en ce qui a trait à l'empoisonnement des populations d'oiseaux par le mercure, on conclut que l'emploi, sur une grande échelle, de grains traités au mercure a, tout au moins, un effet néfaste certain sur la production d'œufs viables.

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Introduction

Organic mercury derivatives introduced 50 years ago are now commonly applied to wheat, barley and oat seeds to control such cereal diseases as smut and bunt. Variations of these compounds have since been developed (Sharevelle, 1962). They include alkylmercury derivatives–containing primarily the methyl homologue–highly effective in controlling various seed-borne diseases while being relatively harmless to plants. Alkylmercury compounds, highly toxic (Grolleau, 1965) and stable in the body (Friberg, 1959), have been used extensively in the last 20 years. This development is undesirable for wildlife as mercury is picked up from uncovered treated grain by seed-eating birds and mammals and passed on to their predators.

Borg *et al.* (1969) reported several hazardous cases of mercury levels in Sweden's wildlife which they ascribed to seed treated with alkylmercury. Fimreite, Fyfe and Keith (1970) recently reported high levels in ring-necked pheasants (*Phasianus colchicus*) and partridges (*Perdix perdix*) collected in the grain-growing districts of Alberta where use of mercury-treated seed is common.

Basic information obtained in controlled experiments is useful in understanding the biological effects of mercury contamination and the significance of mercury levels in wildlife. The effect of mercury on reproduction has not been extensively studied. Borg *et al.* (1969) found reduced hatchability in eggs of pheasant hens fed on grain treated with one level of mercury for just 9 days. Hatchability was also low in artificially incubated eggs collected in agricultural districts where mercury seed dressings are widely used. Tejning (1967) has made a more comprehensive study of chickens *(Gallus gallus)*.

I have investigated the effects of grain treated with methylmercury on egg production, shell formation, hatchability and embryonic and chick mortality in the ring-necked pheasant. Food consumption and general observations on health were also noted as these may indirectly influence reproduction.

I chose the ring-necked pheasant because it is a typical seed-eating bird common to grain growing districts, its diet consists largely of grain, wild specimens frequently contain high mercury levels, and it is an important game bird.

Materials and methods

Experimental birds

The 192 nine-month old test pheasants were obtained from Al Straib's Pheasantry, Aylmer, Ontario and taken in January 1969, to the Niska Waterfowl Research Station, Guelph, Ontario. There they were confined in two 1,000-ft^2 pens before transfer to their respective experimental pens.

Diet and feeding regime

The feed contained 50 per cent wheat and barley mixture and 50 per cent CO-OP duck breeder ration (17 per cent protein) until 2 weeks before the experiment began, after which time the birds received pure breeder ration. Food, grit, oyster shells and water were freely available.

During the experiment the diet consisted of one-third pelleted pheasant breeder ration (18 per cent protein) (United CO-OPerative of Ontario), and two-thirds grain mixture (half wheat, half barley). The percentage and duration of treated grain in the diet are explained in the section on *Experimental design and statistical analysis.* A ration of 90 gm per bird was dispensed daily in relatively deep, open feeders placed on 24- by 36-in. trays. Every third day the leftover feed was collected and weighed to determine food consumption. Grit, oyster shells and water were always available.

It was assumed that untreated grain, treated grain and pellets were consumed in the same proportion as they were given in the diet. This, as mentioned above, is not completely true, but since only a negligible amount of food was left over, the figures should be sufficiently accurate. It was impractical to separate the pellets from the grain for individual measurement.

The mercury compound

Panogen 15, the seed dressing employed, containing 2.5 per cent of its active ingredient methylmercury dicyandiamide ($CH_3Hg{\cdot}NHC\genfrac{}{}{0pt}{}{\diagup NH}{\diagdown NHCN}$) is probably the most commonly used dressing in Canada. The recommended treatment rate, ¾ oz per bushel, corresponds to 12 mg Hg/kg of wheat or 15 mg/kg of barley. As Panogen is somewhat volatile and mercury may be lost in storage, I purchased the seed on March 25, soon after it was treated, and kept it in sealed glass containers throughout the experiment.

Experimental design and statistical analysis

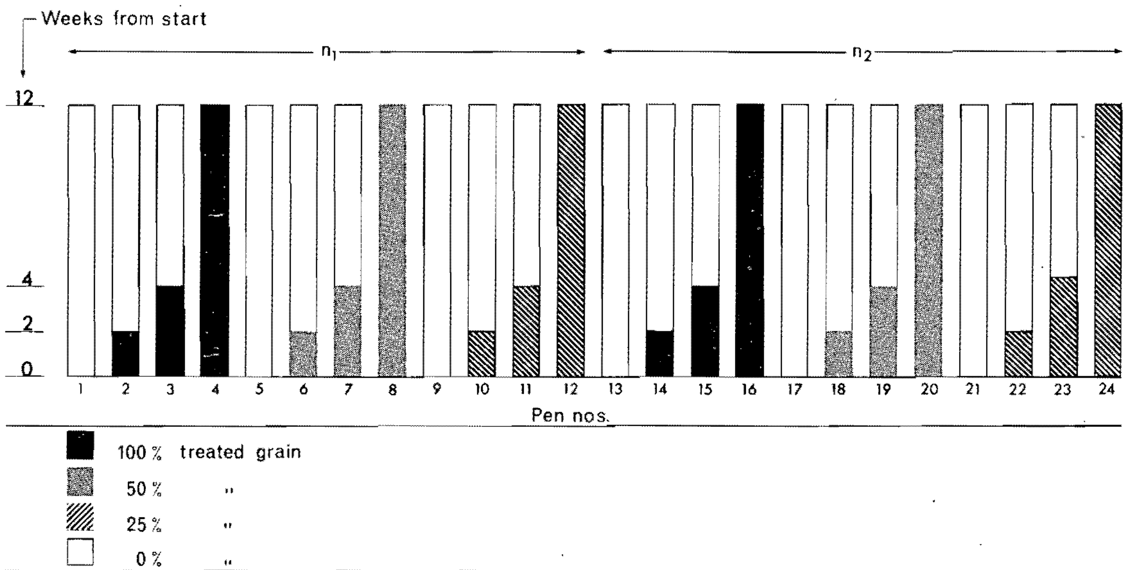
Figure 1 shows how the experiment was designed. Two variables were involved: (a) mercury level – 100, 50 and 25 per cent mercury-treated grain in the diet, and (b) duration of mercury feeding period – 2, 4 and 12 weeks. There were nine experimental and three control groups, each containing two sub-groups or pens, for a total of 24 pens. Each pen held seven hens and one cock. The groups wil be identified by the proportion of treated grain in the grain mixture (expressed as a percentage) and by the length of time (expressed in weeks) that they received treated grain. For example, the group (pens 8 and 20) fed 50 per cent treated grain throughout the 12-week experiment will be referred to as group 50/12.

The birds were weighed three times: 2 weeks before the experiment began, 4 weeks from its start, and 10 or 12 weeks from the beginning of the study, at time of slaughter. Those that died during the experiment were examined by the Department of Pathology, University of Guelph.

All birds except those in pens 21 to 24 were weighed, banded and penned about 2 weeks before the experiment began, so that they could settle down in their new environment. Unfortunately pens 21 to 24 could not be prepared until 3 or 4 days before the start. Each pen measured 22 m^2 (2.2 by 10 m or 3.3 by 6.6 m), was divided by wire netting and roofed at one end.

Figure 1. Plan of experiment to show effects of dietary methylmercury on ring-necked pheasants. Each group consisted of two subgroups (pens, housing seven hens and one cock) one from n_1 and one from n_2. Mercury levels in diet (percentage treated grain) and length of experimental feeding periods are shown.

Figure 1



Variance analyses on the data were made by computer according to a method of Bone (1965). All percentages were *arc sine* transformed (arc sin $\sqrt{p}$) before being used as the basis for analysis. The significance of differences observed in egg weight was determined by *t*-tests.

Collection and incubation of eggs

Eggs were collected at 7 PM daily, more often in hot weather and in pens where egg-eating occurred. One average-sized egg from each pen was chemically analysed weekly; all others but broken or shell-less eggs were weighed soon after collection and stored at 15° to 18°C until incubation.

Two Jamesway 2940 incubators were used for incubation and hatching. The eggs were turned four times a day, kept at a temperature of 37.1° to 37.4°C and set every two or three days.

Chicks and unhatched eggs

Shortly after hatching, the chicks were given small numbered wingtags; one day after hatching they were removed from the incubators and placed in brooders maintained at 27° to 30°C. All unhatched eggs were opened and the age of the dead embryo determined according to the method of Labisky and Opsahl (1958). Chick mortality during the first 2 weeks after hatching was also recorded.

Mercury determinations

Five hens from each group were killed after 10 weeks and the mercury content in their livers determined. Analysis of liver and weekly egg samples was done at the Laboratory of Toxicology, University of Guelph, according to a method developed by Oliver and Funnell (1958).

Results

General health observations

The results indicate that the mercury levels used here cause no increase in adult mortality (Table 1). On the contrary, no deaths whatever occurred in groups fed 100 and 50 per cent treated grain throughout the experiment, and all the cocks remained alive and healthy, with no diminution in their capacity to copulate. In no case could mercury poisoning be diagnosed with certainty. But some mercury-treated birds had extensive demyelination of the spinal cord; and egg peritonitis, staphylococcal infections and pneumonia were observed in some dead hens.

The pheasants were infected by lice *(Menacanthus stramineus)*, and one contained three pairs of gape worms *(Syngamus trachea)*. Evidence of sickness appeared only a few days before death except in the cases of single hens from pens 1 and 22, which for several weeks exhibited weakness in the extremities, progressing slowly into ataxia.

Food consumption and mercury intake

Although the analysis of variance (Table 2) revealed highly significant differences in food consumption referable to both dietary mercury levels and feeding period, the differences are rather small in magnitude (Table 3, Fig. 2). Only the consumption of group 100/12 differed significantly ($P<0.01$) from the controls (Table 4). The other groups ate practically all their daily ration except during the fourth and fifth weeks, when consumption declined in all the test groups and controls. The leftover feed included more barley than wheat and usually very few breeder pellets. No difference was detected in the consumption of treated versus untreated grain.

Table 1 shows that most of the birds, particularly those that were the heaviest at the beginning, lost weight during the experiment: the average loss was less than 10 per cent. Some of the lightest birds gained weight, however, and there seemed to be no relationship between weight loss or gain and amount of mercury ingested.

Table 1
Initial weight, mortality and weight changes of pheasants fed methylmercury-treated grain.

Percentage treated grain of grain ration	Weeks fed Hg-treated grain	Initial weight of birds, grams		Mortality during experiment, no. of birds	Weight lost (—) or gained (+), % initial weight	
		Mean	Range		Mean	Range — +
100	0 (Control 1)	1414	1170 – 1815	3	— 6.5	19.3 – 11.1
	2	1337	1140 – 1745	2	— 3.9	16.3 – 18.4
	4	1386	1150 – 1820	2	— 5.0	18.9 – 13.9
	12	1462	1340 – 1780	0	— 4.4	12.9 – 13.9
50	0 (Control 2)	1352	1018 – 1720	1	— 6.1	18.3 – 16.5
	2	1351	1090 – 1840	2	— 7.1	16.7 – 9.2
	4	1334	1090 – 1740	0	— 3.8	21.2 – 18.6
	12	1468	1085 – 1950	0	—10.0	20.3 – 3.3
25	0 (Control 3)	1364	1085 – 1920	0	— 5.0	24.5 – 11.7
	2	1381	1050 – 1950	2	— 7.0	23.3 – 17.6
	4	1318	1050 – 1670	1	— 6.1	18.7 – 7.8
	12	1288	1060 – 1755	1	— 4.2	18.0 – 16.2

Figure 2. Weekly food consumption of pheasants receiving diets in which 100, 50 or 25 per cent of the grain portion had been treated with MMD.

Figure 2

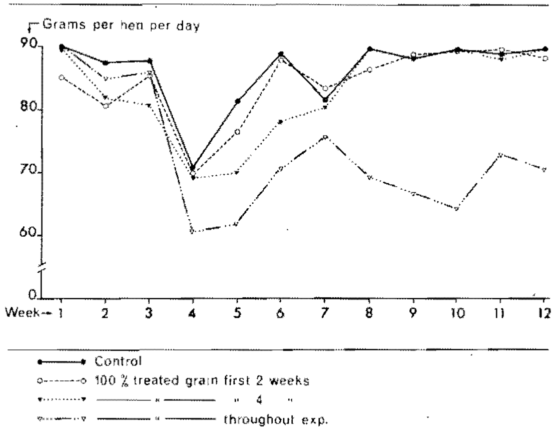


Figure 2 (continued)

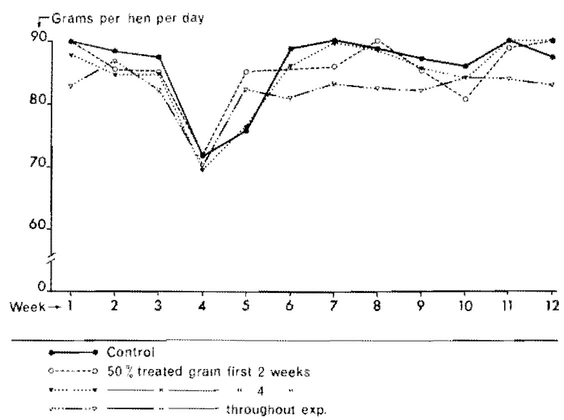


Table 2
Analysis of variance for food consumption, egg production, frequency of shell-less eggs, hatchability, chick production and embryonic mortality of pheasants fed methylmercury-treated grain.

		Food consumption, grams/hen/day		Egg production, eggs/hen/day		Shell-less eggs, % eggs laid		Hatchability, % eggs incubated		Chick production, chicks/hen/day	
Sonrce of variation	df	MS	F	MS	F	MS	F	MS	F	MS	F
A (Hg levels)	2	278.310	10.83**	0.022	0.97	0.036	4.26*	0.379	13.47**	0.091	8.77**
B (Length of feeding period)	3	605.733	23.58**	0.350	15.08**	0.234	27.21**	0.557	19.79**	0.474	45.24**
A × B (Interaction)	6	212.050	8.25**	0.089	3.83**	0.038	4.45**	0.063	2.26*	0.057	5.52**
C (Weeks in experiment)	11	508.955	19.81**	0.375	16.16**	0.055	6.48**	0.199	7.08**	0.081	7.74**
A × C (Interaction)	22	29.555	1.15	0.013	0.59	0.006	0.70	0.015	0.54	0.010	0.96
B × C (Interaction)	33	47.970	1.86	0.039	1.69	0.044	5.15**	0.073	2.61	0.029	2.81**
A × B × C (Interaction)	66	27.783	1.08	0.023	1.02	0.006	0.79	0.029	1.05	0.010	1.02
Error	144	25.684		0.023		0.008		0.028		0.010	
Total	287										

*P < 0.05
**P < 0.01

Figure 2 (continued)

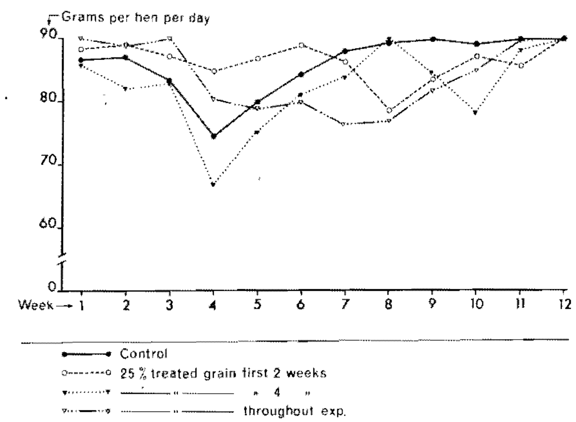


Table 3
Total food consumption, intake of mercury and mercury residues in liver of pheasants fed methylmercury-treated grain.

Hg-treated grain in diet, % grain ration	Weeks fed Hg-treated grain	Food consumption, kg/hen	Estimated consumption of mercury, mg/hen	Mercury in liver,* ppm Mean	Mercury in liver,* ppm Range
100	2	7.10	6.25	0.98	0.37 – 2.28
	4	6.98	12.38	4.44	2.20 – 6.80
	12	6.13	33.66	7.83	4.03 – 13.70
50	2	7.18	3.38	0.59	0.34 – 1.11
	4	7.12	6.29	1.87	0.93 – 2.97
	12	6.88	18.91	4.47	3.36 – 7.62
25	2	7.26	1.71	0.68	0.00 – 1.55
	4	6.92	3.05	1.15	0.39 – 3.26
	12	6.43	9.69	1.86	0.59 – 5.08
0 (Controls)	0	7.23	0.00	0.09	0.00 – 0.66

*Based upon 5 specimens from each group (killed 10 weeks from start of the experiment).

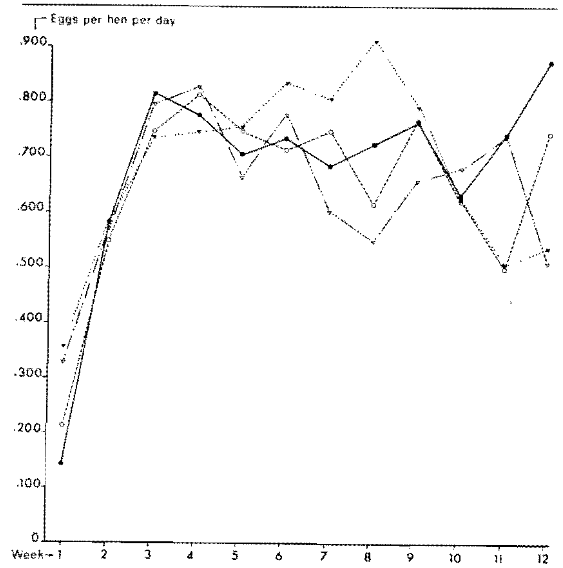
Table 2 (continued)
Analysis of variance for food consumption, egg production, frequency of shell-less eggs, hatchability, chick production and embryonic mortality of pheasants fed methylmercury-treated grain.

		Embryonic mortality, % eggs incubated					
		Days in incubation period					
		0 – 8		9 – 16		17 – 24	
Source of variation	df	MS	F	MS	F	MS	F
A (Hg levels)	2	0.419	19.21**	0.001	1.56	0.010	1.34
B (Length of feeding period)	3	0.480	22.02**	0.001	1.36	0.017	2.23
A × B (Interaction)	6	0.084	3.86**	0.000	1.07	0.006	0.80
C (Weeks in experiment)	11	0.207	9.49**	0.001	1.85	0.030	3.75**
A × C (Interaction)	22	0.026	1.21	0.001	1.68	0.008	1.02
B × C (Interaction)	33	0.064	2.94**	0.001	1.62*	0.004	0.60
A × B × C (Interaction)	66	0.014	0.65	0.000	0.88	0.007	0.92
Error	144	0.021		0.000		0.008	
Total	287						

*P < 0.05
**P < 0.01

Figure 3. Weekly egg production of pheasants receiving diets in which 100, 50 or 25 per cent of the grain portion had been treated with MMD.

Figure 3



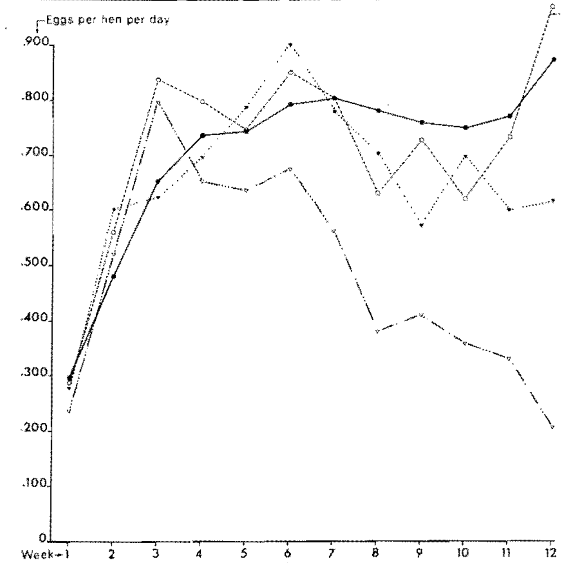
Control
25 % treated grain first 2 weeks
" 4 "
throughout exp

Mercury residues in birds and eggs

Table 3 shows the mercury levels found in the liver samples obtained from each group after 10 weeks. Although the levels varied greatly, they correlated well with the estimated mercury consumption. Mercury levels in the eggs varied considerably, but were relatively low. Even the eggs from hens receiving the largest amounts of Panogen contained only 1.5 ppm mercury.

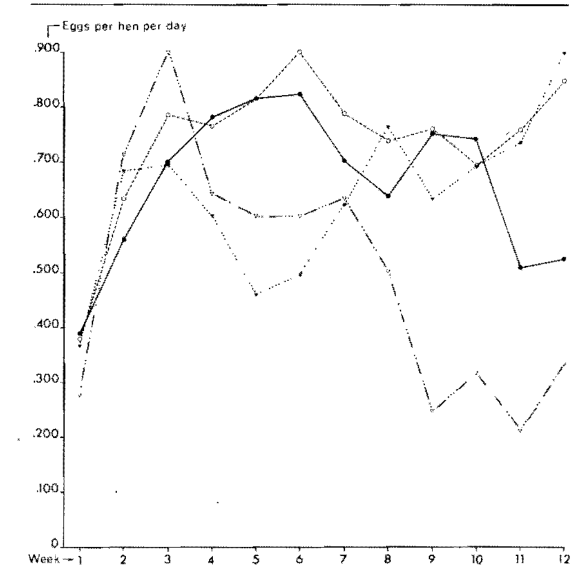
The levels peaked after the hens had eaten treated grain for 4 to 7 weeks: the higher the dietary level of Hg, the shorter the time to peak. After 4 to 7 weeks the mercury content of eggs decreased even though the contaminated diet continued. Eggs from hens receiving treated grain

Figure 3 (continued)



Control
50 % treated grain first 2 weeks
" 4 "
throughout exp

Figure 3 (continued)



Control
100 % treated grain first 2 weeks
" 4 "
throughout exp

Table 4
Comparisons of groups of pheasants fed methylmercury-treated grain with the appropriate controls as to food consumption, egg production, frequency of shell-less eggs, hatchability, chick production and embryonic mortality. All comparisons were F-tests with 1,46 df.

Comparisons with controls†	Food consumption, grams/ hen/day	Egg production, eggs/ hen/day	Shell-less eggs, % eggs laid	Hatchability, % eggs incubated	Chick production, chicks/ hen/day	Embryonic mortality, % eggs incubated — Days in incubation period: 0–8	9–16	17–24
	F	F	F	F	F	F	F	F
100/2	0.86	2.23	0.83	0.09	0.08	1.15	3.70	0.00
100/4	2.68	0.36	1.38	7.45**	13.83**	16.61**	0.40	0.03
100/12	32.27**	7.23**	5.41*	33.03**	34.23**	11.31**	0.07	0.11
50/2	0.04	0.07	4.90*	0.02	0.02	0.12	0.04	1.04
50/4	0.34	0.50	0.48	1.32	5.81*	0.10	0.30	3.52
50/12	3.95	12.99**	12.24**	4.22*	31.69**	12.54**	0.19	1.32
25/2	0.09	0.46	5.43*	2.59	6.81*	5.61*	0.55	0.02
25/4	3.01	0.00	1.80	0.83	2.71	1.26	0.10	0.74
25/12	1.14	0.28	5.05*	7.05*	7.25**	5.04*	3.65	0.03

*Significantly different from controls ($P < 0.05$).
**Significantly different from controls ($P < 0.01$).
†The groups are referred to according to per cent (100, 50, 25) treated grain of total grain ration and weeks (2, 4, 12) fed treated grain.

Table 5
The overall reproductive success in pheasants fed methylmercury-treated grain.

Hg-treat. grain in diet, % gr. ration	Weeks fed Hg-treated grain	Pen No.	Eggs per hen	Percentage of laid eggs: Shell-less	Percentage of laid eggs: Broken	Percentage of laid eggs: Taken for analysis	Percentage of laid eggs: Incubated	Embryo mortality, %, Days of incubation: 0–8	Embryo mortality, %, Days of incubation: 9–16	Embryo mortality, %, Days of incubation: 17–24	Hatchability, % incubated eggs	Chicks hatched per hen	Chick mortality first 2 weeks, %
100	0	1	54.3	2.7	7.7	3.6	86.0	28.1	1.4	17.7	52.8	27.4	13.8
		13	57.9	1.3	4.5	3.2	91.0	25.5	2.1	20.8	51.6	29.4	14.4
		Mean	55.6	2.0	6.2	3.4	88.4	26.9	1.7	19.2	52.2	28.4	14.1
	2	2	62.1	1.8	7.3	2.8	88.1	30.3	0.9	20.9	47.9	30.3	23.3
		14	62.3	3.6	5.4	2.6	88.4	36.3	0.3	17.8	45.6	27.6	12.2
		Mean	62.2	2.7	6.4	2.7	88.2	33.3	0.6	19.3	46.8	28.8	17.9
	4	3	52.2	3.1	4.7	4.0	88.2	46.0	0.7	22.6	30.7	15.6	12.6
		15	54.7	2.6	4.2	3.2	90.0	44.6	1.8	17.5	36.1	19.0	21.8
		Mean	53.4	2.9	4.5	3.7	88.9	45.3	1.2	20.1	33.4	17.3	17.6
	12	4	35.8	0.8	7.8	3.7	87.7	57.5	1.4	21.0	20.1	6.9	25.6
		16	48.6	15.2	3.2	2.8	78.8	42.6	2.8	18.5	36.1	13.7	23.3
		Mean	41.8	8.9	5.2	3.2	82.7	49.5	2.2	19.6	28.7	10.3	24.1
50	0	5	67.3	0.7	3.8	3.1	92.4	24.1	0.5	17.6	57.8	39.0	13.7
		17	50.0	1.7	6.8	3.8	87.7	13.1	1.6	16.3	51.0	25.5	19.9
		Mean	59.1	1.1	5.0	3.4	90.8	26.9	0.9	17.1	55.1	32.2	16.0
	2	6	60.7	0.9	4.5	3.1	91.6	15.4	1.8	28.8	54.0	31.2	19.9
		18	59.2	4.7	12.5	3.3	79.4	27.3	1.4	16.4	54.9	30.9	12.1
		Mean	60.0	2.8	8.6	3.2	88.7	20.9	1.6	23.1	54.4	31.3	16.2
	4	7	50.2	2.4	2.8	3.0	91.8	25.9	2.0	20.3	51.8	25.2	17.7
		19	60.1	0.3	4.7	3.2	91.8	26.9	0.9	31.2	41.0	24.7	18.2
		Mean	55.0	1.3	3.8	3.1	91.8	26.4	1.4	26.2	46.0	24.9	17.9
	12	8	42.8	11.5	9.1	3.5	75.9	42.4	1.8	15.2	40.6	14.7	22.7
		20	37.6	11.0	9.8	2.8	76.4	37.6	2.1	22.2	38.1	12.3	13.5
		Mean	40.3	11.3	9.5	3.1	76.1	40.2	1.9	18.5	39.4	13.5	18.5
25	0	9	61.0	0.5	6.0	2.9	90.6	23.3	1.7	21.4	53.6	33.1	11.9
		21	53.5	0.9	4.2	3.2	91.7	18.5	1.3	22.7	57.5	29.0	19.2
		Mean	57.3	0.7	5.1	3.0	91.2	21.0	1.5	22.1	55.4	31.6	15.5
	2	10	63.4	3.8	7.1	3.1	86.0	37.1	0.9	19.9	42.1	25.8	18.3
		22	44.4	2.9	10.0	4.7	82.4	23.9	1.5	21.8	52.8	22.3	17.3
		Mean	54.5	3.5	8.3	3.6	84.6	32.2	1.1	20.6	46.1	24.1	17.9
	4	11	64.2	2.4	5.5	2.8	89.3	23.2	1.3	25.6	49.9	31.0	20.9
		23	50.0	0.7	9.1	2.8	87.4	35.3	2.9	16.7	45.1	22.5	18.4
		Mean	57.4	1.6	7.1	2.8	88.5	28.4	2.0	21.7	47.9	26.8	19.9
	12	12	61.9	6.9	4.2	2.9	86.0	37.1	2.8	23.0	37.1	19.9	23.9
		24	47.6	0.0	11.0	3.6	85.4	22.4	2.3	18.9	56.4	23.9	14.7
		Mean	53.9	3.8	7.2	3.2	85.8	30.5	2.5	21.2	45.8	21.9	18.9

Table 6
Mean weights ± standard errors (grams) of eggs laid by pheasants fed methylmercury-treated grain.

Weeks into experiment	Hg-treated grain in diet grain ration 100%: Weeks fed Hg-treated grain 2	100%: Weeks fed Hg-treated grain 4	100%: Weeks fed Hg-treated grain 12	Hg-treated grain in diet grain ration 50%: Weeks fed Hg-treated grain 2	50%: Weeks fed Hg-treated grain 4	50%: Weeks fed Hg-treated grain 12
1	32.61 ± .447	31.78 ± .645	32.78 ± 1.002	30.82 ± .851	31.56 ± .543	32.00 ± .510
2	32.56 ± .434	32.57 ± .398	32.57 ± .435	30.89 ± .501*	31.85 ± .368	33.10 ± .431
3	32.24 ± .468	31.74 ± .339	32.25 ± .287	31.15 ± .395*	32.58 ± .575	33.71 ± .406**
4	31.69 ± .570	31.04 ± .422	31.45 ± .419	31.49 ± .356	31.63 ± .500	33.66 ± .362**
5	31.67 ± .569	30.33 ± .513**	30.50 ± .345**	32.03 ± .418	31.83 ± .524	32.79 ± .601
6	31.96 ± .262**	30.49 ± .740**	30.10 ± .534**	32.86 ± .235	31.28 ± .315**	32.07 ± .477*
7	31.87 ± .424**	30.73 ± .597**	29.94 ± .379**	32.31 ± .494	31.24 ± .294**	31.38 ± .677**
8	31.62 ± .535**	30.15 ± .672**	29.75 ± .648**	32.70 ± .718	30.72 ± .377**	31.57 ± .738
9	31.41 ± .353**	28.63 ± .424**	30.27 ± 1.102	31.96 ± .380**	29.89 ± .380**	31.17 ± .760**
10	32.43 ± .436*	28.73 ± .307**	29.13 ± 1.115**	31.56 ± .384**	30.12 ± .420**	30.53 ± .985*
11	32.93 ± .340	28.66 ± .400**	29.00 ± 1.683**	32.14 ± .481**	30.09 ± .454**	32.57 ± 1.122
12	32.38 ± .291*	29.18 ± .404**	28.00 (1 egg only)	31.97 ± .506*	30.60 ± .502**	27.00 (2 eggs only)

*Significantly different from controls ($P < 0.05$)
**Significantly different from controls ($P < 0.01$)

Table 6 (continued)
Mean weights ± standard errors (grams) of eggs laid by pheasants fed methylmercury-treated grain.

Weeks into experiment	Hg-treated grain in diet grain ration 25%: Weeks fed Hg-treated grain 2	25%: Weeks fed Hg-treated grain 4	25%: Weeks fed Hg-treated grain 12	Hg-treated grain in diet grain ration 0 (Controls): Weeks fed Hg-treated grain 0
1	31.22 ± .411	32.51 ± .566	31.48 ± .540	31.96 ± .390
2	31.36 ± .269	32.84 ± .403	31.94 ± .563	32.36 ± .320
3	32.66 ± .483	32.92 ± .332	31.87 ± .375	32.48 ± .331
4	32.69 ± .384	32.56 ± .443	31.85 ± .314	31.81 ± .331
5	32.38 ± .280	33.18 ± .470	31.25 ± .351**	32.80 ± .297
6	32.65 ± .453	32.51 ± .430	32.08 ± .303**	33.15 ± .235
7	32.43 ± .476	32.60 ± .406	31.75 ± .485**	33.30 ± .241
8	32.38 ± .482	32.13 ± .382**	30.70 ± .395**	33.26 ± .278
9	31.92 ± .545**	32.52 ± .537*	31.20 ± .320**	33.56 ± .286
10	32.21 ± .343**	32.85 ± .507*	31.00 ± .465**	33.56 ± .238
11	32.36 ± .769	33.31 ± .665	31.14 ± .347**	33.84 ± .294
12	33.04 ± .766	33.35 ± .417	30.53 ± .425**	33.51 ± .397

*Significantly different from controls ($P < 0.05$)
**Significantly different from controls ($P < 0.01$)

Figure 4. Effects of dietary methylmercury on the size and colour of pheasants' eggs. The eggs marked 4 were laid by a group fed 100 per cent treated grain through 4 weeks, whereas those marked 5 were laid by control hens. Eggs are in actual size in centimetres.
Photo by W. N. Holsworth.

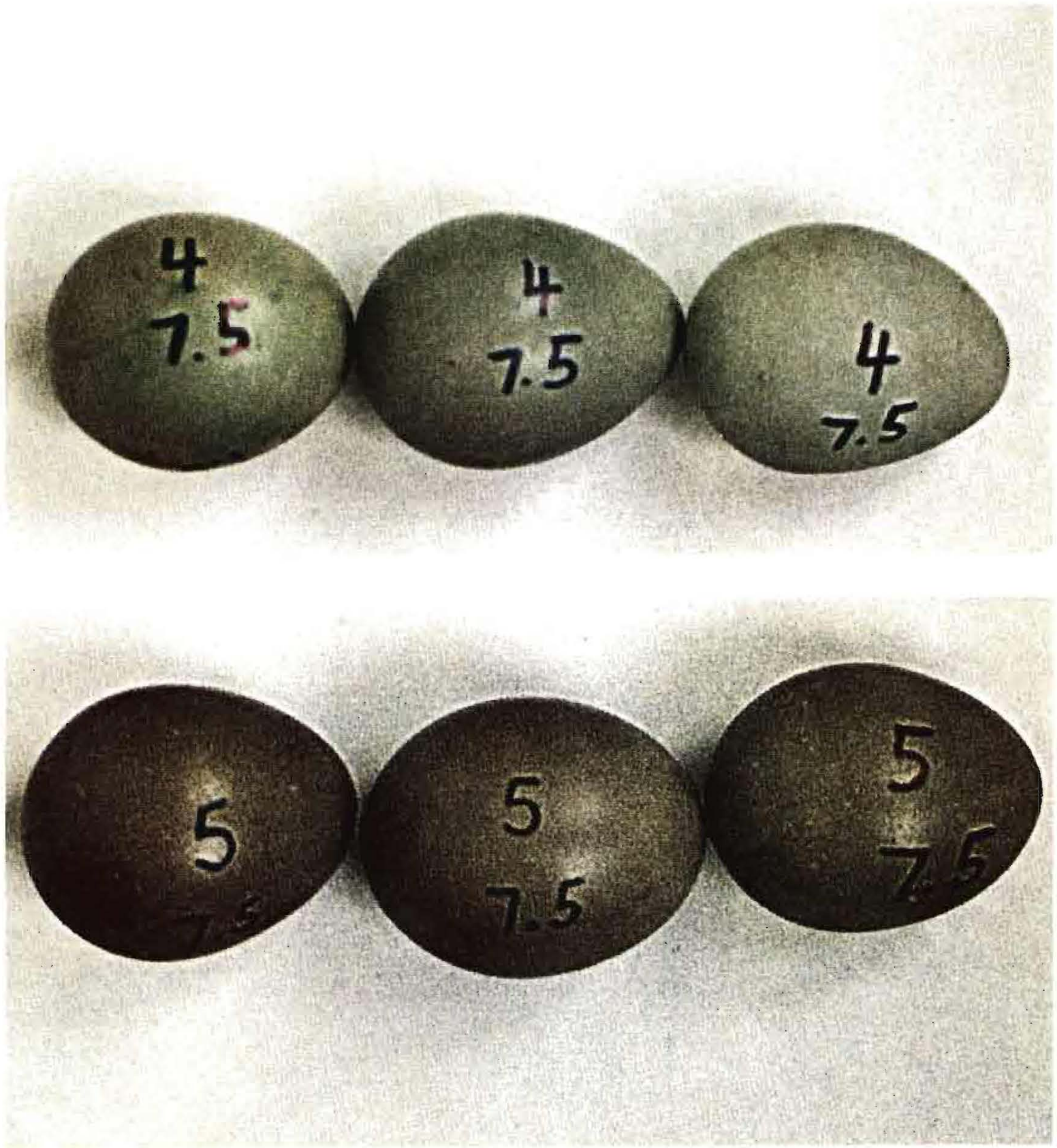
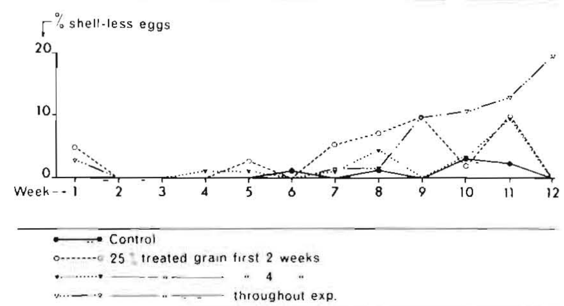


Figure 5. Frequency of shell-less eggs laid by pheasants receiving diets in which 100, 50 or 25 per cent of the grain portion had been treated with MMD.

Figure 5



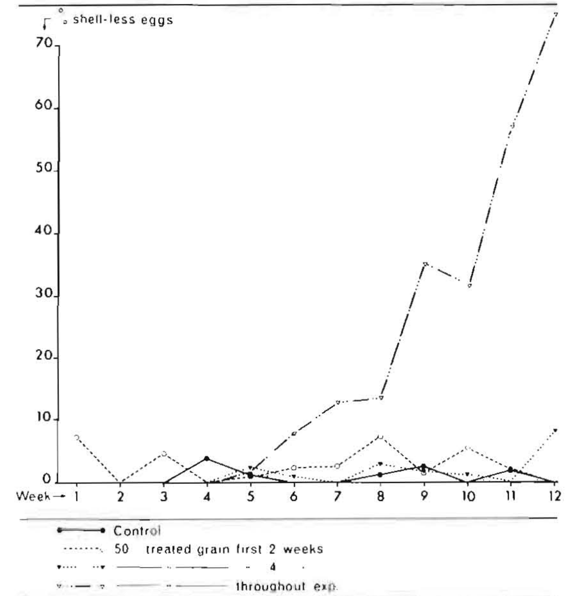
only for the first 2 weeks seldom contained a detectable amount of mercury during the last 2 or 3 weeks of the experiment. In general, mercury levels in the eggs reflected those in the hens' diet.

Egg production

The total number of eggs laid in each pen, expressed as eggs per hen, is given in Table 5. The weekly egg production, expressed as eggs per hen per day, is charted in Figure 3.

The overall analysis of variance (Table 2) shows that the length of time the pheasants were subjected to the contaminated diet resulted in statistically significant ($P<0.01$) differences in egg production, but that the mercury level in the diet was not a significant factor. There is, however, a significant interaction ($P<0.05$) between these factors. The length of the treated diet and the number of weeks completed in the experiment show significant interaction, but there are no important second-order interactions. Table 4 indicates that only groups 100/12 and 50/12 differ significantly ($P<0.01$) from the controls. Egg production in group 100/4 declined for about 5 weeks (Fig. 3), then gradually increased, until it even surpassed the production of the control group during the last 2 weeks.

Figure 5 (continued)



The low production in pen 22 is at least partly explained by two factors: one hen was ill for several weeks, and this pen was one of those (21, 22, 23, 24) not ready for occupancy until 3 days before the experiment began. The hens in all these pens produced fewer eggs than the others within their respective groups.

Although eggs were collected more frequently from pens where they were being broken and subsequently eaten, it was impossible to prevent some from being broken. When remnants of eggs were found they were recorded (Table 5) with those broken accidentally. Egg-eating occurred fairly frequently in pens 4, 18 and 24, and occasionally in pens 12, 20 and 23. Shell-less eggs were probably eaten in pens 4 and 24; very few shell-less eggs and a lower egg production were found in these pens when they were compared

Figure 5. (cont'd). Frequency of shell-less eggs laid by pheasants receiving diets in which 100, 50 or 25 per cent of the grain portion had been treated with MMD.

Figure 6. Hatchability (percentage of incubated eggs) in groups receiving diets in which 100, 50 or 25 per cent of the grain portion had been treated with MMD.

Figure 5 (continued)

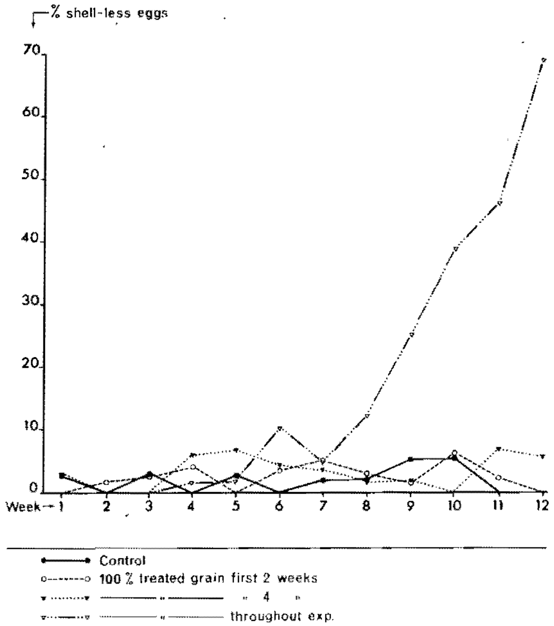


Figure 6

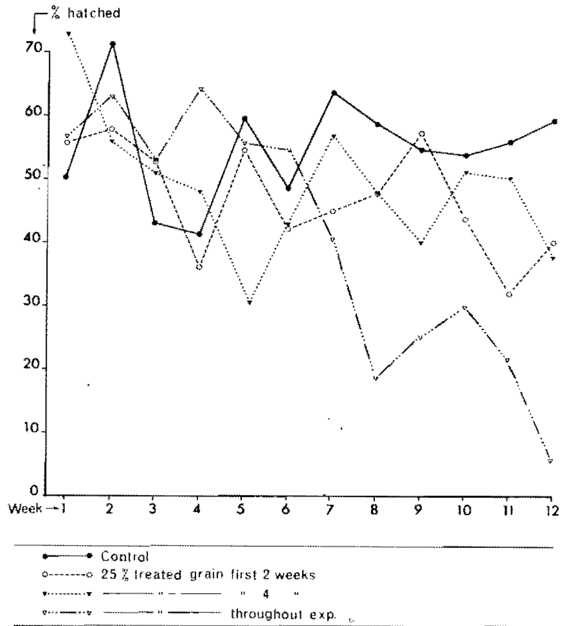


Figure 6 (continued)

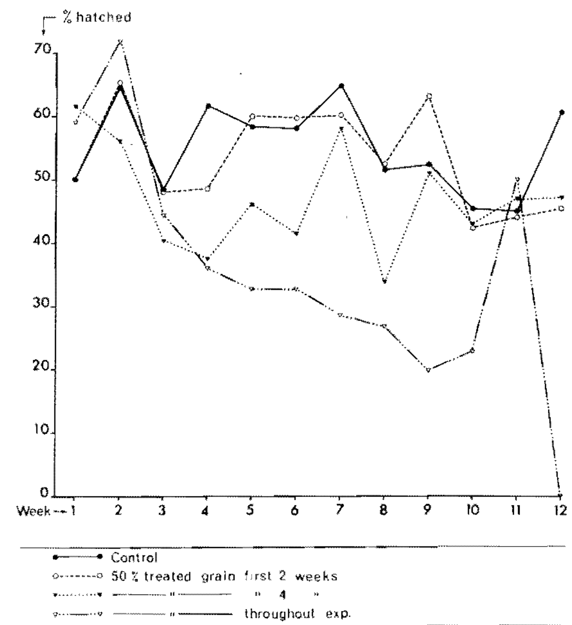
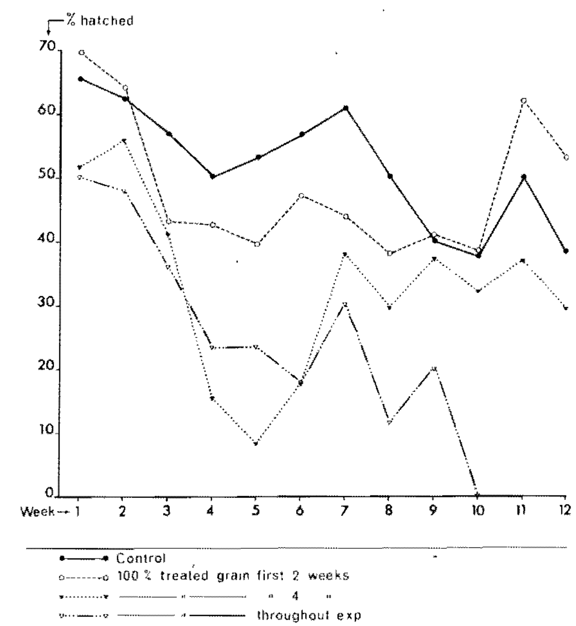


Figure 6 (continued)



with pens 12 and 16. The eating of shell-less eggs may account for the low production figures.

Group 100/2 produced 11.4 per cent more eggs than did its control, indicating that this level of dietary mercury for a short period may stimulate egg production.

Egg weight and abnormalities

Weight

Mean weights of all (except shell-less and broken) eggs are given in Table 6. Student's t-test analysis showed highly significant differences between the most contaminated groups and their controls from the fifth week onwards. The influence of mercury was more pronounced in the groups receiving 100 per cent treated grain, but

Table 7
The influence of dietary methylmercury on egg production and hatchability in pheasants.

Comparisons with controls*	Percentage reduction (—) or increase (+) Egg production	Hatchability†
100/2	+11.37	—10.37
100/4	— 3.96	—36.00
100/12	—24.82	—46.11
50/2	+ 1.52	— 1.27
50/4	— 6.94	—16.52
50/12	—38.81	—28.49
25/2	— 4.88	—16.79
25/4	+ 0.02	—13.54
25/12	— 5.93	—17.33

*The groups on contaminated diets are referred to according to per cent (100, 50, 25) treated grain of total grain ration and weeks (2, 4, 12) fed treated grain.
†Calculated as:

$$\frac{\text{\% hatched of comparing groups} - \text{\% hatched of controls}}{\text{\% hatched of control}}$$

Table 8
Analysis of variance of mortality in chicks hatched from eggs laid by pheasants fed methylmercury-treated grain.

Source of variation	df	MS	F
A (Hg levels)	2	1.369	< 1 ns*
B (Length of period fed Hg-treated grain)	3	14.863	1.136 ns
A × B (Interaction)	6	5.439	< 1 ns
Error	12	13.077	
Total	23		

*ns — Not significant

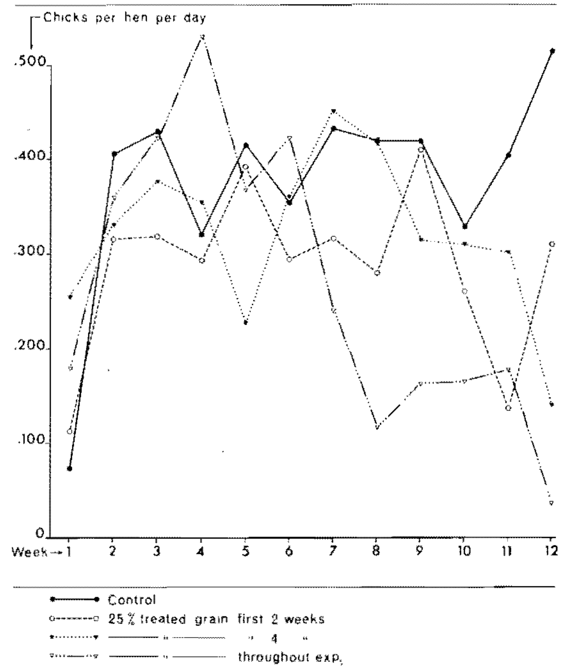
Table 9
The influence on chick mortality of dietary methylmercury fed to pheasant breeding stock. All comparisons were F-tests with 1. 2 df.

Comparisons with controls*	Chick production, chicks/hen/day F
100/2	0.38
100/4	0.41
100/12	37.32**
50/2	0.05
50/4	0.16
50/12	0.03
25/2	0.42
25/4	1.12
25/12	0.41

*The groups are referred to according to per cent (100, 50, 25) treated grain of total grain ration and weeks (2, 4, 12) fed treated grain
**Highly significantly different from controls ($P < 0.01$)

Figure 7. Chick production in groups receiving diets in which 100, 50 or 25 per cent of the grain portion had been treated with MMD.

Figure 7



during the last 3 or 4 weeks the eggs from all contaminated groups were definitely lighter. For the groups receiving treated grain for only the first 2 or 4 weeks, the effect was latent; they produced lighter eggs much later in the experiment.

Colour

Abnormally coloured eggs began to appear after the fourth week, predominantly in eggs from group 100/12, but also in groups 100/4 and 50/12. The abnormal eggs were usually light greenish or of a white colour rather than the usual olive-buff. The differences in colour and size of eggs from pen 4 (group 100/4) and pen 5 (control) can be seen in Figure 4.

Figure 7 (continued)

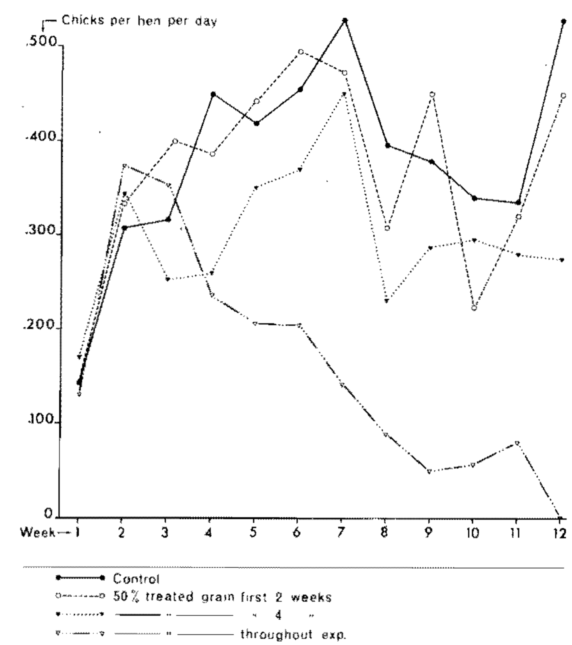
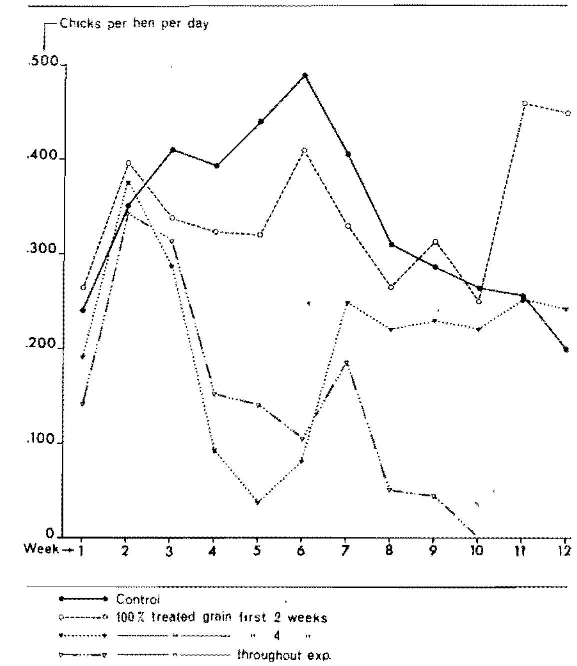


Figure 7 (continued)



Shell-less eggs

Shell-less eggs appeared in all groups; but 100/12, 50/12 and 25/12 differed in that they produced an abnormally high number of such eggs in the last 4 weeks (Table 5). Variance analysis shows (Table 2) that the duration of the feeding period is the most important factor here. Since shell-less eggs were often eaten in pens 4 and 24, more of this kind of egg must have been produced than would be indicated by Table 5 and Figure 5.

Hatchability

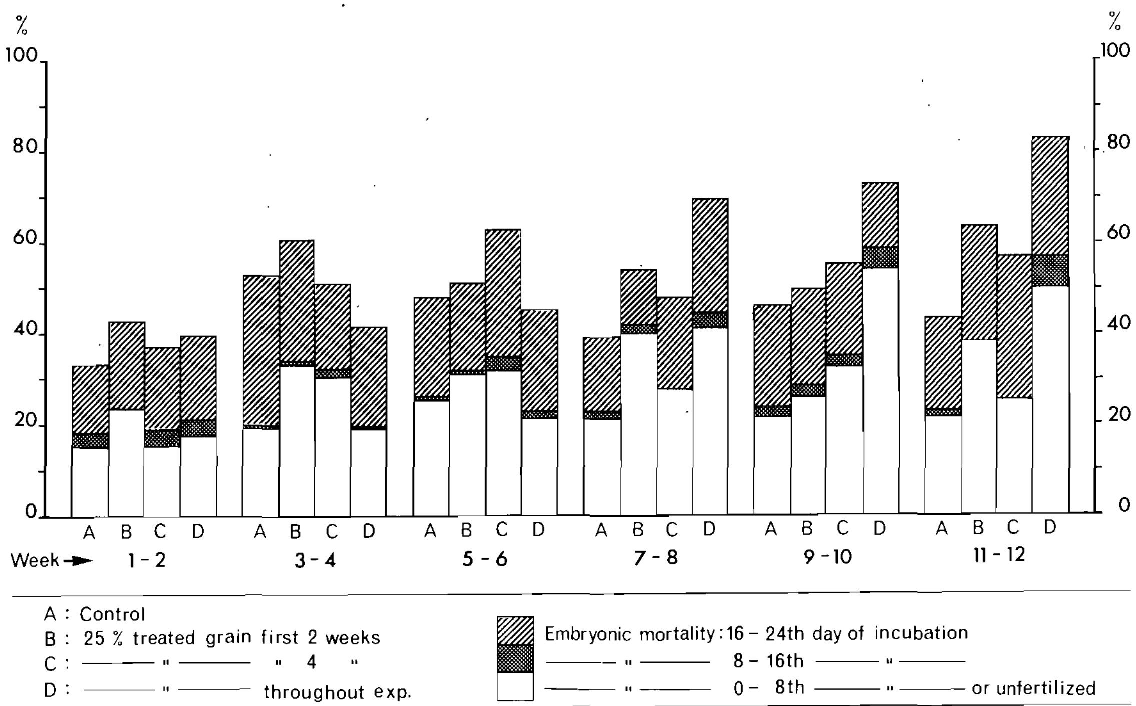
Variance analysis of the data presented in Table 5 and Figure 6 revealed a difference in hatchability ($P<0.01$) that was related to both the mercury level and the duration of the contaminated diet. As evident in Table 4, groups 100/12, 50/12, 25/12 and 100/4 differed significantly from the control. The decline in hatchability of eggs from group 100/4 was most noticeable 1 or 2 weeks after the mercury diet ended. The temporary decline seen in groups 100/2 and 50/4 was not significant ($P>0.05$).

Mercury levels in egg samples with significantly decreased hatchability ranged between 0.5 and 1.5 ppm.

The overall hatching percentages in the control groups, which vary between 52 and 55, may seem to be low; however, in this study hatchabil-

Figure 8. Embryonic mortality (percentage of incubated eggs) in groups receiving diets in which 100, 50 or 25 per cent of the grain portion had been treated with MMD.

Figure 8



ity is expressed as the percentage of incubated eggs, not of fertilized eggs, and all small eggs were incubated.

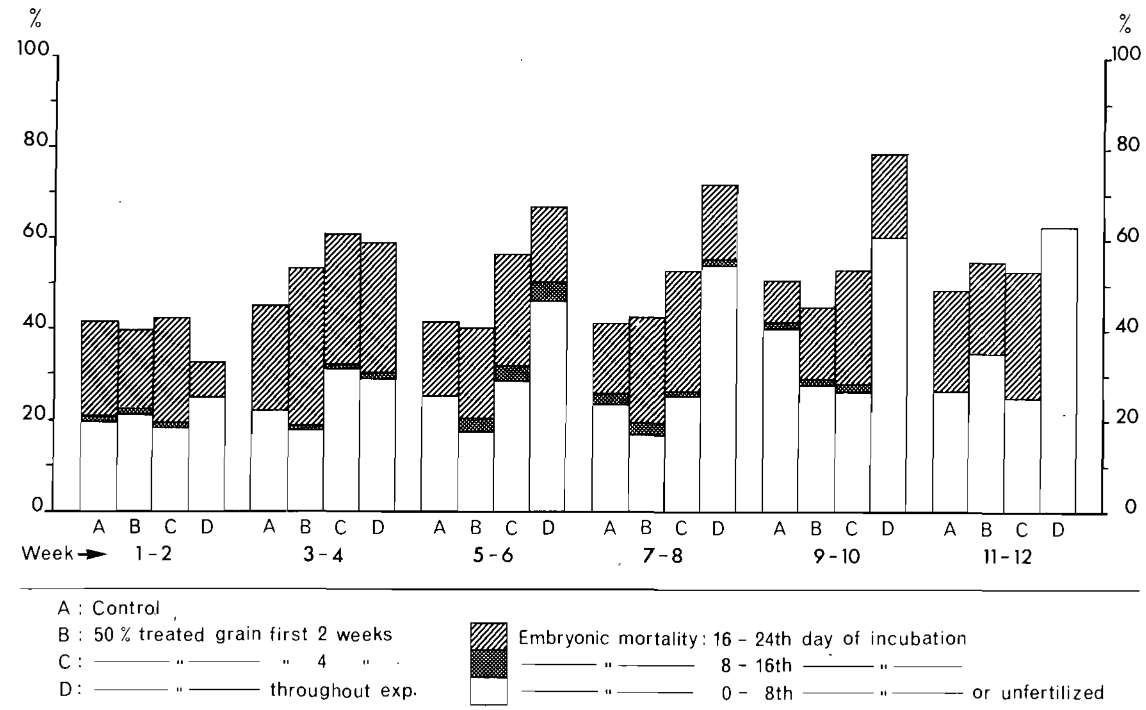
The incubation period varied between 23 and 25 days, averaging 24 days in both the control and mercury-contaminated groups.

Chick production

Chick production (the number of chicks hatched per hen) is affected by egg production, hatchability, and proportion of shell-less eggs produced. In this experiment the aspect of hatchability appeared to be the most vulnerable to the effects of mercury and therefore to have the greatest effect on chick production (Table 7). The variance analysis indicated (Table 2) that both mercury level and duration of mercury feeding had highly significant effects ($P<0.01$). All groups on contaminated diets except 100/2, 50/2 and 25/4 produced significantly fewer chicks than did the control groups (Table 4).

The results (Table 5, Fig. 7) have been adjusted to include eggs broken or taken for analysis, assuming that their hatchability would be the same as that of the other eggs in their respective groups.

Figure 8 (continued)



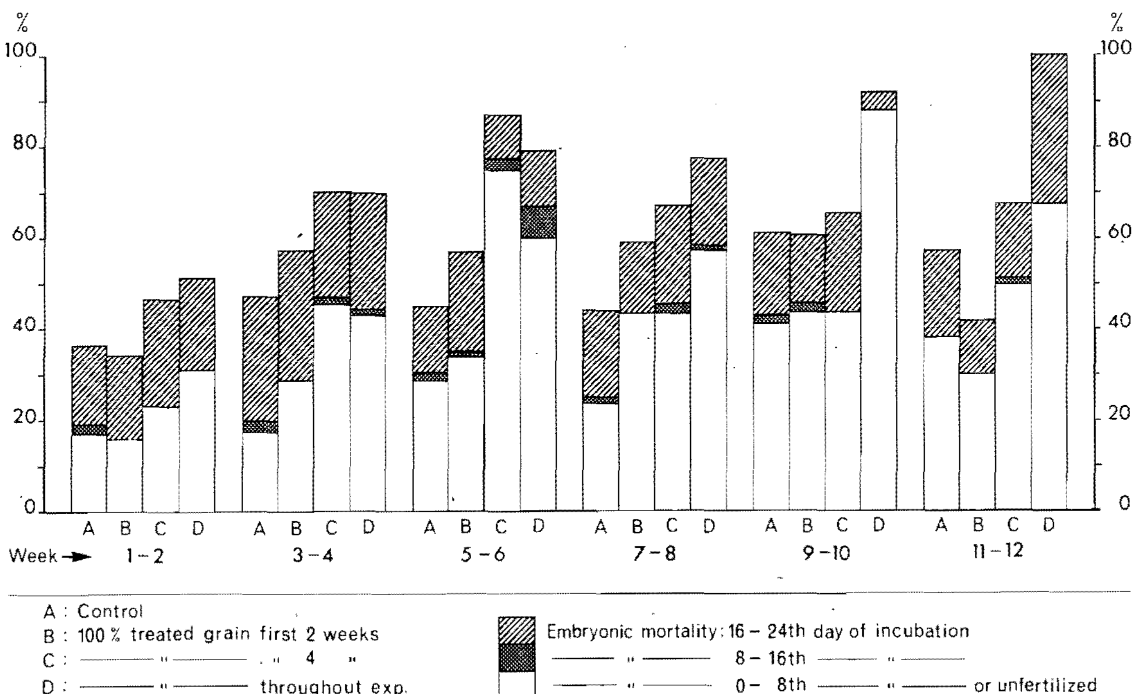
Embryonic mortality

When the unhatched eggs were opened, the stage of development at death was recorded under the following classifications: (1) 0 – 8th day, (2) 9th – 16th day, (3) 17th – 24th day. The results are given in Table 5; Figure 8 shows the variation in embryonic mortality throughout the experiment.

Increased embryonic mortality early in the incubation period is most significant and correlates with both the mercury level in the egg and the duration of the maternal feeding period. Unfertilized eggs are also included and, since only a few had detectable embryos, there was evidently a strong inhibitory effect on fertilization. I cannot explain the comparatively high mortality in group 25/2.

Virtually no embryonic mortality occurred between days 9 and 16 (Fig. 8). When embryonic mortality was low, mortality was divided evenly between the early and late periods, i.e., before and after days 9 and 16 respectively. When high, the mortality was concentrated in the early period. This phenomenon was most evident in the groups receiving the greatest amounts of mercury.

Figure 8 (continued)



Chick mortality

Total chick mortality in the first 2 weeks after hatching is given in Table 5. Variance analysis uncovered no significant difference (Table 8) between either mercury levels or feeding periods, and paired comparison with the controls (Table 9) indicated that only one group suffered much higher mortality than the controls.

Mortality was particularly high at the beginning of the experiment, but at least part of this was accidental; a number of chicks became crippled the first week because, until the problem was detected, brooders with perforated bottoms instead of wires were used. Later, on two occasions, heat lamps in the incubator failed during the night, causing an increased death rate.

Most of the chicks that died succumbed 1 to 3 days after hatching.

Discussion

Romanoff and Romanoff (1949) pointed out that reproduction in birds is affected by a number of environmental, physiological and inherent factors. This was borne out here by the relatively high variance within groups, in spite of the effort made to minimize error. I had designed the experiment with three control groups, each having two replications (subgroups), as had the groups on contaminated diets. In this way the natural variations under the test conditions could be established and this in turn would increase the significance of the evaluation of the effects of the factor concerned: dietary methylmercury.

Health and weight

The hens were little affected by the mercury. The highest mercury level found in the liver was 13.7 ppm, and Borg *et al.* (1969) reported that 30 ppm is a significant mortality level in adult pheasants.

Surprisingly, no hens died in group 100/12 and 50/12, but egg production declined noticeably. Since mortality is greater in high egg production flocks (Romanoff and Romanoff, 1949), the sublethal mercury levels may have reduced this stress or even have combatted the pathogens concerned. The therapeutic properties of mercury compounds are well known (Bidstrup, 1964), and Mellanby (1967) mentioned that mercury-treated grain has been suggested to be advantageous to health. This suggestion coincides with my findings but has proven to be inapplicable to higher dietary mercury levels (Borg *et al.*, 1969). Tejning (1967) found that chickens on a diet of 18.4 ppm mercury displayed signs of neurological disturbances, including difficulty in standing and walking. He did not, however, note these effects in hens given 9.2 or 4.4 ppm mercury, the latter being close to the highest mercury levels in my experiments. Histological examination of the hens in this study receiving the largest amounts of mercury revealed pathological changes in the nervous system, particularly demyelination. These changes probably result from the affinity of alkylmercury to the nervous system (Friberg, 1959) and confirm the findings of Borg *et al.* (1969).

Most of the birds lost weight during the experiment. The variance was similar in controls and in contaminated groups, even in the case of group 100/12, despite its much lower food consumption. The fact that a much lower caloric intake is not reflected in excessive body weight loss must be connected with the greatly diminished egg production of this group. It has been found that even higher dietary alkylmercury levels have had no strong effects on the body weight of adult chickens (Heuser, 1956; Tejning, 1967). The therapeutic properties of mercury provide the probable explanation. Pheasants, like most gallinaceous birds, suffer from a number of parasites and diseases. Within certain limits the therapeutic advantages of mercury outweigh its possible toxic effects on growth and health. But to prove this hypothesis, control birds free of parasites would be needed, and these would be hard to obtain without introducing another therapeutic agent.

Reproduction

Egg production was only moderately affected: total production was strongly reduced only in groups 100/12 and 50/12. The effect on group 100/12 could be ascribed to a lower caloric intake, but since the food consumption of group 50/12 was normal, mercury probably has a direct effect, rather than an indirect one through reduced food consumption.

This conclusion can best be compared with those of Smart and Lloyd (1963). For 8 weeks they fed grain treated with methylmercury dicyandiamide (6 ppm of mercury) to chickens and noted no effect on egg production. Perhaps pheasants and chickens have a species difference in tolerance of mercury.

Group 100/4 showed a strong but temporary decline in egg production; recovery was complete after 3 weeks on a mercury-free diet. Apparently, decreasing egg production is not due to such degenerative effects of methylmercury as heavy demyelination and cell degeneration of the central nervous system, for these symptoms appeared in groups 100/12 and 50/12 as well as group 100/4.

Although egg weight declined most noticeably in the most heavily contaminated groups, in the last weeks of the experiment the effect was noted in most of the contaminated groups, even those whose diet had been mercury-free for several weeks. The relatively long latent period may indicate that a metabolite rather than the mercury compound itself is the cause. Perhaps because the effect was not expected, earlier researchers have not mentioned any change in egg weight.

I found a large number of eggs with abnormal colour, but only in the groups receiving the largest amounts of mercury. This very conspicuous effect may not have been reported before because earlier experiments did not continue long enough to introduce the phenomenon.

Comparatively high numbers of shell-less eggs were produced by the groups receiving treated grain throughout the experiment. The effect was not significant until about the eighth week, when it increased rapidly, and by the sixteenth week reached about 70 per cent in groups 100/12 and 50/12. These findings indicate that the phenomenon appears only after a long mercury feeding period and that the length of the feeding period is a more important factor than the dietary mercury level. Tejning drew the same conclusion (1967); his percentage of shell-less eggs was even higher, possibly because I underestimated the number of eggs eaten. Tejning (1967) maintained that accelerated passage of the egg through the shell-forming portion of the oviduct or inhibition of some necessary enzyme may be the cause of shell-less eggs.

Hatchability was strongly affected by the mercury compound: all contaminated groups showed a lower hatching frequency to some degree. Borg *et al.* (1969) found, on the contrary, that feeding 21 ppm mercury for periods of 3 and 6 days significantly increased the hatching percentage, and only the 9-day feeding period significantly lowered the hatching frequency. The amount of mercury ingested by the hens in the experiment by Borg *et al.* was in all cases well above the smallest doses in this study. The apparent discrepancies between the results of these studies may show that the length of the experimental feeding period is of as much importance as the amounts of mercury ingested, so that a certain amount of dietary mercury may have one effect when ingested for 6 days or less, and another when ingested for 14 days or more. The mercury levels in eggs from groups showing a significant reduction in hatchability varied between 0.5 and 1.5 ppm. Although these levels reflect to a certain degree the mercury levels in the diet, I did not find any clear relationship between mercury levels in eggs and hatchability. Similar findings are reported by Tejning (1967). His explanation is that the hatching prospects may depend upon the duration of mercury feeding as well as upon the mercury amounts in the eggs, which in his case far exceeded those found in this study.

Increased embryonic mortality in the contaminated groups was caused primarily by an increase in the number of unfertilized eggs, including eggs with no detectable embryos. Tejning (1967) and Bäckström (1969) reported a very pronounced accumulation of mercury in the albumen-secreting part of the oviduct and in the albumen; Tejning concluded that possible damage to the spermatozoa by the mercural secretion could occur. It is possible that my findings could be explained on this basis. The spermatozoa could also be damaged before leaving the cock, as the cock had access to treated grain as well as the hens, but this is unlikely, as mercury accumulates to a much lesser extent in the testes than in the oviduct (Tejning, 1967; Bäckström, 1969). No difference was noted between the copulation rate of the controls and any group receiving treated grain.

The mercury compound seems to have had comparatively little effect on chick survival recorded the first 2 weeks after hatching. Only the chicks from the most heavily contaminated group had a significantly higher mortality rate than the control. According to Tejning (1967) about 50 per cent of the mercury is found in the yolk sac at the time of hatching. Only in group 100/12 did mercury accumulate to such levels that it counts as a mortality factor.

Conclusion

This study indicates that methylmercury-treated grain may have gross adverse effects on reproduction in pheasants, even when the laying hens show no symptoms of mercury poisoning.

Reduced hatchability was the most significant result, followed by reduced egg production and increased numbers of shell-less eggs. But chick mortality seems to be only slightly affected.

How and to what extent are these findings related to wild bird populations? Pheasants, other seed-eating birds and their predators in Sweden have often had mercury levels similar to those in the most contaminated groups here (Borg *et al.*, 1969). Similar findings are reported from Canada (Fimreite, Fyfe and Keith, 1970).

Since the highest levels were found during and shortly after the seeding season, the source of contamination is believed to be seed-dressings. This suspicion was further confirmed by Wanntorp *et al.* (1967), who found a considerable drop in the mercury levels of wood pigeons after the 1966 ban on the use of alkylmercury seed-dressings in Sweden.

Thus it is evident that hatchability, at least, can be affected among wild birds where they have access to treated grain.

One cannot draw any conclusion about egg production because wild pheasants lay considerably fewer eggs than pheasants penned for experimental research. Nor can definite statements be made about the effect of mercury on shell formation, as the effect became significant only after about 8 weeks of mercury feeding. Discolouration of the eggs could be ecologically important if such eggs were more easily detected by predators. However, as this phenomenon was observed only in eggs from the most contaminated groups, they would probably not have hatched in any case. Finally, it should be mentioned that nesting behaviour, an important aspect of reproduction, could not be studied in this experiment.

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Appendix 1
Weight and weight changes of test birds.
Hg-treated grain in diet, 100% grain ration

Weeks fed Hg-treated grain	Pen	Bird #	Weight in grams: Before experiment began (Mar. 26–Apr. 2)	Weight in grams: May 2	Weight in grams: June 13* or June 27	Weight gained (+) or lost (—) during the experimental period (surviving birds): Grams	Per cent
0	1	1542♂	1765	1700	1620	—145	— 8.2
(Control 1)		43	1540	1500	Died May 17		
		44	1305	1250	—		
		45	1525	1260	1230	—295	—19.3
		46	1425	1380	1340*	— 85	— 6.0
		47	1455	1300	1450*	— 5	— 0.3
		48	1455	1180	1270	—185	—12.7
		49	1350	1240	1280	— 70	— 5.2
		Mean	1477	1351	1365	—130	— 8.6
	13	2041♂	1815	1850	1760	— 55	— 3.0
		42	1170	1020	940	—230	—19.6
		43	1495	Died Apr. 19	—		
		44	1210	1060	Died May 6		
		45	1190	1320	—		
		46	1375	1530	1390*	+ 15	+ 1.1
		47	1170	1420	1300	+130	+11.1
		48	1395	1380	1300	— 95	— 6.8
		Mean	1352	1577	1338	— 47	— 3.4
2	2	1550♂	1530	1520	1460	— 70	— 4.6
		51	1250	1240	1100*	—150	—12.0
		52	1305	1160	—		
		53	1240	1120	1140	—100	— 8.1
		54	1505	1220	—		
		55	1445	1150	1210	—235	—16.3
		56	1490	1380	1400*	— 90	— 6.0
		57	1260	1110	1270*	+ 10	+ 0.8
		Mean	1378	1237	1263	—105	— 7.7
	14	2049♂	1745	1750	1640	—105	— 6.0
		50	1305	1230	Died June 17		
		51	1140	1390	1350*	+210	+18.4
		52	1430	1400	1330	—100	— 7.0
		53	1260	1290	1320*	+ 60	+ 4.7
		54	1090	1380	Died May 27		
		55	1240	1210	—		
		56	1160	1090	1070	— 90	— 7.6
		Mean	1296	1342	1342	— 5	+ 0.5

Appendix 1 (continued)
Weight and weight changes of test birds.
Treated grain in diet, 100% grain ration

Weeks fed Hg-treated grain	Pen	Bird #	Weight in grams: Before experiment began (Mar. 26 – Apr. 2)	May 2	June 13* or June 27	Weight gained (+) or lost (—) during the experimental period: Grams	Per cent
4	3	1558♂	1820	1550	1580	—240	—13.2
		59	1660	1440	—		
		60	1330	1290	1300*	— 30	— 2.3
		61	1310	1230	1200	—110	— 8.3
		62	1420	1170	1220	—200	—14.1
		63	1440	1490	1540*	+100	+ 6.9
		64	1640	1370	1330	—310	—18.9
		65	1370	1240	Died May 18		
		Mean	1498	1347	1361	— 13.2	— 8.3
	15	2057♂	1540	1500	1560	+ 20	+ 1.3
		58	1150	1350	1230	+ 80	+ 7.0
		59	1285	1080	1130	—155	—12.1
		60	1320	1390	1320*	0	0.0
		61	1260	1290	1240*	— 20	— 1.6
		62	1215	1200	Died May 12		
		63	1225	1170	—		
		64	1200	1220	—		
		Mean	1274	1275	1296	— 15	— 1.1
12	4	1566♂	1780	1810	1610	—170	— 9.5
		67	1360	1180	—		
		68	1340	1370	1450*	+110	+ 8.2
		69	1390	1090	1210	—180	—12.9
		70	1340	1290	1330*	— 10	— 0.7
		71	1370	1280	1380	+ 10	+ 0.7
		72	1690	1440	1500	—190	—11.2
		73	1430	1350	1280*	—150	—10.5
		Mean	1462	1351	1394	— 83	— 5.1
	16	2065♂	1740	1700	1630	—110	— 6.3
		66	1370	1290	1280*	— 90	— 6.6
		67	1405	1560	1600*	+195	+13.9
		68	1380	1290	1300	— 80	— 5.8
		69	1420	1360	—		
		70	1360	1110	1240	—120	— 8.8
		71	1480	1420	—		
		72	1555	1580	1440*	—115	— 7.4
		Mean	1463	1413	1415	— 53	— 3.5

Appendix 1 (continued)
Weight and weight changes of test birds.
Treated grain, 50% grain ration

Weeks fed treated grain	Pen	Bird #	Weight in grams: Before experiment began (Mar. 26 – Apr. 2)	May 2	June 13* or June 27	Weight gained (+) or lost (—) during the experimental period: Grams	Per cent
0	5	1574♂	1660	1600	1500	—160	— 9.6
(Control 2)		75	1490	1340	1280	—210	—14.1
		76	1720	1560	—		
		77	1450	1240	1330	—120	— 8.3
		78	1460	1150	1220*	—240	—16.4
		79	1420	1250	1160*	—260	—18.3
		80	1240	1200	—		
		81	1510	1230	1290	—220	—14.6
		Mean	1493	1321	1296	—201	—13.5
	17	1273♂	1575	1680	1500	— 75	— 4.8
		74	1250	1500	1340	+ 90	+ 7.2
		75	1145	1220	1100	— 45	— 3.9
		76	1200	1160	1110*	— 90	— 7.5
		77	1230	1340	1240*	+ 10	+ 0.8
		78	1030	1330	1200	+170	+16.5
		79	1015	1060	—		
		80	1245	730	Died May 7		
		Mean	1211	1252	1248	+ 10	+ 1.4
2	6	1582♂	1700	1700	1530	—170	—10.0
		83	1090	1000	Died May 11		
		84	1130	1070	1180*	+ 50	+ 4.4
		85	1240	1040	1070	—170	—13.7
		86	1420	1280	1270*	—150	—10.6
		87	1240	1300	—		
		88	1380	1380	—		
		89	1240	1090	1050	—190	—15.3
		Mean	1380	1232	1220	—126	— 9.0
	18	2090♂	1840	1760	1600	—240	—13.0
		2082	1175	1140	1030*	— 45	— 3.8
		83	1405	1460	1390	— 15	— 1.1
		84	1095	1260	—		
		85	1425	1270	Died May 23		
		87	1090	1300	1190	+100	+ 9.2
		88	1200	1080	1000*	—200	—16.7
		89	1350	1380	1250	—100	— 7.4
		Mean	1322	1331	1243	— 83	— 5.4

Appendix 1 (continued)
Weight and weight changes of test birds.
Treated grain, 50% grain ration

Weeks fed treated grain	Pen	Bird #	Weight in grams: Before experiment began (Mar. 26–Apr. 2)	May 2	June 13* or June 27	Weight gained (+) or lost (—) during the experimental period: Grams	Per cent
4	7	1590♂	1740	1740	1670	— 70	— 4.0
		91	1210	1180	970	—240	—19.8
		92	1320	1410	1220	—100	— 7.6
		93	1180	1220	930	—250	—21.2
		94	1280	1420	1380*	+100	+ 7.8
		95	1280	1170	1200*	— 80	— 6.3
		96	1090	1230	1260*	+170	+15.6
		97	1350	1190	—		
		Mean	1309	1319	1232	— 67	— 5.1
	19	2860♂	1613	1560	1510	—103	— 6.4
		2091	1135	1100	—		
		92	1390	1410	—		
		93	1300	1270	1300*	0.0	0.0
		94	1340	1300	1190	—150	—11.2
		95	1450	1510	1400	— 50	— 3.4
		96	1155	1460	1370*	+215	+18.6
		97	1495	1310	1320*	—175	—11.7
		Mean	1359	1365	1348	— 44	— 1.3
12	8	2001♂	1460	1510	1350	—110	— 7.5
		2	1550	1540	1250	—300	—19.4
		3	1580	1480	1360*	—220	—13.9
		4	1350	1360	1360*	+ 10	+ 0.7
		5	1610	1530	1500*	—110	— 6.8
		6	1430	1130	1140	—290	—20.3
		7	1950	1830	—		
		8	1680	1280	1340	—340	—20.2
		Mean	1576	1457	1328	—194	—12.4
	20	2816♂	1805	1720	1550	—355	—19.7
		17	1085	1240	—		
		18	1395	1320	1320*	— 75	— 5.4
		19	1325	1350	1370*	+ 45	+ 3.3
		20	1150	1250	1020	—130	—11.3
		21	1325	1400	—		
		22	1270	1220	1210*	— 60	— 4.7
		23	1180	1280	1100	— 80	— 6.8
		Mean	1316	1347	1261	—109	— 7.4

Appendix 1 (continued)
Weight and weight changes of test birds.
Treated grain, 25% grain ration

Weeks fed treated grain	Pen	Bird #	Weight in grams: Before experiment began (Mar. 26–Apr. 2)	May 2	June 13* or June 27	Weight gained (+) or lost (—) during the experimental period: Grams	Per cent
0	9	2009♂	1920	1900	1790	—130	— 6.8
(Control 3)		10	1650	1610	1490	—160	— 9.7
		11	1415	1360	—		
		12	1370	1190	—		
		13	1130	1100	1100	— 30	— 2.6
		14	1520	1470	1380*	—140	— 9.2
		15	1240	1230	1190*	— 50	— 4.0
		16	1195	1120	900	—295	—24.7
		Mean	1430	1372	1308	—134	— 9.5
	21	2824♂	1790	1660	1740	— 50	— 2.8
		25	1085	1210	1210*	+125	+11.5
		26	1270	1320	—		
		27	1175	1100	1060	—115	— 9.7
		28	1190	1310	—		
		29	1215	1320	1110	—135	—11.1
		30	1275	1300	1370*	+ 95	+ 7.5
		31	1390	1440	1550*	+160	+11.5
		Mean	1299	1335	1340	+133	+ 1.2
2	10	2017♂	1950	1900	1760	—190	— 9.7
		18	1440	1420	1330	—110	— 7.6
		1919	1265	1270	970*	—295	—23.3
		20	1420	1320	1300*	—120	— 8.5
		21	1170	1250	—		
		22	1460	1400	1170	—290	—19.9
		23	1500	1460	Died May 26		
		24	1530	1520	—		
		Mean	1466	1442	1306	—201	—13.8
	22	2832♂	1685	1550	1510	—175	—10.4
		33	1390	1390	1380	— 10	— 0.7
		34	1050	1200	—		
		35	1410	1240	1100	—310	—22.0
		36	escaped	—			
		38	1090	1270	Died May 30		
		39	1250	1540	1470	+220	+17.6
		40	1250	1440	1430*	+180	+14.4
		Mean	1296	1375	1378	— 19	— 0.4

Appendix 1 (continued)
Weight and weight changes of test birds.
Treated grain, 25% grain ration

Weeks fed treated grain	Pen	Bird #	Weight in grams: Before experiment began (Mar. 26–Apr. 2)	May 2	June 13* or June 27	Weight gained (+) or lost (—) during the experimental period: Grams	Per cent
4	11	2025♂	1605	1520	1460	—145	— 9.0
		26	1300	1280	—		—
		27	1290	1410	1190*	—100	— 7.6
		28	1295	1340	1200	— 95	— 7.3
		29	1340	1260	1090	—250	—18.7
		30	1300	1300	1190*	—110	— 8.5
		31	1420	1350	1320	—100	— 7.0
		32	1050	1090	1020*	— 30	— 2.9
		Mean	1325	1318	1210	—118	— 8.7
	23	2841♂	1670	1570	1630	— 40	— 2.6
		42	1245	1500	—		
		43	1295	1140	—		
		44	1345	1400	1400*	+ 55	+ 4.1
		45	1400	1120	Died May 25		
		46	1050	1130	—		
		47	1270	1110	1080	—190	—15.0
		48	1215	1220	1310	+ 95	+ 7.8
		Mean	1311	1273	1355	— 20	— 1.4
12	12	2033♂	1755	1740	1900	+145	+ 8.2
		34	1175	1080	1060	—115	— 9.7
		35	1060	1340	1220	+160	+15.0
		36	1260	1300	Died May 30		
		37	1235	1140	1090*	—145	—11.7
		38	1290	1220	1190*	—100	— 7.8
		39	1205	1140	—		
		40	1170	1350	—		
		Mean	1268	1288	1292	— 29	— 1.2
	24	2849♂	1720	1580	1470	—250	—14.5
		50	1200	1350	1360*	+160	+13.3
		51	1125	1200	1080	— 45	— 4.0
		52	1285	1110	1060	—215	—16.7
		53	1190	1220	—		
		54	1110	1190	1290	+180	+16.2
		55	1410	1390	1240	—170	—12.1
		2837	1280	1150	1050	—230	—18.0
		Mean	1308	1273	1221	— 81	— 5.1

Appendix 2
Ingredients in CO-OP 18% pheasant breeder pellets.

Ingredients
Wheat and/or oats and/or corn and/or barley, dehydrated alfalfa, shorts, bran, soybean meal and/or corn gluten meal, meat meal, fish meal, lignosol feed binder, whey, fat, calcium phosphate, limestone, salt, antibiotic feed supplement.
Choline chloride, calcium pantothenate, methionine, folic acid, riboflavin, niacin, vitamin A, vitamin B-12, vitamin D, vitamin E, vitamin K, iodine, cobalt, copper, iron manganese, zinc, ethoxyquin.

Guaranteed analysis	
Crude protein (min.)	18%
Crude fat (min.)	3%
Crude fibre (max.)	7.5%
Salt (actual)	0.5%
Calcium (actual)	2.2%
Phosphorus (actual)	0.7%
Added zinc (actual)	0.010%
Vitamin A (min.)	4000 IU/lb.
Vitamin D-3 (min.)	950 IU/lb.

Appendix 3
Ingredients in CO-OP 28% pheasant starter krums.

Ingredients
Wheat and/or oats and/or corn and/or barley, dehydrated alfalfa, shorts, soybean meal and/or corn gluten meal, meat meal, fish meal, lignosol feed binder, whey, fat, calcium phosphate, limestone, salt, antibiotic feed supplement.
Choline chloride, calcium pantothenate, methionine, folic acid, riboflavin, niacin, vitamin A, vitamin B-12, vitamin D, vitamin E, vitamin K, iodine, cobalt, copper, iron manganese, zinc, ethoxyquin.

Guaranteed analysis	
Crude protein (min.)	28%
Crude fat (min.)	3%
Crude fibre (max.)	6%
Salt (actual)	0.25%
Calcium (actual)	1.1%
Phosphorus (actual)	1.0%
Added zinc (actual)	0.010%
Vitamin A (min.)	3000 IU/lb.
Vitamin D-3 (min.)	750 IU/lb.

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