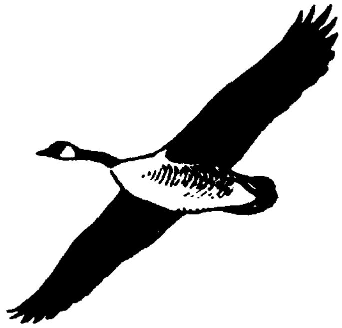
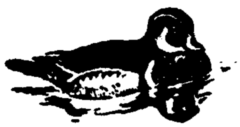
SD-IR-88-02

A Comparison of Biologically Active Elements in Geese in Relation to Avian Cholera





U.S. Fish and Wildlife Service
Fish and Wildlife Enhancement
P.O. Box 986
Pierre, South Dakota 57501

June 1988

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A Comparison of Biologically Active Elements in Geese in Relation to Avian Cholera

Prepared by

Chuck Sowards
U.S. Fish and Wildlife Service
Fish and Wildlife Enhancement
P.O. Box 986
Pierre, South Dakota 57501

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SUMMARY

1. Avian cholera caused an estimated mortality of between 166,000 to 197,000 migrating waterfowl in the Rainwater Basin of Nebraska in the 10-year period 1975 through 1984.

2. Livers were collected from 10 geese with a presumptive diagnosis for avian cholera and 5 geese for controls with a diagnosis of death due to causes other than avian cholera.

3. The 15 livers were analyzed for 14 biologically active elements.

4. It is concluded that there was no direct cause and effect relationship between avian cholera in the 10 geese sampled and the individual elements of selenium, cadmium, copper, chromium, iron, manganese, lead, and zinc.

5. The liver burdens of arsenic, mercury, nickel, and thallium were so low they were considered as having no cause and effect relationship with avian cholera in the geese studied.

6. The concentrations of berylium were quite low. However, the paucity of literature on the subject precluded any assumption in relation to avian cholera.

7. The concentrations of aluminum in the livers of both groups of geese from the Rainwater Basin were 6 to 28 times higher than those of seven other populations of birds unaffected by avian cholera. This difference of aluminum concentrations in the livers should be pursued further in the available literature.

8. Continuation of a literature review is recommended to provide a better basis for the interpretation of the importance of elevated concentrations of aluminum, berylium, and lead in bird livers.

9. Continuing the study of biologically active elements is recommended to relate tissue concentrations of antimony, barium, boron, calcium, magnesium, molybdenum, silver, strontium, and vanadium to avian cholera.

10. A study is recommended to relate the use of agricultural pesticides in waterfowl wintering areas to the springtime occurrence of avian cholera in the Rainwater Basin.

11. Study the possible relationships between the occurrence of mycotoxins and the occurrence of avian cholera in the Rainwater Basin.

Table of Contents

INTRODUCTION

The Rainwater Basin in Nebraska has often been described as the waist of an hourglass with respect to springtime waterfowl migration. The area is located just south of the Platte River near Kearney and Grand Island, Nebraska, and covers an area of about 100 miles (east to west) by 35 miles (north and south). This area is visited each spring by an estimated 4,000,000 to 7,000,000 waterfowl. The birds funnel into the area from as far east as Louisiana, as far south as Central America, and as far west as California. Some species of waterfowl stay in the Rainwater Basin for up to six weeks eating waste agricultural crops and waiting for a break in the weather to continue their migration north to breeding areas. When the break comes, the various species complete the hourglass by fanning out to the northland and arctic areas from Hudson Bay to Siberia. Because of the number of birds involved and the potential for mixing with large populations from other regions, the good health of the birds from the Rainwater Basin is crucial.

Since 1975, avian cholera epizootics in the Rainwater Basin have become an annual spring event with an estimated mortality of between 166,000 to 197,000 waterfowl in the 10-year period 1975 through 1984. There was an estimated mortality of between 72,000 to 80,000 waterfowl in the spring of 1980 alone. Avian cholera is caused by the bacterium *Pasteurella multocida*, and, although extensively studied in relation to domestic birds, the causes of the epizootics in wild birds are not adequately elucidated. Studies by Price and Windingstad (unpublished) indicated that the addition of calcium and magnesium to some waters enhanced the growth of *Pasteurella multocida*. Arthur Kilness, M.D., suggested selenium might be related to avian cholera (personal communication). It is conceivable that selenium could be involved, either by influencing the immune system of the waterfowl or by enhancing the growth of *Pasteurella multocida* as occurs with salmonella cultures when selenium is added to culture media.

The biological activity of selenium is interesting but complicated. It is an essential micronutrient, a known teratogen, a possible mutagen, and at certain concentrations is both a chronic and acute toxicant.

HYPOTHESIS

This study was predicated on the hypothesis that there may be an obvious cause and effect relationship between avian cholera and selenium or one of 13 other biologically active elements.

OBJECTIVES

1. Determine the concentration of selenium and 13 other elements in the livers of white-fronted geese and snow geese which had died from avian cholera, and compare them with the concentrations in livers of geese which had died of causes other than cholera and with healthy birds of other species. Evaluate a probable cause and effect relationship, if possible.

PROCEDURES

White-fronted and snow geese were collected by personnel of the Nebraska Game and Parks Commission during the avian cholera epizootic in the spring of 1986. The livers were collected from 10 geese with a presumptive diagnosis for avian cholera and 5 geese for controls with a presumptive diagnosis as having died of causes other than avian cholera (Table 1).

The intent was to have the presumptive diagnosis verified in the laboratory. After the presumptive diagnosis was made in the field, the samples were shipped in plastic bags which had been stapled closed. During shipping and handling, the bags partially thawed, and enough fluids escaped that bacterial contamination between samples could not be ruled out. Inasmuch as there would have been a long delay to get other samples, the study was conducted on the basis of the presumptive diagnoses.

The analysis of the concentrations of the 14 elements in the livers was done by the Environmental Trace Substances Research Center; Columbia, Missouri 65203.

FINDINGS

(Note: All concentrations discussed in this report are on a dry weight basis unless specifically stated as wet weight.)

Selenium

The mean concentrations of selenium in the livers of the cholera mortality group were 2.3 ug/g and 3.7 ug/g for the control group (Table 1). The selenium concentrations of the two groups of geese were compared with those of four other species of birds from nine locations (Table 2). The Volta Wildlife Area, California, was used as a control area for selenium studies at Kesterson National Wildlife Refuge (NWR) because it was in an area of low selenium. The mean selenium concentration in the livers of two ducks from Volta was 4.1 ug/g. The mean selenium concentration from the livers of three coots from Volta was 5.0 ug/g. The mean selenium concentration in the livers of 10 coots from Juanita Lake, North Dakota, was 2.1 ug/g. The mean selenium concentration in the livers of coots from Sand Lake NWR was 6.3 ug/g and for cormorants was 7.8 ug/g. The mean selenium concentration in the livers of coots from Arrowwood NWR was 9.7 ug/g. Avian cholera has not been a problem in Juanita Lake, Sand Lake NWR, or Arrowwood NWR in the past 10 years, even though all three were undoubtedly visited by waterfowl that had recently departed from the cholera-infested Rainwater Basin of Nebraska.

The selenium burden in the livers of the cormorants from Lake Sharpe, South Dakota, ducks from Kesterson NWR, California, and prairie chickens from the Ft. Pierre National Grasslands, South Dakota, was included to provide a perspective of the high concentrations of selenium that can be found in wild birds (Table 2). The cormorants from Lake Sharpe, with a mean selenium concentration of 24.7 ug/g, and the prairie chickens from the Ft. Pierre National Grasslands, with a mean selenium concentration of 19.3 ug/g, appeared healthy when collected. All of the individual cormorants from Lake Sharpe which had concentrations of selenium over 30 ug/g also had high concentrations of mercury (Table 3). The same was not true of the prairie chickens, all of which had low burdens of mercury.

The mean selenium concentration (2.3 ug/g) in the livers of the geese from the Rainwater Basin, which had died of avian cholera, was similar to that in coot from Juanita Lake, North Dakota, but was lower than that of all of the other populations of birds used for comparison, including the Volta Wildlife Area. The mean selenium concentrations (3.7 ug/g) in the livers of the control geese from the Rainwater Basin were lower than most of the bird populations with which they were compared. In light of this, it is doubtful that the Rainwater Basin geese in this study suffered from excess selenium. The possibility that they suffered from a selenium deficiency was considered.

Data on the selenium requirements of wild waterfowl is scarce. Heinz et al. (1987) provided data on selenium concentrations in livers of mallard ducks versus selenium content of the diet (Table 4). The effect of these concentrations of selenium was evaluated in relation to the number of 21-day old ducklings produced per hen. Based on this evaluation, there was no significant difference in the results of groups of adults with selenium concentrations in the livers ranging from 1.17 to 6.72 ppm. These liver concentrations occurred with sodium selenite fortification to the diets ranging from 0.0 to 10.0 ppm. Although extrapolation of data between species is hazardous, it is noted that a common supplement to turkey diets is 0.2 ppm. This would fall between 0.0 and 1.0 ppm added to the diets in Heinz's studies which provided mean selenium concentrations in the livers of 1.17 and 2.14 ppm and in which there was good duckling production (Table 4). The mean liver selenium concentrations of 2.3 ug/g and 3.7 ug/g for the two groups of geese from the Rainwater Basin were bracketed by the liver concentrations of 1.17 to 6.72 ppm in the ducks which had good reproduction in Heinz's studies (Table 4). On the basis of this comparison, it seems highly unlikely that the geese in this study from the Rainwater Basin suffered from a selenium deficiency.

These limited data contradict the hypothesis that there is a cause and effect relationship between selenium and avian cholera in the Rainwater Basin of Nebraska.

There was no consideration for interactions between selenium and mercury, arsenic, or vitamin E.

Arsenic and Mercury

The burden of arsenic and mercury in the livers of both groups of geese from the Rainwater Basin was too low to be considered inimical to the health of the birds (Table 1).

Aluminum

The aluminum liver concentration of the geese which died of avian cholera ranged from 18 to 109 ug/g with a mean of 56 ug/g. In the control geese, the range was 23 to 141 ug/g with a mean of 61 ug/g (Table 5). The aluminum concentrations in the livers of the Rainwater Basin geese were 6 to 28 times higher than that of any of the seven groups of bird livers analyzed from North and South Dakota (Table 5). No toxicity or nutritional information was located as a basis for comparison.

Although the high aluminum concentrations in the livers of the Rainwater Basin geese are of concern, no basis was found for an assumption relating aluminum to the health of the geese, one way or the other.

Berylium

The liver burdens of berylium appeared quite low; about half are below the level of detection (Table 1). Berylium is known to be toxic in some situations, but the paucity of literature allowed no assumptions in relation to cholera.

Cadmium

Cadmium liver burdens ranged from 0.22 to 2.60 ug/g with a mean of 0.86 ug/g in the avian cholera mortality group and 0.29 to 0.99 ug/g with a mean of 0.68 ug/g in the other mortality control group (Table 1). This seems to be within normal ranges when compared to other studies. The range of cadmium liver concentrations for four green-winged teal in Powderhorn Lake, Texas, (control area) was 0.33 to 1.00 ppm, and the geometric mean was 0.67 ppm (White and Cromartie 1985[1/]). The range and geometric mean for cadmium liver concentrations for five green-winged teal from dredge sites in the same study was 0.33 to 1.67 ppm and 1.0 ppm.[1/]

The liver cadmium concentrations of the two groups of geese from the Rainwater Basin were compared with cadmium concentrations in livers of mallards with a known amount of cadmium chloride added to their diet. The mean liver cadmium concentrations of 0.86 ug/g for the cholera mortality group and 0.68 ug/g for the non-cholera mortality group were similar to those of the control mallards in the study by White and Finley (1978). The control mallards in White and Finley's (1978) study had no cadmium added to their diet of commercial duck breeder mash and had mean cadmium liver concentrations of 0.41 and 1.30 ppm after study periods of 30 and 90 days, respectively.[1/]

[1/]Calculations for dry weight liver concentrations were based on 70 percent moisture.

The cadmium liver concentrations of the Rainwater Basin geese were considerably less than mean concentrations of 1.72, 4.48, and 7.05 ppm found in the livers of ducks whose diet had been supplemented with 2 ppm cadmium chloride (wet weight) for 30, 60, and 90 days (White and Finley 1978).[1/] Mallards in the same study which were fed up to 200 ppm cadmium chloride (wet weight) in their diets for up to 60 days had 109.6 $\pm$ 8.9 ppm wet weight in the liver. There was no mortality or weight loss in these ducks, and there were no significant differences in the average hematocrit and hemoglobin concentrations between the groups of treated birds and controls. The testes of males fed diets fortified with 2, 20, and 200 ppm cadmium were lighter than the controls 30 days after treatment. The cadmium concentrations in the livers of both groups of geese from the Rainwater Basin were only half or less of that of the lowest treatment (2 ppm) by White and Finley.

There is no known dietary requirement for cadmium.

On the basis of these comparisons, it is concluded that cadmium concentrations in both groups of geese from the Rainwater Basin were in a normal range and would not be expected to affect the health of the geese.

Copper

Copper is an essential nutrient in small quantities and is a toxicant in large quantities. The range of the copper content of the livers of the geese which died of avian cholera was 8.6 to 37.7 ug/g with a mean of 24.6 ug/g (Table 6). The range of the copper content in the livers of the control geese was 10.1 to 56.9 ug/g with a mean of 38.3 ug/g.

The copper content of the livers from the Rainwater Basin geese was compared with those from four populations of coots, two populations of cormorants, three colonies of common terns, and a group of prairie chickens (Table 6). All of the coots, cormorants, and prairie chickens appeared healthy at the time of collection. The rate of reproduction, with survival up to 15 days in two of the common tern colonies, was considered at least satisfactory, and it was unknown in the third common tern colony.

Three of the comparison populations had higher mean liver burdens of copper than the geese from the Rainwater Basin, four had lower, and three were in the same range.

On the basis of these comparisons, it is assumed that copper was not an adverse health factor among any of the geese from the Rainwater Basin. No consideration was given to possible synergistic effects of zinc or other biologically active elements when combined with copper.

Chromium

Chromium may be a required micronutrient for geese. It is also toxic at certain concentrations. There was little difference in the chromium content of the livers between the geese which had died of avian cholera and the controls which had died of other causes. The chromium content of 5 of the 15 geese was below the detection limit of <0.1 ug/g dry weight, whereas the other 10 varied from 0.1 to 0.3 ug/g (Table 1). Comparable data was scarce. The chromium content of the livers of 64 birds of three other species (coot, cormorant, and prairie chicken) collected in North and South Dakota was reviewed. None were above the detection limits used which varied from <0.33 to <2.0 ug/g dry weight. The data were also compared with the chromium concentrations of 13-day to 16-day old common terns from three nesting colonies in Rhode Island. In the first group of 14 terns, the chromium concentrations varied from below detection to 18.3 ug/g dry weight, in the second group of 15 terns from below detection to 14.5 ug/g, and in the third group of 6 terns from below detection to 0.97 ug/g (Custer et al. 1986).

On the basis of this very limited data, it is assumed that there is no relationship between chromium and avian cholera in the geese from the Rainwater Basin in this study.

Iron

The mean iron content in the livers of the geese from the Rainwater Basin which had died of avian cholera was 1,019 ug/g. The mean iron content of the control geese was 2,459 ug/g. These values were compared with the mean values of seven other populations of apparently healthy birds (Table 7). Six of the seven apparently healthy populations had higher mean iron concentrations than the mean of 1,019 ug/g for the geese which had died of cholera, and one was considerably lower. Six of the seven apparently healthy populations had lower mean concentrations of iron than the control geese from the Rainwater Basin. The group of prairie chickens had a much higher mean concentration.

The range of the individual iron values of the apparently healthy populations bracketed those of both of the groups of the Rainwater Basin geese, with large margins both higher and lower.

On the basis of these data, there is no basis for an assumption of a cause and effect relationship between iron and avian cholera in the geese in this study from the Rainwater Basin.

Manganese

The mean manganese burdens in the livers of the geese from the Rainwater Basin which had died of avian cholera was 10.1 ug/g, and the control group was 8.9 ug/g (Table 8). No studies were located relating to liver concentrations of manganese in wild waterfowl. The National Research Council (1984) recommendation for manganese in the diets of white Pekin ducks is 25 to 40 mg/kg of diet. Maynard and Loosli (1969) suggested a dietary supplement of 55 ppm manganese for chicks and 33 ppm for breeding hens. A general recommendation for a manganese supplement in animal feeds is 25 to 40 ppm (Warden 1970).

The manganese concentration in the livers of the Rainwater Basin geese was compared with those found in the livers of coots, cormorants, common terns, and prairie chickens from ten other locations (Table 8).

The mean manganese content in the livers of these populations ranged from 13.2 to 36.0 ug/g. This is higher than the means of 8.9 and 10.1 ug/g for that of the two groups of geese from the Rainwater Basin. There is an overlap between the individual geese with the higher liver burdens of manganese from the Rainwater Basin and the individuals with the lighter burdens from the other populations.

While there is no assurance that the manganese requirements and tolerance of geese is not significantly different from the four other species of birds with which they were compared, these data suggest that the geese from the Rainwater Basin did not suffer from an excess of manganese. The overlap of some of the individuals from the Rainwater Basin with healthy individuals from other populations provides some indication that at least some of the individuals had adequate amounts of manganese.

These data provide a basis for the assumption that there was no relationship between manganese and avian cholera in the geese in this study from the Rainwater Basin

Nickel

The concentrations of nickel ranged from <0.1 to 0.3 ug/g among the geese from the Rainwater Basin (Table 1). No comparable data was located. It is assumed, but not certain, that these liver concentrations are below the limits of biological activity.

Lead

Two of the birds in the control group of geese which had died of causes other than cholera had lethal concentrations of lead in the liver of 55.5 and 74.7 ug/g (Table 1). One other bird in this group had a concentration of 16 ug/g which may have caused or contributed to death. One goose in the group which had died of avian cholera had an elevated liver lead concentration of 13 ug/g; this concentration of lead may have contributed to its death, either as a direct toxicant or by suppression of the immune system. The other geese in this group had lead concentrations that ranged from 0.4 to 1.1 ug/g (Table 1). Although this is well below the concentration of 2 ppm wet weight suggested by Dr. Milton Friend (1985) as the threshhold for elevated liver concentrations, no studies were located that provided assurance that, even at these low concentrations, there was no adverse effects on the immune system. The possibility of biological activity due to the interactions of lead and other metals which occurred in the livers of the geese in relatively high concentrations cannot be ruled out. However, these data provide no basis for an assumption that there was a relationship between lead and avian cholera in 9 of the 10 geese from the Rainwater Basin which had died of avian cholera.

It is interesting to note that the two birds in the control group which had the very high concentrations of lead also had the highest concentrations of mercury, selenium, copper, iron, and zinc. One of them also had the highest concentration of aluminum.

Thallium

Thallium was below the detection limit in all cases (Table 1). This is assumed, but not known, to be below the level of biological activity.

Zinc

Zinc is a required nutrient for many physiological functions but is toxic at high concentrations. A zinc requirement for geese was not found in the literature. Warden (1970) suggested 100 to 200 ppm zinc in animal diets as a general guide. What liver burden would be developed at that concentration of zinc fortification is not known.

The zinc content in the livers of geese which had died of avian cholera ranged from 69 to 133 ug/g with a mean of 99 ug/g. The control group had a range of 32 to 186 ug/g with a mean of 133 ug/g (Table 1).

The liver burdens of zinc in the livers of the Rainwater Basin geese were compared with those of 10 groups of four other species of birds (Table 9). The coots, cormorants, and prairie chickens collected in North and South Dakota had zinc concentrations in the same range as the Rainwater Basin geese. The common terns from Rhode Island had concentrations that were similar but somewhat lower.

It does not seem likely that the Rainwater Basin geese are suffering from a nutritional deficiency of zinc when the liver burdens are in the same range as the amount recommended in the diet as a general nutritional requirement. It is unlikely that the Rainwater Basin geese are suffering from either an excess or deficiency of zinc when their liver content is in a similar range as that of 10 other groups of wild birds representing four other species.

These data provide a logical basis for an assumption that zinc per se is not involved in the cause of avian cholera in the geese in this study from the Nebraska Rainwater Basin. No consideration was given to possible interactions between zinc and other biologically active elements.

CONCLUSIONS

On the basis of the available data, it was concluded that there was no direct cause and effect relationship between avian cholera in the geese from the Rainwater Basin of Nebraska, which were included in this study, and the individual elements of selenium, cadmium, copper, chromium, iron, manganese, and zinc.

The liver burdens of arsenic, mercury, nickel, and thallium were low enough that they were considered as having no cause and effect relationship with avian cholera.

The concentrations of berylium were very low. However, the paucity of data relating to berylium precluded any assumption in relation to avian cholera.

The aluminum concentrations in both groups of geese from the Rainwater Basin were high, 6 to 28 times as high as that from other populations, but no data was located as a basis to judge harmful concentrations. Further review of the literature or laboratory studies is needed to interpret these data.

Two geese from the control group had lethal concentrations of lead in the liver, and one had liver burdens approaching lethal concentrations. One goose in the group which had died of avian cholera had liver burdens approaching lethal concentrations. The rest of the geese of both groups had lead liver burdens well below the 2 ppm wet weight threshhold for elevated lead concentrations.

RECOMMENDATIONS

1. Continue literature review until a better interpretation of aluminum, lead, and berylium data is possible.

2. Continue the study of biologically active elements of antimony, boron, barium, calcium, magnesium, molybdenum, silver, strontium, and vanadium for a possible relationship to avian cholera.

3. Initiate a study to relate agricultural pesticides to cholera in the Rainwater Basin to include:

   a. A review of the nonpersistent pesticides (and their toxic metabolites) which may have been widely used in the wintering grounds in the two-month period preceding the arrival of the waterfowl in the Rainwater Basin.

   b. A review of the persistent pesticides (and their toxic metabolites) which may have been widely used in the wintering areas during the previous year.

   c. Have livers and/or other appropriate tissue analyzed for such pesticides and/or their metabolites from geese dying of avian cholera and from controls of free flying, apparently healthy birds.

   d. Have all tissue frozen in chemically clean jars.

   e. Obtain laboratory confirmation as to the presence or absence of *Pasteurella multocida* in waterfowl with presumptive diagnosis of avian cholera and the control group.

   f. If analytical funds are available, the sample should be sufficient to support multivariate statistical tests.

4. Study the possible relationship between the occurrence of mycotoxins and the occurrence of avian cholera.

ACKNOWLEDGMENTS

The field biologists for the Nebraska Game and Parks Commission collected the geese in the Rainwater Basin. The staffs at the Rainwater Basin Wetland Management District, Sand Lake National Wildlife Refuge, and the Pierre, South Dakota, Fish and Wildlife Enhancement Office assisted in collecting and transporting specimens. Joe Gabig, Alan Trout, Mark Wilson, and Ron Windingstad provided helpful suggestions. Dr. Steve Hamilton provided editorial advice, and Cheryl Alley made it happen with her patience about grammar, spelling, and construction.

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Table 1. - A comparison of the concentrations of 14 biologically active elements in the livers of ten wild geese whose death was attributed to avian cholera and five controls (ug/g dry weight).

No.	Species	Presumptive Diagnosis of Avian Cholera	Percent Moisture	Biologically Active Elements													
				AS	HG	SE	AL	BE	CD	CR	CU	FE	MN	NI	PB	TL	ZN
1	Whitefront	Yes	69.8	<0.2	0.01	2.6	56	0.01	2.60	0.1	22.1	1,030	14.4	0.2	0.7	<0.7	133
2	Whitefront	Yes	70.6	<0.2	0.02	2.6	109	0.02	0.55	0.2	37.7	854	10.5	0.2	1.1	<0.7	94
3	Whitefront	Yes	67.5	<0.2	0.01	2.1	18	0.01	0.83	<0.1	13.6	583	6.7	0.1	0.9	<0.7	83
4	Whitefront	Yes	72.4	<0.2	0.02	2.3	29	0.01	1.1	0.1	23.7	934	10.1	0.2	0.5	<0.7	114
5	Whitefront	Yes	67.6	<0.2	0.00	2.0	71	0.01	0.34	0.2	30.0	727	10.2	0.2	0.4	<0.7	69
6	Whitefront	Yes	67.3	<0.2	0.03	1.9	62	0.01	1.5	0.2	17.0	1,370	9.4	0.1	0.4	<0.7	85
7	Whitefront	Yes	70.2	<0.2	0.02	2.2	63	<0.01	0.37	<0.1	36.6	895	12.4	<0.1	0.7	<0.7	117
8	Whitefront	Yes	70.5	<0.2	0.03	2.4	28	<0.01	0.68	<0.1	35.6	1,050	9.5	0.2	0.6	<0.7	106
9	Whitefront	Yes	68.8	<0.2	0.02	2.0	18	<0.01	0.22	<0.1	21.3	871	8.9	<0.1	0.4	<0.6	93
10	Snow	Yes	68.3	<0.2	0.03	2.7	106	<0.01	0.45	<0.1	8.6	1,880	8.7	0.1	13	<0.7	99
Mean			69.3	<0.2	0.020	2.3	56	<0.01	0.86	0.1	24.6	1,019	10.1	0.1	1.9	<0.7	99
11	Whitefront	No	60.7	<0.2	0.01	1.0	24	<0.01	0.83	0.3	10.1	215	3.8	0.3	16	<0.7	32
12	Whitefront	No	70.8	<0.2	0.10	4.7	141	0.01	0.62	0.1	42.0	4,210	13.5	0.2	55.5	<0.7	186
13	Whitefront	No	71.7	<0.2	0.08	4.9	23	<0.01	0.99	0.2	50.3	5,020	5.7	0.1	74.7	<0.7	182
14	Whitefront	No	71.2	<0.2	0.02	3.2	50	<0.01	0.69	0.1	32.1	1,480	9.9	0.1	0.7	<0.7	145
15	Snow	No	70.8	<0.2	0.10	4.6	68	<0.01	0.29	<0.1	56.9	1,370	11.7	0.1	1.3	<0.7	118
Mean			69.0	<0.2	0.06	3.7	61	<0.01	0.68	0.1	38.3	2,459	8.9	0.2	29.6	<0.7	133

Table 2. - Comparison of selenium liver burdens among geese from the Rainwater Basin, Nebraska, and birds from nine other sites (ug/g dry weight).

Species	Location	Reference	Selenium Range	Selenium Mean	Number of Specimens	Remarks
Whitefront and snow geese	Rainwater Basin, NE		1.9-2.7	2.3	10	Avian cholera mortality
Whitefront and snow geese	Rainwater Basin, NE		1.0-4.9	3.7	5	Mortality other than avian cholera
Ducks	Volta Wildlife Area, CA	(1)	3.9-4.4	4.1	2	Area of low native selenium
Coots	Volta Wildlife Area, CA	(1)	4.4-5.6	5.0	3	Area of low native selenium
Coots	Juanita Lake, ND	(2)	1.2-4.1	2.1	4	Source of selenium unknown
Coots	Sand Lake NWR, SD	(2)	4.6-9.3	6.3	9	Source of selenium unknown
Cormorants	Sand Lake NWR, SD	(3)	6.1-11.7	7.8	10	Source of selenium unknown
Cormorants	Lake Sharpe, SD	(3)	10.5-55.6	24.7	11	Source of selenium unknown
Ducks	Kesterson NWR, CA	(1)	19-43	28.6	2	Irrigation return water
Coots	Kesterson NWR, CA	(1)	21-63	37.2	3	Irrigation return water
Coots	Prairie Wetlands, Eastern SD	(3)	2.3-6.9	3.8	7	Surrounding soil
Coots	Wall Lake, SD	(3)	4.1-9.8	6.0	10	Surrounding soil
Coots	Arrowwood NWR, ND	(3)	5.9-11.8	9.7	7	Unknown
Prairie chickens	Ft. Pierre National Grasslands, SD	(3)	4.8-54	19.3	6	High selenium in local soil, prairie chickens apparently healthy

(1) Ohlendorf et al. 1986
(2) Ludden, Albert, 1987, Bismarck Field Office FWS, ND
(3) Unpublished data - Pierre Field Office FWS, SD

Table 3. - Comparison of selenium and mercury levels in the livers of cormorant and prairie chicken from Central South Dakota (ug/g dry weight).

No.	Species	Age	Element Concentrations Se	Element Concentrations Hg	Collection Site
1	Cormorant	J	12.1	3.7	Lake Sharpe, Stanley County, SD
2	Cormorant	A	14.9	10.1	Lake Sharpe, Stanley County, SD
3	Cormorant	A	55.6	215.3	Lake Sharpe, Stanley County, SD
4	Cormorant	A	30.7	102.3	Lake Sharpe, Stanley County, SD
5	Cormorant	A	13.3	41.0	Lake Sharpe, Stanley County, SD
6	Cormorant	A	50.0	113.3	Lake Sharpe, Stanley County, SD
7	Cormorant	J	10.5	3.5	Lake Sharpe, Stanley County, SD
8	Cormorant	J	10.9	3.4	Lake Sharpe, Stanley County, SD
9	Cormorant	J	15.4	8.4	Lake Sharpe, Stanley County, SD
10	Cormorant	J	12.6	4.6	Lake Sharpe, Stanley County, SD
11	Cormorant	A	45.3	125.4	Lake Sharpe, Stanley County, SD
	Mean		24.7	57.4	
1	Prairie chicken	U	4.8	<0.16	Ft. Pierre National Grasslands, Stanley County, SD
2	Prairie chicken	U	33.	<0.16	Ft. Pierre National Grasslands, Stanley County, SD
3	Prairie chicken	U	54.	<0.16	Ft. Pierre National Grasslands, Stanley County, SD
4	Prairie chicken	U	6.3	<0.14	Ft. Pierre National Grasslands, Stanley County, SD
5	Prairie chicken	U	6.8	<0.16	Ft. Pierre National Grasslands, Stanley County, SD
6	Prairie chicken	U	11.	<0.17	Ft. Pierre National Grasslands, Stanley County, SD
	Mean		19.3	<0.16	

Table 4. - Selenium content in the livers of mallard ducks fed various concentrations of selenium (Heinz et al. 1987).

Type of Selenium	Selenium Added to the Diet (ppm)	Number of Ducks Treated (5 Male/5 Female) 1/	Selenium Content of Liver (ppm-dry wt.)	Duckling Production to 21 Days 2/ No. of Hens	Ducklings per Hen
Sodium selenite	0	10	1.19	11	9.7
Sodium selenite	1	10	2.16	10	9.2
Sodium selenite	5	10	4.33	10	7.7
Sodium selenite	10	10	6.72	10	8.1
Sodium selenite	25	10	13.1	9	0.2
Sodium selenite	100	1	41.4	-	0.0
Selenomethionine	10	10	22.9	5	2.0

1/ Female and male mallards were reported separately on Heinz's data. The numbers of each sex were equal and were combined for comparison of Rainwater Basin geese collected without regard to sex. The selenium concentrations in the livers of the males were consistently and significantly higher than those of the females in Heinz's study. Data was converted to dry weight on the basis of 71 percent moisture. Ducks were on feed four weeks or longer.

2/ Ducklings were fed diets with the same concentration of selenium as that of their parents.

Table 5. - A comparison of aluminum concentrations in the livers of geese from the Rainwater Basin, Nebraska, with three species of birds from six other locations (ug/g dry weight).

Species	Location	Aluminum Range	Aluminum Mean	Number of Specimens	Remarks
Whitefront & snow geese	Rainwater Basin, NE	18-109	56	10	Avian cholera mortality
Whitefront & snow geese	Rainwater Basin, NE	23-141	61	5	Mortality other than avian cholera
Coots	Prairie Wetlands, Eastern SD	3.7-12.8	9.0	7	Apparently healthy, wild
Coots [1/]	Wall Lake, SD	<1.1-7.6	4.6	10	Apparently healthy, wild
Coots [1/]	Sand Lake NWR, SD	<1.2-9.9	3.0	13	Apparently healthy, wild
Coots [1/]	Arrowwood NWR, ND	<1.2-9.9	3.2	7	Apparently healthy, wild
Cormorants [1/]	Sand Lake NWR, SD	<1.2-7.2	2.2	10	Apparently healthy, wild
Cormorants [1/]	Lake Sharpe, SD	<0.7-6.9	2.7	11	Apparently healthy, wild
Prairie chickens	Ft. Pierre National Grasslands, SD	3.4-9.0	5.2	6	Apparently healthy, wild

1/ When a reading was below the detection limit, the value halfway between the detection limit and zero was used to calculate the range and the mean.

Table 6. - A comparison of copper burdens in the livers of geese from the Rainwater Basin, Nebraska, with four species of birds from nine other locations (ug/g dry weight).

Species	Location	Copper Range	Copper Mean	Number of Specimens	Remarks
Whitefront and snow geese	Rainwater Basin, NE	8.6- 37.7	24.6	10	Avian cholera mortality
Whitefront and snow geese	Rainwater Basin, NE	10.1- 56.9	38.3	5	Mortality other than cholera
Coots	Prairie Wetlands, Eastern SD	12.5- 77.1	44.3	7	Apparently healthy, wild
Coots	Wall Lake, SD	10.6- 59.8	34.7	10	Apparently healthy, wild
Coots	Sand Lake NWR, SD	6.6- 29.2	15.4	13	Apparently healthy, wild
Coots	Arrowwood NWR, ND	31.5-144.0	88.1	7	Apparently healthy, wild
Cormorants	Sand Lake NWR, SD	10.2- 24.0	13.2	9	Apparently healthy, wild
Cormorants	Lake Sharpe, SD	11.1- 23.5	15.2	11	Apparently healthy, wild
13-16 day old common terns	Providence Barge, RI	20.6-181.1	59.3	14	Satisfactory reproduction
13-16 day old common terns	Wickford Tower, RI	19.5- 82.7	28.7	15	Satisfactory reproduction
13-16 day old common terns	Price Neck, RI	24.8- 29.7	26.5	6	Reproduction but rate was unknown
Prairie chickens	Ft. Pierre National Grasslands, SD	12.0- 17.0	14.2	6	Apparently healthy, wild

Table 7. - A comparison of iron concentrations in the livers of geese from the Rainwater Basin, Nebraska, with that in the livers of three other species of birds from six other locations (ug/g dry weight).

Species	Location	Iron Range	Iron Mean	Number of Specimens	Remarks
Whitefront and snow geese	Rainwater Basin, NE	583-1,880	1,019	10	Avian cholera mortality
Whitefront and snow geese	Rainwater Basin, NE	215-5,020	2,459	5	Mortality other than avian cholera
Coots	Prairie Wetlands, Eastern SD	1,273-3,797	2,339	7	Apparently healthy, wild
Coots	Wall Lake, SD	605-3,759	2,033	10	Apparently healthy, wild
Coots	Sand Lake NWR, SD	399-5,098	1,877	13	Apparently healthy, wild
Coots	Arrowwood NWR, ND	180-4,852	1,678	7	Apparently healthy, wild
Cormorants	Sand Lake NWR, SD	141-1,140	456	10	Apparently healthy, wild
Cormorants	Lake Sharpe, SD	522-2,392	1,242	11	Apparently healthy, wild
Prairie chickens	Ft. Pierre National Grasslands, SD	580-10,000	3,433	6	Apparently healthy, wild

Table 8. - A comparison of manganese concentrations in the livers of geese from the Rainwater Basin, Nebraska, with four species of birds from nine other locations (ug/g dry weight).

Species	Location	Manganese Range	Manganese Mean	Number of Specimens	Remarks
Whitefront and snow geese	Rainwater Basin, NE	6.7-14.4	10.1	10	Avian cholera mortality
Whitefront and snow geese	Rainwater Basin, NE	3.8-13.5	8.9	5	Mortality other than avian cholera
Coots	Prairie Wetlands, Eastern SD	18.9-61.3	36.0	7	Apparently healthy, wild
Coots	Wall Lake, SD	13.5-28.1	18.1	10	Apparently healthy, wild
Coots	Sand Lake NWR, SD	9.5-30.6	18.9	13	Apparently healthy, wild
Coots	Arrowwood NWR, ND	13.7-40.6	21.2	7	Apparently healthy, wild
Cormorants	Sand Lake NWR, SD	13.3-18.0	16.0	10	Apparently healthy, wild
Cormorants	Lake Sharpe, SD	12.0-31.6	17.1	11	Apparently healthy, wild
13-16 day old common terns	Providence Barge, RI	13.0-29.0	18.9	14	Satisfactory reproduction
13-16 day old common terns	Wickford Tower, RI	12.5-23.6	18.6	15	Satisfactory reproduction
13-16 day old common terns	Price Neck, RI	14.9-22.3	18.4	6	Reproduction but rate was unknown
Prairie chickens	Ft. Pierre National Grasslands, SD	12-15	13.2	6	Apparently healthy, wild

Table 9. - A comparison of zinc concentrations in the livers of geese from the Rainwater Basin, Nebraska, with that in livers of four other species of birds from nine locations (ug/g dry weight).

Species	Location	Zinc Range	Zinc Mean	Number of Specimens	Remarks
Whitefront and snow geese	Rainwater Basin, NE	69-133	99	10	Avian cholera mortality
Whitefront and snow geese	Rainwater Basin, NE	32-186	133	5	Mortality other than avian cholera
Coots	Prairie Wetlands, Eastern SD	104-148	131	7	Apparently healthy, wild
Coots	Wall Lake, SD	127-221	170	10	Apparently healthy, wild
Coots	Sand Lake NWR, SD	76-131	100	13	Apparently healthy, wild
Coots	Arrowwood NWR, ND	116-238	161	7	Apparently healthy, wild
Cormorants	Sand Lake NWR, SD	77-124	98	10	Apparently healthy, wild
Cormorants	Lake Sharpe, SD	69-112	91	11	Apparently healthy, wild
Prairie chickens	Ft. Pierre National Grasslands, SD	83-110	94	6	Apparently healthy, wild
13-16 day old common terns	Providence Barge, RI	29-153	77	14	Satisfactory reproduction
13-16 day old common terns	Wickford Tower, RI	56-119	86	15	Satisfactory reproduction
13-16 day old common terns	Price Neck, RI	19-79	41	6	Reproduction but rate was unknown