ILLINOIS NATURAL HISTORY SURVEY
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Urbana Illinois

*Employed on co-operative projects with one of several agencies: University of Illinois, Illinois Agricultural Extension Service, Illinois Department of Conservation, United States Army Surgeon General's Office, United States Department of Agriculture, United States Fish and Wildlife Service, United States Public Health Service, and others.

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Photographs not otherwise credited are by William E. Clark or by Charles L. Scott.

A few of the 2,000 wild mallards that were victims of a lead poisoning outbreak near Grafton, Illinois, in January, 1948. (Photograph from Western Cartridge Company.)

Lead Poisoning as a Mortality Factor in Waterfowl Populations

FRANK C. BELLROSE

THE mortality resulting from lead poisoning in populations of wild waterfowl has been a cause of concern to conservationists for many years. This concern has grown out of the knowledge that lead poisoning is of common occurrence among waterfowl, that this poisoning results from the ingestion of lead by the birds in their feeding, and that large numbers of lead pellets fired from the guns of hunters lie in lakes and marshes visited by waterfowl.

Phillips & Lincoln (1930:166), over two decades ago, stated: "From this account it will be seen that lead poisoning due to eating shot is of common occurrence, and it seems reasonable to presume that the disease will continue and even increase in the great ducking marshes of the country. The ultimate conclusions as to its effect upon the supply of waterfowl are hazardous to imagine." A few years later Dr. E. C. O'Roke of the University of Michigan was quoted in *Michigan Waterfowl Management* (Pirnie 1935: 75–6) as follows: "Considering the enormous quantity of lead that there must be in the vicinity of blinds that have been shot over for decades, it is reasonable to conclude that the potential danger from lead poisoning is great and should be considered in any waterfowl management program. In the writer's opinion lead poisoning is the disease which takes the greatest toll of adult ducks in this section of the country."

This theme was reiterated by Cottam (1949:339–40) who, in discussing further needs in wildlife research, suggested that "direct and indirect effects of lead shot in the digestive tracts of birds may be an exceedingly important stumbling block in the restoration of waterfowl. At the close of the hunting season live birds are carrying in their bodies an alarming amount of lead, and this condition may be much more widespread than we have realized. There is urgent need to ascertain the effects of the lead shot used in hunting."

These remarks point up the generally recognized need for further appraisals of the problem, which was brought home to officials of the Illinois Natural History Survey and Western Cartridge Company (the latter now the Winchester-Western Cartridge Division of Olin Mathieson Chemical Corporation) at the time of a publicized die-off of wild ducks, frontispiece, near Grafton, Illinois, in January of 1948 (Jordan & Bellrose 1951:10–1). As a result of a common interest in the problem of lead poisoning in waterfowl, the two groups supported a joint research project embracing the following objectives: (1) evaluation of losses from lead poisoning in wild waterfowl, (2) investigation of lead alloys and other metals as materials for possible use as nontoxic shot, and (3) determination of the physiological effects of lead poisoning in waterfowl.

The present paper is devoted primarily to the evaluation of losses resulting from lead poisoning in wild waterfowl populations. Two reports have been published which presented preliminary findings on this subject (Bellrose 1951; Jordan & Bellrose 1951). Efforts to develop a nontoxic shot were treated in a paper dealing with the value of various shot alloys in relation to lead poisoning (Jordan & Bellrose 1950); additional data on this subject are presented herein. Findings as to the physiological effects of lead poisoning on captive waterfowl have been discussed in a paper by Jordan & Bellrose (1951).

The approach toward evaluating the importance of lead poisoning in wild waterfowl was threefold: (1) appraisal of the incidence and magnitude of waterfowl die-offs resulting from lead poisoning, (2) appraisal of the incidence of

ingested lead shot among waterfowl populations in fall and early winter, and (3) appraisal of waterfowl losses resulting from the ingestion of various quantities of lead shot per bird.

ACKNOWLEDGMENTS

The writer is most grateful to the many persons in various parts of the North American continent who furnished material and data. Without their aid, it would have been impossible to appraise the importance of lead poisoning on such an extensive basis.

The sources of much of the information outside of Illinois are acknowledged in the text or tables. However, the sources of material and data related to the occurrence of lead shot in waterfowl gizzards have been so numerous as to make such acknowledgment cumbersome. Acknowledgment is made here to those persons who sent 100 or more waterfowl gizzards for examination: Harold M. Swope, Colorado; E. B. Chamberlain, Jr., Florida; William P. Baldwin, Jr., Georgia and South Carolina; Robert L. Salter, Idaho; James D. McCall and Russell E. Mumford, Indiana; Richard K. Yancey and Charles W. Bosch, Louisiana; Howard L. Mendall, Maine; Gordon T. Nightingale and Dave Grice, Massachusetts; Forrest B. Lee, Minnesota; Harvey Miller, Nebraska; Fred E. Wright, Nevada; T. Stuart Critcher and Yates M. Barber, Jr., North Carolina; Brandt V. Hjelle, North Dakota; William B. Morse, Oregon; Ray Murdy and Clair T. Rollings, South Dakota; J. R. Singleton, Texas; Allen G. Smith, Utah.

The following biologists contributed data on the incidence of ingested lead shot found in waterfowl gizzards examined primarily for food contents: Ian McT. Cowan, British Columbia; Carol M. Ferrel and Howard R. Leach, California; E. B. Chamberlain, Jr., Florida; Richard K. Yancey, Louisiana; Howard L. Mendall, Maine; Leroy J. Korschgen and Charles E. Shanks, Missouri; Donald D. Foley, New York; T. Stuart Critcher, North Carolina; Charles K. Rawls, Jr., Tennessee; Allen G. Smith, Utah; Robert G. Jeffrey and Charles F. Yocom, Washington.

Many persons provided information on waterfowl die-offs resulting from lead poisoning. I especially wish to thank Richard E. Griffith, John J. Lynch, John W. Perkins, and Edward B. Davis of the United States Fish and Wildlife Service, and Richard K. Yancey and Morton M. Smith of the Louisiana Wild Life and Fisheries Commission for their excellent co-operation.

Edwin R. Kalmbach and Arnold L. Nelson of the United States Fish and Wildlife Service provided suggestions and unpublished reports on lead poisoning in waterfowl. Johnson A. Neff of the same agency submitted an unpublished report on band recoveries from experimental mallards, some untreated and some dosed with six No. 6 shot pellets each, near Denver, Colorado.

Dr. Harlow B. Mills, Chief of the Illinois Natural History Survey, and the late Charles H. Hopkins and Ray Holmes, both of Olin Mathieson Chemical Corporation, who initiated this study as a result of their interest in a die-off of wild ducks near Grafton, Illinois, in 1948, continued their interest and aid throughout the study. Dr. Thomas G. Scott, Head of the Survey's Wildlife Research Section, and Mrs. Frances Robbins, Dr. Ralph E. Yeatter, and Dr. Carl O. Mohr, all of that section, gave many helpful suggestions which improved both the study and the paper. John C. Dear and Charles E. Gillham of the Olin Mathieson Chemical Corporation helped many times in many ways. James S. Ayars of the Natural History Survey edited the manuscript.

Without the financial assistance provided by Olin Mathieson Chemical Corporation, much of this study would have been impossible.

LEAD POISONING DIE-OFFS

The most dramatic expressions of lead poisoning in waterfowl are die-offs in which large numbers of birds in relatively small areas perish in short periods of time. Most of those persons who are seriously concerned about lead poisoning among waterfowl have been convinced of the importance of the malady through witnessing one or more die-offs. Because

of its emotional impact on any person who sees it, a waterfowl die-off is an event that is remembered and chronicled for a number of years.

Three approaches have been made by the author of this paper in evaluating the importance of die-offs among waterfowl in the United States: (1) a study of the

Fig. 1.—Opened duck gizzards and the ingested lead shot they contained. Black spots on the horny linings of the gizzards mark areas of tissue destruction by lead salts.

Fig. 2.—Two mallard stomachs: the lower one from a lead-free duck, the upper from a lead-poisoned duck. The glandular stomach attached to the gizzard of the lead-poisoned mallard shows impaction of small grains. The impaction of food resulting from malfunctioning of the gizzard is one of the symptoms of lead poisoning in waterfowl.

literature, (2) personal on-the-spot investigations of die-offs in Illinois and Louisiana, and (3) a canvass of state and federal conservation agencies for recent records of lead poisoning outbreaks among waterfowl.

In studying several large outbreaks of lead poisoning in Illinois, 1940–1954, and at Catahoula Lake, Louisiana, 1953, the author and his associates undertook a tally of all dead and dying ducks found and of feathers marking the demise of birds. Rough compensations were made for areas not covered and for the time of each sampling in relation to the period of the outbreak. An estimate was made of the duck population in each area.

Samples of dead and dying ducks were collected. These ducks were sexed, aged, weighed, and fluoroscoped. Fluoroscopic procedure was similar to that described by Jordan & Bellrose (1950:158) and by Bellrose (1953:341). Examinations were made of lead shot pellets in gizzards of a number of dead ducks and were found to agree closely with fluoroscopic findings. Gizzards from lead-poisoned ducks are shown in figs. 1 and 2.

Early Die-Offs

Records of lead poisoning in North American waterfowl date back to the latter half of the nineteenth century. From remarks made by Phillips & Lincoln (1930:164), it is assumed that lead poisoning in waterfowl was known at least as early as 1874. According to them, the March, 1894, issue of the *American Field* carried a note reporting that two lots of ducks which were unfit for food (presumably as a result of lead poisoning) were seized at Galveston, Texas. These ducks had been taken at Stephenson Lake, where the disease had been noted for 20 years.

More than 60 years ago, George Bird Grinnell (1894:112) and E. Hough (1894:117) reported in *Forest and Stream* on some of the effects of lead poisoning on waterfowl as determined from observations made during the winter of 1893–94. A few years later, Grinnell (1901:598–601), in addition to reviewing his earlier account on the appearance and behavior of a sick goose and a sick swan at Currituck Sound, North Carolina, stated that lead poisoning occurred among waterfowl in Texas at Galveston, at Stephenson Lake, and on Lake Surprise.

A half century ago, Bowles (1908: 312–3) recorded the loss of a number of mallards (*Anas platyrhynchos*) from lead poisoning on the "Misqually" (presumably Nisqually) Flats of Puget Sound, Washington. McAtee (1908:472) in the same year gave an account of lead poisoning in canvasbacks (*Aythya valisineria*) at Lake Surprise, Texas.

Wetmore (1919:2) reported that several whistling swans (*Olor columbianus*) from Back Bay, Virginia, were examined by the U. S. Biological Survey in January of 1915. Twenty-two to 45 shot pellets were found in the gizzard of each swan, indicating that the birds had been affected by lead poisoning. He reported also that during the summers of 1915 and 1916 in the Bear River marshes of Utah many mallards and pintails (*Anas acuta*) were affected by lead poisoning. These ducks were found in the period June–September, and, although many died, the total was insignificant as compared with losses from other causes in the Bear River marshes.

In discussing lead poisoning, Phillips & Lincoln (1930:165–6) recorded an instance in which "thousands" of ducks were reported dying at Hovey Lake, Indiana, in February, 1922, from an unknown malady that was later diagnosed as lead poisoning. The report they found to be "much exaggerated." They observed that "Possibly the most serious condition exists in Louisiana, where duck mortality from this cause may sometimes be further complicated by internal parasites and possibly at times by lack of food"; that newspapers reported in January of 1925 that "thousands" of ducks were dying in Louisiana, apparently from lead poisoning, for all the specimens examined were found to have ingested lead shot; and that large numbers of ducks died from lead poisoning in the Jacobs and Pecan Lake region of Arkansas in January of 1925.

Van Tyne (1929:103–4) reported that at Houghton Lake, Michigan, in April of 1928, greater scaups (*Aythya marila*) died from lead poisoning. Of 10

stomachs examined by Van Tyne, most contained 40 to 60 pellets of lead, and one contained 80 pellets. Elsewhere in Michigan, Pirnie (1935:74–5) reported that the deaths of five Canada geese (*Branta canadensis*) in Barry County in the spring of 1933, and a similar loss in Cass County in April, 1935, apparently were the result of lead poisoning.

Munroe (1925:160) recorded that one adult trumpeter swan (*Olor buccinator*) and six cygnets had died from lead poisoning in British Columbia during the winter of 1925.

E. R. Kalmbach (unpublished report, March 6, 1930, in files of U. S. Fish and Wildlife Service) observed a lead poisoning die-off of ducks in the coastal marsh area south of Gueydan, Vermilion Parish, Louisiana, in February of 1930. In a 200-acre rice field he found 199 dead ducks: namely, 120 pintails, 71 mallards, and 8 lesser scaups (*Aythya affinis*). Kalmbach believed that the toll in the rice field was greater than that found in any other area of similar size, but that losses occurred throughout 300 or more square miles of marsh. Albert Bonin, a resident of that area, told Kalmbach that sick ducks had been observed in the Florence section for at least 30 years. In Bonin's experience, the spring of 1921 marked the severest outbreak noted in that region.

Shillinger & Cottam (1937:399) recorded the following waterfowl losses from lead poisoning, all in the fall and early winter of 1936: 8 ducks from the coast of North Carolina; 5 mallards from the Pamlico Sound area of Virginia; 14 ducks from Delaware Bay; 12 ducks from northern Ohio; and 100 ducks, most of them mallards, from Boyd Lake, Colorado. The same authors (1937:402) gave an account of a die-off of ducks at the Sand Lake National Wildlife Refuge, South Dakota, during November and December of 1935. Of 113 mallards examined there by John J. Lynch, 103 were deemed victims of lead poisoning. Deaths of 6 other individuals, representing four species of ducks, were attributed to this disease.

Recent Die-Offs

In this review of lead poisoning die-offs, it has been necessary to rely almost entirely upon unpublished accounts for information up to 1937. Since that time only a few reports have been published (Mohler 1945; Bellrose 1947; Ayars 1947; Yancey 1953) but, fortunately, outbreaks have been recorded in letters and reported by biologists of state conservation agencies and the U. S. Fish and Wildlife Service.

Data on most of the known die-offs of waterfowl from lead poisoning for the period beginning with the winter of 1938–39 and extending through the winter of 1956–57 are summarized in table 1. These data have been obtained by contacting all state conservation agencies in the United States, as well as those in Ontario and British Columbia, plus the following branches of the U. S. Fish and Wildlife Service: Wildlife Refuges, Game Management, and Wildlife Research. Most of the information has been obtained from letters and file reports graciously made available by waterfowl biologists of these agencies.

In addition to the information presented in table 1, many details have been made available which could not readily be recorded in tabular form. Therefore, it seems advisable to give a flyway-by-flyway roundup of information on the occurrence of waterfowl die-offs resulting from lead poisoning.

Atlantic Flyway.—Lead poisoning in waterfowl apparently is not an important mortality factor in the Atlantic Flyway. The largest reported losses, table 1, amount to about 600 Canada geese and whistling swans which were picked up over a 10-year period in North Carolina.

The following comments, from letters by waterfowl biologists in that flyway, illustrate the paucity of reports of die-offs from this malady. Dr. C. H. D. Clarke (letter, April 4, 1955) of the Ontario Department of Lands and Forests reported: "I know of no die-off worthy of the name from lead poisoning in Ontario. From time to time we have picked up individual poisoned waterfowl at various places where they are concentrated."

Of the situation in Maine, Howard E. Spencer, Jr. (letter, March 28, 1955), wrote: "I have no knowledge of any die-offs which could be associated in any way with lead poisoning." From Vermont,

Table 1.—Important waterfowl die-offs, 1938–1957, which have been attributed to lead poisoning and for which adequate data have been reported.

Location	Time of Occurrence	Principal Species Involved	Number of Birds Present	Number of Birds Lost	Per Cent of Birds Lost	Authority
ATLANTIC FLYWAY						
North Carolina						
Mattamuskeet National Wildlife Refuge	Jan., March, 1945–1954	Canada goose, whistling swan	.....	580+	.....	Richard E. Griffith (letter, April 1, 1955), U. S. Fish and Wildlife Service
MISSISSIPPI FLYWAY						
Minnesota						
Heron Lake	Dec., 1938	Mallard	10,000	100+	1.0	Gustav Swanson and C. Gordon Fredine, reference cited in footnote to table 4
	Winter, 1939–40	Mallard	.....	200+	.....	
Lake Winnibigoshish	Oct., 1939	Mallard	.....	65+	.....	
Wisconsin						
Rock County	Dec., 1949	Canada goose	5,000	106	2.1	L. R. Jahn (Wisconsin P.-R. Quarterly Progress Report and letter, Feb. 16, 1955), Wisconsin Conservation Department
Lake Puckaway	April, 1954	Canada goose	.....	120+	.....	
Green Bay	Springs, 1948–1954	Whistling swan	.....	130	.....	
Michigan						
Shiawassee National Wildlife Refuge	Winter, 1953–54	Mallard	200–2,500	75	3.8–30.0	Richard E. Griffith (letter, April 1, 1955)
	March–April, 1954	Whistling swan	200–3,000	100	5.0–33.3	
Iowa						
Carr and Mud lakes	Winter, 1940	Mallard	.....	600	.....	Everett B. Speaker (letter, Feb. 23, 1955) and James G. Sieh (letter, Feb. 22, 1955), Iowa Conservation Commission
Forney Slough	Winter, 1948	Mallard	.....	1,500	.....	
Lost Island Lake	Jan., 1954	Mallard	.....	100	.....	
Illinois						
Henry	Jan., 1940	Mallard	5,000–10,000	200–300	2.0–6.0	Author of present paper
Chautauqua National Wildlife Refuge	Winters, 1941–1957	Mallard	1,400,000	13,000	0.9	
Grafton	Jan., 1947–1948	Mallard	120,000	3,000	2.5	
Batchtown National Wildlife Refuge	Dec., 1953	Mallard	150,000	500	0.3	
Hull	Feb., 1955	Mallard	100,000	1,000	1.0	
Indiana						
Hovey Lake	Winters, 1947–1957	Mallard	.....	1,430	.....	James D. McCall (letters, Feb. 5 and March 11, 1955), Indiana Department of Conservation; Martin 1957
	Winter, 1953	Canada goose	4,000	219	5.5	
Willow Slough	Jan.–Feb., 1955–1957	Mallard	480,000	700	0.145	
		Canada goose	4,000	40	1.0	
Missouri						
Chariton County	Winter, 1949	Mallard	10,200	1,000	9.8	Charles T. Shanks (letter, Feb. 15, 1955), Missouri Conservation Commission; Kenneth Krumm (letter, March 4, 1958), U. S. Fish and Wildlife Service
Squaw Creek National Wildlife Refuge	Winters, 1945–1957	Mallard, pintail	1,400,000	16,000	1.1	
Swan Lake National Wildlife Refuge	Dec., 1952–1954	Mallard	450,000	800	0.2	

Mingo Swamp National Wildlife Refuge	Nov.–Dec., 1952–1954	Mallard	165,000	600+	0.4	Richard E. Griffith (letter, April 1, 1955)
Arkansas						
Claypool Reservoir	Dec., 1953–Feb., 1954	Mallard	250,000	16,000	6.4	John W. Perkins (letter, Feb. 12, 1954), U. S. Fish and Wildlife Service
Louisiana						
Catahoula Lake	Winters, 1950–1955	Mallard	138,000	15,000	10.9	Richard K. Yancey (letter, May 10, 1955), Louisiana Wildlife and Fisheries Commission; John J. Lynch (letter, Feb. 17, 1955), U. S. Fish and Wildlife Service
		Pintail	380,000	5,300	1.4	
Fenton	Jan.–Feb., 1954	Mallard	10,000	600	6.0	
		Pintail	25,000	1,400	5.6	
Vinton	Feb., 1955	Blue and snow geese	25,000	300–400	1.2–1.6	
CENTRAL FLYWAY						
South Dakota						
Sand Lake National Wildlife Refuge	Winters, 1945–1954	Mallard	.....	10,700+	.....	Richard E. Griffith (letter, April 1, 1955)
Lake Andes National Wildlife Refuge	Winters, 1951–1954	Mallard	120,000–200,000	1,200–2,000	1.0–1.7	
Nebraska						
Salt Lake	March, 1945	Blue and snow geese	4,000	100	2.5	Mohler (1945:49)
Capitol Beach Lake	Mid-March to mid-April, 1951–1953	Blue and snow geese	.....	510	.....	George Schildman (Quarterly Progress Reports, Project 15-R-9), Nebraska Game, Forestation, and Parks Commission
Kansas						
Reeves Lake (Grant County)	Jan., 1953	Mallard	25,000	200–250	0.8–1.0	George W. Sciple (unpublished report), U. S. Fish and Wildlife Service
Texas						
Lubbock County	Winter, 1944	Ducks	.....	5,000–10,000	.....	Oscar L. Chapman (letter, June 18, 1945), U. S. Department of the Interior
Muleshoe National Wildlife Refuge	Dec., 1946	Ducks	.....	160	.....	
Aransas County	Jan.–Feb., 1949	Lesser scaup	.....	100	.....	
PACIFIC FLYWAY						
Utah						
Bear River Migratory Bird Refuge	Winters, 1947–1954	Mallard, whistling swan, redhead	.....	300+	.....	Richard E. Griffith (letter, April 1, 1955)
California						
San Francisco and Suisun Bay areas	1939	Pintail	850,000	9,000–10,000	1.1–1.2	Donald D. McLean (unpublished report), reference cited in footnote to table 4
Salton Sea National Wildlife Refuge	Winters, 1944–1954	Pintail, green-winged teal	400,000	4,000	1.0	Richard E. Griffith (letter, May 17, 1955)

William R. Miller (letter, May 19, 1955) reported: "I have on a few occasions seen what to my mind was a case of death due to lead poisoning." James A. Lee (letter, March 29, 1955) reported: "As far as I can ascertain, we have never had a waterfowl die-off in New Hampshire attributable to lead poisoning." Charles L. McLaughlin (letter, May 23, 1955) reported: "I have no authentic records of ducks dying of lead poisoning in Massachusetts, and it is my opinion that this type of mortality is unimportant in the state. A few years ago reports of large scale mortality from lead poisoning in the coastal wintering black ducks was reported, but investigation revealed that the mortality was due to starvation rather than lead." Ruth S. Billard (letter, May 3, 1955) reported as follows for the Connecticut State Board of Fisheries and Game: "We are not aware of any waterfowl succumbing from lead poisoning." Thomas J. Wright (letter, April 26, 1955) reported: "Rhode Island, to the best of my knowledge, has never had any waterfowl losses that could be attributed to lead poisoning."

From New York, Donald D. Foley (letter, May 3, 1955) wrote: "There are without doubt many instances of such poisoning in this state, particularly in late winter and early spring, of which we are not aware. However, we feel that the over-all picture is not too serious as to direct mortality." L. G. McNamara (letter, April 27, 1955) reported: "As far as we know, lead poisoning is not a problem in New Jersey." Robert E. Stewart (letter, May 21, 1955) of the U. S. Fish and Wildlife Service, in referring to the Maryland marshes, reported: "On several occasions, during the past years, diving ducks which appeared unable to fly were collected and found to contain worn lead pellets." In Delaware, Everett B. Chamberlain (letter, April 11, 1955) knew of only two duck deaths which were suspected to be from lead poisoning.

In Virginia, C. P. Gilchrist, Jr. (letter, June 20, 1955), expressed his belief that some ducks are lost to lead poisoning, but not in large enough numbers to be brought to the attention of the Commission of Game and Inland Fisheries.

Farther south, T. Stuart Critcher (letter, May 13, 1955), reporting from North Carolina, remarked: "To my knowledge we have no records of losses in waterfowl populations as a result of lead poison. Undoubtedly, such losses do occur from time to time." Dr. J. H. Jenkins (letter, May 12, 1955) of the University of Georgia wrote: "I don't know of a single case of lead poisoning of waterfowl in Georgia. For one thing, there is very little shooting over established marshes." E. B. Chamberlain, Jr. (letter, April 22, 1955), reported concerning lead poisoning: "So far as we have been able to determine, there have never been any large scale losses of waterfowl in Florida due to this cause."

Mississippi Flyway.—All but three states in the Mississippi Flyway have reported die-offs of waterfowl as a result of poisoning from ingested lead shot, table 1. Among the largest losses have been those reported from Louisiana. The largest die-offs in Louisiana have been at Catahoula Lake in La Salle Parish, where 20,300 ducks are estimated to have died from lead poisoning in the period 1950–1955. Lead poisoning among the waterfowl of Catahoula Lake probably dates back farther than 1930, for E. R. Kalmbach in his 1930 report (on file, U. S. Fish and Wildlife Service) mentions a duck malady as occurring in previous years at that lake.

The largest known single outbreak of lead poisoning occurred in the Claypool Reservoir area near Weiner, Arkansas, between mid-December of 1953 and mid-February of 1954. John W. Perkins (letter, February 12, 1954), game agent for the U. S. Fish and Wildlife Service, estimated that during that period 16,000 ducks, most of them mallards, succumbed to lead poisoning.

A similar die-off of mallards had previously occurred there in early February of 1951. The die-off was investigated by John J. Lynch (letter, February 9, 1951) of the U. S. Fish and Wildlife Service, who reported seeing over 50 carcasses on less than 3 acres of the 1,300 acre reservoir. He concluded that the casualties "numbered in the thousands." Furthermore, Lynch stated that a die-off of similar proportions occurred on the same reservoir in the winter of 1948–49.

In Missouri, the largest reported die-off of ducks from lead poisoning took place at the Squaw Creek National Wildlife Refuge, where 10,000 out of 150,000–205,000 mallards died during the winter of 1956–57. In the previous winter, 5,000 mallards out of the 200,000 on the refuge died from lead poisoning. Other die-offs occurred there every winter at least as far back as 1945; reported mortality varied from 50 to 300 victims per year. Additional die-offs of mallards occurred at Dalton Cut-off in Chariton County in 1949 and at the Swan Lake National Wildlife Refuge in 1939, 1952, 1953, and 1954.

Hovey Lake, Posey County, Indiana, has been a trouble spot for many years. As mentioned earlier, Phillips & Lincoln (1930:165) reported ducks dying there from lead poisoning as far back as 1922. The largest die-off there in recent years, an estimated 1,000 ducks, took place during the winter of 1947–48 (James D. McCall, letter, February 5, 1955). Reported losses since then have been sporadic and rather small, except for the death of 219 Canada geese in 1953 and 120 in 1955–56 (Martin 1957:114). Small die-offs, aggregating 678 birds, are reported to have occurred at Hovey Lake, the Kankakee State Game Preserve area (Starke County), and the Willow Slough State Game Preserve (Newton County) during January and February, 1955.

Since 1947, wherever large numbers of mallards have wintered in central Illinois, there have been some outbreaks of lead poisoning. Most of the reported die-offs have occurred on, or in the vicinity of, the Chautauqua National Wildlife Refuge, near Havana, where 13,000 ducks are estimated to have died from lead poisoning in the period 1941–1957, table 1. The largest single outbreak of lead poisoning among waterfowl of Illinois occurred there in January and February of 1957, when an estimated 5,000 succumbed. The second largest die-off occurred at Stump Lake, north of Grafton, where 3,000 mallards were victims of lead poisoning in January, 1948.

In Iowa, sporadic outbreaks of lead poisoning among ducks have been noted since 1936, according to Everett B. Speaker (letter, February 23, 1955), but only one die-off amounted to over 1,000 birds, table 1. That one took place at Forney Slough, in Fremont County, during the winter of 1948.

Reported losses from lead poisoning among waterfowl in the lake states of Minnesota, Wisconsin, and Michigan have been minor, table 1. In Wisconsin, small losses of whistling swans occurred in the Green Bay area in the springs of 1948–1954. L. R. Jahn (letter, February 16, 1955) reported that, although ducks were victims of lead poisoning in both spring and fall, their losses had been sporadic. H. J. Miller (letter, February 23, 1955) wrote that Michigan had not known an appreciable die-off of ducks from lead poisoning since the taking of waterfowl records was begun in 1940. In the spring of 1942, 16 whistling swans were found dead from lead poisoning on widely separated marshes of southeastern Michigan. In the winter of 1953–54, 100 whistling swans and 75 mallards were reported as dying from lead poisoning at the Shiawassee National Wildlife Refuge, near Saginaw (Richard E. Griffith, letter, April 1, 1955).

After studying the mortality in large populations of ducks wintering, 1949–1952, on the Detroit River in Michigan, Hunt & Ewing (1953:362, 367) considered lead poisoning to be of little importance as a mortality factor.

In Ohio, lead poisoning has evidently been a minor problem, for Delmar Handley (letter, April 28, 1955) stated that only a few ducks and geese had been found afflicted by this disease. A suspected case of lead poisoning in Tennessee waterfowl was reported by Parker Smith (letter, May 5, 1955) as affecting 40 or 50 mallards along the Obion River in February, 1954.

In three states of the Mississippi Flyway, Kentucky, Mississippi, and Alabama, lead poisoning losses have not been reported (letters: Frank Dibble, April 12, 1955; W. Walter Beshears, Jr., May 9, 1955; and Alec Bumsted, March 1, 1955), but some losses undoubtedly occur in those states.

Central Flyway.—Although die-offs of waterfowl from lead poisoning have occurred at several places in the Central Flyway, they have not been so large as

those in the Mississippi Flyway, table 1. Largest losses in the Central Flyway have been reported from the Sand Lake National Wildlife Refuge area of South Dakota, where more than 10,700 mallards succumbed to lead poisoning over a span of 10 winters.

A large die-off of ducks reported in Lubbock County, Texas, during the winter of 1944 was a most unusual one. Details were reported in a letter (June 18, 1945) from Oscar L. Chapman, then Assistant Secretary of the Department of the Interior, to the Secretary of War, Henry L. Stimson. Excerpts are as follows: "During the past winter approximately 800 wild ducks were found dead at two small lakes on the grounds of the Lubbock Army Air Field, Texas. Field studies conducted by the Fish and Wildlife Service of this Department revealed that these losses were due primarily to lead poisoning resulting from ingestion of lead shot which drop into one of these lakes during skeet practices. Studies conducted by Army personnel indicated that 80 per cent of the dead ducks examined contained lead pellets in their gizzards. . . . It is estimated that the annual loss from the two lakes is between 5,000–10,000 ducks, many of which perish on their northward migration. This estimate is substantiated by numerous reports of emaciated dead and live ducks being found or seen in areas north of Lubbock."

In Nebraska, George V. Schildman (letter, March 5, 1955) reported sizable die-offs of blue geese (*Chen caerulescens*) and lesser snow geese (*Chen hyperborea*) from lead poisoning, table 1. In regard to loss of ducks, he stated: "The numerous rainwater basins in Clay, Fillmore, and York counties provide some losses each spring. . . .The losses are commonplace, but—to my knowledge—haven't been conspicuous and concentrated. However, these basins cover an extensive area, and the total loss may be considerable."

According to Richard E. Griffith (letter, April 1, 1955): "Minor losses have been reported from the Salt Plains Refuge (Oklahoma), usually in single isolated cases. An occasional bird with lead poisoning is picked up on other refuges throughout the Southwest, but in most instances it is felt the shot was ingested prior to arrival." Griffith reported some fatalities among mallards at the Fort Peck Game Range in Montana, where 5,000 to 17,000 winter. Elsewhere in Montana, Wynn G. Freeman (letter, April 23, 1955) reported he had found no waterfowl suffering from lead poisoning.

Other waterfowl biologists in the Central Flyway who have yet to find mortality in waterfowl from lead poisoning are B. A. Fashingbauer (letter, February 17, 1955), North Dakota; Robert L. Patterson (letter, February 8, 1955), Wyoming; and Levon Lee (letter, February 19, 1955), New Mexico.

Pacific Flyway.—The largest outbreaks of lead poisoning among waterfowl of the Pacific Flyway have been reported from California, table 1. In 1939, ducks estimated at 9,500 died from lead poisoning in the Central Valley, San Francisco Bay, and Suisun Bay areas of California, table 1, but it is not known to what extent die-offs approach this number every year, for the problem was investigated in detail in only that year by the California Department of Fish and Game. In the winters beginning in 1944 and ending in 1954, 4,000 ducks were estimated to have become victims of lead poisoning at the Salton Sea National Wildlife Refuge in southern California.

Both the Tule Lake and the Lower Klamath National Wildlife refuges in northern California, according to Richard E. Griffith (letter, May 17, 1955), have sections heavily shot over, and yet reported losses from lead poisoning have been surprisingly low.

From Utah, Noland F. Nelson (letter, February 19, 1955) reported regarding lead poisoning: "During the past 10 years of waterfowl management work on Utah's marshlands, I have observed no large die-offs of waterfowl resulting from lead poisoning. However, a few lead poisoning losses have been recorded every year. These recorded losses were almost always during the winter and early spring months on some of the areas of heavy shooting around Great Salt Lake. . . . A few emaciated mallard, pintail, shoveler, and whistling swan have been examined almost every winter and a large per cent have contained ingested lead shot.

The keeper of a local aviary rescued 33 sick whistling swans one winter and 28 died from lead poisoning."

In discussing losses of waterfowl from lead poisoning at the Bear River Migratory Bird Refuge, Utah, Richard E. Griffith (letter, April 1, 1955) emphasized that the loss cited, table 1, was a minimum one and should not be construed as a reliable indicator of total mortality. He reported that outbreaks of lead poisoning occurred when ice restricted the birds to a limited feeding area. The development of this situation was most apparent among the 10,000–12,000 whistling swans wintering at the refuge, for they began to die from lead poisoning as soon as the feeding areas became restricted by ice.

Thirteen trumpeter swans affected by lead poisoning were found by Dr. Ian McT. Cowan (Tener 1948:12) in February of 1943 on Vancouver Island, British Columbia. However, only a very few ducks have been found ill from lead poisoning in that province (E. W. Taylor, letter, March 22, 1954).

In regard to lead poisoning in Washington, Henry A. Hansen (letter, February 26, 1955) wrote: "It has been a rare and isolated case that weak or dead ducks have been found to have lead shot in their gizzards in this state since we organized the waterfowl research project in 1947. In no instance have we found a trouble spot that might require remedial action."

Chester E. Kebbe (letter, April 21, 1955) reported that, although an outbreak of lead poisoning had not been noticed in Oregon, he believed that research would reveal large numbers of waterfowl dying each year from ingested shot. Richard E. Griffith (letter, May 17, 1955) reported that records at the Malheur National Wildlife Refuge in southwestern Oregon indicated that there had been no losses from this malady in the previous 7 years. A few waterfowl, mostly diving ducks, were victims of lead poisoning at that refuge in 1942.

C. Vic Oglesby (letter, March 31, 1955) reported: "There have been no major die-offs nor any approaching even moderate die-offs in Nevada within the past 10 years. A very few birds, primarily shovelers, fall victim to lead poisoning each fall on the Stillwater Wildlife Management Area located near Fallon, Nevada. This is our largest public hunting area and bears the bulk of the waterfowl shooters within the state."

In Arizona, no losses of waterfowl from lead poisoning have been reported during the past 10 years, according to Wesley B. Fleming (letter, February 8, 1955).

Undoubtedly not all the outbreaks of lead poisoning among waterfowl during the past decade have been reported. However, it is believed that outbreaks discussed in this paper include the most important die-offs from lead poisoning, and that these outbreaks represent a cross section of such conditions in the United States. Today there are only a few places in this country where 1,000 or more ducks might succumb from lead poisoning and not be noticed. Past experience shows that the public becomes alarmed when large numbers of dead ducks are observed and that it reports such events to conservation authorities or the press.

Moreover, waterfowl are prone to concentrate in and around refuges; refuge personnel would be among the first to become aware of and report any unusual waterfowl mortality. Since the early 1930's, there have been numerous federal refuges, manned with technically trained personnel, well distributed throughout the four flyways.

In addition to the waterfowl die-offs that attract public attention, there are the scattered day-to-day losses that pass unnoticed. These day-to-day losses are extensive; their magnitude is explored later in this paper on the basis of the incidence of ingested shot in waterfowl populations and the toxicity of various doses of lead shot.

Lead poisoning outbreaks have occurred more commonly in the Mississippi Flyway than in all the other flyways combined. In both the Mississippi and Central flyways, mallards have been the principal victims in all but a few die-offs. A rough estimation of the annual rate of loss of mallards in outbreaks of lead poisoning in the Mississippi Flyway is 1 per cent.

Frequency of Die-Offs

Some areas have outbreaks of lead poisoning in waterfowl rarely, some occa-

sionally, and others with rather consistent frequency. For example, in Illinois there has been but one outbreak of lead poisoning near Henry in 18 years; near Grafton there have been two outbreaks in 12 years; at the Chautauqua National Wildlife Refuge there have been outbreaks in 10 of the last 13 years.

The frequency and magnitude of lead poisoning outbreaks in a particular area are influenced largely by the following factors: the size of late fall and winter populations of mallards and other species of ducks with similar feeding habits; the kind and amount of food available; the amount of lead shot present as a result of shooting pressure; the availability of shot, determined by bottom conditions, water levels, and ice cover.

One reason that the Chautauqua National Wildlife Refuge area has been the scene of many outbreaks of lead poisoning in waterfowl is that generally 100,000 to 400,000 mallards winter there, making it usually the area of largest winter concentration in Illinois. Another reason is that nearby Quiver Creek, which remains partly open during the coldest weather, attracts a large proportion of the wintering population to its shot-laden stream bed.

Water levels, food, and a lack of ice cover combined to cause the exceptionally large die-off of 5,000 mallards in the Chautauqua area during the winter of 1956–57. A rise in water resulted in the flooding of millet and smartweed beds adjacent to the refuge shortly after the hunting season closed. This area had been heavily shot over, and mallards congregated there for a week before a freeze-up forced them to leave. Most of them moved to Quiver Creek. Two to 3 weeks later, mallards in the Quiver Creek area commenced dying by the hundreds.

Other areas in the Mississippi Flyway where there have been consistently frequent outbreaks of lead poisoning include Catahoula Lake, Louisiana, 4 out of 6 years; Claypool Reservoir, Arkansas, 3 out of 8 years; and Squaw Creek National Wildlife Refuge, Missouri, 8 out of 13 years.

Seasons of Die-Offs

As shown by data in table 1, most waterfowl die-offs from lead poisoning have occurred during the late fall and early winter months, after the close of the hunting season. Only a very few die-offs have been noted during the hunting season, even though in the southern zone the season has usually extended to January 10 or 15. Two large outbreaks have been reported during the hunting season: One of these occurred at Catahoula Lake, Louisiana, during the last two weeks of November and the first week of December in 1950; the other took place in the Claypool Reservoir area of Arkansas between mid-December of 1953 and early February of 1954.

Outbreaks of lead poisoning are unusual during the early fall months. Hunter activity keeps ducks out of heavily gunned areas where shot pellets are most heavily deposited, and, as shown later, a sizable number of the ducks suffering from the effects of lead poisoning are shot by hunters.

Outbreaks of lead poisoning seldom have been noted among waterfowl during the spring. Principal losses at this season have been among swans and geese. Whistling swans have been recorded as dying during the spring at Green Bay, Wisconsin, and on the Shiawassee National Wildlife Refuge, Michigan, table 1. A die-off of Canada geese took place in April, 1954, at Lake Puckaway, Wisconsin. In Nebraska, losses of blue geese and snow geese have occurred for a number of years during March and April. Greater scaups were reported by Van Tyne (1929:103–4) as dying at Houghton Lake, Michigan, during April, 1928. In the spring of 1921 near Florence, Louisiana, many ducks died from lead poisoning, according to Albert Bonin, quoted in an unpublished report by E. R. Kalmbach.

There are no records to indicate that in recent years wild waterfowl have died from lead poisoning during the summer months. However, Wetmore (1919:2) stated that during the summers of 1915 and 1916 he handled many ducks affected by lead poisoning in the Bear River Delta of Great Salt Lake, Utah. In spite of numerous and intensive investigations on botulism and other waterfowl problems at the Bear River Migratory Bird Refuge, lead poisoning losses have not been recorded there during the summer since

Wetmore (1919) reported on his field work of 1915 and 1916.

Species Affected by Die-Offs

Individuals of most species of waterfowl have been recorded at one time or another as victims of lead poisoning. In addition to those species listed in table 1, the following species have been reported as victims: trumpeter swan, white-fronted goose (*Anser albifrons*), gadwall (*Anas strepera*), baldpate (*Mareca americana*), blue-winged teal (*Anas discors*), cinnamon teal (*Anas cyanoptera*), shoveler (*Spatula clypeata*), canvasback, greater scaup, common goldeneye (*Bucephala clangula*), and ruddy duck (*Oxyura jamaicensis*). The largest number of species reported from any one area was found by Donald D. McLean (unpublished report, California Department of Fish and Game) in the San Francisco and Suisun Bay areas of California. He reported 257 pintails, 45 shovelers, 15 baldpates, 13 green-winged teals (*Anas carolinensis*), 7 mallards, 2 lesser Canada geese, 1 cinnamon teal, and 1 canvasback in a group of waterfowl which had succumbed from lead poisoning.

Although individuals of many species have died from lead poisoning, it is evident that the mallard has been the principal victim in outbreaks of lead poisoning across the nation, table 1. In the Pacific Flyway the pintail has made up the largest number of victims. In the Mississippi Flyway, however, where mallards and pintails have frequented the same areas, mallard losses have been proportionately greater, table 1. Die-offs of the Canada goose, blue goose, and snow goose have been reported for several places, table 1, but losses in these die-offs have been comparatively small.

An investigation of a lead poisoning outbreak at Catahoula Lake, Louisiana, in January of 1953 pointed up important differences in the mortality rates of species. During the period of the outbreak, the waterfowl population was composed of 30,000 pintails, 25,000 mallards, 5,000 green-winged teals, and small numbers of a few other species. Although pintails outnumbered mallards in the population, 5,500 mallards and 1,000 pintails were estimated to have died from lead poisoning. In a 3-day period, 243 mallards and only 26 pintails were picked up. Not a single dead or incapacitated green-winged teal was found.

From these observations, it was deduced that the habits of the several species of ducks were such as to account for the different mortality rates. Observations of the feeding ducks plus unpublished food habits studies of ducks at Catahoula Lake by Richard K. Yancey of the Louisiana Wild Life and Fisheries Commission suggested that both feeding traits and food preferences were involved. Ducks of all three species, mallard, pintail, and green-winged teal, were feeding extensively in flooded beds of chufa (*Cyperus esculentus*), but mallards were puddling more commonly into the bottom for tubers of this plant than were pintails, which were probably feeding more commonly on the floating seeds. Green-winged teals appeared to be feeding almost entirely on floating seeds.

Apparently, in puddling into the bottom mud, mallards came into contact with the lead shot more frequently than did pintails, and pintails more frequently than did green-winged teals. The form of the food they consumed undoubtedly influenced mortality among those ducks ingesting shot. Jordan & Bellrose (1951:18) reported that ducks that fed on small seeds were less affected by ingested lead than were those that fed on corn. The tubers of chufa and the kernels of corn appear to have similar physical properties and they may be expected to have similar effects.

Incidence of Lead Shot in Die-Offs

Biologists investigating outbreaks of lead poisoning among waterfowl in the Mississippi Flyway, 1938–1955, examined samples of dead and dying mallards for ingested shot, tables 2 and 3. Although 10.4 per cent of the drakes, table 2, and 13.0 per cent of the hens, table 3, found in the outbreaks carried no shot in their gizzards, most, if not all, of these were lead-poisoned victims. James S. Jordan (unpublished report) found in controlled experiments with captive mallards that 21 per cent of those dosed with one to four No. 6 shot pellets had no pellets in their gizzards at time of death.

Table 2.—Incidence of various ingested shot levels found among drake mallards picked up level is meant the number of ingested lead shot pellets found in a gizzard.) For each state are

Location	0 Pellet		1 Pellet		2 Pellets		3 Pellets		4 Pellets		5 Pellets	
	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent
South Dakota	4	11.8	17	50.0	8	23 5	5	14 7	0	0 0	0	0.0
Minnesota...	17	13.8	36	29.3	22	17.9	15	12.2	10	8 1	4	3 3
Missouri....	6	14.0	8	18.6	5	11.6	6	14 0	9	20.9	5	11 6
Illinois....	37	11.9	90	29 0	49	15.8	36	11.6	18	5.8	23	7 4
Arkansas....	3	4.1	6	8.2	20	27.4	8	11.0	5	6.9	3	4 1
Louisiana...	5	4.6	3	2.8	15	13.9	16	14.8	20	18.5	15	13.9
Total....	*72*	....	*160*	....	*119*	...	*86*	..	*62*	....	*50*	.....
Average..	.....	10.4	....	23.2	.....	17.2	....	12.4	....	9.0	.....	7.2

Table 3.—Incidence of various ingested shot levels found among hen mallards picked up level is meant the number of ingested lead shot pellets found in a gizzard.) For each state

Location	0 Pellet		1 Pellet		2 Pellets		3 Pellets		4 Pellets		5 Pellets	
	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent
South Dakota	0	0.0	12	48.0	7	28.0	3	12.0	3	12.0	0	0.0
Minnesota..	11	15.5	30	42.3	13	18.3	7	9.9	3	4 2	3	4.2
Missouri....	3	11.1	7	25.9	3	11.1	6	22.2	5	18.5	1	3.7
Illinois....	32	18.1	57	32.2	30	17.0	19	10.7	7	4 0	5	2.8
Arkansas...	6	22.2	7	25.9	2	7.4	3	11.1	2	7 4	1	3.7
Louisiana...	8	5.9	11	8.1	21	15.6	31	23 0	16	11.9	18	13.3
Total....	*60*	....	*124*	....	*76*	.....	*69*	....	*36*	.....	*28*	.....
Average..	.....	13 0	.....	26.8	.....	16 5	.....	14.9	.....	7.8	.....	6 1

It is apparent that most, if not all, waterfowl found dead without ingested shot in a lead poisoning outbreak had previously ingested lead, but that the lead had passed from their digestive tracts at such late stages of illness that the birds failed to recover. The low proportion of free-flying, lead-poisoned mallards found without ingested shot, as compared with the proportion of lead-poisoned penned birds without ingested shot, suggests that birds in the wild that succeed in voiding shot are more likely to survive than are penned birds.

Considerable variation was evident in the amounts of ingested lead shot in mallard drakes found dead or dying in four areas. The lowest number of shot pellets per duck was among those affected by lead poisoning at the Sand Lake National Wildlife Refuge, South Dakota, in December of 1951, fig. 3. The next smallest number of ingested shot pellets per duck was among birds picked up, 1941–1954, in the vicinity of the Chautauqua National Wildlife Refuge, Illinois. The mallards of the Claypool Reservoir, Arkansas, and the Catahoula Lake, Louisiana, outbreaks had a larger number of ingested shot pellets per duck than did those of the Illinois outbreaks, fig. 3.

Differences between the four areas in numbers of pellets per drake are believed to have resulted mainly from the differences in (1) availability of shot and (2) diet. The quantity of shot ingested by ducks of a given species is roughly proportional to the availability of shot. Diet has an important influence on the survival of ducks that have ingested lead, according to Jordan & Bellrose (1951:18–21), who reported that the harmful effect of ingested lead was most evident in ducks fed on whole corn and much less

in a dead or moribund condition in lead poisoning die-offs in six states, 1938–1955. (By shot given the number and per cent of drakes represented at each shot level.

6 PELLETS		7 PELLETS		8 PELLETS		9 PELLETS		10 PELLETS		OVER 10 PELLETS		TOTAL	
Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent
0	0 0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	34	100.0
8	6 5	2	1.6	1	0.8	0	0 0	3	2.4	5	4.1	123	100.0
1	2 3	1	2 3	1	2.3	1	2.3	0	0.0	0	0.0	43	99.9
9	2 9	5	1 6	7	2.3	4	1.3	6	1.9	26	8.4	310	99.9
6	8.2	2	2 7	4	5.5	6	8.2	2	2.7	8	11.0	73	100.0
10	9 3	6	5 6	5	4.6	2	1.8	4	3.7	7	6.5	108	100.0
34	. . .	*16*	. . . .	*18*	. . .	*13*	. . . .	*15*	. . . . .	*46*	. . . .	*691*	. . . .
. . . . .	4 9	. . . . .	2 3	. . . .	2 6	. . . .	1.9	. . . . .	2.2	. . . . .	6.7	. . . . .	100.0

in a dead or moribund condition in lead poisoning die-offs in six states, 1938–1955. (By shot are given the number and per cent of hens represented at each shot level.

6 PELLETS		7 PELLETS		8 PELLETS		9 PELLETS		10 PELLETS		OVER 10 PELLETS		TOTAL	
Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent
0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	25	100.0
2	2.8	0	0.0	1	1.4	1	1.4	0	0.0	0	0.0	71	100.0
0	0.0	0	0.0	2	7.4	0	0.0	0	0 0	0	0.0	27	99.9
5	2 8	1	0 6	2	1.1	1	0.0	1	0.6	17	9.6	177	99.5
2	7.4	2	7 4	0	0.0	0	0.0	1	3 7	1	3.7	27	99.9
10	7.4	8	5.9	2	1.5	5	3.7	1	0.7	4	3.0	135	100.0
19	. . . . .	*11*	. . . . .	*7*	. . . . .	*7*	. . . . .	*3*	. . . .	*22*	. . . .	*462*	. . . . .
. . . .	4.1	. . . . .	2.4	. . . . .	1 5	. . . . .	1 5	. . .	0.6	. . .	4.8	. . . .	100.0

evident in ducks fed on leafy vegetation and the seeds of tame rice, millet, and smartweed.

The high percentage of birds with a small number of pellets per bird among the victims in South Dakota probably was a result of (1) lack of easy availability of shot and (2) accelerated losses induced by cold weather and the high toxicity of lead when associated with the corn diet to which the birds were restricted during the winter. Mallards wintering in Illinois, too, were largely restricted to a corn diet, but they had available to them much more shot.

The large numbers of shot pellets per bird found in mallard drakes in Arkansas and Louisiana die-offs indicate the availability of large quantities of shot. The small number of drakes without ingested shot, table 2, suggests an excellent survival of those that had voided shot. Apparently, the mallard drakes of Arkansas and Louisiana had a better survival rate than those of South Dakota and Illinois because they had a better diet and milder weather.

AVAILABILITY OF LEAD

The availability of lead shot to waterfowl utilizing a particular body of water is determined by the following factors: (1) the shooting intensity, or amount of shot deposited on the bottom, (2) the firmness of the bottom material, (3) the size of the shot pellets deposited, (4) the depth of water above the bottom, and (5) ice cover.

The amount of lead deposited on lake and marsh bottoms as shot pellets from the guns of waterfowl hunters is tremendous. A conservative estimate of the number of shells fired for every duck

bagged is five; if every shell were of 12 gauge and contained No. 6 shot, then about 1,400 shot pellets would be deposited for every duck bagged.

In Illinois, the annual kill at some public shooting grounds has been as high as six ducks per acre, but for all Illinois duck hunting areas over a period of years the kill has averaged about one and one-half ducks per acre per year. The amount of lead shot deposited in Illinois River valley lakes is calculated to be approximately 2,100 pellets per acre per year. Because of the scattered distribution of blinds, many acres of waterfowl habitat are untouched by spent shot, while small areas near blinds have an annual deposition of shot many times as great as the calculated average for the larger acreage of which they are a part. Most blinds are located on or adjacent to the best waterfowl feeding grounds. In such situations, waterfowl are more likely to pick up shot in their feeding activities than if the blinds, and therefore the pellets, were more evenly distributed.

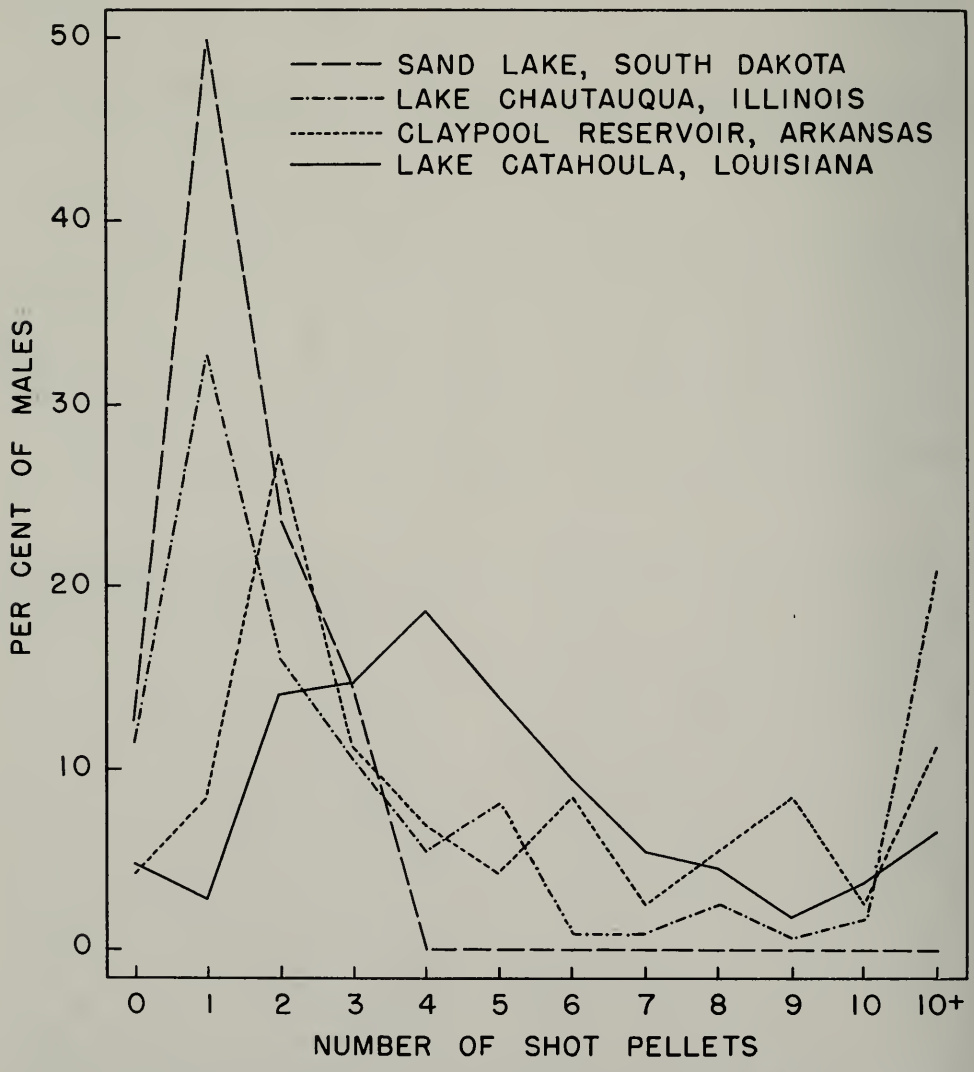

Fig. 3.—Incidence of various levels of ingested lead shot found in gizzards of drake mallards picked up in a dead or moribund condition in each of four areas in which lead poisoning die-offs occurred, 1941–1954. Data, except those for Illinois, are from table 2.

A number of surveys have been made of lake and marsh bottoms in an effort to ascertain the availability of lead shot to waterfowl. Wetmore (1919:9–10), in his pioneering investigation of lead poisoning, examined mud from two areas at the mouth of the Bear River in Utah. In one area he found no shot pellets within 30 to 70 yards of a blind, but he found pellets at sampled 20-yard intervals from 70 yards to as far as 210 yards from the shooting point. He found most pellets at a distance of 130 yards, where he recovered 1 to 12 in each sieve filled with mud. In the other area, Wetmore found 1 to 13 pellets at each sampling point; most of the pellets had penetrated through 10 to 12 inches of a soft upper layer of mud to a lower layer of hardened clay.

More recent studies, table 4, show the concentrations of lead pellets in bottom samples, most of them taken without specific orientation to shooting blinds. The bottom material sampled varied in thickness from 2 to 10 inches.

The greatest concentration of lead shot that has been reported was at Lake Puckaway, Wisconsin, table 4. Hartmeister & Hansen (1949:18–22), after investigating three Wisconsin shooting areas, re-

Table 4.—Number of lead shot pellets per square foot and per acre found in samples of the bottom soils of various lakes and marshes used extensively by waterfowl in North America. The bottom samples varied from approximately one-half inch to 10 inches in thickness.*

State	Area	Year and Season	Number of Square Feet in Sample	Number of Pellets Per Square Foot	Number of Pellets Per Acre
California...	Sacramento Valley	1939, 1940	60	0.45	19,602
	North Bay, San Francisco	Springs	120	0.78	33,977
	Suisun Bay		260	0.58	25,265
	Delta		80	0.20	8,712
	South Bay, San Francisco		240	0.79	34,412
	San Joaquin Valley		120	1.37	59,677
	South Coast		40	0.48	20,908
Minnesota...	Lakes on Carlos Avery Refuge	1939–1940 Winter	80	0.41	17,859
	Lakes adjacent to Carlos Avery Refuge		94	0.37	16,117
	Rice Lake		53	0.55	23,958
	Rush Lake		11	0.00	0
	Heron Lake		36	1.47	64,032
	24 Lakes		249	0.14	6,098
Wisconsin...	Lake Puckaway	1949	100	2.71	118,048
	Clam Lake	Winter	67	1.06	46,174
	Horicon Marsh		53	0.08	3,485
Manitoba...	Portage Creek, Delta Marsh	1950	186	1.17	50,965
	Cadham Point, Delta Marsh	Summer	195	0.39	16,988
Michigan....	Saginaw Bay	?	45	0.27	11,761
	Maumee Bay	?	200	0.27	11,761
Indiana.....	Willow Slough	1956	14	0.93	40,511
		Spring, Fall	14	1.07	46,609
Illinois.....	Quiver Lake	1950	22	0.00	0
	Moscow Bay	Summer	60	0.04	1,742

*Sources of data: California: "Lead poisoning of California waterfowl," unpublished report by Donald D. McLean, Bureau of Game Conservation, California Division of Fish and Game; Minnesota: unpublished reports by Gustav Swanson and C. Gordon Fredine, in Cooperative Wildlife Investigations, University of Minnesota and Minnesota Division of Game and Fish, Vol. 1, 1937–1939; Vol. 2, 1939–1940; Wisconsin: Hartmeister & Hansen 1949; Manitoba: "Occurrence of lead shot in a waterfowl breeding marsh," by George K. Brakhage, unpublished quarterly report of the Missouri Wildlife Research Unit, July–September, 1950; Michigan: "Waterfowl survey of Saginaw Bay, Lake St. Clair, Detroit River, Lake Erie and the marshes adjacent to these waters," by Herbert J. Miller, unpublished final report, P-R Project 13-R, Michigan Department of Conservation, January 1, 1943; Indiana: Martin 1957.

ported 2.71 pellets per square foot (equivalent to 118,048 pellets per acre) at Lake Puckaway, less than half as many pellets per square foot at Clam Lake, and a "negligible amount of lead shot available to waterfowl" on Horicon Marsh. Lake Puckaway, they reported, has a bottom of sand and gravel covered by a thin layer of vegetable matter 1 to 6 inches in depth. Clam Lake has a similar bottom. The difference between the areas in number of pellets per square foot may reflect differences in hunting pressure.

Hartmeister & Hansen (1949:19) concluded: "Sampling on Horicon marsh revealed a practically negligible amount of lead shot available to waterfowl, in spite of the fact that this area is probably as heavily hunted as any lake or marsh in the state of Wisconsin. Obviously, lead shot are soon made unavailable to waterfowl where deep layers of muck and peat are present."

Bottom samples were taken at the Carlos Avery Refuge in Minnesota 5 years after it had been closed to shooting; yet shot pellets were about as numerous there as in adjacent lakes that were hunted during the 5-year period (unpublished Minnesota report cited in table 4 footnote). At Rush Lake, a mud-bottomed water area, no lead shot was found in samples taken 15 years after it had been closed to hunting. The highest concentration of lead shot found in the Minnesota lakes sampled was at Heron Lake, which has a hard clay bottom and had been heavily shot over, table 4.

Bottom samples taken at Willow Slough in Indiana by Dale N. Martin (1957:113) revealed about the same concentration of lead shot pellets on October 17, 1956, as on April 26, 1956, table 4. Apparently, during the 6-month period the shot had not settled deeper into the bottom. The bottom area sampled was composed of one-half to 1.5 inches of silt and plant debris over firm sand.

In California waterfowl areas, Donald D. McLean (unpublished report cited in table 4 footnote) took bottom samples at levels of 0–2 inches, 4–6 inches, and 8–10 inches below the surface of the bottom. At these three levels he found 61 per cent of the shot in the top layer, 30 per cent in the middle layer, and 9 per cent in the lowest layer. There was a noticeable difference between places; areas with hard bottoms had most of the shot pellets at depths of less than 6 inches while areas with soft bottoms had a greater proportion of shot deeper in the soil. McLean reported that at the Bolsa Chica Club, in southern California, there was a heavy concentration of shot lying on hardpan under 5.5 inches of soft mud.

Both Portage Creek and Cadham Point in the Delta Marsh of Manitoba are traditional shooting sites. Portage Creek receives much heavier shooting pressure than does Cadham Point, and shot pellets were more numerous there, table 4. In view of the soft mud bottoms of both areas, the amount of shot found was surprisingly high. George K. Brakhage stated in an unpublished report cited in a table 4 footnote that the highest concentrations of shot in the Cadham Point area were along those transects nearest the decoy placement. In Michigan, Herbert J. Miller stated in an unpublished report cited in a table 4 footnote that at Maumee Bay shot pellets were twice as numerous in areas protected from severe wave action as in the exposed areas. Part of this difference may have resulted from differences in shooting pressure, but Miller believed that the wave action and currents were largely responsible in that they covered much of the lead with sediment.

Bottom samples taken during the summer of 1950 from two heavily shot-over lakes in the Illinois River valley showed few lead shot pellets, table 4; samples were taken from the top 2 inches of the bottoms of these lakes. Undoubtedly only a small amount of lead shot was found because the expended shot sank in the soft mud and during spring floods was covered by a layer of silt. A study on the silting of Lake Chautauqua (Stall & Melsted 1951:10), an Illinois River valley lake, showed an average annual silt accumulation of 110 acre-feet in a basin of 3,562 acres.

In water areas with silt or peat bottoms, there is, apparently, only a slight carry-over of lead shot (within the soil depths at which most ducks search for food) from one season to the next. Lead shot is, therefore, most readily available to waterfowl in the fall and winter, dur-

ing and immediately following the hunting season. High water levels during the spring over much of the fall waterfowl habitat, which includes most shooting grounds, greatly diminish the availability of lead shot. Most breeding grounds are lightly hunted; therefore, waterfowl are only slightly exposed to lead shot during the breeding season.

As part of a study on lead shot in mud-bottomed lakes, an experiment was conducted by the writer at Quiver Lake, in the Illinois River valley, near Havana. Two areas of the lake bed were selected: one soft, the other moderately firm. In each area, three ceramic pipes, each 8 inches in diameter, were sunk into the soil of the lake bottom during August of 1952, a period in which the water was only a few inches deep; the upper mouth of each pipe was flush with the top layer of soil of the lake bottom. On the soil in the upper mouth of each pipe, 150 grams of shot pellets were deposited: in each of the two areas were one pipe with No. 4 shot, one with No. 6 shot, and one with No. 7½ shot.

Slightly over a year later, September 3, 1953, five 1-inch layers of soil were removed from each of five pipes and screened for lead shot. The sixth pipe, the one in soft mud that contained 4's, had been dislodged and could not be used further in the experiment.

The data in table 5 show that the smaller the shot size, the smaller the amount of recovered lead. Evidently wave action dislodged quantities of shot pellets, especially 7½'s, and scattered them outside the pipes. From the distribution of the remaining pellets, there was, with the exception of 7½'s on the moderately firm bottom, evidence that the larger the size, the more prone the pellets were to sink in the bottom soil. In the soft bottom soil, most of the shot had settled to the 1–2-inch layer, but, in the moderately firm bottom soil, the bulk of the shot was in the top 1-inch layer. However, in both bottom types, some shot had settled to the 4–5-inch layer.

Ground and aerial observations of dabbling ducks feeding in Illinois marshes indicate that most of these ducks feed on or in the top inch of the bottom material. Shovelers and green-winged teals have been watched for many hours wading through shallow water and skimming the surface of the bottom. From the air, their "mud trails" in otherwise clear water give further evidence of their characteristic feeding activities. Blue-winged teals may feed in a manner similar to that commonly observed for green-wings, but they appear to do more tipping-up to puddle deeper into the bottom mud.

Pintails do considerable skimming of the bottom in water only a few inches

Table 5.—Data indicating the penetration of lead shot pellets into bottom soil of two different types at Quiver Lake, near Havana, Illinois. Figures show for each of five pipes, 8 inches in diameter, placed with upper mouth flush with lake bottom, the number of grams of shot pellets recovered at various soil depths, September 3, 1953, and the percentage of the recovered shot that was recovered at each depth. At the upper mouth of each pipe, 150 grams of shot pellets, No. 7½ or No. 6, had been deposited on August 13, 1952.

Depth of Soil	Soft Bottom				Moderately Firm Bottom					
	No. 7½ Shot		No. 6 Shot		No. 7½ Shot		No. 6 Shot		No. 4 Shot	
	Grams Recovered	Per Cent Recovered	Grams Recovered	Per Cent Recovered	Grams Recovered	Per Cent Recovered	Grams Recovered	Per Cent Recovered	Grams Recovered	Per Cent Recovered
0–1 inch	26.0	35.6	20.0	18.8	31.4	55.2	70.7	76.8	71.0	56.5
1–2 inches	40.8	55.9	81.0	76.1	15.1	26.5	18.1	19.7	46.0	36.6
2–3 inches	4.0	5.5	4.5	4.2	8.4	14.8	2.2	2.4	5.8	4.6
3–4 inches	1.5	2.0	0.9	0.9	1.5	2.6	1.0	1.1	2.1	1.7
4–5 inches	0.7	1.0	0.0	.....	0.5	0.9	0.0	.....	0.7	0.6
Total	*73.0*	*100.0*	*106.4*	*100.0*	*56.9*	*100.0*	*92.0*	*100.0*	*125.6*	*100.0*

deep, but, in deeper water, they are prone to puddle out pockets several inches in depth. Mallards, in Illinois at least, dig deeper pockets than do pintails, but these are seldom more than 6 inches in depth. According to Wetmore (1919:3), mallards and pintails dig away mud to a depth of 6 to 18 inches and over an area 1 to 15 feet in diameter as they search for food. Such extensive digging on the part of ducks has been observed by the present writer only around trap sites where large numbers of birds have sifted through bottom soil day after day for bait. Under such circumstances, mallards have created holes as large as 2 feet in depth, 25 feet in length, and 10 feet in width.

Field observations and food habits studies indicate that, where underwater leafy aquatics occur, baldpates and gadwalls feed almost entirely upon these plants, seldom, if ever, sifting through bottom soils for food.

Not only does the depth at which lead shot occurs in bottom soils determine its availability to different species of ducks; the depth of water above the bottom is also a factor. Species of ducks differ to some extent in preferred feeding depths. Dabbling ducks usually utilize waters less than 15 inches in depth, and diving ducks feed at depths of many feet. Among the diving ducks, redheads (*Aythya americana*) and ring-necked ducks (*Aythya collaris*) are prone to feed in shallower water than are lesser scaups and goldeneyes.

When, in late fall or winter, ice fails to cover waterfowl feeding grounds that have been heavily shot over, the stage may be set for a large die-off of ducks. Ice almost invariably forms first on the shoal water of ponds, marshes, and lake margins such as are commonly used by ducks for feeding and hunters for shooting. The sealing of these waters by ice makes the large quantities of shot on such areas unavailable to waterfowl. At the same time it may cause the ducks to congregate in spring holes and spring-fed streams not covered by ice. If such areas have been heavily hunted, they are potential sources of large die-offs caused by lead poisoning.

The extent to which the various species of waterfowl are exposed to shot pellets on the bottoms of marshes and lakes is influenced by the feeding habits of the birds and by the kinds of foods available, as well as by the numbers of shot pellets available.

INGESTED LEAD SHOT IN MIGRATING DUCKS

The incidence of ingested lead shot in migrating waterfowl populations (the percentages of ducks that carried ingested lead at the time gizzards were collected) was determined by (1) fluoroscopic examination of live-trapped ducks, (2) compilation of data obtained from other investigators who had examined waterfowl gizzards for food content, and (3) fluoroscopic and direct examination (Bellrose 1951:126–7) of gizzards numbering many thousands that co-operating biologists had collected, especially for this study, from ducks in hunters' bags. Most of the data were from ducks migrating southward in fall and early winter.

Shot in Live-Trapped Ducks

During the fall months of 1948, 1949, 1950, and 1953, 5,148 mallards were live-trapped and fluoroscoped at the Chautauqua National Wildlife Refuge, near Havana, Illinois, fig. 4. Ingested lead shot was found in the gizzards of 10.14 per cent of these birds, but more than two-thirds of the gizzards with shot contained only one pellet each, table 6. Because the refuge has been closed to hunting since 1944, it is doubtful if much, or any, of the lead was picked up at the trapping site.

Almost twice as many juvenile as adult male mallards carried ingested shot, table 6. The data indicate that more hens than drakes carried ingested shot, but the sample on which the data are based is believed biased by an unduly large proportion of hens fluoroscoped late in the season, when the incidence of birds carrying shot was at its highest.

Pintails, blue-winged teals, and wood ducks (*Aix sponsa*) were caught in baited traps during September at Moscow Bay, 10 miles south of Havana. Examination of these birds by fluoroscopy revealed an incidence of ingested lead that was unusually high for these species, table 7. The high incidence may have occurred because the traps were on a heavily shot-

over area, which, combined with intensive feeding by the ducks, resulted in exposure of the birds to unusually large quantities of lead.

At the trapping site, lead shot was available equally to the three species, and, in September, it was unlikely that the birds were obtaining shot elsewhere. Yet, among the species, there were differences in incidence of ingested shot, table 7. Proportionally more pintails than wood ducks and proportionally more woodies than blue-winged teals carried ingested shot. Apparently, there is a relationship between the weight of a duck and its intake of food and lead. Perhaps under similar conditions of food and feeding, the duck species with the largest individuals have the highest percentages of individuals with ingested lead shot, table 7.

In two of the three species, table 7, an appreciably greater percentage of juveniles than of adults carried ingested lead shot; in the pintail there was little difference in shot incidence between age groups. In the pintail, blue-winged teal, and wood duck, there were only slight differences between the sexes with respect to incidence of shot, but, in the lesser scaup, proportionally twice as many drakes as hens carried ingested shot, table 7. The lesser scaups represented in table 7 were trapped on another area near Havana in April, 1953.

The seasonal incidence of ingested lead shot among mallards trapped at the Chautauqua National Wildlife Refuge during the fall months of 1949 and 1950 is shown in table 8. Most of the mallard groups fluoroscoped early in the season had a

Fig. 4.—An X-ray head and fluoroscopic screen used at the Havana laboratory of the Illinois Natural History Survey to determine the incidence of ingested lead shot in wild waterfowl trapped alive as well as in dead and moribund birds picked up in the field. Each bird was placed in the cone, which was rotated in front of the fluoroscopic screen. This procedure presented to view more than one plane of the bird's body and thereby resulted in more precise location of pellets than was possible in a single plane view. (Photograph from the *Journal-Star*, Peoria, Illinois.)

Table 6.—Incidence of various ingested shot levels found among mallards trapped and fluoroscoped at the Chautauqua National Wildlife Refuge near Havana, Illinois, during the fall months, 1948–1950 and 1953. (By shot level is meant the number of ingested lead shot pellets found in a gizzard.) For each sex and age class are given the number and per cent of fluoroscoped ducks represented at each shot level.

Sex and Age Class	Number Fluoroscoped	1 Pellet		2 Pellets		3 Pellets		4 Pellets		5 Pellets		Over 5 Pellets		Total Ducks With Shot	
		Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent
Male, adult	3,290	186	5.65	39	1.19	12	0.36	7	0.21	1	0.03	4	0.12	249	7.57
Male, juvenile	1,558	156	10.01	32	2.05	13	0.83	15	0.96	5	0.32	4	0.26	225	14.44
Male, all ages	4,848	342	7.05	71	1.46	25	0.52	22	0.45	6	0.12	8	0.17	474	9.78
Female, all ages	300	28	9.33	12	4.00	2	0.67	1	0.33	4	1.33	1	0.33	48	16.00
Total	*5,148*	*370*	.....	*83*	.....	*27*	.....	*23*	.....	*10*	.....	*9*	.....	*522*	.....
Average	.....	.....	7.19	.....	1.61	.....	0.52	.....	0.45	.....	0.19	.....	0.17	.....	10.14

Table 7.—Incidence of ingested lead shot among ducks of four species trapped and fluoroscoped near Havana, Illinois, at various times, 1949–1953.

Species	Year	Month	Adults		Juveniles		Drakes		Hens	
			Number Examined	Per Cent With Lead	Number Examined	Per Cent With Lead	Number Examined	Per Cent With Lead	Number Examined	Per Cent With Lead
Pintail	1950	September	66	12.1	87	11.5	96	11.5	57	12.3
Blue-winged teal	1949–1951	September	273	5.5	1,677	7.6	850	8.1	1,100	6.7
Wood duck	1950	September	308	6.8	340	11.8	409	9.5	239	9.2
Lesser scaup	1953	April	.....	.....	.....	.....	400	9.0	112	4.5

lower percentage of individuals with ingested shot than had groups fluoroscoped later in the season. The decline in the incidence of ingested shot among birds fluoroscoped in the December 20–24 period may have occurred as a result of the freeze-up of the lakes a week or two before, or as a result of a rapid die-off of lead-poisoned birds in a period of cold weather.

Erratic changes in incidence of ingested shot from period to period were evidence of population changes brought about by the arrival and departure of migrating mallards that varied greatly from flight to flight in the amounts of ingested lead they carried.

A few waterfowl in Illinois have been fluoroscoped in late winter or spring for evidence of ingested lead shot. Ingested shot was found in a moderate percentage of the lesser scaups examined, table 7. It was found in a very small percentage of the birds in one group of pintails; it was not found in another group of pintails nor in a sample of Canada geese, table 9.

Many ducks in other states have been fluoroscoped for evidence of ingested lead shot, table 10. In Michigan, small percentages of mallards and black ducks (*Anas rubripes*) were found to carry ingested lead during the winter and spring months. Lesser scaups that were fluoroscoped during the spring months contained no ingested shot. Examination of wintering ducks (most of them black ducks, canvasbacks, lesser scaups, and redheads) by Hunt & Ewing (1953:362) along the Detroit River disclosed that less than 4 per cent of 7,700 ducks fluoroscoped had lead in their gizzards.

Of more than 1,000 ducks, most of them black ducks, that were fluoroscoped during the fall, winter, and spring months in New York, only a very small proportion carried ingested lead, table 10. Only a small proportion of mallards trapped during the winter months in South Dakota had lead in their gizzards.

Of six species of ducks fluoroscoped during the summer months in the Great Salt Lake Basin of Utah, the mallard was the only species in which a moderately large proportion of individuals carried ingested lead, table 10.

An astoundingly large proportion of the mallards, pintails, and redheads, and a smaller proportion of the blue-winged teals fluoroscoped during the summer at Delta Marsh, Manitoba, carried ingested lead shot, table 10. All of the redheads and most of the blue-winged teals and pintails were juveniles. The findings of Elder (1950:501) agree with Illinois data in indicating that juvenile ducks are more likely to ingest lead shot than are adults; at Delta, over twice as large a percentage of juveniles as of adult mal-

Table 8.—Periodic incidence of ingested lead shot among mallards trapped at the Chautauqua National Wildlife Refuge near Havana, Illinois, during the fall months of 1949 and 1950.

Period	Number of Ducks Fluoroscoped		Number of Ducks With Shot		Per Cent of Ducks With Shot		
	1949	1950	1949	1950	1949	1950	Average
Oct. 26–30	129	2	6	1	4 65	50.00	5.34
Oct. 31–Nov. 4	224	153	8	6	3.57	3.92	3.71
Nov. 5–9	161	408	14	19	8.70	4.66	5.80
Nov. 10–14	194	435	12	32	6.19	7.36	7.00
Nov. 15–19	361	382	22	44	6.09	11.52	8.88
Nov. 20–24	385	333	30	33	7.79	9.91	8.77
Nov. 25–29	352	194	40	22	11.36	11.34	11.36
Nov. 30–Dec. 4	150	69	11	20	7.33	28 99	15.07
Dec. 5–9	274	24	30	11	10.95	45.83	13.76
Dec. 10–14	54	3	6	1	11 11	33.33	12.28
Dec. 15–19	22	12	6	2	27.27	16.67	23.53
Dec. 20–24	64	54	7	6	10.94	11.11	11.02
Total	*2,370*	*2,069*	*192*	*190*			
Average					8.10	9.18	8.60

lards were found with lead in their gizzards, and over three times as large a percentage of juvenile as of adult pintails carried ingested lead.

On other breeding ground areas—Whitewater Lake, Manitoba, and Eyebrow Lake, Saskatchewan—Elder (1950: 501) examined 3,300 ducks during the summer months of 1948 and 1949 and found that less than 1 per cent of the individuals of any species carried ingested lead. Undoubtedly, most breeding ground areas would show a low incidence of ingested shot among waterfowl. The Delta Marsh, which is one of the most heavily shot-over areas in Canada, is an exception.

Shot in Ducks Bagged by Hunters

With the help of wildlife biologists in almost every state of the Union and some Canadian provinces, the Illinois Natural History Survey obtained data on the ingested lead shot found in the gizzards of more than 40,000 waterfowl bagged by hunters in the autumn and early winter

Table 9.—Incidence of ingested lead among pintails and Canada geese trapped and fluoroscoped in Union County and pintails trapped and fluoroscoped in Henderson County, Illinois, 1952 and 1953.

SPECIES	PLACE	YEAR	MONTH	NUMBER EXAMINED	PER CENT WITH LEAD
Pintail	Henderson County	1952	April	42	0.24
Pintail	Union County	1953	February	95	0.00
Canada goose	Union County	1953	February	61	0.00

Table 10.—Incidence of ingested lead shot among waterfowl fluoroscoped in several areas and at different seasons during the period 1941–1954.

AREA	SPECIES	YEAR	SEASON	NUMBER FLUORO-SCOPED	PER CENT WITH INGESTED SHOT
Michigan*	Mallard and black duck	1941, 1942	Winter	682	1.2
	Mallard and black duck	1941, 1942	Spring	182	0.4
	Lesser scaup	1941, 1942	Spring	105	0.0
New York†	Black duck	1949–1953	Fall, Winter, Spring	1,063	0.1
	Other species			144	0.0
South Dakota‡	Mallard	1950–1954	Winter	3,115	3.1
Utah**	Mallard	1950, 1951	Summer	122	5.7
	Gadwall	1950, 1951	Summer	16	0.0
	Baldpate	1950, 1951	Summer	98	0.0
	Pintail	1950, 1951	Summer	2,199	0.6
	Green-winged teal	1950, 1951	Summer	213	0 0
	Shoveler	1950, 1951	Summer	77	1.3
Manitoba††	Mallard	1948, 1949	Summer	537	18.4
	Pintail	1948, 1949	Summer	391	15.6
	Blue-winged teal	1948, 1949	Summer	549	4.9
	Redhead	1948, 1949	Summer	52	48.1

*From "Waterfowl survey of Saginaw Bay, Lake St. Clair, Detroit River, Lake Erie and the marshes adjacent to these waters," by Herbert J. Miller. Unpublished final report, P-R Project 13-R, Michigan Department of Conservation, January 1, 1943.

†From letter of February 18, 1954, by Donald D. Foley, New York Conservation Department.

‡From letter of March 7, 1955, by Ray Murdy, South Dakota Department of Game, Fish and Parks.

**Summarized from Heuer 1952.

††Summarized from Elder 1950:501.

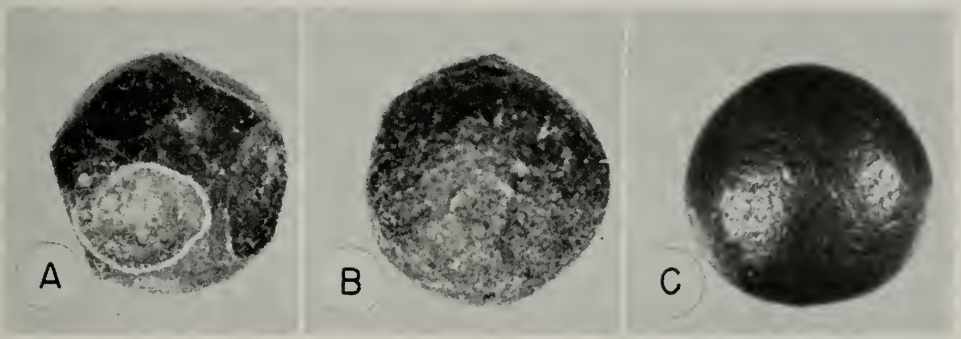

Fig. 5.—Shot pellets from the gizzards of wild ducks bagged by hunters. Pellets *A* and *B* were from the same gizzard. Pellet *A* entered the gizzard lumen from the charge that killed the bird. Pellet *B* had been ingested previously. Pellet *A* exhibits craters caused by the striking of this pellet against others in passage through the shotgun barrel. Pellet *B* has been somewhat smoothed by abrasion in the gizzard; under magnification, the surface of this pellet shows pitting and flaking. Pellet *C*, another ingested pellet from another gizzard, shows surface erosion resulting from the action of digestive juices in the gizzard.

months of the period 1938–1953. Lead pellets, two ingested and one not ingested, are shown somewhat magnified in fig. 5. The number of shot pellets and the species of ducks represented were known for each of 36,145 gizzards; data from these gizzards were used in an analysis of the incidence of shot among each of the principal kinds of waterfowl of North America, table 11.

Variations in Shot Incidence Among Species.—The incidence of ingested lead shot was about seven times as great among ducks as among geese, table 11. Less than 1 per cent of the Canada geese and less than 3 per cent of the blues and snows were found to have lead in their gizzards; the numbers of shot pellets per gizzard were exceedingly low.

There was a wide range in incidence of ingested shot among the different kinds of ducks, table 11. Kinds in which less than 2 per cent of the gizzards contained lead were bufflehead (*Bucephala albeola*), green-winged teal, mergansers (*Mergus* spp.), wood duck, shoveler, and gadwall. Kinds in which lead was found in more than 2 and less than 5 per cent of the gizzards were blue-winged teal, baldpate, and common goldeneye; in more than 5 and less than 10 per cent, ruddy duck, mallard, black duck, and pintail; in more than 10 per cent, canvasback, lesser scaup, redhead, and ring-necked duck.

It is apparent that, with the exception of the last-named group, all of which belong to the genus *Aythya*, there is no relationship between the incidence of shot and the phylogeny of the birds.

Shillinger & Cottam (1937:402) believed that ingestion of lead shot was related to the availability, or lack of availability, of grit, for they stated: "While lead poisoning is widely distributed throughout all sections of this country, evidence seems to indicate that it is more severe in those sections where there is a deficiency of available gravel that may serve as grit in the gizzard of the birds."

Tener (1948:38) believed grit preferences to be a factor influencing shot ingestion by waterfowl. He noted that only fine sand appeared in baldpate and green-winged teal gizzards, and that a large proportion of the gizzards of these species contained no shot. He speculated that lead pellets were too large to be selected as grit by these species.

If waterfowl were prone to pick up lead shot for grit, then it would seem reasonable to expect many species which pick up large-sized grit particles to have ingested more shot pellets than the numbers recorded for them in table 11. Ducks that commonly pick up grit particles that are larger than a No. 6 shot and that show a low incidence of shot are wood duck, bufflehead, and common goldeneye. The gizzards of geese contain quantities of large grit particles, but the incidence of shot among geese is lower than among ducks, table 11.

Table 11.—Incidence of various ingested shot levels among important waterfowl species, as determined from gizzards obtained during fall and early winter months from hunters in many sections of North America, 1938–1953. For each species are given the number and the per cent of ducks represented at each shot level. (By shot level is meant the number of ingested shot pellets found in a gizzard.)

Species	Number of Gizzards Examined	1 Pellet		2 Pellets		3 Pellets		4 Pellets		5 Pellets		6 Pellets		Over 6 Pellets		Total	
		Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent
DUCKS																	
Mallard	17,066	757	4.44	194	1.14	80	0.47	31	0.18	24	0.14	9	0.05	64	0.38	1,159	6.79
Black duck	2,206	120	5.44	27	1.22	15	0.68	6	0.27	1	0.05	3	0.14	11	0.50	183	8.30
Gadwall	1,141	14	1.23	2	0.18	2	0.18	1	0.09	1	0.09	0	0.00	1	0.09	21	1.84
Baldpate	1,577	42	2.66	4	0.25	1	0.06	0	0.00	0	0 00	0	0.00	3	0.19	50	3.17
Pintail	4,530	241	5.32	51	1.13	27	0.60	19	0.42	12	0.26	1	0.02	51	1.13	402	8.87
Green-winged teal	2,272	23	1.01	4	0.18	1	0 04	1	0.04	1	0.04	0	0.00	1	0.04	31	1.36
Blue-winged teal	479	8	1.67	2	0.42	1	0.21	0	0.00	0	0.00	0	0.00	0	0.00	11	2.30
Shoveler	1,439	19	1.32	1	0.07	0	0.00	1	0.07	1	0.07	0	0.00	1	0.07	23	1.60
Wood duck	379	5	1.32	1	0.26	0	0.00	0	0.00	0	0 00	0	0 00	0	0.00	6	1.58
Redhead	597	56	9.38	11	1.84	4	0.67	0	0.00	1	0.17	1	0.17	8	1.34	81	13.57
Ring-necked duck	698	65	9.31	10	1.43	9	1.29	2	0.29	0	0.00	2	0.29	11	1.58	99	14.18
Canvasback	1,216	107	8.80	13	1.07	12	0.99	4	3.29	1	0.08	3	0.25	4	3.29	144	11.84
Lesser scaup	886	67	7.56	19	2.14	12	1.35	3	0.34	0	0.00	1	0.11	14	1.58	116	13.09
Common goldeneye	256	4	1.56	2	0.78	2	0.78	0	0.00	1	0.39	0	0.00	0	0.00	9	3.52
Bufflehead	144	1	0.69	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0 00	1	0.69
Mergansers	137	2	1.46	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0 00	2	1.46
Ruddy duck	388	14	3.61	3	0.77	1	0.26	0	0.00	0	0.00	1	0.26	2	0.52	21	5.41
Subtotal	*35,411*	*1,545*	.....	*344*	.....	*167*	.....	*68*	.....	*43*	.....	*21*	.....	*171*	.....	*2,359*	.....
Subaverage	.....	.....	4.36	.....	0.97	.....	0.47	.....	0.19	.....	0.12	.....	0.06	.....	0 48	.....	6.66
GEESE																	
Canada goose	511	4	0.78	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	4	0.78
American brant	32	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
White-fronted goose	78	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Blue and snow geese	113	1	0.88	1	0.88	1	0.88	0	0.00	0	0.00	0	0.00	0	0.00	3	2.65
Subtotal	*734*	*5*	.....	*1*	.....	*1*	.....	*0*	.....	*0*	.....	*0*	.....	*0*	.....	*7*	.....
Subaverage	.....	.....	0.68	.....	0.14	.....	0.14	.....	0.00	.....	0.00	.....	0.00	.....	0.00	.....	0.95
Total	*36,145*	*1,550*	.....	*345*	.....	*168*	.....	*68*	.....	*43*	.....	*21*	.....	*171*	.....	*2,366*	.....
Average	.....	.....	4.29	.....	0.95	.....	0.46	.....	0.19	.....	0.12	.....	0.06	.....	0.47	.....	6.55

Evidence that the size of grit usually ingested by individuals of a species of water bird is not related to the ingestion of shot by individuals of that species is apparent from a study of the stomach contents of 792 coots (*Fulica americana*). Lead shot was found by Jones (1940:11) in only 12, or 1.5 per cent, of 792 stomachs. Gravel was found in all but 7 of the 792 stomachs and averaged 33 per cent of the gross contents. The low incidence of shot in the stomachs was attributed by Jones to the habit that the coots have of dabbling for food on the surface of the water as well as to their inability to sift through bottom material with their chicken-like bills. Yet it is reasonable to assume that they could pick up shot pellets with their bills as readily as they could pick up grit particles.

Food preferences and feeding habits of the various species of waterfowl appear to be largely responsible for the differences in the incidence of ingested shot among the species. The following discussion of feeding habits tends to support this thesis. Figures in parentheses following the name of a kind of waterfowl indicate the percentage of gizzards in which shot pellets were found, as presented in table 11.

Shovelers (1.60) and green-winged teals (1.36) feed on the surfaces of mud flats and marsh bottoms. Gadwalls (1.84) and baldpates (3.17) feed upon the vegetative parts of aquatic plants and seldom have occasion to dig into the bottom soil where shot pellets are present.

Wood ducks (1.58) feed so extensively on fruits of woodland plants (Martin, Zim, & Nelson 1951:65) that they seldom puddle or sift through lake and marsh bottoms for food. Mergansers (1.46) feed principally on fish and therefore have less occasion to ingest shot than have species which search through bottom materials for food.

Common goldeneyes (3.52) and buffleheads (0.69) are prone to frequent large, open bodies of water, over which there is little shooting, and more than 70 per cent of their food is made up of animal life, especially crustaceans and insect larvae (Cottam 1939:132). These animal organisms are found at or near the surface of the bottom; ducks feeding upon them need not sift bottom material, as do those feeding upon the tubers, rootstocks, and seeds of aquatic plants.

Mallards (6.79) and pintails (8.87) do considerable feeding in grainfields, which may somewhat reduce their exposure to deposited lead shot. However, when feeding in lakes and marshes, they are, for the most part, active in heavily shot-over areas. Moreover, their habit of puddling deep into the bottom soil for seeds exposes them to deposited lead more frequently than other dabbling species, excepting the black duck, which behaves similarly.

Redheads (13.57), ring-necked ducks (14.18), canvasbacks (11.84), and lesser scaups (13.09) normally dive for food in comparatively shallow water in their search for seeds, tubers, and rootstocks of aquatic plants. Plant items, according to Cottam (1939:53), make up 60 to 90 per cent of the food of these ducks. The combined effect of feeding in heavily shot-over waters and the types of food taken result in a higher frequency of ingested shot pellets in this group of diving ducks than in any other group or species of waterfowl.

Regional Variations in Shot Incidence.—The incidence of ingested lead shot among ducks of 11 important species was determined for each of the North American flyways by examination of 39,610 gizzards collected in the fall and early winter months of 1938–1954, table 12.

The incidence of ingested lead was lowest in ducks of the Central Flyway. There were only small differences between the figures for North Dakota, South Dakota, Nebraska, and Colorado; for Texas the incidence of shot was several times as high as that for any other state in the flyway. In the Dakotas, only the shoveler, redhead, and canvasback showed an appreciable incidence of ingested lead, whereas in Texas most species showed a high incidence of such lead.

The incidence of ingested shot pellets was about twice as high among ducks of the Atlantic Flyway as among those of the Central Flyway, table 12. The incidence figures were higher for Massachusetts, North Carolina, and South Carolina and Georgia than for Maine, New York,

a group of other Atlantic states, and Florida. With few exceptions, waterfowl gizzards from the above states came from areas near or on the Atlantic Coast; most samples from New York and Florida were from the interior areas of those states. Species in the Atlantic Flyway with the highest incidence of ingested lead shot were the pintail, canvasback, and redhead. Next in order were the mallard

Table 12.—Regional incidence of ingested lead shot among ducks of 11 important species; the United States and Canada, 1938–1954.

Flyway	Mallard		Black Duck		Gadwall		Baldpate		Pintail	
	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot
Atlantic										
Maine	7	14.3	725	4.8	1	0.0	....	.....	13	15.4
Massachusetts	....	.....	1,268	7.5	....	.....	4	0.0	....	.....
New York	77	6.5	425	4.5	1	0.0	12	0.0	32	12.5
Pennsylvania, New Jersey, Delaware, Maryland, Virginia	59	1.7	207	2.9	14	21.4	5	0.0	13	61.5
North Carolina	....	.....	30	10.0	....	.....	50	4 0	18	0.0
South Carolina and Georgia	77	9.1	66	13.6	95	3.2	38	0.0	56	10.7
Florida	3	0.0	5	0.0	15	0.0	15	13.3	15	20.0
Total	*223*	.....	*2,726*	.....	*126*	.....	*124*	.....	*147*	.....
Average	...	6.3	.....	6.1	.....	4.8	...	3.2	.....	15.7
Mississippi										
Minnesota	371	12.4	9	11.1	18	5.6	23	0.0	102	12.7
Illinois	5,259	7.9	27	18.5	109	0.0	162	0 0	951	5.9
Indiana	247	23.5	93	28.0	13	0.0	17	5.9	34	11.8
Missouri	415	2.4	4	0.0	8	12.5	8	0 0	35	2.9
Tennessee	696	11.6	17	5.9	174	1.2	38	5.3	102	4.9
Arkansas	3,494	7.2	....	.....	....	.....	....	.....	.....	.....
Louisiana	319	15.1	7	0.0	127	2.4	38	2.7	160	28.1
Total	*10,801*	.....	*157*	.....	*449*	.....	*286*	.....	*1,384*	.....
Average	...	8.4	.....	21.0	....	1.6	.....	1.4	.....	9.0
Central										
North Dakota	1,186	1.9	.....	.....	171	0.6	74	1.4	161	0.6
South Dakota	1,123	2.6	.....	.....	9	0.0	13	0.0	26	0.0
Nebraska	1,252	3.1	.....	.....	2	0.0	63	0.0	8	0.0
Colorado	292	2.1	.....	.....	....	.....	....	.....	.....	.....
Texas	65	15.4	.....	.....	18	11.1	25	0.0	51	15.7
Total	*3,918*	.....	.....	.....	*200*	.....	*175*	.....	*246*	.....
Average	....	2.7	.....	.....	....	1.5	....	0.6	.....	3.7
Pacific										
British Columbia	138	17.4	.....	.....	2	0.0	37	0.0	55	16.4
Washington	598	5.0	.....	.....	6	0.0	120	1.7	118	11.0
Oregon	214	4.7	.....	.....	9	0.0	57	7.0	102	7.8
Idaho	502	5.8	.....	.....	....	.....	29	3.5	23	13.0
Utah	1,086	12.5	.....	.....	285	2.1	451	3.8	2,776	7.9
Nevada	30	20.0	.....	.....	22	0.0	7	0.0	25	12.0
California	697	7.4	.....	.....	158	1.3	383	4.7	1,596	9.9
Total	*3,265*	.....	.....	.....	*482*	.....	*1,084*	.....	*4,695*	.....
Average	....	8.8	.....	.....	.....	1.7	....	3.9	....	8.8

and the lesser scaup, the black duck, and the ring-necked duck.

The incidence of ingested shot among ducks of the Pacific Flyway was only slightly higher than that found in the Atlantic Flyway, table 12. Ducks near Vancouver, British Columbia, showed a higher incidence of ingested shot than did those in any other area of the flyway. In contrast, ducks in adjacent Washington

data are from 39,610 gizzards collected during fall and early winter months from hunters in

Green-Winged Teal		Shoveler		Redhead		Ring-Necked Duck		Canvasback		Lesser Scaup		Total Ducks	
Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot
99	3.0	.....	.....	.....	.....	90	3.3	.....	.....	40	7.5	975	4.8
15	6.7	.....	.....	.....	.....	3	0.0	.....	.....	79	2.5	1,369	7.2
55	1.8	.....	.....	66	6.1	9	0.0	27	11.1	213	8.0	917	5.8
38	2.6	.....	.....	2	0.0	2	0.0	5	20.0	4	0.0	349	5.7
33	3.0	.....	.....	68	11.8	4	0.0	93	11.8	5	0.0	301	8.3
42	2.4	8	0.0	.....	.....	61	9.8	1	0.0	5	0.0	449	7.1
12	0.0	5	0.0	.....	.....	25	4.0	2	0.0	6	0.0	103	5.8
294	.....	*13*	.....	*136*	.....	*194*	.....	*128*	.....	*352*	.....	*4,463*	.....
.....	2.7	.....	.....	.....	8.8	.....	5.2	.....	11.7	.....	6.3	.....	6.3
18	0.0	40	2.5	44	15.9	79	29.1	132	4.6	88	12.5	924	11.8
400	0.8	60	0.0	15	13.3	120	17.5	224	7.6	451	11.5	7,778	7.3
17	5.9	12	0.0	7	14.3	50	26.0	16	0.0	20	20.0	526	20.5
56	0.0	9	0.0	8	12.5	20	10.0	3	0.0	32	3.1	598	2.7
63	3.2	18	11.1	4	0.0	266	14.7	31	16.1	95	23.2	1,504	9.3
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	3,494	7.2
157	3.8	13	0.0	.....	.....	70	7.1	7	0.0	107	26.2	1,005	14.0
711	.....	*152*	.....	*78*	.....	*605*	.....	*413*	.....	*793*	.....	*15,829*	.....
.....	1.7	.....	2.0	.....	14.1	.....	17.0	.....	6.8	.....	14.9	.....	8.6
9	0.0	29	0.0	90	7.8	.....	.....	194	5.2	47	2.1	1,961	2.2
19	0.0	18	5.6	20	0.0	5	0.0	13	7.7	33	0.0	1,279	2.4
46	0.0	.....	.....	.....	.....	.....	.....	11	0.0	24	4.2	1,406	2.8
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	292	2.1
11	9.1	7	14.3	194	10.3	25	8.0	4	25.0	30	3.3	430	10.7
85	.....	*54*	.....	*304*	.....	*30*	.....	*222*	.....	*134*	.....	*5,368*	.....
.....	1.2	.....	3.7	.....	8.9	.....	6.7	.....	5.4	.....	2.2	.....	3.1
29	0.0	2	50.0	.....	.....	1	0.0	.....	.....	10	20.0	274	13.1
125	0.0	7	0.0	6	16.7	3	0.0	7	14.3	8	25.0	998	4.9
41	2.4	10	10.0	.....	.....	1	0.0	4	25.0	4	0.0	442	5.7
7	0.0	1	0.0	1	0.0	.....	.....	.....	.....	6	16.7	569	6.0
1,201	0.5	791	1.0	209	23.4	.....	.....	793	11.9	13	7.7	7,605	7.1
25	0.0	46	2.2	4	25.0	1	0.0	6	33.3	1	0.0	167	7.8
281	1.8	650	1.7	54	5.6	.....	.....	61	21.3	15	0.0	3,895	6.7
1,709	.....	*1,307*	.....	*274*	.....	*6*	.....	*871*	.....	*57*	.....	*13,950*	.....
.....	0.7	.....	1.5	.....	19.7	.....	.....	.....	12.7	.....	10.5	.....	6.8

Table 13.—Incidence of ingested lead shot among ducks of 10 species at Hovey Lake, near Mount Vernon, Indiana; the data are from gizzards collected in the waterfowl hunting seasons of 1949, 1950, and 1951.

Species	1949		1950		1951	
	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot
Mallard	90	35.6	56	12.5	61	9.9
Black duck	39	43.6	18	16.7	19	15.8
Gadwall	5	0.0	5	0.0	3	0.0
Baldpate	4	0.0	3	0.0	4	0.0
Pintail	17	5.9	6	0.0	3	0.0
Green-winged teal	7	0.0	3	0.0	2	0.0
Shoveler	2	0.0	2	0.0	7	0.0
Ring-necked duck	15	46.7	16	5.9	10	20.0
Canvasback	4	0.0	6	0.0	5	0.0
Lesser scaup	4	25.0	6	0.0	7	28.6
Total	*187*		*121*		*121*	
Average		31 5		7.1		10.7

showed the lowest incidence of shot for the flyway; gizzards collected from Washington were from numerous areas scattered over the state.

Among the ducks of Utah and Nevada, the incidence of ingested shot was slightly greater than the average for the flyway. Among the ducks of Oregon and Idaho, the incidence figure was below the flyway average. The incidence figure for the ducks of California approximated the flyway average. The data from Utah were obtained from material collected at the Bear River Migratory Bird Refuge; the data from Nevada were obtained largely at the Stillwater Wildlife Management Area. Material from Oregon, Idaho, and California were from numerous, widely distributed areas.

In the Pacific Flyway, the incidence of ingested shot was highest among the redhead, canvasback, and lesser scaup, lower in the mallard and pintail, and still lower in the baldpate, gadwall, shoveler, and green-winged teal.

The incidence of ingested shot was

Table 14.—Incidence of ingested lead shot among ducks of 12 species in Illinois; the data are from gizzards collected in the fall months, 1938–1953, from waterfowl hunters in the Illinois and Mississippi river valleys.

Species	Illinois River			Mississippi River		
	Number Examined	Number With Shot	Per Cent With Shot	Number Examined	Number With Shot	Per Cent With Shot
Mallard	4,784	405	8.47	475	7	1.47
Gadwall	104	0	0.00	5	0	0.00
Baldpate	154	0	0.00	8	0	0.00
Pintail	920	52	5.65	31	4	12.90
Green-winged teal	373	3	0.80	27	0	0.00
Blue-winged teal	121	1	0.83	8	0	0.00
Shoveler	57	0	0.00	3	0	0 00
Wood duck	19	0	0.00	7	0	0.00
Redhead	12	2	16.67	2	0	0.00
Ring-necked duck	113	19	16.81	7	2	28.57
Canvasback	88	10	11.36	136	7	5.15
Lesser scaup	144	34	23.61	307	18	5.86
Total	*6,889*	*526*		*1,016*	*38*	
Average			7.64			3.74

higher among ducks of the Mississippi Flyway than among those of any other flyway, table 12. The highest incidence figure for the Mississippi Flyway was for ducks taken in Indiana; these figures were not typical for the state, as the bulk of the samples on which they were based were from Hovey Lake, near Mount Vernon. Hovey Lake is noted for lead poisoning losses in waterfowl.

The incidence of ingested shot was high among the ducks of Louisiana and Minnesota; moderately high for those of Illinois, Tennessee, and Arkansas; and quite low for those of Missouri.

The gizzard collections from Minnesota, Illinois, and Missouri constituted representative samples for those states. In Tennessee, almost all the data were from Reelfoot Lake. In Arkansas, the gizzards were from ducks shot at clubs within a 35-mile radius of Stuttgart. Both Reelfoot Lake and the Stuttgart area provide a large share of the duck hunting in their respective states. Material from Louisiana was largely from Catahoula Lake and the Delta region of the Mississippi River.

In the Mississippi Flyway, the incidence figure for lead shot was higher in the black duck than in any other species, but the data were biased by the large number of black duck gizzards taken at Hovey Lake, Indiana, where the incidence of lead was extremely high. It was very high in the ring-necked duck, lesser scaup, and redhead; it was moderately high in the pintail, mallard, and canvasback; it was low in the shoveler, green-winged teal, gadwall, and baldpate.

The variation in the proportion of ducks with shot in their gizzards at Hovey Lake was very pronounced over a 3-year period, table 13. In 1949, the highest incidence of ingested shot found anywhere in the United States was recorded at Hovey Lake, but in 1950 and 1951 the figure for the area was close to the average for the Mississippi Flyway.

The extremely high incidence figures for Hovey Lake in 1949 were probably influenced by the hunters' kill of a large number of ducks affected by lead poisoning. Up to the end of the 1949 hunting season, the Indiana Department of Conservation permitted hunters to jump-shoot ducks. Since that time, duck hunting at Hovey Lake has been restricted to blinds. Jump shooters, in wading the brush-covered shore of Hovey Lake, hunted a zone in which ducks suffering from lead poisoning were prone to concentrate. Because the sick ducks had difficulty in flying, hunters bagged unusually large numbers of them.

A reduction in the incidence of ingested lead occurred in the mallard in 1951 at Hovey Lake, evidently because high water, which raised the lake level during the latter part of the hunting season, made lead shot less easily available to this duck. The increased depth failed to reduce the ingestion of shot by diving ducks.

A comparison of the incidence of ingested shot in ducks taken along the Illinois River with those taken along the Mississippi River in Illinois, table 14, disclosed a marked difference between the two areas. The figure for the Illinois River is more than twice that for the Mississippi. The differences in shot incidence between the two areas were especially marked in the mallard, canvasback, and lesser scaup, the only species that were represented by adequate samples in both areas.

The Mississippi River normally carries a much heavier load of sediment than does the Illinois River. Data presented by Suter (1948, plate 1) for the period 1935–1945 showed that the Illinois River at Peoria carried an average of 100 p.p.m. for 300 days per year, whereas the Mississippi River at Quincy carried an average of almost 300 p.p.m. for the same number of days. Apparently lead shot is covered more quickly in the Mississippi, with its heavier load of sediment, than in the Illinois.

Periodic Variations in Shot Incidence.—The incidence of ingested lead shot in mallard populations migrating through the Illinois River valley in autumn was determined for weekly periods by examination of 2,499 gizzards collected from hunters in 1938–1940, table 15.

As in the case of mallards which were live-trapped and fluoroscoped, table 8, the percentage of hunter-killed birds that carried ingested shot was lower early in the season than late; up to mid-November, 5.7 per cent of the gizzards examined con-

tained shot, while after mid-November 7.8 per cent contained shot.

The incidence of shot among hunter-killed birds, table 15, varied from week to week as in live-trapped mallards, table 8. In Minnesota, as in Illinois, a pronounced weekly variation in the incidence of ingested lead has been reported (Reid 1948:126). These periodic variations in the incidence figures appear attributable in part to population shifts associated with migration.

Figures on the occurrence of ingested shot among waterfowl taken during the summer and fall months at or near the Bear River Migratory Bird Refuge, Utah, are given in table 16. Ingestion of shot was uncommon during the summer months, except for the mallard in 1951, but it was relatively common for several species in the fall.

It is evident that much of the lead ingested by ducks in Illinois and in Utah had been fired from hunters' guns in the same year it was picked up by the ducks. Apparently, much of the shot fired by duck hunters during a hunting season penetrates sufficiently deep into lake and marsh bottoms by the following summer to be out of reach of feeding waterfowl.

Data in table 11 and those reported by Shillinger & Cottam (1937:401) permit a comparison of the incidence of ingested lead among waterfowl in two periods separated by more than 20 years. According to Arnold L. Nelson (letter, December 13, 1955), 77 per cent of the gizzards reported on by Shillinger & Cottam were collected in the period 1908–1916; all gizzards represented in table 11 were col-

Table 15.—Periodic incidence of ingested lead shot among mallards in Illinois; the data are from 2,499 gizzards collected from waterfowl hunters in the Illinois River valley, 1938–1940.*

PERIOD	NUMBER OF GIZZARDS EXAMINED	PER CENT WITH SHOT
Oct. 11–17	82	2.44
18–24	227	7.05
25–31	456	3.73
Nov. 1–7	377	8.75
8–14	296	4.73
15–21	455	7.69
22–28	324	9.88
Nov. 29–Dec. 5	216	7.41
Dec. 6–12	66	0.00

*Data from food habits study of Illinois ducks by Harry G. Anderson, June 1, 1939–June 30, 1941, leader of Federal Aid Project 2-R, Illinois Natural History Survey and Illinois Department of Conservation, cooperating.

Table 16.—Incidence of ingested lead shot among ducks of seven species at or near the Bear River Migratory Bird Refuge, Utah, summer and fall, 1950 and 1951. Summer data are based upon fluoroscopy of ducks apparently suffering from botulism; fall data are from duck gizzards collected from hunters.

SPECIES	1950		1951	
	Per Cent With Shot		Per Cent With Shot	
	Summer	Fall	Summer	Fall
Mallard	3.2	15.1	14.3	8.9
Gadwall	0.0	0.7	0.0	2.7
Baldpate	0.0	3.2	0.0	3.9
Pintail	0.6	10.0	0.6	5.8
Green-winged teal	0.0	0.2	0.0	0.2
Shoveler	1.8	0.9	0.0	1.1
Redhead	0.0	21.1	0.0	23.2
Average	0.8	6.7	0.7	5.6

Table 17.—Incidence of ingested lead shot among mallards taken in two different periods of years in the Illinois River valley; data are from gizzards collected from hunters.

YEARS	NUMBER OF GIZZARDS EXAMINED	NUMBER WITH SHOT	PER CENT WITH SHOT
1938–1940	2,371	165	6.96
1948–1950	2,005	240	11.97

lected in the period 1938–1953. The comparison is limited to six species of ducks—mallard, pintail, redhead, ring-necked duck, canvasback, and lesser scaup—which are listed in both periods.

In five of the six species (the exception, lesser scaup), the incidence of ingested shot recorded for the 1938–1953 period, table 11, was much higher than that for the earlier period. The per cent of gizzards containing shot increased for the five species as follows: mallard from 2.41 to 6.79, pintail from 1.14 to 8.87, redhead from 3.14 to 13.57, ring-necked duck from 3.29 to 14.18, and canvasback from 9.77 to 11.84.

Shillinger & Cottam (1937:401) reported lead in 39.42 per cent of the lesser scaup gizzards, but over one-third of their sample was from the vicinity of Marquette, Wisconsin, where shot was found in 76.5 per cent of the gizzards. The large sample from an atypical area materially biased the results.

The incidence of ingested lead among mallards in the Illinois River valley during two different periods—1938–1940 and 1948–1950—is shown in table 17. In a

Table 18.—Incidence of various ingested shot levels found among ducks of seven species; data are from 2,184 duck gizzards (each of which contained ingested lead) collected during the fall and early winter months from hunters in North America, 1938–1954. (By shot level is meant the number of ingested shot pellets found in a gizzard.) For each species are given the number and per cent of ducks represented at each shot level.

Species	1 Pellet		2 Pellets		3 Pellets		4 Pellets		5 Pellets		6 Pellets		Over 6 Pellets		Total	
	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent
Mallard	757	65.3	194	16.7	80	6.9	31	2.7	24	2.1	9	0.8	64	5.5	1,159	100.0
Black duck	120	65.6	27	14.8	15	8.2	6	3.3	1	0.6	3	1.6	11	6.0	183	100.0
Pintail	241	60.0	51	12.7	27	6.7	19	4.7	12	3.0	1	0.2	51	12.7	402	100.0
Redhead	56	69.1	11	13.6	4	4.9	0	0.0	1	1.2	1	1.2	8	9.9	81	100.0
Ring-necked duck	65	65.7	10	10.1	9	9.1	2	2.0	0	0.0	2	2.0	11	11.1	99	100.0
Canvasback	107	74.3	13	9.0	12	8.3	4	2.8	1	0.7	3	2.1	4	2.8	144	100.0
Lesser scaup	67	57.8	19	16.4	12	10.3	3	2.6	0	0.0	1	0.9	14	12.0	116	100.0
Total	*1,413*	....	*325*	....	*159*	....	*65*	....	*39*	....	*20*	....	*163*	....	*2,184*	.....
Average	.....	64.7	....	14.9	....	7.3	....	3.0	....	1.8	....	0.9	....	7.4	.....	100.0

Table 19.—Incidence of high levels of ingested lead shot (20 or more pellets in gizzard) among ducks of seven species; data are from gizzards collected from North American hunters in the autumn and early winter months, 1938–1954.

Species	Number of Gizzards With Pellets	Number of Pellets in Individual Gizzards	Number of Ducks	Per Cent of Gizzards With 20 or More Pellets Each
Mallard	1,159	20, 60, 93, 107, 137	5	0.43
Black duck	183	25	1	0.55
Pintail	402	20, 20, 22, 23, 25, 38, 48, 60, 110	9	2.24
Redhead	81	.....	0	0.00
Ring-necked duck	99	31, 37, 65	3	3.03
Canvasback	144	53	1	0.69
Lesser scaup	116	21, 21, 43, 46, 52, 58, 64, 172	8	6.90
Total	*2,184*	.....	*27*	.....
Average	.....	.....	.....	1.24

decade, the incidence figure for Illinois mallards almost doubled.

Increases in the percentage of waterfowl ingesting lead have paralleled increases in the number of waterfowl hunters. Because there is expectation that the number of duck hunters will continue to increase, it can be anticipated that lead poisoning will become a greater hazard to waterfowl than it is at present.

Incidence of Various Shot Levels. —The incidence of various levels of ingested lead shot found among ducks of seven species in North America in the autumn and early winter months of 1938–1954 is shown in table 18 and fig. 6. (By level of ingested lead shot, or shot level, is meant the number of ingested shot pellets found in a gizzard.) The various shot levels have an important bearing on the rate of mortality in ducks for, as will be shown later, the larger the number of ingested shot pellets per duck, the higher is the death rate, other factors being equal.

Of 2,184 duck gizzards that contained lead when collected from hunters in many parts of North America in 1938–1954, 64.7 per cent contained one pellet each, table 18; 14.9 per cent contained two pellets each. Only 7.4 per cent of the gizzards containing shot pellets contained more than six pellets each.

Comparatively few ducks killed by North American hunters during the fall months in the period 1938–1954 carried 20 or more ingested shot pellets each, table 19. The maximum number of pellets recorded was 172, in a lesser scaup gizzard. Cottam (1939:39) reported 1 to 58 pellets in individual gizzards of lesser scaups shot near Marquette, Wisconsin, in April, 1909; Shillinger & Cottam (1937:403) reported that 179 pellets were found in the gizzard of a pintail victim of lead poisoning.

Data in table 19 indicate that pintails, ring-necked ducks, and lesser scaup ducks are more likely to have large numbers of pellets per gizzard than are the ducks of other species.

The large numbers of shot pellets found in gizzards of pintails, ring-necks, and lesser scaups are probably a reflection of the ability of these species to tolerate the toxic effects of lead, as well as a reflection

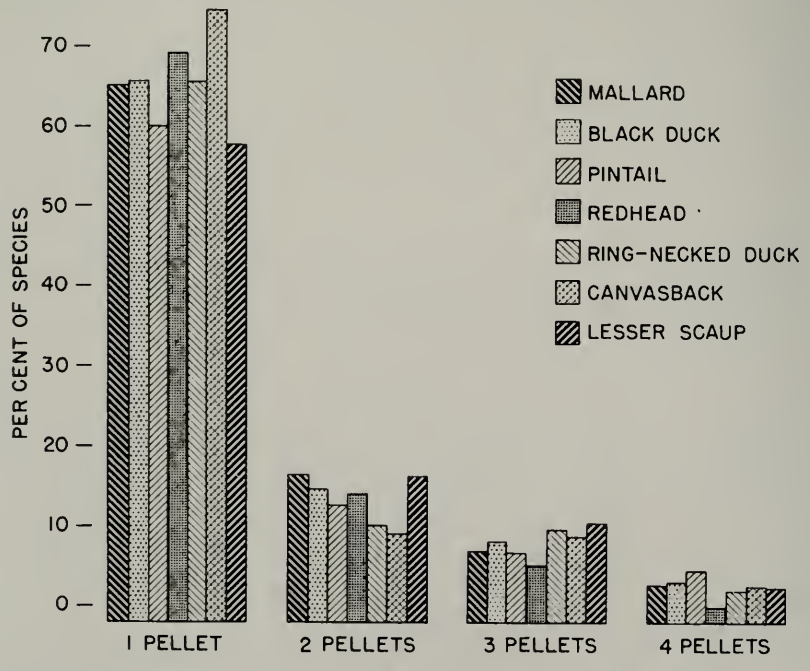

Fig. 6.—Incidence of four levels of ingested shot found in gizzards of ducks of seven species in the autumn and early winter months of 1938–1954. Data are from table 18 and represent ducks shot by hunters in many parts of North America.

of their proclivity to pick up large numbers of pellets. For example, pintails are only slightly more prone than mallards to ingest shot, table 11, but the percentage of gizzards containing 20 or more shot pellets each was almost six times as great in pintails as in mallards, table 19. The percentage of gizzards containing ingested shot was about the same in redheads, ring-necked ducks, canvasbacks, and lesser scaups, table 11, but larger percentages of gizzards with 20 or more shot pellets each were found among the ring-necked ducks and scaups.

As shown by Jordan & Bellrose (1951: 18), the ability of ducks to survive lead poisoning is influenced by the physical form of the food consumed. The higher survival rate of pintails than of mallards may be related to the greater numbers of small seeds and the paucity of corn in the diet of the pintails. Lesser scaups, which consume at least twice as much animal life per bird as any other ducks listed in table 19 (Cottam 1939:53), apparently can tolerate lead to a greater degree than the ducks of other species. Thus, it appears that animal matter is more favorable than vegetable matter to survival of ducks that have ingested lead, and that various forms of vegetable matter differ greatly in their effects on birds that have ingested lead, fig. 7.

LEAD IN WILD MALLARDS DOSED AND RELEASED

Certain effects of lead poisoning on mallards in the wild were determined by the following experiment. In the autumns of 1949, 1950, and 1951, several thousand migrating mallards were trapped at Lake Chautauqua. Some of these ducks were dosed with either one, two, or four No. 6 shot pellets each, then banded, and released. Other ducks trapped at the same time were banded and released, undosed, to serve as controls.

In 1949 and 1950, the trapped mallards were taken to the Havana field laboratory of the Illinois Natural History Survey, where they were fluoroscoped before being banded and released. Ducks known to carry ingested lead when trapped were not included in the experiment. In 1951, when the X-ray unit was being repaired and could not be used for fluoroscopy, undoubtedly some ducks carrying ingested lead when trapped were released as dosed or control birds. The number of these was, of course, unknown but it was probably relatively small.

In 1949, only adult mallard drakes were included in the experiment. In 1950 and 1951, both adult and juvenile drakes and, in 1951, hens also were included in the experiment.

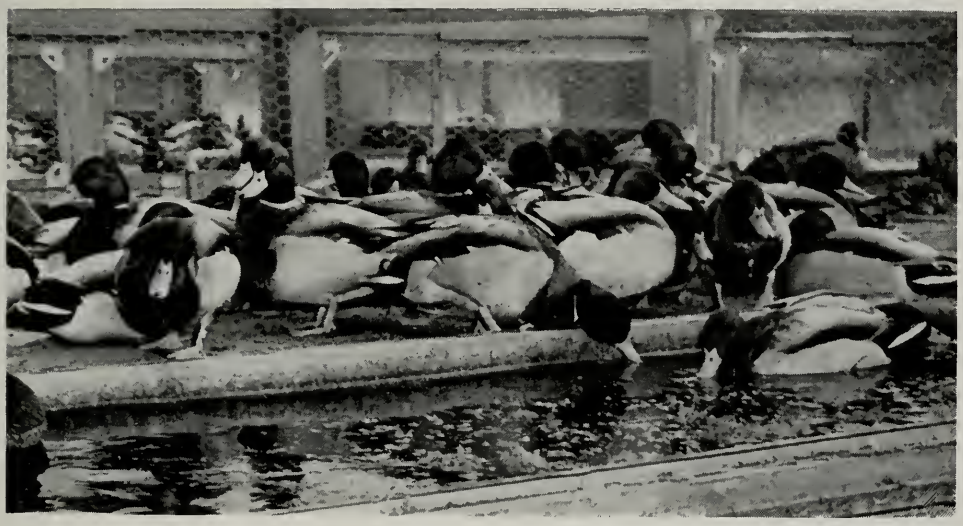

Fig. 7.—Penned mallards, dosed with lead shot, feeding upon coontail, apparently one of the best vegetable foods for alleviating the effects of ingested lead.

In 1949, 559 mallards were dosed with one No. 6 shot pellet each before being released, and 560 lead-free birds were released, undosed, to serve as controls. Of the 1,172 mallards used in the experiment in 1950, 391 were dosed with one No. 6 pellet each, 392 were dosed with two No. 6 pellets each, and 389 were released, undosed, to serve as controls. In 1951, 2,016 mallards were used as follows: 504 drakes were dosed with one No. 6 pellet each, 504 drakes were dosed with four No. 6 pellets each, 501 hens were dosed with one No. 6 pellet each, and 507 drakes were undosed.

Because of the considerable cost of handling the mallards used in this experiment, it was deemed advisable to obtain reports of as many band recoveries as possible from the hunters who shot the birds. As an inducement to hunters to report bands, 759 ducks released in 1949 were banded with U. S. Fish and Wildlife Service reward bands (which provided a certificate and booklet for each person returning one or more bands); 360 were marked with standard Fish and Wildlife Service bands. In 1950 and 1951, each mallard in the experiment was banded with a special $2.00 reward band, as well as the standard U. S. Fish and Wildlife Service band. The ratio of reward to standard bands recovered was more than 2 to 1 (Bellrose 1955).

Bands recovered from the mallards used in the experiment revealed significant differences between the dosed and the control birds. The dosed birds, some of which became afflicted with lead poisoning, had (1) a greater vulnerability to hunting, (2) lower ability to migrate, and (3) higher over-all mortality rates in the first year after being banded and released (from time of banding through the following August).

Effect of Lead on Vulnerability to Hunting

That mallards carrying lead in their gizzards were more vulnerable to hunting than were lead-free mallards is shown in tables 20–23. In 1949, mallards dosed with one No. 6 shot pellet each were 1.84 times as vulnerable to hunting as were the controls, table 20. In 1950, they were 1.19 times as vulnerable, and, in 1951, they were 1.41 times as vulnerable. The year-to-year variation in vulnerability probably resulted from differences in food and weather conditions.

Unfortunately, the effect of two and of four No. 6 shot pellets for each bird was evaluated for only 1 year. In 1950, the kill rate of mallards dosed with two No. 6 shot pellets each was 1.89 times as great as the kill rate among the controls, table 20. A year later, the kill rate among mallards dosed with four shot pellets each was 2.12 times as great as the kill rate among ducks not dosed with shot.

During the first 5 days after the mallards in the experiment were released,

Table 20.—Relative hunting vulnerability exhibited by wild drake mallards dosed with lead and those not dosed, as measured by the ratio between dosed and undosed birds in the per cent of the banded ducks that were recovered in the season of banding. The 3,807 drakes used in the experiment were trapped at the Chautauqua National Wildlife Refuge, near Havana, Illinois, in the hunting seasons of 1949–1951. Some of the birds were banded, dosed with one, two, or four No. 6 lead shot pellets each, and released. Others, the controls, were banded and released undosed.

Year	Number Banded				Number Recovered				Per Cent Recovered				Relative Vulnerability Dosed : Control		
	Controls	Pellet Dose			Controls	Pellet Dose			Controls	Pellet Dose					
		1	2	4		1	2	4		1	2	4	1 Pellet	2 Pellets	4 Pellets
1949	560	559	. . .	. .	19	35	. .	. .	3.39	6.25	. . . .	. . . .	1.84:1.00	. . . . .	. . . . .
1950	389	391	392	. .	50	60	95	. .	12.85	15.35	24.23	. . . .	1.19:1.00	1.89:1.00	. . . . .
1951	507	504	.	504	47	66		99	9.27	13.10	. .	19.64	1.41:1.00	. . . . .	2.12:1.00
Total	*1,456*	*1,455*	*392*	*504*	*116*	*161*	*95*	*99*	. . .	. . .	. .	. . .	. . . . .	. . . . .	. . . . .

the birds treated with lead were bagged at about the same rate as the untreated controls, tables 21–23. During the subsequent 6–10-day period, there was a pronounced increase in the bag of treated ducks, especially in those dosed with two or four shot pellets each.

In the dosed wild mallards, the ingestion of lead shot did not appear to affect behavior until after the first 5 days. In the mallards that were dosed with one shot pellet each, and that did not die of lead poisoning, the behavior appeared to be most severely affected in the 6–15-day period after ingestion; in mallards that were dosed with two or four shot pellets each, and that survived, the period in which behavior was severely affected appeared to be longer. The data suggest that most wild mallards that become affected by lead poisoning during the hunting season either die in the second or third week following ingestion of shot or they begin their recovery by the early part of the fourth week.

Penned wild mallards that were dosed with lead exhibited weakness and fatigue during the second and third weeks after being dosed; these symptoms increased in severity during the third and fourth weeks (Jordan & Bellrose 1951:5–6). The keel bone became prominent, and often the

Table 21.—Relative hunting vulnerability exhibited by wild drake mallards dosed with one No. 6 lead shot pellet each and those not dosed, as measured by band recoveries in each of six periods, fall and early winter, 1949–50. The data are for birds trapped, banded, and released at the Chautauqua National Wildlife Refuge in the fall months of 1949; 559 of the birds were dosed and 560 were not dosed.

Days After Dosage	0 Pellet		1 Pellet		Total	
	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period
0–5	5	45.5	6	54.5	11	100.0
6–10	2	28.6	5	71.4	7	100.0
11–15	1	11.1	8	88.9	9	100.0
16–20	4	57.1	3	42.9	7	100.0
21–25	2	50.0	2	50.0	4	100.0
26–60	5	45.5	6	54.5	11	100.0
Total	*19*		*30*		*49*	

Table 22.—Relative hunting vulnerability exhibited by wild drake mallards dosed with one or with two No. 6 lead shot pellets each and those not dosed, as measured by band recoveries in each of six periods, fall and early winter, 1950–51. The data are for birds trapped, banded, and released at the Chautauqua National Wildlife Refuge in the fall months of 1950; 391 were dosed with one pellet each, 392 were dosed with two pellets each, and 389 were not dosed.

Days After Dosage	0 Pellet		1 Pellet		2 Pellets		Total	
	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period
0–5	8	38.1	6	28.6	7	33.3	21	100.0
6–10	3	13.0	8	34.8	12	52.2	23	100.0
11–15	7	21.9	8	25.0	17	53.1	32	100.0
16–20	6	22.2	5	18.5	16	59.3	27	100.0
21–25	4	36.4	3	27.2	4	36.4	11	100.0
26–60	5	33.3	7	46.7	3	20.0	15	100.0
Total	*33*		*37*		*59*		*129*	

Table 23.—Relative hunting vulnerability exhibited by wild drake mallards dosed with one or with four No. 6 lead shot pellets each and those not dosed, as measured by band recoveries in each of six periods, fall and early winter, 1951–52. The data are for birds trapped, banded, and released at the Chautauqua National Wildlife Refuge in the fall months of 1951; 504 were dosed with one pellet each, 504 were dosed with four pellets each, and 507 were not dosed.

Days After Dosage	0 Pellet		1 Pellet		4 Pellets		Total	
	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period
0-5	9	29.0	11	35.5	11	35.5	31	100.0
6-10	4	11.4	9	25.7	22	62.9	35	100.0
11-15	7	16.3	10	23.3	26	60.5	43	100.0
16-20	6	22.2	8	29.7	13	48.1	27	100.0
21-25	4	30.8	6	46.2	3	23.1	13	100.0
26-60	7	25.0	11	39.3	10	35.7	28	100.0
Total	*37*	.....	*55*	.....	*85*	.....	*177*	.....

wings of an affected duck assumed a "roof-shaped" or drooping appearance.

Symptoms typical of those found during the fourth week in penned birds appear in wild ducks mainly at times of severe die-offs. Apparently, at other times, affected ducks either recover or are taken by hunters or predators in a shorter period of time and in a less extreme state of emaciation.

Effect of Lead on Migration Rate

That lead poisoning has a pronounced effect upon the migration of ducks is indicated by differences in miles traveled by groups of mallards undosed and by similar groups of mallards dosed with one, two, or four No. 6 shot pellets each, tables 24–26. In 1949, a group of mallards dosed with one shot pellet each had a larger percentage of its bands recovered within a 50-mile radius of the banding station than had the undosed control group, table 24. In 1950, a group of mallards dosed with one pellet each had a somewhat smaller percentage of its bands recovered within the 50-mile zone than had the controls, but a group of mallards

Table 24.—Effect of ingested lead shot on migration of mallards, as measured by distances traveled by dosed and by undosed birds before they were shot by hunters. The data are for birds trapped and released at the Chautauqua National Wildlife refuge in the fall months of 1949; 559 of the birds were dosed with one No. 6 shot pellet each and 560 were not dosed. Figures show for dosed and for undosed ducks the per cent of recovered bands (those recovered in year of banding and for which distance data are available) that were recovered at various distances from the point of banding and release.

Miles From Place of Banding	0 Pellet		1 Pellet	
	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period
0–50	11	55.0	21	60.0
51–100	1	5.0	1	2.9
101–150	0	0.0	0	0.0
151–200	4	20.0	1	2.9
201–300	3	15.0	5	14.3
301–400	1	5.0	7	20.0
401 and over	0	0.0	0	0.0
Total	*20*	*100.0*	*35*	*100.1*

dosed with two pellets each had a much larger percentage of its recoveries fall within the 50-mile zone than had the control group, table 25. In 1951, one shot pellet for each bird seemed to have little effect on migration, but four pellets for each bird greatly retarded migration. Less than 5 per cent of the bands recovered from the mallards dosed with four pellets each were taken farther than 50 miles from the banding station, table 26.

Manifestly, the weakness and fatigue associated with lead poisoning reduces the movement of ducks. The larger the amount of ingested lead per bird, the greater is apt to be the reduction of movement by the affected segment of the population. In areas where lead poisoning is of outbreak proportions, it is reasonable to conclude that the bulk of the sick birds have picked up shot within their daily feeding radius, usually less than 50 miles. Conversely, it can be assumed that only a small percentage of the ducks that have

Table 25.—Effect of ingested lead shot on migration of mallards, as measured by distances traveled by dosed and by undosed birds before they were shot by hunters. The data are for birds trapped and released at the Chautauqua National Wildlife Refuge in the fall months of 1950; 391 of the birds were dosed with one No. 6 shot pellet each, 392 were dosed with two pellets each, and 389 were not dosed. Figures show for dosed and for undosed ducks the per cent of recovered bands (those recovered in year of banding and for which distance data are available) that were recovered at various distances from the point of banding and release.

Miles From Place of Banding	0 Pellet		1 Pellet		2 Pellets	
	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period
0–50	14	58.3	16	53 3	33	76.7
51–100	1	4.2	0	0.0	1	2.3
101–150	0	0 0	0	0.0	1	2.3
151–200	1	4.2	0	0 0	0	0.0
201–300	1	4.2	3	10.0	5	11.6
301–400	7	29.2	11	36.7	3	7.0
401 and over	0	0.0	0	0.0	0	0.0
Total	*24*	*100 1*	*30*	*100 0*	*43*	*99 9*

Table 26.—Effect of ingested lead shot on migration of mallards, as measured by distances traveled by dosed and by undosed birds before they were shot by hunters. The data are for birds trapped and released at the Chautauqua National Wildlife Refuge in the fall months of 1951; 504 of the birds were dosed with one No. 6 shot pellet each, 504 were dosed with four pellets each, and 507 were not dosed. Figures show for dosed and for undosed ducks the per cent of recovered bands (those recovered in year of banding and for which distance data are available) that were recovered at various distances from the point of banding and release.

Miles From Place of Banding	0 Pellet		1 Pellet		4 Pellets	
	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period
0–50	36	69.2	51	67.1	94	95.9
51–100	4	7.7	7	9.2	0	0.0
101–150	0	0 0	1	1 3	1	1.0
151–200	2	3.9	4	5.3	0	0 0
201–300	4	7.7	7	9.2	1	1.0
301–400	6	11.5	4	5.3	1	1.0
401 and over	0	0 0	2	2.6	1	1.0
Total	*52*	*100 0*	*76*	*100.0*	*98*	*99.9*

become ill from lead poisoning have migrated farther than 50 miles from where they ingested shot.

Effect of Lead on Year-of-Banding Mortality Rate

The mortality rates of the dosed and the undosed mallards in the year of banding or the first year (to end of following August) after being banded and released are indicated by data in table 27. Each

1950:8–12) as to have only a minor effect upon the mortality rates.

Most of the year-of-banding mortality rates for the undosed, or control, groups in the experiment were lower than even the lowest of the year-of-banding mortality rates for mallards reported by Bellrose & Chase (1950:8–12). In the Bellrose & Chase study, a correction factor was used for bandings made during the hunting season, and mortality rates were

Table 27.—The year-of-banding mortality rates of wild, free-flying mallards undosed and of similar mallards dosed with one, two, or four No. 6 lead shot pellets each. The data are for mallards trapped, banded, and released at the Chautauqua National Wildlife Refuge near Havana, Illinois. The mortality rates were derived as explained in the section entitled "Effect of Lead on Year-of-Banding Mortality Rate."

Year of Banding	Sex of Duck*	Age of Duck†	Shot Dose	Number of Ducks Banded	Band Recoveries in Year of Banding		Band Recoveries First 4 Years After Banding		Mortality Rate (Per Cent)	
					Number	Per Cent	Number	Per Cent	Year of Banding	Difference Between Dosed and Undosed Ducks
1949 ...	M	A	0	560	19	3 39	143	25.53	13.3	.....
	M	A	1	559	35	6.26	155	27.73	22.6	9.3
1950....	M	A	0	278	33	11.87	106	38.13	31.1	.....
	M	A	1	274	45	16.42	103	37.59	43.7	12.6
	M	A	2	277	74	26.71	99	35.74	74.7	43.6
	M	J	0	111	17	15.32	43	38 74	39.5	.....
	M	J	1	117	15	12.82	35	29.91	42.9	3.4
	M	J	2	115	21	18.26	49	42.61	42.9	3 4
1951....	M	A	0	300	24	8.00	77	25.67	31 2	.....
	M	A	1	324	42	12 96	91	28.09	46.2	15.0
	M	A	4	284	58	20.42	80	28.17	72 5	41.3
	M	J	0	207	23	11.11	73	35.27	31.5	.....
	M	J	1	180	24	13.33	66	36.67	36.4	4.9
	M	J	4	220	41	18.64	65	29.55	63.1	31 6
1939–1943‡	F	?	0	7,897	390	4.94	1,094	13 85	35.6	.....
1951....	F	?	1	501	87	17.37	151	30.14	57.6	22.0

*M = male; F = female.
†A = adult; J = juvenile.
‡No control hens were available at time of 1951 experiment; so recoveries for the first 4 years from bandings of hen mallards at the Chautauqua National Wildlife Refuge, 1939–1943, were used for the control data.

mortality rate was derived by comparing the shrinkage in the population in the year of banding (as measured by year-of-banding band recoveries) to the population at the time of banding (as measured by the total band recoveries at the end of the fourth year after banding). For example, the mortality rate for adult undosed males released in 1949 was found by dividing 19 by 143, table 27. Although not all mallards of a banded group are dead by the end of the fourth year after being banded, the proportion of the group alive is so small (Bellrose & Chase calculated from the corrected percentages, rather than the numbers, of bands recovered.

In each year and in each sex and age class for which data were collected, the mallards dosed with lead shot had a higher mortality rate during the year of banding than the control, or undosed, mallards, table 27.

For adult drake mallards dosed with one shot pellet each, in 1949, 1950, and 1951, the year-of-banding mortality rates were 9.3, 12.6, and 15.0 per cent, respectively, greater than the mortality rates for

the controls. Adult drake mallards dosed with two shot pellets each in 1950 had a year-of-banding mortality rate that was 43.6 per cent greater than that of drakes of the same age class used as controls in the same year. Adult drakes dosed with four pellets each in 1951 had a year-of-banding mortality rate that was slightly, and unaccountably, lower than that of birds of the same sex and age class dosed with two pellets each in 1950.

Juvenile drake mallards in 1950 and 1951 had lower year-of-banding mortality rates than those of adult drakes dosed with the same number of pellets each. One group of juvenile drakes dosed with one shot pellet each and another group dosed with two shot pellets each in 1950 had year-of-banding mortality rates only 3.4 per cent greater than the rate for the controls. Juvenile drakes dosed with four pellets each in 1951 had a mortality rate that was 31.6 per cent greater than that of the juvenile controls but 9.4 per cent less than that of adult drakes dosed with the same number of pellets each in the same year.

Because in 1951 no mallard hens were banded and released to serve as controls for 501 hens dosed in that year with one shot pellet each, no comparison of band recovery rates could be made between dosed and undosed females released in the same year. However, band recovery figures were available for 7,897 undosed mallard hens banded and released in the period 1939–1943. The year-of-banding band recovery rate for the hens dosed, banded, and released in 1951 was 22.0 per cent greater than the recovery rate for the undosed hens banded and released in 1939–1943.

At the Rocky Mountain Arsenal, near Denver, Colorado, wild mallards were banded, dosed with lead shot, and released in late winter months, 1950 and 1951, by Johnson A. Neff and Charles C. Sperry of the U. S. Fish and Wildlife Service and Irving R. Poley of the Colorado Department of Game and Fish, table 28. Band data for 1951 were not used because, as Neff (letter, February 5, 1955) reported, a chemical pollution of the water may have caused mortality which would bias subsequent band recoveries.

Wild mallards were caught in the late winter months of 1950 and divided into two groups, each consisting of 200 drakes and 125 hens that at the time of capture were free of lead in their gizzards, as determined from fluoroscopy. The ducks were banded, those in one group were dosed with six No. 6 lead shot pellets each, and all were immediately released. The difference in band recoveries between the control and the dosed groups from the 1950 hunting season through the 1954 season provided an index to the magnitude of mortality caused by the ingestion of six No. 6 shot pellets per duck, table 28.

If there had been no mortality from lead poisoning among the dosed mallards, the number of band recoveries in the subsequent hunting seasons would have been similar for the dosed and the undosed groups. The fact that there were almost three times as many band recoveries in subsequent hunting seasons from the undosed drakes as from the dosed drakes, table 28, suggests that the mortality ratio

Table 28.—Number and per cent of bands recovered, 1950–1954, from mallards trapped, banded, and released at the Rocky Mountain Arsenal, Denver, Colorado, February 13–March 21, 1950. Before release, half of the males and half of the females were dosed with six No. 6 shot pellets each, and the others were released, undosed, to serve as controls.*

Sex	Shot Dose	Number of Ducks Banded	Number of Bands Recovered	Per Cent of Bands Recovered
Male	0	200	56	28.0
Male	6	200	19	9.5
Female	0	125	13	10.4
Female	6	125	12	9.6

* Experiments conducted by Johnson A. Neff and Charles C. Sperry of the U. S. Fish and Wildlife Service and Irving R. Poley of the Colorado Department of Game and Fish.

between drakes that ingest six lead pellets each and those that ingest no lead is approximately 3 to 1. The difference in band recoveries between undosed and dosed hens was so slight as to indicate little mortality from lead poisoning.

An apparent reason for the large difference in the mortality rates between the Colorado drakes and hens is that in late winter and early spring hens are less susceptible than drakes to lead poisoning. Illinois experiments made with captive mallards under controlled conditions showed that during the spring hens are less susceptible to lead poisoning than are drakes (Jordan & Bellrose 1951:21). With the approach of the breeding season, the consumption of food by captive hens greatly increased until it exceeded that by captive drakes. Apparently the greater food consumption by hens during this particular period was the primary factor responsible for the greater survival rate of the Colorado hens. Illinois data suggest that, during the fall, hen mallards are much more susceptible than drakes to lead poisoning. The year-of-banding mortality rate for wild, free-flying mallard hens dosed with one No. 6 lead pellet each was about one-fourth greater than the highest year-of-banding mortality rate for mallard drakes similarly dosed, table 27. Among penned mallards, the mortality rate of hens was approximately double the mortality rate of drakes except in spring (Jordan & Bellrose 1951:21).

As shown by differences in mortality rates between dosed and undosed birds, at each shot level tested juvenile drakes were much less susceptible to lead poisoning than were adult drakes, table 27. The lower susceptibility of the juveniles was more marked at the one- and two-shot levels than at the four-shot level. The greater food intake by juveniles seems to account for their lower susceptibility (Jordan & Bellrose 1951:20).

There is good evidence that the drake class of the mallard population is composed almost equally of adults and juveniles. The following mortality rates have been calculated on the assumption that the numbers of adults and juveniles are equal and that the percentages on which the rates are based (in farthest right column of table 27) hold true throughout the populations: In mallard drakes, one No. 6 shot pellet per bird produces an increase in the mortality rate of about 9 per cent (12.6 and 3.4, 15.0 and 4.9 averaged); two pellets about 23 per cent (43.6 and 3.4 averaged); four pellets about 36 per cent; and six pellets about 50 per cent.

Because of the smaller number of experiments conducted with hens than with drakes, it is more difficult to appraise mortality from lead poisoning in the hens. However, the available data suggest that, among hens and drakes with identical ingested shot levels, hens probably suffer twice as great a mortality as drakes in the fall and a small fraction of the mortality of drakes in late winter and spring.

PREVENTING LEAD POISONING

When Green & Dowdell (1936) reported on the apparent feasibility of a lead-magnesium alloy shot for the prevention of lead poisoning in waterfowl, conservationists anticipated the eventual development of this or some other shot that would prove to be nontoxic to waterfowl and acceptable to hunters. However, no shot (with the possible exception of iron shot) has been developed which meets the requirements of both nontoxicity to waterfowl and present shooting standards.

A study of shot alloys by Jordan & Bellrose (1950) at the Havana laboratory of the Illinois Natural History Survey did not substantiate the findings of Green & Dowdell (1936:487–8) that lead-magnesium shot, upon its disintegration in the gizzard of a duck, fig. 8, did not cause lead poisoning. On the contrary, Jordan & Bellrose (1950:166–7) found that lead-magnesium shot, in spite of its disintegration in the gizzard, was as toxic as commercial lead shot.

Two other types of lead alloy shot tested by Jordan & Bellrose (1950: 165–7), lead-tin-phosphorus shot and lead-calcium shot, were not less toxic than commercial shot.

A proposal to coat commercial shot pellets with a nylon plastic was investigated. Theoretically, at least, pellets so coated would have a good opportunity to pass out of the gizzard before the plastic was abraded away and the lead exposed. It

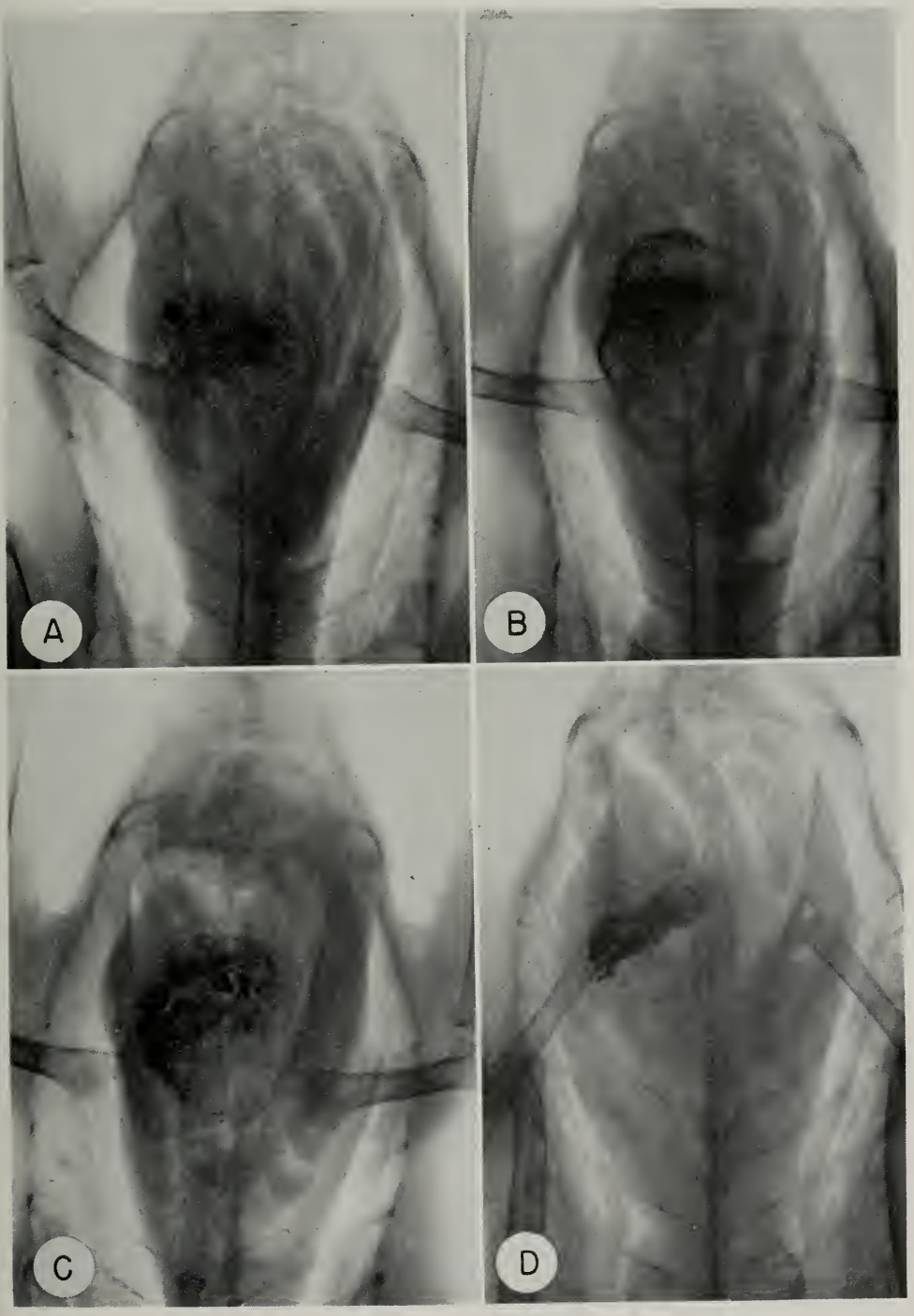

Fig. 8.—The breakup of three lead alloy shot pellets containing magnesium (2 per cent) in the gizzard of a mallard; *A*, 1 hour after ingestion; *B*, 24 hours after ingestion; *C*, 96 hours after ingestion; *D*, 144 hours after ingestion. As shown in *D*, the gizzard has failed to expel a large proportion of the lead particles. Despite its disintegration in the gizzard, the lead alloy shot containing magnesium was as toxic as commercial lead shot.

Table 29.—Relative effectiveness of iron shot and commercial lead shot as measured by the per cent of sample (game-farm mallards) bagged with No. 4 and No. 6 shot fired from 12-gauge full-choke gun at each of four ranges, 1950 and 1951.

Range in Yards	Iron Shot				Lead Shot			
	No. 4		No. 6		No. 4		No. 6	
	Number in Sample	Per Cent Bagged	Number in Sample	Per Cent Bagged	Number in Sample	Per Cent Bagged	Number in Sample	Per Cent Bagged
35	6	100	6	100	10	100	10	100
40	20	90	20	90	20	100	20	90
50	20	75	20	55	24	88	28	79
60	20	45	8	12	20	70	18	22

was found, through administering pellets of nylon plastic to mallards at the Havana laboratory, that this material was very resistant to abrasion. However, efforts to coat shot pellets with nylon plastic were unsuccessful. Metallurgists of the Winchester-Western Cartridge Division of the Olin Mathieson Chemical Corporation were unable to coat commercial lead shot with nylon plastic because the spread between the melting point of lead and the congealing point of the nylon plastic was too small.

Several metals generally regarded as being nontoxic to waterfowl were considered as substitutes for lead. Domestic availability, price, physical and mechanical properties, and corrosion resistance were the judgment criteria. Of all the metals considered, iron was the only one available in sufficient quantity and low enough in price to warrant further investigation. From the standpoint of properties alone (excluding availability and price), there are metals that would make as good or even better shot pellets. Gold is an extreme example. It is soft, nontoxic, noncorrosive, and heavier than lead. However, its price and lack of availability immediately rule it out.

Pellets made from an iron alloy were tested at the Illinois Natural History Survey Havana laboratory for toxicity to waterfowl. Penned wild mallards were dosed, each with 10 No. 6 iron pellets. The ducks showed no ill effects as a result of the ingestion of iron.

The Winchester-Western Cartridge Division expended considerable time and effort in the development of a satisfactory shot of iron alloy. Early difficulties in making true spheres, excessive abrasion

Table 30.—Relative effectiveness of iron shot and commercial lead shot as measured by the average number of No. 4 and No. 6 pellets that hit the trunks of game-farm mallards, and the per cent of pellets hitting the trunks that penetrated to the trunk cavities, at each of four ranges, 1950 and 1951. The shot was fired from a 12-gauge full-choke gun.

Range in Yards	Iron Shot				Lead Shot			
	No. 4		No. 6		No. 4		No. 6	
	Average Number of Trunk Hits	Per Cent of Trunk Hits Penetrating to Trunk Cavities	Average Number of Trunk Hits	Per Cent of Trunk Hits Penetrating to Trunk Cavities	Average Number of Trunk Hits	Per Cent of Trunk Hits Penetrating to Trunk Cavities	Average Number of Trunk Hits	Per Cent of Trunk Hits Penetrating to Trunk Cavities
35	8 3	60	16.2	43	6 6	65	11.6	47
40	6.8	39	11 8	27	5.7	68	8 8	41
50	3 9	21	4.9	17	3 2	59	5.2	33
60	2 4	17	1.9	2	2 5	48	3.4	18

of gun barrels, and range limitations were for the most part overcome. A special shooting process (Patent No. 2,544,678) was developed. By repeated annealing in furnaces with controlled atmospheres, the iron alloy was substantially reduced in hardness. Many thousands of shot shells fired with iron shot loads showed that soft iron had little, if any, adverse effect on modern gun barrels and adjustable chokes.

One of the principal disadvantages of using iron shot for shot shell loads is that its lower density reduces its effectiveness at maximum ranges. In 1950 and 1951, the relative killing power of iron shot and of lead shot was investigated by shooting game-farm mallards under controlled conditions (Bellrose 1953:353–5).

No. 4 and No. 6 shot were used at ranges of 35, 40, 50, and 60 yards, table 29. Iron shot and lead shot fired from a 12-gauge, full-choke gun showed no difference in killing power at 35 yards, but iron shot declined in relative effectiveness as the ranges increased.

At ranges of 35 and 40 yards, the number of pellets hitting the trunks of ducks averaged higher for iron shot than for lead shot, table 30. For comparable ranges and shot sizes, the percentage of pellets hitting the trunks that penetrated to the body cavities was greater for lead shot.

The greater number of hits registered on game-farm ducks by iron shot than by lead shot at the short ranges can be explained by the larger load of iron pellets in each shot shell. Because of the lower density of iron, more iron pellets than lead pellets of the same size can be loaded in a shot shell having the same powder charge. A standard 12-gauge duck load contains about 169 No. 4 lead pellets; such a load would contain about 250 iron pellets. Because the impact potential of shot at long range increases with increases in size of shot, some compensation can be made for the relative decline in killing power of iron shot at long range by using iron shot one size larger than that customarily used in lead shot, that is, No. 4 instead of No. 5 in a given situation.

There are no insurmountable obstacles to the use of iron shot for waterfowl hunting. The conclusion which Winchester-Western drew from extensive research was that an iron shot acceptable for most shot shell requirements could be produced. However, the required manufacturing investment would be large, and this factor, coupled with uncertainty concerning customer acceptance, convinced Winchester-Western that manufacture of iron shot was not feasible unless drastic action was needed to save waterfowl from serious lead poisoning losses.

If drastic action should at any time be necessary, the U. S. Fish and Wildlife Service could require waterfowl hunters to shoot only shells containing iron shot; shells with such a load could be so marked that inspection by conservation officers would insure compliance with regulations.

DISCUSSION

The incidence of ingested lead shot in the segment of a duck population harvested by waterfowlers is not representative of the entire population nor the entire year. It is representative of only a part of the population (the segment harvested) and a short period of time (the time of sampling).

The percentage of ducks that have ingested shot at some time during the year, or during the period in which most ingestion of shot occurs, may be calculated through application of correction factors that take into account (1) the fact that ducks carrying lead are more vulnerable to hunting than are lead-free ducks and (2) the fact that most ducks ingesting lead either void the lead or die of poisoning within about 4 weeks.

As shown by experiments in which wild mallards were trapped, banded, and released, some dosed with lead and others not dosed, the birds dosed with one No. 6 shot pellet each were about 1.5 times (1.19–1.84, table 20) as vulnerable to hunting as were the controls; those dosed with two pellets each were 1.89 times as vulnerable as the controls; and those dosed with four pellets each were 2.12 times as vulnerable. The incidence of lead in an entire population at any one time is therefore less than the incidence of lead in the segment of the population taken by hunters; for the populations discussed in this paper the incidence of lead can be calculated by applying 1.5, 1.9, and

2.1 as correction factors at the one-, two-, and four-pellet levels.

Application of the correction factor designed to nullify hunting bias at the one-pellet level indicates that during the hunting season an average of 2.96 per cent of the mallards of North America are carrying one ingested lead pellet each, table 31. The application of correction factors at other shot levels is shown in table 31. The correction factors for three-, five-, and six-plus-pellet levels were derived through interpolation or extrapolation.

Daily during the fall and winter months, some ducks in the North American population are ingesting shot pellets, some are voiding them, some are dying from their effects, and some are recovering.

Unpublished Natural History Survey reports of laboratory studies by James S. Jordan show that penned wild mallards that have ingested one or more No. 6 shot pellets each may eliminate the pellets as early as the first week after ingestion or they may retain them as long as several weeks, until the pellets have become thin wafers 0.05 inch or less in diameter. The appearance of lead pellets that have spent various periods of time in the gizzards of ducks is shown in fig. 9.

The penned wild mallards that were dosed by Jordan with one No. 6 shot pellet each and that showed few or no indications of lead poisoning had eliminated the pellets by the thirty-first day. The average period of lead retention by the ducks in this category was 18 days. Mallards that were dosed with two or with four pellets each and that showed no significant manifestation of lead poisoning had eliminated the pellets about as rapidly as those dosed with one pellet each.

The penned mallards that were dosed with one No. 6 shot pellet each and that showed moderate to severe effects of lead poisoning had eliminated no pellets in the first week; at the end of 4 weeks, only 27 per cent of these ducks had voided all the pellets with which they had been dosed.

Twenty-one per cent of 119 penned mallards that had eliminated all shot pellets they had been given (one to four pellets each) died from lead poisoning. A study of the history of these ducks led to the conclusion that a large proportion of the ducks that retain lead shot for 3 or more weeks die from its effects.

As previously discussed, most mallards in the wild that die from lead poisoning perish in the second or third week after they have ingested lead. Most mallards

Table 31.—Estimated percentages of North American mallard population lost as a result of lead poisoning. The figures for the various shot levels have been corrected for hunting bias and population turnover. (By shot level is meant the number of ingested shot pellets found in the gizzard of a duck.)

Shot Level	Shot Incidence*	Hunting Bias Correction Factor†	Shot Incidence Corrected for Hunting Bias‡	Shot Incidence Corrected for Turnover**	Mortality Rate (Per Cent)††	Per Cent of Population Lost§
1	4.44	1.5	2.96	17.76	9	1.60
2	1.14	1.9	0.60	3.60	23	0.83
3	0.47	2.0§§	0.24	1.44	30§§	0.43
4	0.18	2.1	0.09	0.54	36	0.19
5	0.14	2.2§§	0.06	0.36	43§§	0.15
6	0.05	2.3§§	0.02	0.12	50§§	0.06
6+	0.38	2.4§§	0.16	0.96	75§§	0.72
Total	*6.80*	. . . . .	*4.13*	*24.78*	. . . . .	*3.98*

*From table 11.
†From table 20, nearest 0.1.
‡Derived as explained on pages 279 and 280 (at one-pellet level: $4.44 \times 1.5 = 2.96$).
**Turnover correction factor 6, derived as explained on page 281.
††Derived as explained on page 276. These figures are for mallard drakes of the Mississippi Flyway, but they are applicable to the continental mallard population.
§Derived by multiplying mortality rate (per cent) by shot incidence corrected for turnover.
§§Derived by interpolation or extrapolation from available data.

that ingest lead have either died or recovered within 4 weeks.

Observations in the field and in the laboratory indicate that a mallard that survives ingestion of lead will have eliminated the lead 18 days, on the average, after ingestion; a mallard that dies with lead still in its gizzard will die 21 days, on the average, after ingestion. Because of these observations, 20 days have been chosen as the average period of turnover of leaded mallards in the wild.

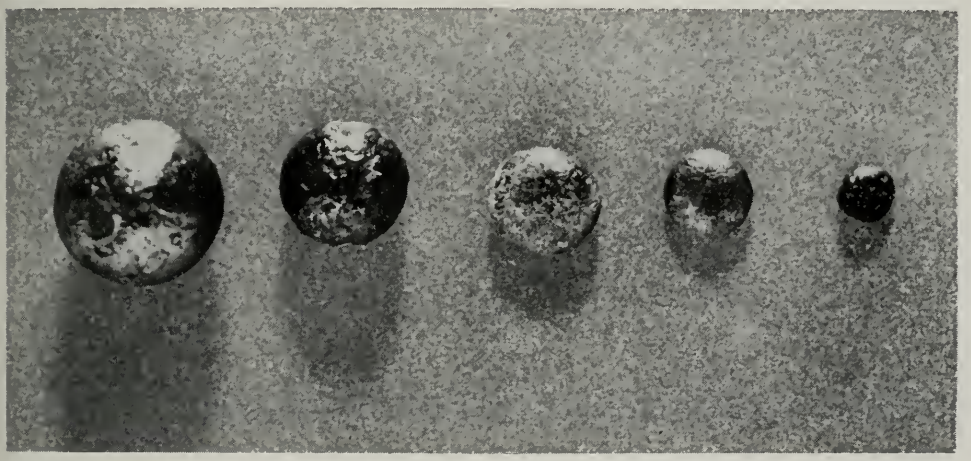

Fig. 9.—The appearance of No. 6 lead shot pellets that spent various periods of time in the gizzards of ducks.

As indicated by the presence of lead in duck gizzards collected from hunters and by lead poisoning die-offs, the lead poisoning "season" (the period of greatest exposure to lead deposited in feeding areas from the guns of hunters) is a 120-day period that begins with November and ends with February. If, as believed, mallard gizzards collected at any one time are representative of only a 20-day turnover period, the number of mallards ingesting lead in the 120-day lead poisoning "season" is six times the average of the numbers obtained from samples taken in the "season." Then the factor to be used in correcting for turnover is 6.

This correction factor applied to incidence figures corrected for hunting bias indicates that approximately one-fourth of the wild mallards of North America in any one year ingest lead shot, table 31.

There is evidence that a much larger proportion than one-fourth of some duck populations ingest lead shot. Malysheff (1951), after making chemical analyses for lead in the bones and livers of waterfowl taken in the Lower Fraser Valley of British Columbia, reported that 52.1 per cent of the 79 mallards he examined had at one time or another in their lives ingested lead; at the time of examination only about 16 per cent of the mallards had lead in their gizzards and about 36 per cent had survived previous lead ingestion. Malysheff found that 38.2 per cent of 35 pintails showed evidence of lead; 22.9 per cent had lead in their gizzards at the time of examination, and approximately 15 per cent had survived previous lead ingestion.

Mortality rates for Mississippi Flyway mallards dosed with lead shot are presented in table 31; the figures have been adjusted for survival differences between adults and juveniles, as discussed on page 276. Figures for dosages of three, five, six, and six-plus pellets have been derived by interpolation or extrapolation.

If the lead poisoning mortality rates for mallards in other parts of North America are approximately the same as in the Mississippi Flyway, then for the entire North American mallard population the annual loss due to lead poisoning can be calculated, table 31. The figure 1.60 derived for the per cent of the mallard population lost as a result of ingestion of one shot pellet per duck has greater

reliability than the other figures, as it is based on a greater number of field data.

The calculations on which the figures in table 31 are based have many shortcomings. However, the figure 3.98 arrived at as the percentage of the mallard population lost as a result of ingestion of lead shot is at least a "calculated estimate."

The figures in table 31 need qualification and interpretation. They do not take into account the number of mallards carrying lead that are harvested by hunters and so are not wasted. Because ducks carrying lead are more vulnerable to hunting than are ducks that are free of lead, table 20, a considerable proportion of the mallards classified as lost in table 31 are bagged by hunters. The results of twice-weekly surveys of public shooting grounds in central Illinois during recent hunting seasons indicate that the waste, or unharvested loss, due to lead poisoning is about one-fourth less than the 3.98 per cent calculated as the total loss, or approximately 3 per cent.

The estimated 3 per cent waste due to lead poisoning represents day-to-day, noncatastrophic losses and does not include such spectacular losses as those associated with die-offs, in which large proportions of localized populations fall victim to lead poisoning. On the basis of data in table 1, it is estimated that, for mallards of the Mississippi Flyway, to the 3 per cent waste mentioned above should be added 1 per cent to cover the die-off losses, a total of 4 per cent. For mallards of other flyways, the die-off losses are markedly less, table 1.

Mallards have made up the bulk of the ducks found in important lead poisoning die-offs in the United States in recent years, table 1. This fact is construed to mean that the mallard is more susceptible to lead poisoning than other species of waterfowl.

Most available evidence points to the pintail as the species second to the mallard in susceptibility to lead poisoning, table 1. Malysheff (1951) found the pintail even more susceptible than the mallard in small samples taken in British Columbia. Although, as table 11 indicates, in North America as a whole a greater percentage of pintails than of mallards ingested shot, the influence of the more beneficial diet of the pintail is evinced by the relatively lower losses among ducks of this species on areas where both pintail and mallard have been involved in important lead poisoning die-offs, table 1.

The extremely low shot incidence found in the blue-winged teal, green-winged teal, shoveler, and wood duck precludes lead poisoning as a cause of appreciable losses in these species. In addition to having a low rate of shot ingestion, the baldpate and the gadwall feed largely upon leafy aquatic vegetation, food highly beneficial in alleviating the effects of ingested lead; mortality from lead poisoning is considered to be almost negligible in these species.

Noticeable lead poisoning die-offs are extremely rare in the redhead, ring-necked duck, canvasback, and lesser scaup, table 1, even though these species have the highest incidence of ingested shot recorded among waterfowl, table 11. It must be concluded, therefore, that lead poisoning is not an important mortality factor in ducks of the genus *Aythya*. This fact seems attributable to their beneficial diets.

In spite of a low rate of shot ingestion by Canada, blue, and snow geese, table 11, these species have become victims of lead poisoning die-offs on a surprisingly large number of occasions, table 1, but, in each case, the per cent of the population lost has been low. Inasmuch as these geese feed primarily on corn in the areas where the die-offs have occurred, diet appears as an important factor contributing to their mortality.

As mentioned above, approximately 4 per cent of the mallard population of the Mississippi Flyway is wasted annually as a result of lead poisoning. The annual mallard waste in other flyways is estimated to be between 3 and 4 per cent. The annual waste due to lead poisoning among all species of waterfowl in all North American flyways is estimated to be between 2 and 3 per cent of the population.

Several students of waterfowl have feared that in addition to direct losses due to lead poisoning there are possible indirect losses, such as lead-induced sterility. Wetmore (1919:11) and Shillinger & Cottam (1937:400) are among the authors who have voiced concern over possi-

ble sterility. This concern has been fostered by evidence that lead reduced the virility of domestic poultry and acted as an abortifacient in mammals.

In two laboratory studies which have been made on the effect of ingested lead on sterility in waterfowl, the conclusion was reached that the lead had little perceptible effect upon reproduction. Of the first study, with game-farm mallards, Cheatum & Benson (1945:29) stated that: "These few data indicate that among the mallard drakes used, those which recovered from lead poisoning did not exhibit a significant loss of fertility." From the second study, in 1948 and 1949, in which both drake and hen game-farm mallards were used, Elder (1954:322) concluded that: "Leaded birds received 18 shot while on a grain diet, and the resulting toxemia was very severe. However, normal birds did not exceed leaded birds in fertility, embryonic success, or hatchability. But in both years the normal hens surpassed leaded hens in fecundity for the season."

Rarely do waterfowl in the wild ingest as many as 18 shot pellets per duck, and seldom do waterfowl in the wild recover from toxemia as severe as that exhibited by ducks in the 1949 experiments by Elder.

At the present time, lead poisoning losses in waterfowl do not appear to be of sufficient magnitude to warrant such drastic regulations as, for example, prohibition of the use of lead shot in waterfowl hunting. Should lead poisoning become a serious menace to waterfowl populations, iron shot provides a possible means of overcoming it.

Although lead poisoning apparently does not at the present time cause mortality of such magnitude as to endanger the North American waterfowl population, it nevertheless poses an important problem for the future. In the past, the incidence of lead poisoning has increased as numbers of waterfowl hunters have increased. Because further increases in the numbers of these hunters are expected, the search for the best possible solution to the lead poisoning problem should be continued.

From a compassionate as well as a management viewpoint, lead poisoning is a problem that should concern every sportsman. Birds that die from lead poisoning suffer for 2 or 3 weeks preceding death.

SUMMARY

1. The mortality resulting from lead poisoning in wild waterfowl has been a cause of concern to conservationists for many years.

2. A publicized die-off of ducks from lead poisoning near Grafton, Illinois, in January, 1948, brought the problem to the attention of officials of the Western Cartridge Company (now Winchester-Western Cartridge Division of Olin Mathieson Chemical Corporation) and the Illinois Natural History Survey. This resulted in a joint research project on lead poisoning in waterfowl; research was conducted largely at the field laboratory of the Survey on the Chautauqua National Wildlife Refuge, Havana.

3. The objects of the research project were threefold: (1) evaluation of losses from lead poisoning in wild waterfowl, (2) investigation of lead alloys and other materials for possible use as nontoxic shot, and (3) determination of the physiological effects of lead poisoning on waterfowl. This paper is concerned primarily with an evaluation of the losses from lead poisoning.

4. The approach toward evaluating the importance of lead poisoning involved appraisal of (1) the incidence and magnitude of waterfowl die-offs resulting from lead poisoning, (2) the incidence of ingested lead shot among waterfowl populations in fall and early winter, and (3) the extent of waterfowl losses resulting from the ingestion of various quantities of lead shot.

5. The history of lead poisoning in North American waterfowl dates back to the latter half of the nineteenth century. Losses in the nineteenth century or early twentieth century were reported from Stephenson Lake and Lake Surprise, Texas; Currituck Sound, North Carolina; Puget Sound, Washington; Back Bay, Virginia; and Hovey Lake, Indiana.

6. A survey conducted among state and federal conservation agents and agencies indicates that in recent years the waterfowl losses from lead poisoning have

been largest in the Mississippi Flyway and have been followed in order by losses in the Pacific, Central, and Atlantic flyways.

7. In recent years, certain areas in the United States have been the scenes of several sizable die-offs of waterfowl affected by lead poisoning. Among these areas are Catahoula Lake, Louisiana; Claypool Reservoir, Arkansas; Lake Chautauqua National Wildlife Refuge, Illinois; and Squaw Creek National Wildlife Refuge, Missouri.

8. Most of the notable waterfowl die-offs from lead poisoning have occurred in late fall and early winter months, after the close of the hunting seasons. Few losses of ducks have been noted in the spring, but losses of whistling swans and of Canada, blue, and snow geese have been reported at that time. There are no recent records of waterfowl succumbing from lead poisoning during the summer months.

9. The mallard has been the principal species involved in sizable lead poisoning die-offs across the nation. The pintail has predominated in losses recorded in the Pacific Flyway. Where both species occur together in the Mississippi Flyway, losses in the mallard have been relatively higher.

10. In the Mississippi Flyway, 1938–1955, 10.4 per cent of the mallard drakes and 13.0 per cent of the mallard hens picked up in die-offs carried no ingested shot. In experiments with penned mallards dosed with one to four No. 6 shot pellets each, 21 per cent voided shot before death. These figures suggest that birds in the wild that succeed in voiding shot are more likely to survive than are penned birds that void shot.

11. Data from four widely separated areas in which die-offs of mallards occurred indicate that differences between the areas in the numbers of ingested shot pellets per drake resulted mainly from differences in availability of shot and in diet of ducks in the die-off areas.

12. The availability of lead shot pellets to waterfowl on a particular body of water is determined by (1) the shooting intensity, or amount of shot on the bottom, (2) the firmness of the bottom material, (3) the size of the shot pellets involved, (4) the depth of water above the bottom, and (5) ice cover.

13. The extent to which various species of waterfowl are exposed to shot pellets on the bottoms of marshes and lakes is influenced by the feeding habits of the birds and by the kinds of food available, as well as by the numbers of shot pellets available.

14. The incidence of ingested shot pellets in migrating waterfowl populations was determined by (1) fluoroscopic examination of live-trapped ducks, (2) compilation of data obtained from investigators who had examined waterfowl gizzards for food content, and (3) fluoroscopic and direct examination of gizzards, numbering many thousands, obtained from ducks in hunters' bags.

15. Fluoroscopy of trapped ducks caught at baited traps on a heavily shot-over area revealed that the birds had ingested abnormally large numbers of shot pellets. Among three species, blue-winged teal, wood duck, and pintail, feeding together, there appeared to be a relation between the percentage of ducks ingesting shot pellets and the size of individuals. The species with the largest individuals had the highest percentage of individuals with ingested lead. In two of the species, an appreciably greater percentage of juveniles than of adults carried ingested lead.

16. Fluoroscopy by wildlife technicians on waterfowl breeding grounds during the summer months revealed a low incidence of ingested shot among ducks in Utah and Saskatchewan, but a high incidence among those at the Delta Marsh, Manitoba, which is one of the most heavily shot-over areas in Canada.

17. Examination of 36,145 gizzards of waterfowl bagged by hunters in North America revealed many differences among species in incidence of ingested lead. Less than 1 per cent of the Canada geese and less than 3 per cent of the blues and snows had lead in their gizzards. Among the ducks, the percentages carrying ingested lead were as follows: less than 2 per cent of the buffleheads, green-winged teals, mergansers, wood ducks, shovelers, and gadwalls; between 2 and 5 per cent of the blue-winged teals, baldpates, and common goldeneyes; between 5 and 10 per cent of the ruddy ducks, mallards,

black ducks, and pintails; more than 10 per cent of the canvasbacks, lesser scaups, redheads, and ring-necked ducks.

18. A study of the feeding habits of the various species of ducks in relation to shot incidence indicated that grit preferences do not influence shot ingestion.

19. The incidence of ingested lead shot was lowest among waterfowl of the Central Flyway, higher among those of the Atlantic, slightly higher still among those of the Pacific, and highest among those of the Mississippi Flyway. State and local variations in shot incidence within each flyway were numerous. The incidence of ingested lead was more than twice as high among ducks taken along the Illinois River as among those taken along the Mississippi.

20. Examination of live and hunter-killed ducks indicated that much of the lead ingested by waterfowl had been fired from the guns of hunters in the season of ingestion. Apparently, much of the shot fired during a hunting season eventually penetrated so deep into lake and marsh bottoms that by the following summer it was out of the reach of waterfowl.

21. Increases in the percentage of waterfowl ingesting lead have paralleled increases in the number of waterfowl hunters. Because there is expectation that the number of duck hunters will continue to increase, it can be anticipated that lead poisoning will become more prevalent among waterfowl than it is at present.

22. The magnitude of the shot level (number of pellets in a gizzard) has an important bearing on the rate of mortality of waterfowl. Among 2,184 gizzards containing lead shot, 64.7 per cent contained only one pellet each, 14.9 per cent contained two pellets each, and only 7.4 per cent more than six pellets each.

23. A field experiment showed that ducks afflicted with lead poisoning during the hunting season are more likely to be bagged than are healthy birds. Wild mallards that were dosed with one No. 6 shot pellet each and released were 1.5 times as vulnerable to hunting as were undosed controls; those dosed with two shot pellets each were 1.9 times as vulnerable; and those dosed with four shot pellets each were 2.1 times as vulnerable.

24. Among the dosed wild mallards, the ingestion of lead shot pellets did not appear to affect behavior until after the first 5 days. Among birds dosed with one shot pellet each, and that did not die of lead poisoning, the period of affliction appeared to persist for about 15 days; among those dosed with two to four shot pellets each, the period was longer.

25. The weakness and fatigue apparent in dosed wild mallards that suffered from lead poisoning reduced the ability of the ducks to migrate. The larger the number of ingested shot pellets per bird, the greater was the reduction in movement. Band recoveries from a group of mallards dosed with four pellets each showed that less than 5 per cent of the birds migrated farther than 50 miles from the banding station at which they were dosed.

26. Among the dosed wild mallards in 1950 and 1951, at each dosage level the mortality rate from lead poisoning was higher for adult drakes than for juvenile drakes. During the fall months, mortality was higher among hens than among drakes, but by late winter the situation was reversed. Differences in mortality rates among mallards of different ages and sexes were attributed primarily to differences in the quality and quantity of food consumed.

27. In a population of wild mallard drakes, a population made up equally of adults and juveniles, one No. 6 pellet per bird is estimated to cause an increase in mortality rate of about 9 per cent, two pellets per bird an increase of about 23 per cent, four pellets per bird an increase of about 36 per cent, and six pellets per bird an increase of about 50 per cent.

28. An effort to find a lead alloy shot pellet that was nontoxic to waterfowl was unsuccessful. However, iron shot was found to be nontoxic. Most of the difficulties of manufacturing iron shot pellets were overcome by technicians of the Winchester-Western Cartridge Division of the Olin Mathieson Chemical Corporation. At present the principal disadvantage in using iron shot pellets for waterfowl hunting is that they are less effective at maximum ranges than are lead pellets.

29. In determining the importance of

lead poisoning in a waterfowl population, it is necessary to eliminate the hunting bias of samples and to ascertain the period of turnover of migrating mallards that are carrying lead in their gizzards.

30. Incidence figures corrected for hunting bias and turnover suggest that approximately one-fourth of the wild mallards of North America in any year ingest lead shot.

31. It is estimated that, each year, approximately 4 per cent of the mallards in the Mississippi Flyway die in the wild as a result of lead poisoning and that an additional 1 per cent of the mallards in the flyway are afflicted with lead poisoning but are bagged by hunters.

32. For all waterfowl species in North America, the annual loss due to lead poisoning is estimated to be between 2 and 3 per cent of the population.

33. Two studies made outside of Illinois indicate that lead poisoning in waterfowl does not seriously curtail the reproductive capacity of ducks that recover from the malady.

34. At the present time, lead poisoning losses do not appear to be of sufficient magnitude to warrant such drastic regulations as, for example, prohibition of the use of lead shot in waterfowl hunting. Should lead poisoning become a more serious menace to waterfowl populations, iron shot provides a possible means of overcoming it. Because of the increasing numbers of waterfowl hunters and the increasing incidence of lead poisoning, as well as because of the suffering that results among waterfowl seriously afflicted with the malady, the search for the best possible solution to the lead poisoning problem should be continued.

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