January 1989

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Prairie Nat. 21(3):137-146. 1989.

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ABSTRACT — Substrate samples were taken from eight marshes in southern Nebraska during the summers of 1985 and 1986 when the marshes were relatively dry. Each sample was 12 inches square by 2 inches deep. The number of samples per marsh ranged from 66 to 112, with transect lengths ranging from 71 to 201 m. Based on a 97.5% recovery rate, these marshes contained an average of 47,217 lead and 5849 steel shot per hectare. Ranges were from 20,690 to 90,286 pellets per hectare for lead and 0 to 14,044 pellets per hectare for steel.

Ingestion of spent lead pellets resulting in lead poisoning of waterfowl is a long-recognized phenomenon (Grinnel 1894, 1901; Hough 1894; Phillips and Lincoln 1930). The U.S. Fish and Wildlife Service (USFWS), in 1976, estimated that 2.7 million kilograms of lead shot may be deposited in lakes and marshes of the United States each year. Ingestion of this shot by birds can lead to death. Lead poisoning may result in a 2-3% annual loss to the North American waterfowl population (Bellrose 1959).

The area selected for this study was the Rainwater Basin of Nebraska, which is a region of palustrine wetlands in the south central portion of the state. This area is characterized by 0.5- to 405-ha marshes, which are often dry for part of the year, that serve as migratory and spring staging areas for 5 to 7 million waterfowl (USFWS and Nebraska Game and Parks 1986). Steel shot has been required for waterfowl hunting since 1978 on these wetlands. Initially, however, steel shot was available only in 12 gauge shells, and lead shot was allowed for other gauge shells. In 1980, steel shot was required for all waterfowl hunting on these areas, in 1982 it was required for all shotgun hunting on public wetlands, and in 1986 steel shot was required statewide for all waterfowl hunting.

Even with the implementation of these regulations, lead shot may remain available for many years (Bellrose 1959, Wycoff et al. 1971). Lack of data on the amount of steel versus lead shot that may be available to waterfowl in Nebraska wetlands, along with the suspicion of sublethal lead poisoning in conjunction with our annual fowl cholera die-off, prompted this study.

PROCEDURES

Study Areas

During the summers of 1985 and 1986, sampling was conducted on seven USFWS Waterfowl Production Areas (WPA's) and one state Wildlife Management Area (WMA) in south central Nebraska (Fig. 1) to determine the concentration of lead and steel shot in the soil. Twenty samples were also taken from a local federal refuge. Sites were selected primarily because of the hypothesis that lead shot may be tied to the avian cholera die-offs that have occurred on these areas in varying degrees since the early 1970s. Mallard Haven was split into east and west segments because the western end of the basin was owned by a local gun club and the east end was a Federal WPA.

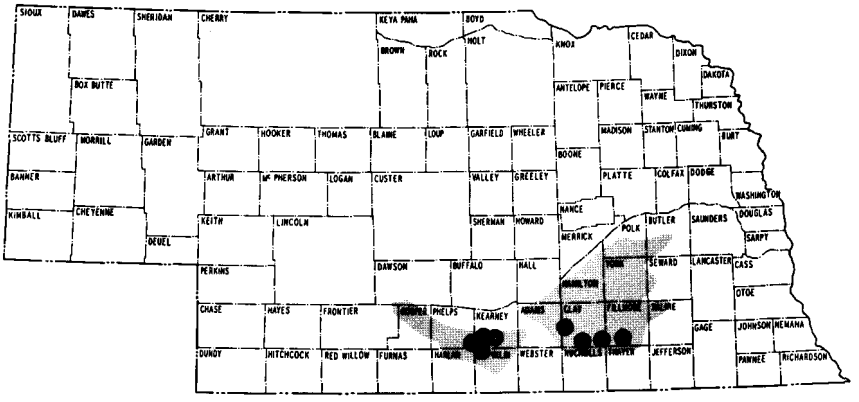

Figure 1. Location of rainwater basins sampled in this study. Numbers 1-4 are in the western rainwater basins, and numbers 5-8 are in the eastern rainwater basins. 1: Sacramento Wildlife Management Area. 2: Quadhammer Lagoon Waterfowl Production Area (WPA). 3: Prairie Dog Marsh (WPA). 4: Lindau Lagoon (WPA). 5: Harvard Marsh (WPA). 6: Massie Lagoon (WPA). 7: Hansen Lagoon (WPA). 8: Mallard Haven (WPA).

Equipment and Materials

Equipment used in collecting and processing soil samples included: (1) maps of each study area for measurement and layout of sample collection grid; (2) a welded, angle-iron, 12x12x2-inch sampling frame, sharpened on the bottom edge; (3) a sharpened, flat-bottom shovel; (4) a weed whip; (5) an 8-pound sledge hammer to pound the frame into ground on dry areas; (6) 8-foot pieces of conduit to flag the main transect through a marsh; (7) wire stake flags to mark sample sites on the perpendicular transects; (8) compass; and (9) a distance measuring wheel. An all-terrain vehicle was used to facilitate collecting and transporting samples and equipment.

Samples were stored in labeled 12x18-inch heavy-duty plastic bags. Equipment at the laboratory included: 5-gallon buckets, a standard 595-micron sieve, a magnet, a fluoroscope, and a shot disk with known size shot displayed (kindly supplied by Federal Cartridge Corporation).

Transects were set up on each marsh with an objective of collecting 50 to 100 samples at each site. Samples were not taken at specific distances from blinds, as they have been in other studies (Jessen and Round 1959, Anderson 1982, Humburg and Babcock 1982, Esslinger and Klimstra 1983, Furness 1986). Rather, transects were established across the marshes in any area that could provide water huntable for waterfowl in normal wet years. Transects ranged from 71 m to 201 m (233 to 660 ft) and were laid out with an all-terrain vehicle, compass, and measuring wheel. Collection sites were marked by placing flags on an 8-foot section of electrical conduit on the main central transect. The other transects ran at 90° angles to this main transect and were flagged at ground level at specific intervals.

A welded angle iron frame one square foot inside diameter by two inches deep was used to provide the sample. Normally a sharpened, flat-bladed shovel was used to remove the soil sample from the angle iron frame and place it in a labeled plastic bag.

Analysis involved first reducing sample volume to a size that would cover the bottom of a 9x13-inch plastic cake pan to a depth of 1 to 2 cm. A sample was placed in a 5-gallon bucket and flushed with water. Water, vegetation, and suspended material were allowed to flow out. Shot, being heavier, stayed in the bottom of the bucket (verified by spiked samples yielding a 97.5% recovery rate for 40 samples). Finally, samples were fluoroscoped to locate shot. Difficulties arose when large numbers of soil concretions were present. Soil concretions appear on the fluoroscope, are fairly round, range in size from 1 to 10 mm, and can appear similar to oxidized steel shot. They contain primarily iron but also varying amounts of magnesium, aluminum, silicon, sodium, and manganese. However, they are non-magnetic and steel shot could be separated from them with a magnet. Hand searching of dried samples was used to locate lead pellets.

The basins were divided into two groups, four eastern basins and four western basins. During the 1978 through 1987 hunting seasons, water was available for duck hunting approximately 50% of the time in the western basins examined. Hunting was primarily available on Prairie Dog Marsh and West Sacramento

WMA, mainly because of fall pumping of groundwater rather than normal rainfall. For the eastern basins studied, water was available for waterfowl hunting approximately 85% of the time, and fall pumping was utilized only 22% of the time. The first year of steel shot regulations (1978) was dry, and the only place studied with huntable water was West Sacramento WMA.

RESULTS AND DISCUSSION

Lead and steel shot were found on all basins except West Sacramento WMA where only lead pellets were recovered (Table 1). In 324 samples from the four eastern basins, an average of 0.59 pellets per sample were found. Of the 190 pellets recovered, 84% were lead and 16% steel. Eight pellets were the most found in a single sample, taken from Massie Lagoon. Two lead alloy .22 caliber bullets were also found in this sample. On the four western basins, where water was not as prevalent, an average of 0.35 pellets was found per sample. Of the 121 recovered, 93% were lead and 7% were steel. Lindau Lagoon had a single sample which yielded the most pellets (9). Although samples were taken on transects across the entire basin rather than at specified distances and distances and directions from blinds, most of the shot should have occurred around blind areas. This finding was obvious from "hot spots." Several of these hot spots were presumed to be around sites of blinds established before the areas came under state management.

The amount of shot found in soil samples (Table 2) suggests that lead shot persists in basin soils. The shot present may not be entirely from waterfowl hunting (Table 1), because upland game hunting with lead shot was permitted on some of these areas prior to 1985. Pheasant (*Phasianas colchicus*) hunting is popular on the basins; high crow (*Corvus brachyrhyncos*) populations on the Sacramento WMA for several years also attracted hunters to the basin. The large number of #8 and #7½ shot found at Sacramento (32.5%) may be indicative of crow hunting activities (Table 1). Hunting of these species adds to the lead burden available to waterfowl when the areas are flooded, hence, beginning in 1982 steel shot has been required for all shotgun hunting on these areas.

Anderson (1982) suggested that the pellet density threshold for lead poisoning problems was 20,000 lead shot per acre. Based upon this criterion, Lindau Lagoon in the west and Harvard Marsh and Hansen Lagoon in the east could be considered potential problem areas (Table 2). If samples had been taken only from areas assumed to be around old blinds, every basin examined except Prairie Dog Marsh would have exceeded Anderson's (1982) lead threshold. This finding is disconcerting considering that lead has been banned for waterfowl hunting on these areas since 1978. Such a high level of lead residue is a matter of concern because lead poisoning is still very probable.

Two unpublished studies completed prior to the implementation of steel shot regulations provide information on shot availability (Nebraska Game and Parks Commission unpubl. data). In 1975, Jack Sinn, Nebraska Game and Parks Commission wildlife biologist, took soil samples (1 foot square and 2 inches deep) from three of the eastern marshes examined in this study. The 2-inch depth

Table 1. Size of shot found in sediment samples.

Basin Name	No. Samples N	Lead Shot Size 2	4	5	6	7½	8	All Sizes	Steel Shot Size BB	1	2	4	6	All Sizes
East														
Hansen Lagoon	55		14	2	23	2	4	45	2			5		7
Harvard Marsh	109	10	25		19	3	2	59		1	3	6	1	11
Massie Lagoon	90	1	5	6	20	3	1	36			4	1	1	6
Mallard Haven*	70	1	6	1	6	6		20	1		3	2		6
Mallard Haven East	34	1	4	1	2	5		13			1			1
Mallard Haven West	36		2		4	1		7	1		2	2		5
Total	324	12	50	9	68	14	7	160	3	1	10	14	2	30
West														
Prairie Dog Marsh	96	1	3	1	11	2		18			1	1	1	3
W. Sacramento WMA	112		5	4	18	5	8	40						
Lindau Lagoon	66	3	13		16	2	1	35			1			1
Quadhammer Lagoon	68	3	5	3	5	4		20			2	1	1	4
Total	342	7	26	8	50	13	9	113			4	1	1	8

*Mallard Haven was split into East and West, since the East end is a Federal WPA and the West end is a privately owned club.

Table 2. Shotgun pellets found in soil samples from Rainwater Basin in south central Nebraska.

Name	N	Transect Length Meters	(ft)	% Samples w/shot	% Samples w/Pb Shot	% Samples w/Fe Shot	No. Pb Shot Hectare	(Acre)[a]	No. Fe Shot Hectare	(Acre)
Western Basins										
Prairie Dog Marsh	96	145	(475)	15.6	11.5	3.1	10,690	(8,377)	3,438	(1,392)
Sacramento	112	81	(265)	27.7	27.7	—	39,410	(15,956)	—	—
Lindau Lagoon	66	71	(233)	28.8	28.8	1.5	55,593	(22,508)	1,588	(634)
Quadhammer Lagoon	68	122	(400)	22.0	22.0	—	32,373	(13,107)	—	—
Total or Mean	342			23.4	22.2	1.2	35,500	(14,393)	1,292	(523)
Eastern Basins										
Harvard Marsh	109	152	(500)	37.4	32.2	9.6	64,129	(25,964)	10,529	(4,263)
Massie Lagoon	90	152	(500)	22.2	18.9	5.6	45,256	(18,323)	7,341	(2,972)
Hansen Lagoon	55	122	(400)	45.5	43.6	10.9	90,286	(36,554)	14,044	(5,686
Mallard Haven E.	34	201	(660)	29.4	29.4	2.9	42,191	(17,082)	3,245	(1,314)
Mallard Haven W.	36	152	(500)	30.6	19.4	13.9	22,343	(9,046)	15,326	(6,205)
Total Mallard Haven	70			30.0	24.3	8.6	31,529	(12,765)	9,704	(3,929)
Total or Mean	324			33.8	29.8	8.7	57,800	(23,402)	10,404	(4,212)

[a]Shot numbers are based upon a 97.5% recovery rate which was determined by spiking samples.

was chosen because puddle ducks feed most often and most heavily in this zone, especially if water levels are high. These samples were normally taken 10 to 250 yards from existing blinds. Sinn estimated lead pellet densities to be 26,136 shot/acre at Harvard Marsh, 17,424 shot/acre at Hansen Lagoon, and 37,026 shot/acre at Massie Lagoon.

Darold Walls took samples in 1977 from all the eastern basins included in this study (USFWS files). The goal was to take 100 random samples (12"x12"x2") around existing blinds. Unfortunately, soil concretions were mistaken as lead shot and the samples were consolidated. However, 351 samples contained 293 lead shot and 11,800 soil concretions. The extrapolated average concentration of lead shot for the four basins was 36,362 shot/acre.

Only general comparisons can be made to these earlier studies: (1) Apparently more lead shot occurs in Hansen Lagoon now than in 1975, and (2) the eastern basins were, and still are, potentially dangerous reservoirs for lead. With approximately the same sample size as Walls (324 vs. 351 by Walls), we found 190 shot vs. 293 lead shot found by Walls. There may or may not be a decrease in available lead shot in these basins. Direct comparison with this study is not valid because of differences in sampling selection.

Private blind sites in the western basin area were examined after the 1986 mandatory steel shot season (Hurt, 1986, Nebraska Game and Parks, unpubl. data). Based upon recently emptied shell cases, 26 blinds contained 752 empty shells (Table 3). Steel shot was apparently used in at least 80% of the blinds. Of these, however, 75% also had empty lead shells. It is realized that people reload shells, and lead shells may also be removed to avoid leaving incriminating evidence in a blind. At that time steel shells were normally not reloaded. Even though there has been a change over to steel shot loads, there may still be considerable use of lead in private blinds. Use of lead shot was not found for Mallard Haven on which the private sector appeared to be complying with steel shot regulations much better than hunters using the public area. Because of access, Mallard Haven West was frequently checked more closely by a conservation officer than the public area. Officers checking hunters in the field (primarily on public basins, including those in the study) felt that compliance to the steel shot regulations approached 90%.

Based upon conservation officer reports and the amount of oxidation found on the lead shot, it appears that while some hunters are still adding to the lead deposited in the basins, most of the shot has been present for several years. These basins characteristically have a clay pan bottom under several centimeters of silt and loose vegetable matter. Consequently, a barrier occurs preventing shot from settling out of reach of waterfowl. Shot is covered as a result of siltation, wind erosion, and vegetative decomposition. According to soil experts in Nebraska, the annual buildup of silt and organic matter each year is approximately 1¼ cm or less, depending on available water run-off. With current water control practices, insufficient rainfall, and decreased farming on these public areas, little new sediment accumulates. The mat buildup of soil and organic matter on the study area would probably be less than 1¼ cm per year.

Table 3. Number of empty shells (12 ga.) that were found in blinds. (Hurt, 1986, Nebraska Game and Parks Commission files).

Blind	Steel	Lead	Total
1	0	6	6
2	29	18	47
3	50	6 (three-410 ga.)	56
4	11	5	16
5	37	8 (three-20 ga.)	45
6	6	15	21
7	20	31	51
8	7	21	28
9	0	14	14
10	0	13 (20 ga.)	13
11	0	18 (eleven-20 ga.)	18
12	20	0	20
13	10	7 (three-20 ga.)	17
14	11	6	17
15	12	0	12
16	12	0	12
17	20	6	26
18	40	0 (one empty 12 ga. lead shellbox)	40
19	8	9	17
20	112	6	118
21	33	0	33
22	89	7	96
23	8	0	8
24	0	3	3
25	5	0	5
26	10	3	13
TOTAL	550 (73.1%)	202 (26.9%)	752

McMurtrey Lagoon was sampled to gain insight into the time shot remained within the reach of waterfowl. Located between Harvard Marsh and Massie Lagoon, this basin has been an unhunted USFWS refuge for 25 years. For over 20 years prior to that, McMurtrey was part of the Hastings Naval Ammunition Depot and was hunted only by Navy personnel. Ten samples were taken from locations where blinds were reportedly located, and ten samples were taken from an area where lead poisoning had occurred in the past. Only one very oxidized

lead pellet was found and that was in the area where lead poisoning had previously been observed.

According to Bellrose (1959), the availability of lead shot to waterfowl is determined by the following factors: (1) shooting intensity (amount of shot deposited), (2) type of bottom material, (3) size of the shot pellets deposited, and (4) depth of the water. With 100% compliance, items 1 and 3 should have no effect on future lead availability. The type of bottom material and the depth of water appear to be the most critical factors affecting the Rainwater Basin today. The potential for waterfowl picking up lead shot could be greatly reduced if the basin areas were disked when water conditions allow. It is believed that lead shot may remain accessible to waterfowl in Nebraska basins for at least 20 years, even if lead deposition ceased immediately.

ACKNOWLEDGMENTS

A special thanks to Al Trout of the U.S. Fish and Wildlife Service for use of their all-terrain vehicle and to Kit Hams, Jim Hurt, Brad Seitz, Frank Andelt, Randy Stutheit, Jim Bruner, and Darryl Meints for help in sample collection. Assistance in shot recovery by Ron Dey, Darryl Meints, Kit Hams, and Matt Oates was greatly appreciated. Thanks also to Margo Ems for typing and to Bill Baxter, Kit Hams, Carl Wolfe, Joe Gabig, Larry Witt, and Liz Huff for review and editing.

This study was funded by the Nebraska Game and Parks Commission under Federal Aid in Wildlife Restoration Project Number W-79-R.

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Received 9 November 1988. Accepted 24 July 1989.