Effects of Mechanical Manipulation and Time on Lead Pellet Distribution in Arkansas Wetlands

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Abstract: Lead poisoning occurs when birds forage in habitats containing lead pellets and ingest and store pellets in their digestive systems. Lead pellets have been banned from use in waterfowl hunting in the United States since 1991; however, residual pellets may remain in wetlands and be available to foraging waterfowl. The purpose of this study was to evaluate changes in lead pellet distribution over time and to determine effects of soil disturbance (disking) on the prevalence of lead pellets in surface and subsurface soils of a 423-ha managed wetland in the Mississippi Alluvial Valley of Arkansas. We collected 128 soil core samples at Halowell Waterfowl Rest Area in 2008 as baseline data and compared results with a previous study of lead pellet distribution at the same wetland in 1992. After disking of a portion of the study site in 2008, we collected soil core samples in the same locations as 2008 from disked or undisked portions of the wetland. We used X-rays to detect pellets in soil core samples and then manually sifted through each sample in which a pellet was indicated. We tested for differences in lead pellet distribution between time periods and between treatment (disking) and control plots using chi-square analysis. We found 30 lead pellets in 2008, which did not differ from the number of lead pellets detected in 1992 ($\chi^2 = 0.95$, $P = 0.33$); however, we did find a greater frequency of lead in surface (top 5 cm) soils in 2008 than in 1992 ($\chi^2 = 13.1$, $P < 0.01$). Disking did not affect overall lead pellet frequency ($\chi^2 = 1.32$ $P = 0.23$), although pellet frequency in surface soils was greater in undisked areas ($\chi^2 = 3.29$, $P < 0.05$). While overall lead pellet densities in disked and undisked areas were both above the level considered available to waterfowl, lead pellet density in the upper 5 cm of the soil column was over four times greater in undisked areas (145,587 pellets/ha) compared to disked areas (31,847 pellets/ha). Disking can effectively reduce lead pellet density in wetlands where long-term accumulation of lead pellets has resulted in high concentrations. We recommend additional research evaluate lead pellet concentrations on private wetlands and agricultural fields, especially rice fields, to better assess changes in lead pellet distribution on a landscape scale.

Key words: lead pellet, disking, waterfowl, wetlands

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Lead poisoning has been recognized as an important mortality factor for waterfowl since the late 1800s. Avian lead poisoning occurs when birds forage in habitats containing lead pellets and ingest and store lead pellets in their gizzards, where grinding and chemical action reduce the lead to soluble form which is then absorbed in the large intestine (Pain 1991). One of the first studies to quantify the effects of lead pellets on waterfowl populations estimated 1.6 to 2.4 million ducks died annually between 1938–1954 due to lead poisoning (Bellrose 1959). More recently, Tavecchia et al. (2001) reported 19% lower survival rate among waterfowl containing two or more lead pellets in the gizzard compared to unaffected birds. Ingestion of lead pellets can also have sublethal effects on waterfowl, including lower body mass and changes in habitat use, which may indirectly influence waterfowl survival (Sanderson and Bellrose 1986, Hohman et al. 1990).

Within six years of the 1991 nationwide conversion to nontoxic shotgun pellets for waterfowl hunting, nontoxic pellets comprised 40%–90% of pellets ingested by waterfowl and mortality from lead poisoning was reduced by 68% within the Mississippi Flyway (Moore et al. 1998, Anderson et al. 2000). However, in wetlands with high lead pellet density, ingestion of lead pellets deposited prior to lead regulations may still be a management concern. Following a five-year ban on lead use at Sacramento National Wildlife Refuge, Ramsey (1993) reported no change in lead pellet ingestion rates among mallards (*Anas platyrhynchos*) in areas with high pellet density (>2 million pellets/ha). Although a wide variation in lead pellet density has been reported by numerous studies, concentrations greater than 49,420 pellets/ha were considered dangerous to waterfowl populations (Anderson and Havera 1989) and concentrations of 21,527 pellets/ha were considered "available in quantity" to waterfowl by Jessen and Lound (1959).

Numerous studies have identified substrate type, especially soil firmness, as one of the main factors influencing subsidence rate of spent pellets (Bellrose 1959, Bachman and Low 1973, White and Stendell 1977, Mudge 1984, Flint 1998). Softer sediments, such as sand and pond sediments, are more conducive to rapid settling of pellets and therefore reduce the time that pellets are available to waterfowl (Mudge 1984). Firmer sediments, such as clay, can reduce subsidence rates and allow pellets to accumulate near the surface over many years, resulting in high pellet densities available to waterfowl over a longer period of time (Bachman and Low 1973, Mudge 1984, Pain 1991). Subsidence and settlement rates of lead pellets in different substrate types have been documented in numerous studies over relatively short time scales (≤ 3 years; Mudge 1984, Pain 1991, Flint 1998); however, little is known about pellet subsidence over longer time frames.

Mechanical soil disturbance, specifically disking or plowing, has been effective in redistributing pellets deeper into the soil profile, thereby making them less available to foraging waterfowl. Fredrickson et al. (1977) compared lead pellet density in cultivated and uncultivated moist-soil wetlands and reported tillage reduced lead pellet availability in surface soils (upper 5.1 cm). Esslinger and Klimstra (1983) reported tillage from a moldboard plow and disk reduced lead pellets by 86% in the top inch of soil. Wooley (1979) found that 50% of lead pellets existed 3–5 inches below the soil surface, suggesting that tillage or a hardpan may allow pellets to accumulate at these depths. While the effects of tillage on lead shot distribution have been documented in several habitats including agricultural fields, emergent wetlands, and tidal marshes, little research has been conducted in forested wetlands, a habitat used heavily by waterfowl and hunters in the Lower Mississippi Alluvial Valley. Therefore, the objectives of this study were to evaluate changes in lead pellet frequency over time (16 years) and determine the effects of mechanical manipulation on lead pellet frequency at a formerly forested waterfowl management area in the Mississippi Alluvial Valley of Arkansas.

Study Area

Halowell Waterfowl Rest Area (WRA) (3419N, 9139W) is a 243-ha impoundment in Arkansas County, Arkansas, within the 13,700-ha Bayou Meto Wildlife Management Area (WMA). Soils at Halowell WRA are classified as Perry silty clay which is described as poorly drained and tillable only within a narrow range of moisture content (USDA 1972). According to soil surveys, these soils contract and crack when dry and expand and seal over when wet. Water permeates the soil rapidly until soil cracks seal and then enters the substrate very slowly (USDA 1972).

Halowell WRA was acquired by the Arkansas Game and Fish Commission (AGFC) in 1957 and is managed primarily for waterfowl (Griffee 2002). Historically, intense hunting pressure at Halowell WRA resulted in deposition of large amounts of lead pellets in the substrates (Moser 1992, Griffee 2002). Lead poisoning has been documented in waterfowl in this area, and AGFC restricted the use of lead shot there in 1982, nine years prior to the nationwide ban on lead shot (Moser 1992, Griffee 2002). The area has been managed as a waterfowl rest area since the 1989–90 waterfowl season.

Halowell WRA has been primarily managed as moist-soil wetland habitat since 1992, with management activities including chemical treatments and controlled burns to set back succession. Recently AGFC decided to move from this passive style of moist-soil management to a more active role consisting of disking to release the seed bank; however, before 2008, no part of the study area had been disked. Vegetation type was consistent over the course of this study with dominant species consisting of barnyard grass (*Echinochloa* sp.) and Pennsylvania smartweed (*Polygonum pennsylvanicum*), with foxtail (*Setaria* sp.) prevalent on topographically higher areas. Primary undesirable species included cocklebur (*Xanthium strumarium)* and coffeebean (*Sesbania macrocarpa*) throughout Halowell WRA, with floating primrose-willow (*Ludwigia peploides*) prevalent in water transfer ditches. Two 4-ha patches in the NW and SW areas of Halowell WRA were dominated by toothcup (*Ammania coccinea*) and beggarticks (*Bidens* sp.) respectively.

Methods

To collect baseline data in June 2008 we followed methods described by Moser (1992), and established four parallel, evenly spaced half-mile transects in each of four quadrats of the reservoir (Figure 1). We collected eight soil core samples (9.53-cm diameter, 20.30-cm deep) at randomly-selected sites along each transect (32 samples per quadrat and 128 total samples). Approximately 30% of the study area (including portions of three quadrats) was disked once in October 2008. In May 2009, using methods outlined above, we collected 145 additional core samples to determine if soil disturbance changed lead pellet distribution. We collected 40 core samples from disked areas and 105 samples from undisked areas to serve as a control.

All soil samples were placed in custom-fit boxes to maintain spatial integrity of the soil column. Preliminary testing indicated good detection of lead and steel pellets when samples were exposed to X-rays at 110 Kvz and 100 milliamps for 1⁄30 of a second on a 300ma, 125- Kvp X-ray machine; therefore, these X-ray levels were used to test all core samples for metal pellets. We quantified pellet depth in the soil column by measuring distance from pellet locations to soil surface on radiograph images. All samples with indicated or possible pellet radiograph images were manually searched to locate pellets. Similar to Moser (1992), each soil sample was separated into surface (0–5 cm) or subsurface subsamples (6–10, 11–15, and 16–20 cm) and washed through 2.0-mm and 1.5-mm sieves to recover pellets. Recovered pellets were tested for magnetism and hardness to determine lead or steel composition. We calculated pellet densities at each sampling depth interval by dividing the total number of pellets detected at that depth interval by the total surface area of samples and converted density estimates to pellets per hectare. We analyzed differences in lead pellet

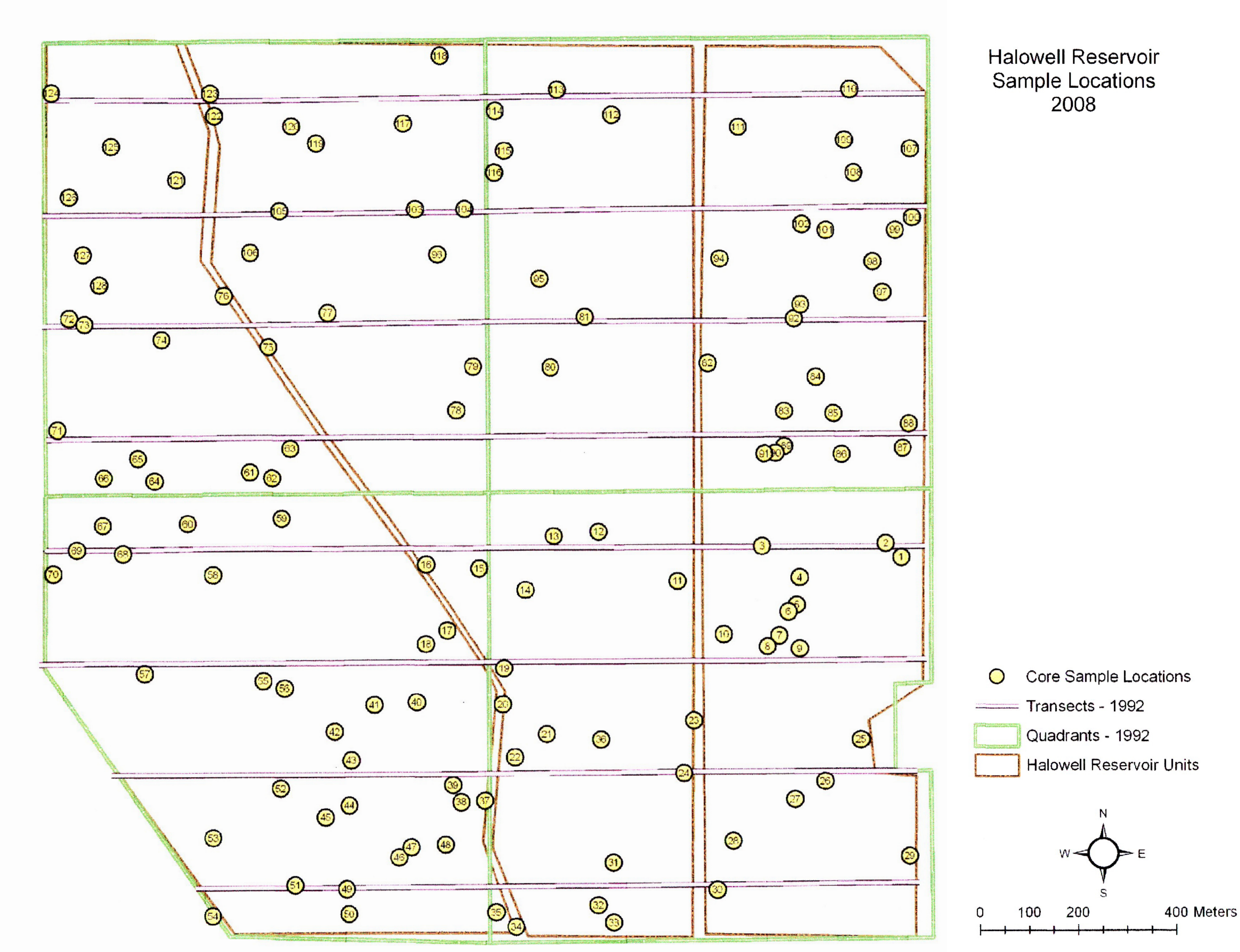

Figure 1. Transect and sampling locations of soil core samples collected at Halowell Waterfowl Rest Area, Arkansas County, Arkansas, during 2008 and 2009.

frequency between this study and Moser (1992) using chi-square analysis (SAS Institute 1990). We also used chi-square analysis to compare lead pellet frequency at different depth intervals between disked and undisked areas. All analyses were conducted using SAS (SAS Institute 1990), with $\alpha = 0.10$ to evaluate all hypotheses.

Results

We detected a total of 30 pellets from 26 core samples in our baseline samples collected in 2008. Number of lead pellets found in 2008 did not differ from those found by Moser (1992; 24 pellets; $X^2 = 0.95$, $P = 0.33$); however, we found more lead pellets in surface soils (top 5 cm) than Moser (1992; $X^2 = 13.1$, $P < 0.01$; Table 1). We estimated total lead pellet density to be 298,567 pellets/ha (SD = 51,392), whereas Moser (1992) concluded overall lead pellet density to be 258,758 pellets/ha (SD = 135,973). We calculated total lead pellet density in the upper 5 cm of the soil as 139,331 pellets/ha compared to Moser's (1992) estimate of 9,952 pellets/ha in the upper 5 cm of the soil (Table 1).

Table 1. Number and density (pellets/ha) of lead pellets collected at Halowell Waterfowl Management Area sampled in 1992 ($n = 128$) and 2008 ($n = 128$).

Soil column depth (cm)	1992		2008	
	n of pellets	Density	*n* of pellets	Density
0–5	1	9,952	14	139,331
6–10	12	119,427	11	109,475
11–15	9	89,570	4	39,809
16–20	2	19,904	1	9,952

We detected 29 potential pellets in 28 total core samples based

Table 2. Number and density (pellets/ha) of lead pellets collected in disked ($n = 40$) and undisked ($n = 105$) portions of Halowell Waterfowl Rest Area in 2009.

Soil column depth (cm)	Disked		Undisked	
	n of pellets	Density	*n* of pellets	Density
0–5	1	31,847	12	145,587
6–10	5	159,236	4	48,529
11–15	3	95,541	0	0
16–20	0	0	0	0

on X-ray images of disked and control samples collected in 2009; we recovered 25 pellets from 26 samples. We identified all recovered pellets as lead. We recovered 9 pellets from disked areas and 16 pellets from undisked areas. There was no significant difference in pellet frequency between disked and undisked areas ($X^2 = 1.07$ $P = 0.30$). Lead pellet frequency in the upper 5 cm of the soil column was greater in undisked areas ($X^2 = 2.83$, $P = 0.09$), whereas lead pellet frequency at depths of 6–10 and 11–15 cm was greater in disked areas (both $X^2 \geq 3.76$, $P \leq 0.05$; Table 2).

Discussion

Overall, we observed little evidence of lead shot subsidence through surface soils at Halowell WRA from levels measured by Moser (1992). Other estimates of lead pellet density at waterfowl hunting areas throughout the United States range from 15,750 pellets/ha (Rocke et al. 1997) to 5 million pellets/ha (Pain 1992). Pellet density at a wetland can influence ingestion rate. One study reported 34% ingestion rates among mallards foraging in areas with lead densities of 173,200 pellets/ha compared to a 4% ingestion rate by mallards in areas where lead density was 15,750 pellets/ha (Rocke et al. 1997). Based on similarity between our and Moser's estimates of lead pellet density at Halowell WRA, ingestion rates among dabbling ducks have potentially remained unchanged in the past 20 years

Surprisingly, we found more lead pellets in the surface soils than were reported by Moser (1992) 16 years earlier, despite the area having been closed to hunting and the nationwide ban on use of lead shot for waterfowl hunting. We attribute this apparent increase in lead pellet availability in surface soils to sampling design. We used the same sampling design (random transects) as Moser (1992) because we wanted to directly compare results of the two studies. However, because hunter distribution is rarely random within a wetland, lead pellets are likely to be non-randomly distributed. Generally, wildlife-user groups occur in clusters (Garton et al. 2005); therefore, it is likely that lead pellets dispersed by waterfowl hunters occur in a clustered distribution. A better and more consistent method of assessing lead shot distribution within wetlands would be a clustered sampling design. Differences in lead pellets found in 1992 and 2009 may also be attributed to pellet recovery rates. Moser (1992) estimated a pellet recovery rate of 77%; whereas our study had a 100% recovery rate.

Lead pellet concentrations in excess of 49,420 pellets/ha were considered dangerous to waterfowl populations by Anderson and Havera (1989) and concentrations of 21,527 pellets/ha were considered "available in quantity" to waterfowl by Jessen and Lound (1959). Based on our estimates, lead pellet densities in the undisked surface soils of Halowell WRA (194,116/ha) are 3.9 times the level suggested as dangerous by Anderson and Havera (1989) and 9 times the level considered as "available in quantity" by Jessen and Lound (1959) for moderately-hunted areas. However, we found much lower pellet densities in the upper 5 cm of the soil column in disked areas (31,847 pellets/ha) compared to undisked areas (145,587 pellets/ha). Although no studies have quantified the relationship between pellet depth and ingestion rate among waterfowl, some have hypothesized that pellets higher in the soil column may be more available to foraging waterfowl (Fredrickson et al 1977, Peters and Afton 1993, Anderson et al. 2000). Similar to other studies (Thomas et al. 2001), we found disking can effectively reduce lead pellet density in wetlands where long-term accumulation of lead pellets has resulted in high concentrations.

Our results may have implications for lead pellet densities at a larger scale than the 243- ha Halowell WRA. Halowell WRA provides sanctuary to thousands of waterfowl each year in which aerial survey data and field staff ground observations have observed peak waterfowl concentrations in excess of 100,000. Our study area is part of a larger 14,000-ha wetland complex that provides essential wintering habitat to support approximately 3.5 million ducks over the 110-day wintering period (L. Naylor, personal communication). This does not take into account early and late season migrants which also utilize these habitats. Based on similarities in long-term hunting pressure between Hallowell WRA and the hard pan clay soils underlying the entire wetland complex, our estimates of lead pellet density at Hallowell WRA may also be similar for other traditionally intensely-hunted areas within other bottomland hardwood wetlands in the Mississippi Alluvial Valley. However, lead pellet densities at Halowell WRA may not be entirely biologically available to waterfowl due to silty clay soil composition, layers of organic matter, and water depth (Anderson et al. 2000). We recommend the continuation of the current study to evaluate long-term effects of soil disturbance utilizing a clustered sampling design and additional research to evaluate lead pellet concentrations on private agricultural wetlands, especially rice, as well as the different types of forested wetlands within the MAV to better assess changes in lead pellet distribution on a landscape scale and its potential impact on migrating and wintering waterfowl.

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