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AVAILABILITY AND INGESTION OF LEAD SHOTSHELL PELLETS BY MIGRANT BALD EAGLES IN SASKATCHEWAN

MICHAEL J.R. MILLER[1]
Department of Biology, University of Saskatchewan, 112 Science Place, Saskatoon, SK S7N 5E2 Canada

MARK E. WAYLAND
Environment Canada, Prairie and Northern Region, 115 Veterinary Road, Saskatoon, SK S7N 0X4 Canada

ELSTON H. DZUS[2] AND GARY R. BORTOLOTTI
Department of Biology, University of Saskatchewan, 112 Science Place, Saskatoon, SK S7N 5E2 Canada

ABSTRACT.—We determined food habits and prevalence of ingested shotshell pellets in a population of Bald Eagles (*Haliaeetus leucocephalus*) at a waterfowl staging area on the Canadian prairies. Food habits were ascertained through examination of prey remains and regurgitated castings, and by direct observation. Shotshell pellet ingestion was determined by radiography of regurgitated castings and by fluoroscopy of live-trapped eagles. In addition, we collected moribund and dead waterfowl to determine prevalence of lead shotshell pellets within their tissues. Waterfowl formed the bulk of the diet (>70% of prey items). Of 123 waterfowl carcasses examined, 47% contained shotshell pellets ranging in number from 1–7 per bird. Of 118 shotshell pellets removed, 87% were composed of lead, the remainder steel. Less than 2% of regurgitated eagle castings collected (N = 509) contained lead shotshell pellets. Ingested shotshell pellets were found in 9% (6 of 66) of trapped eagles. These conditions should ameliorate with the ban on use of lead shotshell pellets for hunting waterfowl in Canada that was instituted in 1999.

KEY WORDS: *Bald Eagle;* Haliaeetus leucocephalus; *food habits; lead shotshell pellets; lead exposure; Saskatchewan.*

Disponibilidad e ingestión de perdigones de plomo en águilas calvas migratorias en Saskatchewan

RESUMEN.—Determinamos los hábitos alimenticios y la prevalencia de perdigones ingeridos en una población de águilas calvas (*Haliaeetus leucocephalus*) en un área de aves acuáticas en las praderas de Canadá. Los hábitos alimenticios fueron evaluados a través del examen de restos de presas, egagrópilas y observación directa. La ingestión de perdigones fue determinada por radiografías de egagrópilas y por fluoroscopia de águilas atrapadas vivas. Adicionalmente, recolectamos aves acuáticas moribundas para determinar la prevalencia de perdigones de plomo dentro de sus tejidos. Las aves acuáticas conforman la mayoría de la dieta (>70% de las presas). De los 123 cadáveres de aves acuáticas examinadas, 47% contenían perdigones en un rango de 1–7 por ave. De los 118 perdigones removidos, 87% eran de plomo y el resto de acero. Menos del 2% de las egagrópilas recolectadas (N = 509) contenían perdigones de plomo. Los perdigones ingeridos fueron encontrados en el 9% (6 de 66) de las águilas atrapadas. Estas condiciones deben aminorarse con la prohibición del uso de perdigones de plomo en la caza de aves acuáticas en Canadá, instaurada en 1999.

[Traducción de César Márquez]

The presumed major source of lead for raptors is that obtained through ingestion of shotshell pellets or bullet fragments present in tissues of prey animals (Redig et al. 1980, Pattee and Hennes 1983, U.S. Fish and Wildlife Service 1986, Gill and Langelier 1994). Bald Eagles (*Haliaeetus leucocephalus*) are particularly at risk to lead poisoning because they often rely on wounded prey or carrion likely to contain lead shotshell pellets (Pattee and Hennes 1983, Gerrard and Bortolotti 1988).

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[1] Present address: Iolaire Ecological Consulting, 210–112th St., Saskatoon, SK S7N 1V2 Canada.

[2] Present address: Forest Ecology Program Manager, Alberta Pacific Forest Industries, Inc., Box 8000, Boyle, AB T0A 0M0 Canada.

Thus, lead toxicosis has been documented more frequently in Bald Eagles than in any other nonwaterfowl species (Locke and Friend 1992).

In addition to unrecovered birds shot by hunters, free-flying waterfowl often harbor shotshell pellets embedded in body tissues (U.S. Fish and Wildlife Service 1986, Scheuhammer and Norris 1995). Wintering and migrant Bald Eagles frequently use locally abundant food sources such as waterfowl (Steenhof 1976, Sabine and Klimstra 1985, Hennes 1985, Lingle and Krapu 1986, Gerrard and Bortolotti 1988). Thus, it is generally believed that the presence of waterfowl hunting and eagles in a localized area predetermine a high risk of lead poisoning for scavenging eagles (Pattee and Hennes 1983). In Canada, approximately 1500 metric tonnes of lead shotshell pellets are deposited annually into the environment by hunters shooting waterfowl, upland game birds and small mammals (Scheuhammer and Norris 1995).

Lead exposure and poisoning have been documented in both Bald and Golden Eagles (*Aquila chrysaetos*) from specimens collected on the Canadian prairies (Wayland and Bollinger 1999). Because of intense, localized waterfowl hunting in the southern portions of the Canadian prairies during the autumn and the concurrent passage of Bald Eagles with numerous waterfowl, eagles in this area have a high potential for lead exposure and poisoning. The purpose of this investigation was to determine the prevalence of lead shotshell pellets in potential prey items and to document the prevalence of ingestion of lead shotshell pellets by Bald Eagles at a waterfowl staging area under heavy hunting pressure.

STUDY AREA

We examined a congregation of Bald Eagles and waterfowl at Galloway Bay (50°48′N, 108°27′W), an impoundment located on the South Saskatchewan River in southwestern Saskatchewan, Canada. During the fall, in addition to attracting large numbers of Bald Eagles, the river and surrounding submerged floodplain together create favorable staging habitat for up to 700 000 geese and cranes (Roy 1996). The 10′ block (10′ latitude × 10′ longitude) containing Galloway Bay is also among the most heavily used goose-hunting areas in Canada according to the Canadian Wildlife Service's National Harvest Survey (Canadian Wildlife Service unpubl. data).

METHODS

From September–November 1992–95, ancillary to trapping and blood sampling Bald Eagles to estimate lead exposure (Miller et al. in press), we collected data pertaining to food habits. We determined percent occurrence of food items using three techniques: analysis of regurgitated castings, collection of prey remains and direct observation. Each technique potentially under- or overrepresented certain prey items; therefore, we used all three methods simultaneously (Simmons et al. 1991, Mersmann et al. 1992).

Throughout the study area, whole or partially consumed carcasses were salvaged individually, while we compiled smaller items such as feathers or bones. The frequency of occurrence was determined for each species found in a particular day's collection. Prey remains not readily identified were compared with museum reference specimens (University of Saskatchewan and Royal Ontario Museum, Toronto, Ontario, Canada). Avian remains were identified to the lowest taxonomic category possible; all other remains were designated only to class.

Regurgitated castings were placed in separate bags and later fluoroscoped to determine prevalence of metallic shot. Castings were then air-dried at room temperature and examined under a dissecting microscope. A sample of approximately five similar feathers was examined under a compound microscope to determine downy barbule configuration as an aid in identification (Brom 1991) before using a reference collection or feather key (Broley 1950).

Under scientific and salvage permits acquired from Environment Canada, physically injured or moribund waterfowl were captured by hand and euthanized. Carcasses were frozen and later fluoroscoped in the laboratory to ascertain the presence of shotshell pellets. Shot-positive carcasses were radiographed frozen and left to thaw overnight. Shotshell pellets were excised and the tissue type and anatomical location from each embedded pellet or fragment noted. Lead and steel shotshell pellets were differentiated with a magnet.

We observed eagles hunting and eating. When possible, prey remains were retrieved after eagles had ceased feeding or after being flushed by an observer.

In 1994 and 1995, we used a Xi Scan 1000 Portable Radiographic and Fluoroscopic System (Xi Tech, Windsor Locks, CT U.S.A.) to examine the gastrointestinal tract of captured eagles to determine the prevalence of shotshell pellet ingestion (Miller et al. in press). Lead shotshell pellets could not be differentiated from steel or other nontoxic pellets, nor was the size of shotshell pellets determined.

Three eagles recaptured and fluoroscoped in the same season were included in analyses. Unlike blood lead (PbB) concentrations which may take several weeks to return to preexposure levels (Pain 1996), we considered initial and recapture dates independent, as shotshell pellets are likely not retained for long (Hoffman et al. 1981).

Unless indicated, nonparametric statistics were used throughout based on methods presented by Siegel and Castellan (1988). The Y-subscript following χ^2 tests indicates that a Yates' correction for continuity has been applied; the c-subscript following test statistics and z-values indicate that these values have been corrected for tied observations (Siegel and Castellan 1988).

RESULTS

Seventy-two collections were made during 1992–95. Avian remains were found in 97% of all collec-

Table 1. Comparison of prey identification techniques for Bald Eagles at Galloway Bay, Saskatchewan, 1992–95.

PREY	DIRECT OBSERVATION[a]	PREY REMAINS[b,d]	CASTINGS[c,d]
Unknown	22.8	—	—
Avian			
White-fronted Goose	28.1	66.7	49.0
Canada Goose	5.3	20.8	0.7
White Goose[e]	5.3	19.4	3.5
Anser spp.	7.0	22.2	5.6
American Coot	3.5	31.9	27.3
Mallard Duck[f]	3.5	19.4	13.3
Unidentified duck	3.5	13.9	27.3
Unidentified waterfowl	14.0	—	—
Mammals	1.8	8.3	8.4
Fish	5.3	9.7	2.8

[a] % of all observations ($N = 57$).
[b,c] % occurrence in all castings ($N = 143$) or collections ($N = 72$).
[d] Does not total 100% as some items were found in occurrence with other items within the same casting or collection period.
[e] Snow Geese (*Chen caerulescens*) and Ross' Geese (*C. rossii*).
[f] *Anas platyrhynchos.*

tions (70 of 72), while mammals and fish were only found in six and seven (8 and 10%) collections, respectively (Table 1). White-fronted Geese (*Anser albifrons*) were the most common bird and were found in 48 of 72 (67%) collections; American Coots (*Fulica americana*) were the next most common avian prey and occurred in 32% of all collections (Table 1).

Of the 509 castings collected during 1994–95, 143 were examined to determine prey composition. Castings generally consisted of either one species or class (62%), although up to four species were identified in several pellets (3%). Of the three broad categories of prey items, fish and mammals were observed least often and were only found in 2.8% and 8.4% of castings, respectively (Table 1). Birds were the most common prey and were found in all regurgitated castings; six species and three genera were identified (Table 1).

Since observations of foraging eagles were generally made at a distance, assessing diet through feeding observations provided the least opportunity for identification of prey to the lowest taxon (Table 1). Seventy-five percent (43 of 57) of observations were of eagles eating; the remainder were of eagles hunting with no consumption of prey. Birds accounted for at least 71% of all items that were consumed or actively pursued; fish and mammals combined accounted for only 7% of observations (Table 1).

Of note, however, was the response of eagles in 1995 to an avian cholera epizootic. Waterfowl mortality was noted on 22 October and we speculated that the outbreak began six days before on 16 October based on changes in the number of eagles that were observed feeding on the ground from population counts during the same period (Change-point test, $z = -3.62$, $P < 0.001$) (Miller 1999).

Of 123 fluoroscoped waterfowl carcasses of nine species, greater than 91% retrieved were geese; of these, 81% were White-fronted Geese (Table 2). Ducks, Sandhill Cranes (*Grus canadensis*) and American Coots accounted for only 9% of birds retrieved (Table 2). Ninety carcasses were dissected in the laboratory. The remaining 33 birds salvaged from the avian cholera epizootic in 1995 were fluoroscoped on site, and only the number of shotshell pellets present was recorded, as anatomical location could not be determined.

Significantly more birds with embedded shotshell pellets were obtained through sacrificing injured birds (40 of 68) than from specimens found dead through salvage (8 of 55) ($\chi^2_y = 23.226$, $P < 0.001$). Geese ($N = 112$) had a significantly larger median number of embedded shotshell pellets, or burdens, than an aggregate sample of ducks, Sandhill Cranes, and American Coots ($N = 11$) (Wilcoxon-Mann-Whitney, $z_c = -2.992$, $P = 0.0028$).

Embedded shotshell pellets were found in 40% of carcasses and in three of the nine species examined; among these three species, the median number of embedded shotshell pellets did not vary significantly (Table 2) (Kruskal-Wallis one-way ANOVA, df = 2, $H_c = 1.243$, $P = 0.54$). The number of pellets per carcass ranged from 1–7 (Table 2). We could not detect a difference in median shotshell pellet burden per anatomical region among carcasses with shotshell pellets (Kruskal-Wallis one-way ANOVA, df = 2, $P > 0.10$) (Table 2).

No evidence suggested a temporal increase in embedded shotshell pellet burdens in all species combined (Kendall's rank-order correlation, $T_c = 0.059$, $z_c = 0.961$, $N = 123$, $P = 0.34$). Neither did evidence support an increase among White-fronted Geese alone (Kendall's rank-order correlation, $T_c = -0.021$, $z_c = -0.294$, $N = 91$, $P = 0.39$) nor Canada Geese (*Branta canadensis*) (Kendall's rank-

Table 2. Summary of anatomical location and number of shotshell pellets excised from waterbirds at Galloway Bay, 1994–95.

	Shotshell Present?		Pellets	Anatomical Location of Shotshell Pellet[a]							
					Body Region						
Species (N)	N	Y	No./ Carcass	Sub-cutan.[b]	Gizzard	Muscle[d]	Thor.[e]	Abdom.[f]	Legs[g]	Wings Bone[h]
White-fronted Goose (91)	52	39	1–7	21, 5	8, 0	20, 1	6, 0	8, 2	5, 1	25, 3
Canada Goose (14)	6	8	1–4	2, 0	0, 1	3, 0	3, 0	0, 2	2, 0	4, 1
Snow Goose (3)[i]	1	2	1–5	3	0	1	0	0	0	1
Ross' Goose (5)[j]	4	0	—	0	0	0	0	0	0	0
Sandhill Crane (1)	1	0	—	0	0	0	0	0	0	0
Mallard Duck (5)	5	0	—	0	0	0	0	0	0	0
American Coot (3)	3	0	—	0	0	0	0	0	0	0
Green-winged Teal[k] (1)	1	0	—	0	0	0	0	0	0	0
Northern Shoveler[l] (1)	1	0	—	0	0	0	0	0	0	0

[a] The two numbers represent the number of shotshell pellets per location in birds that were collected live or found dead, respectively.
[b] Shotshell pellets just beneath the skin.
[c] Shotshell pellets within the lumen of the ventriculus or within the ventricular wall.
[d] Shotshell pellets within muscle mass throughout the body excluding the legs and wings.
[e] Shotshell pellets within the thoracic region.
[f] Shotshell pellets within the abdominal region.
[g] Shotshell pellets within muscle and bone of the legs.
[h] Shotshell pellets within the bones and muscles of the wings and larger bones of the body were considered nonavailable to eagles.
[i] Birds were found dead.
[j] One specimen was not fluoroscoped.
[k] *Anas crecca.*
[l] *Anas clypeata.*

order correlation, $T_c = 0.269$, $z_c = 1.339$, $N = 14$, $P = 0.090$).

Of all shotshell pellets excised ($N = 118$), 87.3% were composed of lead; the remainder were steel. Individual carcasses harbored either lead ($N = 40$), steel ($N = 2$) shotshell pellets, or both ($N = 6$). Lead shotshell pellets ranged in size from #6 to size BBB; steel shotshell pellets varied from #2 to size T.

During 1994–95, 509 castings were collected. All castings were fluoroscoped to determine if metallic shotshell pellets were present; 10 castings contained one metallic shotshell pellet of undetermined size. Four of 248 (1.6%) and four of 261 (1.5%) castings collected in 1994 and 1995 respectively, contained lead shotshell pellets, while the remaining two castings with shotshell pellets from 1995 contained steel shotshell pellets (2 of 261, or 0.8%). Contrary to our hypothesis, we did not detect an increase in the incidence of shotshell positive castings over the nine week period (16 September–16 November 1994–95) ($\chi^2 = 2.765$, df = 3, $P = 0.22$).

Intragastrointestinal shotshell pellets were observed in six of 69 eagles (8.7%). The 7.8% prevalence of lead exposure as determined from PbB concentrations (Miller et al. in press) was not significantly different from the exposure prevalence ascertained from ingestion of shotshell pellets ($\chi^2_y = 0.001$, $P = 0.96$). The number of ingested shotshell pellets per eagle ranged from 1–2. Four of the six eagles had shotshell pellets located in the abdomen, while the remaining two eagles each had single shotshell pellets present near the crop.

Discussion

Waterfowl were the most common food of Bald Eagles at Galloway Bay. This dependence on waterfowl is typical for Bald Eagles wintering in the western United States (Steenhof 1976, Hennes 1985, Sabine and Klimstra 1985, Lingle and Krapu 1986). White-fronted Geese, the most abundant species at Galloway Bay, were also the most common species consumed. The second-most common prey items were ducks and American Coots, found in 41 and 27%, respectively, of all castings, and 32 and 39%, respectively, of all prey remains.

Occurring in <10% of prey remains, observations or castings, mammals and fish were uncommon in the diet. However, we may have underestimated the proportion of each owing to differences in detectibility (Frenzel and Anthony 1989, Mersmann et al. 1992, Watson et al. 1992).

The occurrence of shotshell pellets in 40% of debilitated or dead waterfowl at Galloway Bay is similar to the 20–30% reported for free-flying and apparently healthy waterfowl throughout the United States and Canada (U.S. Fish and Wildlife Service 1986, Scheuhammer and Norris 1995).

Waterfowl sampled late in or after the hunting season and individuals that have survived successive hunting seasons will often harbor large amounts of embedded shot (Pattee and Hennes 1983, Hennes 1985, U.S. Fish and Wildlife Service 1986). Differences in shotshell pellet burden in waterfowl have also been shown to exist among species (U.S. Fish and Wildlife Service 1986). In general, larger species usually carry greater shotshell pellet burdens than smaller species (U.S. Fish and Wildlife Service 1986), a phenomenon also suggested by our results.

The anatomical location of embedded shot in waterfowl at Galloway Bay was similar to what has been previously reported in other waterfowl species (Perry and Geisler 1980, Hennes 1985). The location of embedded shot may influence the availability of lead for foraging eagles. For example, Sabine and Klimstra (1985) and Hennes (1985) found that nonedible prey remains retrieved from eagle kill sites generally consisted of feathers and bones of the wings, pelvis, and vertebral column. Based on this and on observations of feeding eagles, Hennes (1985) estimated that 75–85% of embedded shot was available to eagles; the remaining shot, such as that deeply embedded into large bones, were considered unavailable as eagles rarely consumed these parts. Our results suggested a similar phenomenon, where 73% of embedded shotshell pellets were considered available to eagles.

Eagles may also secondarily consume lead shotshell pellets that were originally ingested by waterfowl (Locke and Thomas 1996). Although it was difficult to determine whether shotshell pellets in the lumen resulted from gunshot or ingestion (Lumiej and Scholten 1989), data from dead or moribund waterfowl at Galloway Bay indicated a low prevalence of shot in the ventriculus. In Saskatchewan, the proportion of waterfowl with ingested lead shotshell pellets have been reported as generally low (<4%) (Hochbaum 1993, Scheuhammer and Norris 1995). Field hunting, wide dispersal of hunters, and annual cultivation of fields, as occur at Galloway Bay, all act to decrease the availability of lead shot pellets for waterfowl (Hochbaum 1993). Waterfowl in Saskatchewan do not appear to be overly exposed to lead based on surveys of lead content in wing bones (Dickson and Scheuhammer 1993). Therefore, it seems unlikely that eagles at Galloway Bay secondarily consume shotshell pellets originally ingested by waterfowl.

In comparison to other studies that have examined the castings of Bald Eagles that have been feeding on waterfowl (e.g., Griffin et al. 1982, Bengston 1984, Hennes 1985, Nelson et al. 1989), the frequency of castings with shotshell pellets at Galloway Bay was relatively low. While Bengston (1984) argued that castings with shotshell pellets are the best indicators of lead exposure for raptors, Hennes (1985) suggested that shotshell pellets in eagle castings represent a minimum estimate of the true ingestion rate.

Pain et al. (1993 and 1997) and Mateo et al. (1999) noted that the prevalence of lead shotshell pellets in castings of Marsh Harriers (*Circus aeruginosus*) increased with the progression of the hunting season and was higher within than outside the hunting season. However, no temporal trend was detected at Galloway Bay or by Hennes (1985). Hennes (1985) suggested that multiple castings which may be regurgitated by individual eagles after feeding on larger carcasses such as geese may "dilute" the prevalence of ingestion of shotshell pellets and may have masked seasonal increases (Hennes 1985).

The relatively high prevalence of lead shotshell pellets found in waterfowl carcasses and thus, the potential for consumption by eagles contrasted with the apparent low rate of ingestion of shotshell pellets. Hennes (1985) suggested that the rate of ingestion by Bald Eagles would not equal the prevalence embedded in carcasses because of unavailability due to anatomical location; this may have occurred at Galloway Bay. Alternatively, eagles may have been able to detect embedded shotshell pellets within the prey item and avoid them (cf. Stendell 1980). Possible evidence for this occurring at Galloway Bay was observed in one salvaged carcass of a White-fronted Goose that was almost completely defleshed, yet contained several ($N = 4$) shotshell pellets lying between bones in the ventral aspect of the synsacrum and vertebral column.

In an early review of the cases of lead poisoning in Bald Eagles, Feierabend and Myers (1984) indicated that despite definitive diagnoses of lead toxicosis, only 14% of Bald Eagles necropsied in the United States had lead shotshell pellets present in the gastrointestinal tract. Therefore, lead toxicity or exposure in raptors cannot be ruled out solely on the basis of radiographic evidence (Janssen et al. 1986, Langelier et al. 1991), nor can the presence or absence of lead in the ventriculus be used to estimate quantitative lead concentrations (Kramer and Redig 1997). Since ingested shotshell pellets may rapidly erode, dissolve or be voided in the feces leaving no direct evidence of recent ingestion (Bellrose 1959, Scanlon et al. 1980), estimates of shotshell pellet ingestion determined from fluoroscopy likely represent a minimum estimate of actual prevalence and subsequent severity of exposure (Anderson and Havera 1985).

Given the relatively low prevalence of lead exposure (Miller et al. in press) and ingestion of shotshell pellets at Galloway Bay, eagles may be consuming more uncontaminated prey than indicated by our results (Miller et al. 1998). For example, nonanserid species such as American Coots are hunted less intensively and generally have a low prevalence of tissue-embedded shotshell pellets (U.S. Fish and Wildlife Service 1986). Therefore, the lower prevalence of lead ingestion by eagles at Galloway Bay may be partially attributable to the presence of a high proportion of coots in the diet. Moreover, in 1992 and 1995, eagles extensively fed upon moribund or dead waterfowl resulting from an avian cholera epizootic, a source likely to contain less lead shotshell pellets than waterfowl shot by hunters (Miller et al. 1998). Median PbB concentrations in eagles from 1992–95 did not, however, yield any significant differences between years (Miller et al. in press).

Reducing availability of lead shotshell pellets for raptors has long been the focus of management strategies for abating lead exposure amongst these species (Pattee and Hennes 1983, Feierabend and Myers 1984, U.S. Fish and Wildlife Service 1986, Pain et al. 1997). However, in light of recent findings (Kramer and Redig 1997, Miller et al. 1998), other sources of lead such as fragments from rifle bullets, fishing sinkers and lead shotshell pellets in upland game birds may be important. To accurately assess the effect on raptors of banning lead shotshell pellets for waterfowl hunting in the United States in 1991 and Canada in 1999, the importance of other potential sources of lead must be resolved (Elliott et al. 1992).

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