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RESPONSE OF AMERICAN BLACK DUCKS TO DIETARY URANIUM: A PROPOSED SUBSTITUTE FOR LEAD SHOT

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Lead (Pb) shot has been associated with mortality in waterfowl (Trainer and Hunt 1965, Anderson 1975, Stout and Cornwell 1976) and other avian species (Benson et al. 1974, Kaiser et al. 1980, Pattee et al. 1981). Bellrose (1959) indicated that between 2 and 3% of waterfowl populations may be lost yearly to lead poisoning. Incidence of lead shot in waterfowl and estimates of mortality from lead poisoning have decreased slightly (Trost 1980) or not at all (Longcore et al. 1982) in local areas since 1976, when the U.S. Fish and Wild-

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life Service designated certain wetland areas in 32 states as steel shot zones. Studies in specific areas do not give a complete national picture, but do point to remaining problems. Steel shotshells are more expensive than Pb shotshells when purchased in a retail outlet; they cannot be used in all guns and have not been well received by some hunters who question their performance on ducks and geese (Humburg et al. 1982).

Steel is presently the only approved substitute for lead in shot, but uranium (U) has been proposed by metallurgists (C. Zapffe, Baltimore, Md.). Depleted uranium (DU) is produced in large quantities in impure form as a by-product of the manufacture of enriched rods for nuclear reactor cores. It contains <0.2% U^{235} and therefore is of low radioactivity. The main concern regarding potential effects on wildlife is chemical toxicity. DU has several attractive characteristics for potential shot production. In its pure form, it is denser than Pb and, in alloys, might be made to produce shot patterns and velocities attractive to hunters and within the effective range for waterfowl. DU can be alloyed with many other metals and its softness and corrosiveness can be altered over a wide range. Negative aspects for potential U shot include pyrophoricity problems with pure DU, which can be altered by alloying, and the expense of separating DU from other nuclear waste products.

There is little or no information in the literature that could be used to predict either the behavior of DU in shot form in aquatic environments or the toxicity of DU to waterfowl and other birds ingesting pellets. This study was designed as a preliminary examination of chemical toxicity of metallic U to waterfowl. Because U is not available in pellet form, it was not possible to follow the prescribed protocol for testing shot toxicity. Therefore, a simulation of the erosion of shot using continuous dietary U dosage was undertaken. Previous studies (Rozman et al. 1974, Dieter and Finley 1978) have estimated a period of 3 weeks to 3 months for the erosion of #4 Pb shot in the gizzard. Assuming that erosion of U shot of the same size would take place over a similar period, a dosage period of 6 weeks was set for the U study. A dietary dosage of 100 ppm U would supply the approximate amount of U in a pellet the size of #4 shot over the 6-week period, if the erosion rate was comparable to lead. In this study the dosage was bracketed to allow for different U alloys and to simulate erosion from more than 1 pellet at a time.

METHODS

In February 1980, 40 9-month-old American black ducks (*Anas rubripes*) were transferred to 4.6 × 9.1-m outdoor pens with natural ground cover and 908-liter troughs filled by continuously flowing water. Four males and 4 females were randomly assigned to each of 5 pens, and a commercial developer mash with adequate protein, lipid, and carbohydrate for maintenance (Beacon Feeds, Cayuga, N.Y.) was supplied ad libitum. A 2-way analysis of variance confirmed that body weights of neither males nor females varied ($P > 0.05$) among the 5 pens. All birds were held until 17 March 1980, and up to this time none of the birds experienced weight loss. Then dietary dosages of 0, 25, 100, 400, or 1,600 ppm powdered U were supplied in the mash, 1 dosage to each pen. The U was suspended in propylene glycol mixed into the mash at a ratio of 1 : 99 by weight. Control mash contained only propylene glycol.

The black ducks were fed U for 6 weeks. All were weighed weekly and observed

daily for any sign of debility. A 5-ml heparinized blood sample was taken from either the jugular or deep ulnar vein after 3 and 6 weeks on dosage. Ducks were sacrificed with halothane (Halocarbon Laboratories, Inc., Hackensack, N.J.) or CO_2. The proventriculus and duodenum were immediately injected with neutral-buffered formalin to prevent auto-digestion and the carcasses were examined. Carcass, liver, and kidney weights and descriptions of any gross lesions were recorded. Representative samples of kidney tissue from 38 ducks were fixed in 10% neutral-buffered formalin. Segments of heart, proventriculus, gizzard, intestine, liver, lung, spleen, and brain from 5 ducks fed the control diet and 8 ducks fed 1,600 ppm U were also fixed. Formalinized tissues were submitted to American Histolabs, Inc. (Rockville, Md.) for routine histologic processing and staining with hematoxylin and eosin. All slides were scanned at 2.5 and 10× with a light microscope.

Blood samples were stored on ice until centrifugation for separation of plasma from packed cells. Packed cell volume (PCV) was determined by the microhematocrit method. Delta-aminolevulinic acid dehydratase (ALAD) activity was measured with a spectrophotometer in whole blood (Burch and Siegel 1971), as was hemoglobin concentration using the cyanomethemoglobin procedure (Hycel, Inc., Houston, Tex.). Uric acid, aspartate aminotransferase (AST, EC 2.6.1.1), and alanine aminotransferase (AAT, EC 2.6.1.2) were assayed in plasma on a centrifugal analyzer (Centrifichem® Union Carbide Corp., Rye, N.Y.) according to manufacturer's specifications.

Weight data were compared by repeated measure analysis of variance (Winer 1971) separating sex and treatment level interactions; all other measurements were compared using 1- or 2-way ANOVA.

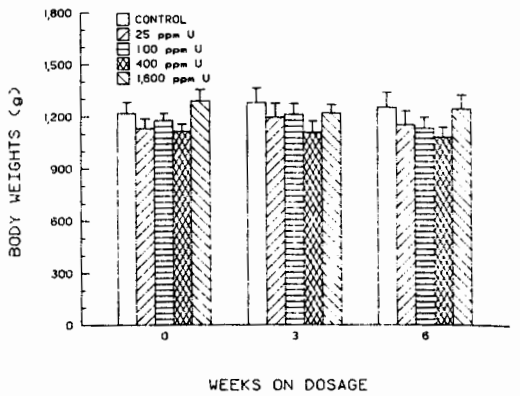
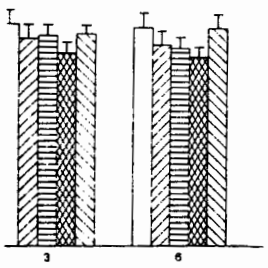


Fig. 1. Body weights (g) of adult black ducks fed 0, 25, 100, 400, or 1,600 ppm U in the diet for a 6-week period. Bar height represents $\bar{x} \pm$ SE for males and females in each group.

RESULTS AND DISCUSSION

Only 1 black duck died while on U dosage. One male in the 100 ppm dietary U dosage group weakened and was harassed by other birds in the pen. It was found dead in the 6th week of the study; necropsy revealed trauma lesions, but no indication of disease or pathological changes in the kidney that are associated with U-induced mortality in mammals (Durbin and Wrenn 1975).

Birds that survived through the dosage period exhibited little indication of treatment-related weight change (Fig. 1). Weight gain and/or loss occurred in all treatment groups, but in no pattern that reflected treatment level or time on dosage. There were transitory treatment effects ($P < 0.05$) in body weight change; these were attributed to the normal fluctuations in weight within any group of birds and were not considered biologically significant or U-induced. Body weights of females were lower ($P < 0.01$) than body weights of males throughout the study in all treatments. No sex-treatment interaction was revealed by the analysis. Males and females did not show the same weight



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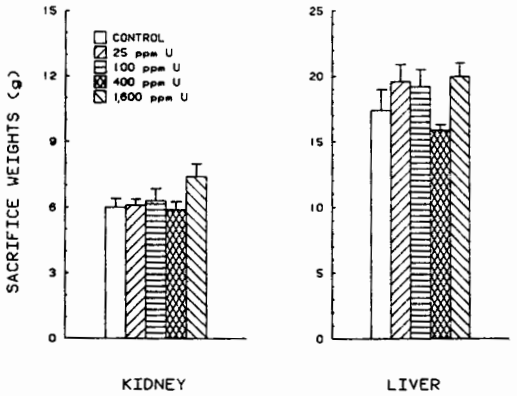

Fig. 2. Kidney and liver weights (g) of black ducks after 6 weeks on a dietary U dosage of 0, 25, 100, 400, or 1,600 ppm. Bar height represents $\bar{x} \pm$ SE for males and females in each group.

patterns over treatment time. Drakes in all groups tended to increase in weight throughout the study until the final week. Hens showed no clear pattern of weight change.

Other measures of sublethal effects from U dosage confirmed the indications of weight data. At sacrifice, there was no alteration in kidney or liver weights (Fig. 2), as seen in U-dosed laboratory mammals (J. Ruedy, unpubl. rep., B.C. Royal Comm. of Inquiry into Health and Environ. Protection in Uranium Mining, 1980). Necropsy results were straightforward; ducks were in fair to excellent flesh. No significant gross or microscopic lesions occurred in black ducks fed 1,600 ppm U for 6 weeks. Kidney examination revealed no lesion in the distal 3rd of the proximal convoluted tubule, as is characteristic of a U challenge in laboratory mammals (Durbin and Wrenn 1975). A few minor lesions including mild bumblefoot, esophagitis, proventriculitis, and hepatic pigmentosis were noted. However, these were as prevalent in controls as in ducks on U dosage and were considered unrelated to dietary U. PCV, hemoglobin, ALAD, uric acid, AST, and AAT were also unaffected by the 6 weeks of treatment (Table 1). It seems likely, then, that there was no sublethal organ damage as a result of U dosage. Plasma AST varied with sex, but not with dietary dosage. No explanation or documentation was found in the literature for this differential level of plasma AST.

Overall, these levels of dietary U did little damage in black ducks fed a nutritionally sound diet. The literature alludes to several possible reasons for this low U

Table 1. PCV (%), hemoglobin (g/dl), and ALAD[a] in whole blood; uric acid (mg/dl), AAT (IU/liter), and AST (IU/liter) in plasma of black ducks after 6 weeks on dietary U dosages of 0, 25, 100, 400, or 1,600 ppm.

	Dosage (ppm U)									
	0		25		100		400		1,600	
	$\bar{x}$[b]	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
PCV	50.4	1.60	52.2	1.25	49.2	0.93	50.9	0.29	50.2	0.92
Hemoglobin	16.4	0.53	17.2	0.59	16.1	0.30	16.6	0.22	16.9	0.32
ALAD	199	10.8	[c]		[c]		[c]		185	20.8
Uric acid	4.7	0.51	5.5	0.62	5.5	0.65	3.8	0.44	4.7	0.36
AST										
Males	13.1	3.33	6.6	0.38	6.5	0.29	8.2	0.92	9.6	0.94
Females	12.0	1.35	11.5	1.89	20.8	4.48	10.6	1.94	12.1	3.02
AAT	20.8	3.91	22.3	0.22	20.3	0.92	17.7	5.53	15.9	1.87

[a] Unit of activity equals a 0.100 increase in absorbance/ml erythrocytes/hour (38 C) at 555 nm with a 1.0-cm light path.
[b] Mean of 8 birds on treatment, except for AST values in which 4 males and 4 females are separately reported.
[c] Not analyzed.

toxicity. First, the species sensitivities among laboratory mammals dosed with U salts may vary by as much as 100-fold. Dogs are generally the most sensitive and strains of white mice are the least sensitive (J. Ruedy, unpubl. rep., 1980). Although most of these studies have used water, not food, as the vehicle of U presentation, the amount of U that caused effects in the laboratory studies was in the range fed to the black ducks (Novikov and Yudina 1970). Waterfowl may thus be relatively insensitive to the chemical toxicity of U. Second, Durbin and Wrenn (1975) considered elemental U to be biologically inert. Only the U salt forms were capable of being absorbed and biologically incorporated. Even dosing with the uranyl oxide form, potentially the most prevalent in aquatic systems (Can. Minist. Natl. Health and Welfare 1979), would result in absorption that would only be in the 0.5–3.0% range in most mammals. Poor absorption of elemental U might also explain the low chemical toxicity for U seen in this study. None of the histological (Goel et al. 1980) or physiological (Novikov 1970, Little 1971) damage cited in the literature was apparent in the black ducks during a 6-week-dosage of substantial dietary U levels.

Several questions must still be answered concerning the chemical toxicity to waterfowl of elemental U in shot form. Altered absorption or toxicity may occur if birds are dosed with a U shot or a shot of a U alloy. Likewise, the toxicity of U and U shot must be tested in birds on a nutritionally deficient diet and 1 that contains a high percentage of corn. These questions can be answered only after an alloy shot has been developed.

Aside from the chemical toxicity of U shot to waterfowl and other avian species that ingest pellets, the behavior and persistence of U in shot form in the aquatic environment must be investigated. This can be done only if the technology for U shot and alloy production is developed. Data collected near military installations that test heavy artillery have shown that U is present in algae in aquatic systems (O'Kelley 1976, Garten et al. 1981) and in vegetation, invertebrates, and small mammals at above background levels on terrestrial sites (Hanson and Miera 1976, Miera et al. 1978, Miera 1980). Altered population densities have not been demonstrated in vertebrates or other species in these studies.

These questions concerning the chemical toxicity and environmental fate and effects of U shot must be investigated before sanctioning of U shot can be considered. Ballistic feasibility and cost of manufacture and purchase are other factors that need appraisal. Our preliminary research findings on the toxicity of U to black ducks indicates that further examination of this metal as a substitute for Pb in shot is justified.

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SECONDARY POISONING OF RED-SHOULDERED HAWKS WITH CARBOFURAN

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Carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate), 1 of the most widely used insecticides in the United States (Eichers et al. 1978), has been linked by several investigators to acute mortality of songbirds, shorebirds, and waterfowl. The birds killed in these incidents ingested the insecticide when feeding in crops treated with foliar spray (Natl. Res. Counc. Can. 1979) or granular formulations of carbofuran (Flickinger et al. 1980; Overgaard et al., 1983; Balcomb et al., 1984; W. Stone, pers. commun.). This pa-