CONDITION BIAS OF HUNTER-SHOT RING-NECKED DUCKS EXPOSED TO LEAD

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Abstract: We evaluated the condition bias hypothesis for ring-necked ducks (*Aythya collaris*) exposed to lead by testing the null hypothesis that ducks shot by hunters do not differ in physiological condition from those collected randomly from the same location. After adjusting for structural body size and $\log_e$ concentration of blood lead, we found that overall body condition differed significantly between collection types and age classes, and marginally between sexes. Ingesta-free body mass of ring-necked ducks sampled randomly averaged 8.8% greater than those shot over decoys, and 99% of this difference was accounted for by lipid reserves. Ingesta, ash, and protein did not differ between collection types; however, after-hatching-year (AHY) birds had 5.1% more ash and 4.8% more protein than did hatching-year (HY) birds. The only sex difference was that males had 4.1% more protein than did females. Ingesta-free body mass, lipids, and protein were negatively related to concentration of blood lead. Collection type-by-concentration of blood lead and age-by-sex-by-concentration of blood lead interactions were not significant. To the extent that lead pellets persist as a cause of disease or mortality, waterfowl biologists should account for lead exposure as a possible source of condition bias when estimating population parameters and modeling survival of ring-necked ducks and other waterfowl species prone to ingest lead. These findings further underscore the problem that ingested lead shotgun pellets pose for waterfowl.

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Key words: ash, *Aythya collaris*, blood lead concentration, body size, body composition, condition bias hypothesis, hunting mortality, ingesta, lipid, protein.

Abundant evidence indicates that waterfowl and other avian species in poor physiological condition are more susceptible to capture or hunting mortality than are otherwise healthy individuals (Bellrose 1959; Weatherhead and Greenwood 1981; Weatherhead and Ankney 1984, 1985). Among waterfowl species commonly shot by hunters, such condition biases have been well documented for canvasbacks (*Aythya valisineria*; Bain 1980), lesser scaup (*Aythya affinis*; Pace and Afton 1999), mallards (*Anas platyrhynchos*; Greenwood et al. 1986, Hepp et al. 1986, Dufour et al. 1993), American black ducks (*Anas rubripes*; Conroy et al. 1989, Dufour and Ankney 1990), and redheads (*Aythya americana*; Bain 1980; but see Krementz et al. 1989, Sheeley and Smith 1989, Krementz et al. 1990). Proximate explanations for the condition bias effect are numerous and in many cases confounded by factors such as sex, age, and exposure to disease. However, most are believed to derive from the principle of local enhancement, whereby feeding and flocking activities of aggregated individuals serve as attractive signals to nutrient-stressed or diseased individuals seeking food (Hinde 1961, Weatherhead and Greenwood 1981).

One preeminent disease that may factor importantly in the dynamics of hunting mortality is exposure to lead derived from spent shotgun pellets and fishing sinkers (U.S. Department of Interior 1988, Pain 1992, Thomas and Owen 1996). Many studies have documented the outright lethal or debilitating effects of ingested lead and subsequent elevated concentrations of blood lead on the immune system, gastrointestinal function, body composition, and organ size (Clemens et al. 1975, Dieter and Finley 1978, Hunter and Woebeser 1979, Jeske and Thul 1986, Hohman et al. 1990, Pace et al. 1999), while others have documented the existence of elevated lead levels in natural populations (Bellrose 1959, Longcore et al. 1982, Havera et al. 1992, Peters and Afton 1993*a*, Custer and Hohman 1994). In some wetland habitats, where densities of both lead pellets and waterfowl are high, lead poisoning of waterfowl is a recurring problem (Yancey 1953, Wills and Glasgow 1964, Smith 1981, Zwank et al. 1985, Koh and Harper 1988, Harper and Hindmarsh 1990), thus compromising abilities of waterfowl to survive over winter, migrate, and successfully breed (Hohman et al. 1990, 1995). Nonetheless, tests of the effect of lead exposure on condition bias in hunter harvests rarely have been conducted (Heitmeyer et al. 1993).

We present here a test of the condition bias hypothesis for ring-necked ducks exposed to lead (see Peters and Afton 1993*a* for a discussion of ingested lead pellets and concentration of blood lead in the same sample). Like other benthic-foraging diving ducks (e.g., canvasbacks, redheads, lesser scaup), ring-necked ducks are prone to ingest lead as they forage in the substrate. For this reason, rates of ingestion of spent lead shotgun pellets by ring-necked ducks and other *Aythya* consistently rank highest among North American waterfowl (Bellrose 1959; Peters and Afton 1993*a,b;* Hohman and Eberhardt 1998; Moore et al. 1998). Catahoula Lake, Louisiana, in particular, is a logical place to study effects of lead on condition bias because recent studies of ring-necked ducks and canvasbacks have documented elevated or toxic lead concentrations in as many as 73–79% of sampled birds (Hohman et al. 1990, Peters and Afton 1993*a*, Custer and Hohman 1994). Corresponding overwinter survival rates for canvasbacks, in turn, have been as low as 57% (Hohman et al. 1995), but those for ring-necked ducks have not been estimated. In this paper, we evaluate the effect of body condition on hunter harvest susceptibility, paying particular attention to concentration of blood lead and its relationship to various body composition components known to be important in the annual cycle (Hohman 1985, 1986; Alisauskas et al. 1990).

METHODS

We collected 93 ring-necked ducks at Catahoula Lake, a 12,000-ha wetland basin and popular waterfowl hunting area in the Mississippi River floodplain of central Louisiana (31°30′N, 92°08′W), between 30 November 1990 and 10 January 1991 (see Wills 1965, Woolington and Emfinger 1989, and Hohman et al. 1990 for descriptions of Catahoula Lake). Fifty-four ring-necked ducks were collected with a shotgun from a boat at night with the aid of lights (hereafter random sample) between 30 November and 9 December 1990, and 39 were shot over decoys by ourselves ($n = 30$) and hunters ($n = 9$; hereafter hunter-shot sample) between 1 January and 10 January 1991 (see Peters and Afton 1993*a* for a complete description of collecting methods). For the random sample, only flocks ≥3 birds were collected to minimize the chance of accidentally collecting obviously lead-sickened birds (Friend 1987). Age (AHY and HY) of birds was determined using plumage and cloacal characteristics (Hochbaum 1942, Carney 1964, Hohman and Cypher 1986).

Within 15 min of collection, blood was removed from the heart with a 3-ml syringe equipped with a heparinized, 20-gauge needle, and transferred to a 3-ml vial containing EDTA anticoagulent (Peters and Afton 1993*a*). Time elapsed between death and blood collection for donated hunter-shot birds ($n = 9$) was not determined but probably was less than 4 hr. Blood was analyzed for lead concentration (ppm) following procedures outlined in Joselow and Bogden (1972) and Anderson and Havera (1985). Concentrations of blood lead ≥0.20 ppm are considered elevated, whereas those ≥0.50 ppm are considered toxic (Friend 1985, Pain 1996).

Eleven morphometric measurements also were recorded for each individual at the field lab shortly after collection, including body mass (±5 g), total length (±1 mm), bill length (±0.1 mm), culmen length (±0.1 mm), wing length (±1 mm), tarsus length (±0.1 mm), keel length (±0.1 mm), head length (±0.1 mm), bill width (±0.1 mm), head width (±0.1 mm), and center rectrix length (±0.1 mm). Contents of esophagus, proventriculus, gizzard, and intestine also were removed, weighed (±0.1 g), and reported as ingesta. Ingesta-free carcasses subsequently were frozen and shipped to C. D. Ankney at the University of Western Ontario for body composition analysis.

Body Condition Analysis

In Ontario, carcasses were thawed and ground 3 times in a Hobart meat grinder (Hobart Corporation, Troy, Ohio, USA) using 3 different sized plates (10, 5, and 3 mm). A 100-g sample of carcass homogenate was then dried to a constant weight at 90°C. Dried carcass homogenates were then homogenized again with the Hobart grinder using the 3-mm plate. Proximate analysis of carcass homogenate was performed as detailed by Alisauskas and Ankney (1985). For each bird, this involved (1) removing lipids from a 10-g subsample using petro-

Table 1. Least squares means (±SE) of body composition measurements (g) and ingesta adjusted for structural body size and blood lead concentration ($\log_e$), by collection type, age, and sex for ring-necked ducks, Catahoula Lake, Louisiana, 1990–91.

Measurement	Category mean ± SE		$F_{1, 87}$	P
	Random-shot (n = 54)	Hunter-shot (n = 39)		
Body mass[a]	762.0 ± 7.3	700.5 ± 10.7	26.08	0.0001
Ingesta	20.7 ± 0.9	21.5 ± 1.3	0.26	0.6094
Lipid	128.9 ± 4.9	68.0 ± 7.2	57.62	0.0001
Ash	26.3 ± 0.3	26.1 ± 0.5	0.15	0.6949
Protein	163.8 ± 1.3	162.6 ± 1.8	0.32	0.5729
	AHY (n = 61)	HY (n = 32)		
Body mass[a]	737.7 ± 7.1	724.8 ± 12.5	0.76	0.3864
Ingesta	21.2 ± 0.9	20.9 ± 1.5	0.03	0.8544
Lipid	100.1 ± 4.7	96.7 ± 8.3	0.12	0.7297
Ash	26.9 ± 0.3	25.6 ± 0.5	4.05	0.0471
Protein	167.0 ± 1.2	159.4 ± 2.1	8.94	0.0036
	Male (n = 59)	Female (n = 34)		
Body mass[a]	737.8 ± 8.0	724.7 ± 14.8	0.46	0.4997
Ingesta	20.1 ± 1.0	22.1 ± 1.8	0.69	0.4076
Lipid	92.4 ± 5.4	104.5 ± 9.8	0.88	0.3499
Ash	26.4 ± 0.3	26.1 ± 0.6	0.15	0.7022
Protein	166.5 ± 1.4	159.9 ± 2.5	3.96	0.0498

[a] Ingesta-free body mass.

leum ether as a solvent (Dobush et al. 1985) in a modified Soxhlet apparatus, (2) multiplying the dry weight of the subsample by the proportion of lipid that it contained (derived from step 1) to determine total lipid mass, and (3) subtracting total lipid mass from dry mass to determine lean dry mass. Lean dry samples of carcass homogenate (6–9 g) were ashed in a muffle furnace at 550°C for 6 hr. The proportion of ash in each sample was used to calculate total ash content of each bird. Total ash subsequently was subtracted from lean dry mass to obtain ash-free lean dry mass as an index of protein (Mainguy and Thomas 1985).

Statistical Analysis

We used multivariate analysis of covariance (MANCOVA) to test whether overall body condition differed between collection types (random sample vs. hunter-shot), age (AHY vs. HY), and sex (PROC GLM; SAS Institute 1990). Response variables in the model were ingesta-free body mass (±5 g), ingesta (±0.1 g), lipid (±0.1 g), ash (±0.1 g), and protein (±0.1 g). To adjust for allometry, we included an index of structural size as a covariate. We first performed a principal components analysis (PROC PRINCOMP; SAS Institute 1990) using the correlation matrix of 10 structural measurements to construct an index of overall body size (PC1) and 9 indices of shape (PC2–10). In this case, PC1 was observed to account for 55.6% of the total variation (eigenvalue = 5.56) and clearly relates to overall body size, as indicated by positive eigenvectors of approximately equal magnitude (0.23–0.38) for all 10 measurements. Corresponding PC1 scores for each measured individual subsequently were entered into the MANCOVA (PROC GLM; SAS Institute 1990). Log_e of concentration (ppm) of blood lead was included as a second covariate following preliminary analyses of non-transformed blood lead data. F-values reported from MANCOVA were determined using Wilks' lambda. All possible interactions including collection type, age, sex, PC1, and concentration of blood lead ($\log_e$) were included in the full model; however, those terms determined to be nonsignificant were removed iteratively, starting with the highest order interaction, until a single most parsimonious model was obtained. Following a significant MANCOVA, we used analysis of covariance (ANCOVA; PROC GLM, SAS Institute 1990) to determine whether individual response variables differed between explanatory variables and varied with covariates. We report least squares means (±SE) for these analyses (LSMEANS; PROC GLM, SAS Institute 1990) and present significant covariate relationships graphically.

RESULTS

Our final model indicated that overall body condition differed significantly between collec-

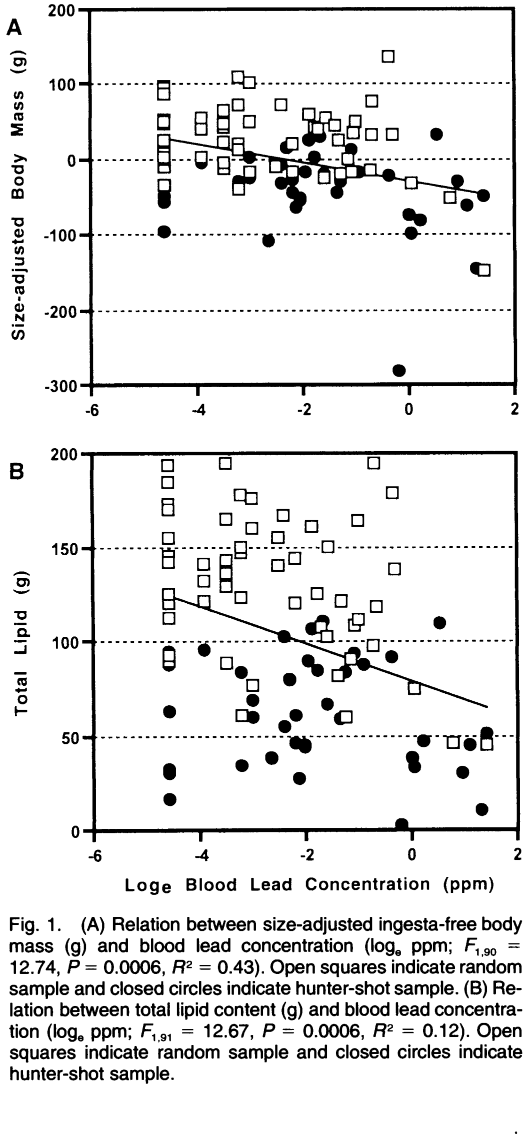

Fig. 1. (A) Relation between size-adjusted ingesta-free body mass (g) and blood lead concentration (log$_e$ ppm; $F_{1,90}$ = 12.74, P = 0.0006, R^2 = 0.43). Open squares indicate random sample and closed circles indicate hunter-shot sample. (B) Relation between total lipid content (g) and blood lead concentration (log$_e$ ppm; $F_{1,91}$ = 12.67, P = 0.0006, R^2 = 0.12). Open squares indicate random sample and closed circles indicate hunter-shot sample.

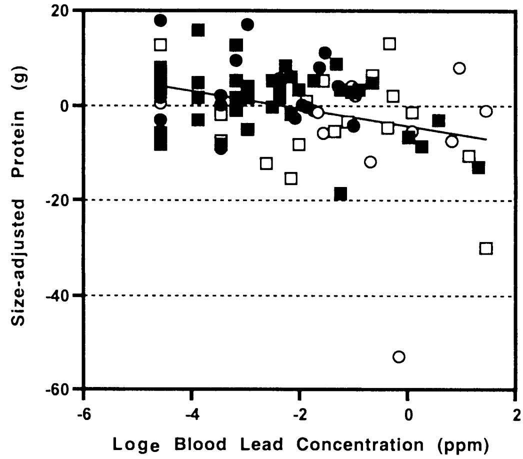

Fig. 2. Relation between size-adjusted protein content (g) and blood lead concentration (log$_e$ ppm; $F_{1,90}$ = 11.46, P = 0.0001, R^2 = 0.59). Closed squares and circles indicate AHY males and AHY females, and open squares and circles indicate HY males and HY females, respectively.

tion types (MANCOVA, $F_{5,83}$ = 16.54, P < 0.0001) and age classes (MANCOVA, $F_{5,83}$ = 3.55, P = 0.0059), and marginally between sexes (MANCOVA, $F_{5,83}$ = 2.24, P = 0.0576). Overall body condition also varied with structural body size (MANCOVA, $F_{5,83}$ = 4.01, P = 0.0026), but not with concentration of blood lead (MANCOVA, $F_{5,83}$ = 1.39, P = 0.2364). However, significant linear relationships between concentration of blood lead and body composition parameters in 3 of 5 subsequent ANCOVAs (P < 0.05) led us to retain lead concentration as a covariate in subsequent univariate analyses. No evidence of colinearity between PC1 and concentration of blood lead was observed ($F_{1,91}$, P > 0.16, R^2 = 0.02), and no interactions among main effects or interactions including PC1 or lead concentration were significant (all Ps > 0.14).

Collection Type, Age Class, and Sex

Despite being collected an average (±SD) of 31 ± 3 days earlier, randomly collected ring-necked ducks had greater ingesta-free body mass and total lipid mass than did hunter-shot birds (Table 1). Approximately 99% of the difference in ingesta-free body mass between collection types was accounted for by lipids. Ingesta, ash, and protein did not differ significantly between collection types (all Ps > 0.57). After-hatching-year ducks had 5.1% more ash and 4.8% more protein than did HY birds (Table 1; ingesta-free body mass, ingesta, and lipid Ps > 0.38). Males had 4.1% more protein than did females (Table 1; ingesta-free body mass, ingesta, lipid, and ash Ps > 0.34). As expected, the structural body size index (i.e., PC1) varied positively with ingesta-free body mass (ANCOVA, $F_{1,87}$ = 11.14, P = 0.0012), ash content (ANCOVA, $F_{1,87}$ = 9.32, P = 0.0030), and protein (ANCOVA, $F_{1,87}$ = 11.23, P = 0.0012), but not ingesta or lipids (Ps > 0.25).

Blood Lead Concentration

Ingesta-free body mass (ANCOVA, $F_{1,87}$ = 5.34, P = 0.0232), lipid (ANCOVA, $F_{1,87}$ = 4.33, P = 0.0403), and protein (ANCOVA, $F_{1,87}$ = 5.03, P = 0.0275) were negatively related to lead concentration in the final model adjusted for collection type, age, sex, and structural body size (Figs. 1, 2). Ingesta and total ash content did not vary significantly with concentration of blood lead (*P*s > 0.20). Collection type-by-concentration of blood lead and age-by-sex-by-concentration of blood lead interactions were not significant (*P*s > 0.27).

DISCUSSION

Our results clearly indicate that ring-necked ducks shot by hunters over decoys generally are in poorer physical condition than those collected randomly. All other factors being equal, we would have expected hunter-shot birds, which were collected an average (±SD) of 31 ± 3 days later, to have gained mass throughout the season (Hohman et al. 1988, Hohman and Weller 1994). Thus, our comparison of collection types was a conservative test. In terms of overall nutrient allocation, differences largely were limited to lipids; i.e., ingesta-free body mass of those sampled randomly averaged about 8.8% greater than those shot by hunters, and 99% of the difference was accounted for by lipid (Table 1). Ingesta, ash, and protein did not differ significantly between collection types. Our results are significant because they reaffirm the fact that condition bias is a common phenomenon among ducks (Bain 1980, Greenwood et al. 1986, Hepp et al. 1986, Dufour et al. 1993, Heitmeyer et al. 1993, Pace and Afton 1999). Adding ring-necked ducks to the list of species that already have been evaluated (i.e., canvasback, lesser scaup, mallard, American black duck, and redhead) further emphasizes the importance of incorporating condition bias indices into survival analyses that otherwise might be confounded by nonrandom mortality.

Size-independent differences in the amounts of ash and protein between AHY and HY birds probably reflect significant age-correlated differences in skeleton ossification and total muscle mass. A similar argument also might be made for between sex differences in size-adjusted protein mass. Muscle mass is expected to be relatively greater in males given their potential for greater physical activity as a consequence of larger overall body size. On the other hand, inverse relationships between size-adjusted ingesta-free body mass, lipid, and protein content and concentration of blood lead further underscore the physiological problems that ingested lead shotgun pellets pose for waterfowl. Nonsignificant interactions with blood lead, however, suggest that debilitating effects of lead do not differ among age, sex, and collection types. Immature ring-necked ducks, in particular, are known to gain mass at higher rates than adults throughout winter, and probably ingest more lead because they spend more time foraging in the substrate (Hohman et al. 1988, Peters and Afton 1993*a*). However, our results contrast those of previous studies (Mautino and Bell 1986, Sanderson and Bellrose 1986) and do not indicate that immature birds differ from adults in sensitivity to lead.

MANAGEMENT IMPLICATIONS

Our results are relevant to band recovery, harvest, survival estimates, and to conservation problems arising from lead intoxication. We advocate continued efforts to monitor and reduce the opportunity for lead exposure in ring-necked ducks and other species. To the extent that spent shotgun pellets persist as a source of environmental pollution, lead exposure is likely to have far-reaching effects on overwinter survival (including hunting mortality), not to mention subsequent abilities to migrate and reproduce successfully. On the other hand, occurrence of and exposure to lead shot is decreasing and will continue to do so for the foreseeable future. Survival analyses that rely upon data gathered from places where lead pellets are common (i.e., many wildlife management areas with long histories of hunting) are likely to be confounded by these factors and must be dealt with accordingly. In conducting studies, researchers need to recognize and account for lead as a possible source of condition bias.

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