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Arsenic, Cadmium, Copper, Lead, and Selenium in Migrating Blue-Winged Teal (*Anas discors* L.)

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Abstract. The blue-winged teal (*Anas discors* L.), an abundant waterfowl species in North America, winters primarily in Mexico, Central America, and South America. Its transcontinental migratory behavior provides the opportunity to examine contaminant acquisition across a diverse biogeographic landscape that has varied environmental regulations and wildlife laws. We determined concentrations of arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), and selenium (Se) in liver samples of blue-winged teal migrating through southern Texas during autumn 1998 ($n = 47$) and spring 1999 ($n = 46$). Concentrations for As (range 0.006 to 0.22 µg/g wet weight [ww]), Cd (range 0.007 to 8.14 µg/g ww), and Pb (range 0.012 to 1.79 µg/g ww) were at background levels for birds, whereas Cu (8.1 to 227.3 µg/g ww) and Se (0.36 to 5.07 µg/g ww) were increased in several individuals. All 24 hatch-year (HY) blue-winged teal had detectable levels of Cd, Cu, Pb, and Se, and eight had detectable levels of As. A seasonal effect was found for Cd, in which the mean Cd concentration in autumn was lower ($p < 0.015$) than in spring. Comparisons between autumn-collected HY and autumn-collected after-hatch-year (AHY) blue-winged teal found the mean concentration of Cd was higher ($p < 0.001$) in AHY birds. A seasonal effect occurred for Cu, in which the mean concentration was higher ($p < 0.001$) in autumn than in spring. Comparisons between seasons using only AHY blue-winged teal found that the mean concentration of Cu was higher ($p < 0.001$) in autumn than in spring. No sex effects ($p > 0.05$) were found for the five elements examined. Results indicated that blue-winged teal were acquiring all five elements; that HY blue-winged teal were exposed to these elements in North America; and that increased Se concentrations in 15% of the 93-bird sample were at levels known to cause impairment in birds.

Interest has continued in monitoring waterfowl for environmental contaminants as a way to assess the health of this economically important group (Ohlendorf *et al*. 1986, Cain & Feierabend 1988; Cohen *et al*. 2000), to evaluate outcomes of contaminant restrictions (Moore *et al*. 1998; Stevenson *et al*. 2005), and to determine effects of biomagnifying contaminants on higher-order trophic levels (Gochfeld & Burger 1982; Cohen *et al*. 2000). With a transcontinental migratory species, this becomes even more important, because they can acquire environmental contaminants across diverse biogeographic and geopolitical landscapes that have varying environmental regulations and laws.

The blue-winged teal (*Anas discors* L.) is an ideal species to evaluate environmental contaminants across a multicountry geographic distribution. First, it is one of the few waterfowl species that has an extensive migratory pattern extending from northern breeding grounds in Alaska and Canada to southern wintering grounds in Mexico, Central America, and South America (Bellrose 1980; Rohwer *et al*. 2002). Second, it is the second most-abundant waterfowl species in North America (United States Fish and Wildlife Service 2004a) and is an actively promoted game species (*i.e.*, special teal season). Third, numerous studies in the United States have focused on elemental contaminants in tissues of diving ducks (Ohlendorf *et al*. 1986; Custer & Hohman 1994; Michot *et al*. 1994; Hothem *et al*. 1998; Custer *et al*. 2003) and various species of diving and dabbling ducks (Di Giulio & Scanlon 1984; Burger & Gochfeld 1985; Gochfeld & Burger 1987; Blus *et al*. 1995), whereas only one peer-reviewed published study examined a suite of eight elements in blue-winged teal from North America (Warren *et al*. 1990).

We initiated this study to determine levels of arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), and selenium (Se) in blue-winged teal migrating through southern Texas. Additionally, we determined whether concentrations varied by season, age, and sex and assessed potential effects on blue-winged teal, based on scientific literature describing the toxicologic impacts of these elements in birds.

Materials and Methods

Sample Collection and Processing

Blue-winged teal were collected by shotgun using steel shot in Kleberg and Nueces counties, Texas, during September 1998 and

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February and March 1999. Both Texas counties are located along the Gulf of Mexico and represent migratory stopover points for autumn migrants wintering in the Tabasco lagoons and in the Isthmus of Tehuantepec, Mexico, as well as returning migrants on their way to breeding grounds in the United States and Canada (Bellrose 1980). Collection periods coincided with blue-winged teal migration through southern Texas (Bellrose 1980). The collection method was chosen to add an element of randomness into the sampling effort and to avoid biases associated with using baited-trap stations. However, this method samples "normal" birds (*i.e.*, those that are capable of flight and maintaining flock membership or pair-bond relationships). Consequently, our collection method did not sample individuals that were found dead or those too weak to fly. Therefore, data presented and interpretations thereof regarding the hazard of these trace elements to blue-winged teal populations should be viewed within this context.

Collections outside the special teal hunting season were conducted under permits issued by the Texas Parks and Wildlife Department (SPR-0498-949) and the United States Fish and Wildlife Service (MB000430). This study was conducted in accordance with Texas A&M University-Kingsville's Institutional Animal Care and Use Committee (Authorization No. Y2K-6-1).

Age (hatch-year [HY] and after hatch-year [AHY]) and sex were determined using plumage characteristics (Carney 1992) and corroborated with characteristics of the bursa and gonads. Carcasses and viscera were separated in the field and placed into individually marked freezer bags. Sealed bags containing viscera were fast frozen in the field by immersion into a container of ethyl alcohol and dry ice. Carcasses and viscera were stored at −10°C. On necropsy, a 10-g sample of liver was excised from each bird with a scalpel, placed in an individually marked plastic bottle (TraceClean, VWR International, West Chester, PA), and refrozen. Bottled liver samples were placed in a Styrofoam container with dry ice and shipped to The Institute of Environmental and Human Health at Texas Tech University for analyses.

Chemical Analyses

All samples were nitric acid digested according to slight modifications of published methods (Reynolds *et al.* 2006). Instrumental analysis was conducted using a PerkinElmer AAnalyst 600 Graphite Furnace-Atomic Absorption Spectrometer (GF-AAS) and PerkinElmer AA WinLab (version 3.71) instrument control software (PerkinElmer Life and Analytical Sciences, Inc., Waltham, MA). Five-point calibration curves were developed for each analyte to provide quantitative instrumental analyses using traceable standards (DOLT-2; NRCC, Ottawa, Canada) for all standard preparations. Complete calibrations were performed daily, and calibration checks were performed after analysis of every 10 digested samples.

The method reporting limit (lowest calibration standard in μg/ml) for each of the elements was As 0.001, Cd 0.00003, Cu 0.002, Pb 0.001, and Se 0.010. The tissue reporting limit (TRL; lowest detectable concentration in tissue based on average tissue weight in μg/g) was As 0.012, Cd 0.0003, Cu 0.024, Pb 0.012, and Se 0.122. For presentation of summary data and statistical comparisons, values lower than the detection limit were replaced with 1/2 TRL.

Elemental values are presented as ww. For comparison with studies reporting dry weight (dw) values, conversion of dw to ww values was based on the assumption that ww moisture content of liver was approximately 70% (Ohlendorf *et al.* 1986).

Statistical Analyses

Nonnormally distributed data were log transformed. Differences in element concentrations were analyzed for main effects (season, age, and sex) and their interactions using analysis of variance or Kruskal-Wallis test (SigmaStat V.3.10, Systat Software Inc., San Jose CA) for data that were unable to meet normality through log transformation.

Results

Ninety-three blue-winged teal were sampled, of which 47 (HY 24 and AHY 23) were collected during September 1998 and 46 during February and March 1999. Autumn-collected blue-winged teal included 34 male and 13 female birds, whereas the spring collection included 23 male and 23 female birds. Mean concentrations and ranges of As, Cd, Cu, Pb, and Se are listed in Table 1. Overall, As had the lowest concentration of the elements examined. In the autumn collection, 27 (57%) blue-winged teal had lower-than-TRL concentrations of As (16 were HY birds), whereas the spring collection yielded 23 (50%) individuals with lower-than-TRL concentrations of As. The remaining elements were found in higher-than-TRL concentrations for each of the birds tested. The next lowest mean concentration after As was Pb, followed by Cd, Se, and Cu (Table 1).

No significant interactions ($p > 0.05$) were found among season, age, and sex for the five elements examined. In addition, no sex effects ($p > 0.05$) were found. A seasonal effect was found for Cd, in which the mean concentration was higher ($p < 0.015$) in spring-collected blue-winged teal (0.73 μg/g) than the mean concentration in autumn-collected birds (0.37 μg/g). In autumn-collected blue-winged teal, the mean concentration of Cd was lower ($p < 0.001$) in HY (0.19 μg/g) than in AHY birds (0.55 μg/g). Only 7 of 24 (29%) HY birds had concentrations >0.2 μg/g, whereas concentrations in 20 of 23 (87%) AHY birds exceeded this value. A seasonal pattern for Cu was found, in which mean Cu was higher ($p < 0.001$) in autumn-collected blue-winged teal (64.5 μg/g) than mean Cu in those collected in spring (33.6 μg/g). In addition, comparisons using AHY blue-winged teal found a higher ($p < 0.001$) mean Cu concentration in those collected in autumn (75.7 μg/g) than in birds collected in spring (33.6 μg/g).

Discussion

Concern continues about waterfowl acquiring environmental contaminants. Clearly, all five trace elements examined in this study are being acquired by blue-winged teal that migrate through southern Texas. Although it is uncertain where exposure occurred in AHY individuals, elements found in HY individuals demonstrated that acquisition occurred before they left the United States for southern wintering areas.

As

As may be a micronutrient for some vertebrates (Eisler 1988a). This has been reported in studies primarily focusing on diving ducks using coastal wetlands (Custer & Hohman 1994; Michot *et al.* 1994; Cohen *et al.* 2000), likely because marine systems tend to concentrate this element (Eisler 1988a). We found no studies reporting As in blue-winged teal. Thus, the current study provides baseline information for this element. The

Table 1. Concentrations (μg/g ww) of As, Cd, Cu, Pb, and Se in liver of blue-winged teal collected in southern Texas during autumn 1998 and spring 1999

Sample	As				Cd			Cu			Pb			Se		
	n	$\bar{x}$	SD	Range[a]	$\bar{x}$	SD	Range	$\bar{x}$	SD	Range	$\bar{x}$	SD	Range	$\bar{x}$	SD	Range
Autumn HY	24	0.01	0.02	0.006–0.08	**0.19**[b]	0.16	0.027–0.66	53.8	33.7	8.6–128.3	0.08	0.08	0.012–0.39	1.41	0.80	0.55–4.07
Autumn AHY	23	0.02	0.05	0.006–0.22	**0.55**	0.25	0.007–1.00	**75.7**[c]	51.5	16.7–227.3	0.18	0.36	0.021–1.79	1.42	0.48	0.60–2.41
Spring AHY	46	0.02	0.03	0.006–0.15	0.73	1.33	0.081–8.14	**33.6**	22.3	8.1–141.7	0.11	0.11	0.019–0.58	1.51	0.82	0.36–5.07
All	93	0.02	0.03	0.006–0.22	0.55	0.97	0.007–8.14	49.2	38.2	8.1–227.3	0.12	0.20	0.012–1.79	1.46	0.74	0.36–5.07

[a] 1/2 TRL for As was 0.006 based on mean tissue weight of 0.823 g; minimum values for each of the remaining elements were higher than their respective TRL.
[b] Cd was significantly different ($p < 0.001$) between autumn HY and autumn AHY blue-winged teal.
[c] Cu was significantly different ($p < 0.001$) between autumn AHY and spring AHY blue-winged teal.

maximum concentration of As was lower than the 5-μg/g ww threshold reported as the upper limit for background levels (Goede 1985). This suggests that individuals sampled in our study were not being substantially exposed to or accumulating As, although coastal wetland habitats are used by migrating blue-winged teal.

Cd

Cd is a nonessential element in which a liver concentration >10 μg/g ww is thought to indicate increased environmental exposure in birds (Eisler 1985a; Scheuhammer 1987). Furness (1996), in his review of the avian literature for Cd, suggested that 40 mg/kg (40 μg/g) Cd in liver tissue of birds should be considered the threshold for Cd poisoning with the caveat that there is wide variation in toxicity among species. Di Giulio (1982), in a penned-mallard (*A. platyrhynchos*) study, reported Cd-induced alterations in energy metabolism at 7.4 μg/g dw (approximately 2.2 μg/g ww) and, based on these findings, suggested that a concentration of 5 μg/g dw (approximately 1.5 μg/g ww) was a reasonable minimum value associated with significant alteration in metabolism. In our study, none of the blue-winged teal had increased levels of Cd (*i.e.*, >10 μg/g), but three adults from the spring collection had concentrations >1.5 μg/g (2.79, 4.29, and 8.14 μg/g).

A seasonal effect was observed for Cd in which blue-winged teal collected in autumn had a lower mean concentration of Cd than those collected in spring. When only AHY birds were compared by season, mean Cd concentrations were not significantly different. Thus, variation appeared to be attributable to HY individuals in the autumn sample, in which mean concentration of the HY birds was significantly lower than that in autumn-collected AHY birds. This finding supports the conclusion of Furness (1996), that Cd accumulates with age in birds. An age effect was observed in blue-winged teal migrating through the Southern High Plains of Texas (Warren *et al*. 1990) and in canvasbacks (*Aythya valisineria*) wintering in Louisiana (Custer & Hohman 1994). However, Michot *et al*. (1994) did not find age-specific Cd variation in redheads (*Aythya americana*) wintering in coastal Louisiana and Texas.

Cu

Cu is an essential element that serves various metabolic purposes in animals (Schroeder *et al*. 1966; Eisler 1998). Eisler (1998) reported that birds can acquire Cu from natural sources and human-related activities, including copper production, burning fossil fuels, and aquatic biocides. Waterfowl accumulate this essential micronutrient (Di Giulio & Scanlon 1984; Gochfeld & Burger 1987; Warren *et al*. 1990). In the present study, mean concentrations were higher than those reported in migratory blue-winged teal from the Southern High Plains of Texas (Warren *et al*. 1990) and other waterfowl (Michot *et al*. 1994; Mateo & Guitart 2003). The maximum value of Cu in our study (227.3 μg/g) was twice the mean concentration (367 μg/g dw, approximately110 μg/g ww) found in common eiders (*Somateria mollissima*) using a heavily polluted Norwegian fjord (Lande 1977). Unfortunately, background and toxic levels for Cu in wild birds have not been clearly established (Eisler 1998), and it is uncertain if the increased concentrations found in blue-winged teal represent a health hazard.

A seasonal effect was found for Cu in which it appeared to be acquired in autumn-collected blue-winged teal but lost in spring-collected birds. This seasonal pattern was observed in muscle (but not liver) tissue by Warren *et al*. (1990), who suggested that lower levels observed in spring-collected blue-winged teal might reflect depleted reserves as Cu was mobilized for feather production. In addition, Osborn (1979) found Cu to vary seasonally in starlings (*Sturnus vulgaris*), particularly in relation to molt; he attributed changing concentrations of Cu to seasonal changes in fat content of liver.

Pb

Lead is an element with no known benefit to organisms (Eisler 1988b). Lead intoxication in waterfowl is primarily caused from ingestion of Pb shotshell pellets and has been well documented in the literature (see review of Pain 1996). In our study, mean concentrations and maximum observed values of Pb were lower than levels considered to have negative effects on waterfowl (Longcore *et al*. 1974; Pain 1996; Beyer *et al*. 1998). To decrease exposure to Pb by waterfowl, Pb shotshells for waterfowl hunting have been banned by the United States government since 1991 (United States Fish and Wildlife Service 2004b). In Canada, nontoxic shotshells have been required for hunting in wetland areas beginning in 1997 (Scheuhammer & Norris 1995). However, substantial amounts of Pb remain in wetland ecosystems and represent a source of continued contamination (Thomas & Guitart 2003). Additionally, Mexico has not established countrywide regulations aimed at decreasing use of Pb shot (Thomas & Guitart 2005); only one nontoxic shot zone has been established, which is in the state of Yucatan (Scheuhammer & Norris 1995). This suggests that exposure could also be occurring on wintering areas south of the United States border. Based on spring collections, there is no evidence that blue-winged teal migrating through southern Texas are being exposed to increased levels of Pb on wintering grounds south of the United States. However, Schulz *et al*. (2002) found that testing hunter-shot mourning doves (*Zenaida macroura*) had underestimated Pb toxicosis because the sample included only those birds still capable of flight. Thus, our collection method may not adequately reflect Pb exposure and acquisition.

Se

Of concern is the increased concentration of Se found in several blue-winged teal. Although this element is a micronutrient, excessive amounts have adverse consequences for avifauna (Eisler 1985b). In his review, Hoffman (2002) reported evidence of decreased immune system function at 5 μg/g (ww) Se in liver of adult mallards and increased plasma glutathione peroxidase (GPX) activity at 2 μg/g (ww) Se in liver. Increased GPX activity resulting from Se exposure is an indication of oxidative stress (Hoffman 2002). Heinz (1996), summarizing findings of various avian studies, suggested that reproductive impairment in egg-laying female birds could occur when Se in liver exceeds 3 μg/g and noted that various sublethal effects occur in birds when Se exceeds 10 μg/g. In our study, Se did not exceed 10 μg/g in any individual; however, three male birds and one female bird (4% of blue-winged teal) had levels exceeding 3.0 μg/g, and 14 blue-winged teal (15%) had Se levels ≥2.0 μg/g, suggesting at least some negative effect.

In conclusion, we found that migratory blue-winged teal were acquiring each of the five trace elements in North America; that there was a seasonal effect for Cd and Cu; and that there was an age effect for Cd. Maximum values were within background levels reported in birds for As, Cd, and Pb, whereas increased concentrations occurred for Cu and Se. Although Cu had the highest concentrations found of the elements examined, it remains uncertain at what level this micronutrient elicits sublethal effects in avian wildlife (Eisler 1998). Finding Se concentrations sufficient to cause impairment in 15% of the individuals sampled suggests that some negative effects are occurring in blue-winged teal migrating through southern Texas.

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