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Coal fly ash basins as an attractive nuisance to birds: Parental provisioning exposes nestlings to harmful trace elements

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ABSTRACT

Birds attracted to nest around coal ash settling basins may expose their young to contaminants by provisioning them with contaminated food. Diet and tissues of Common Grackle (*Quiscalus quiscala*) nestlings were analyzed for trace elements to determine if nestlings were accumulating elements via dietary exposure and if feather growth limits elemental accumulation in other tissues. Arsenic, cadmium, and selenium concentrations in ash basin diets were 5× higher than reference diets. Arsenic, cadmium, and selenium concentrations were elevated in feather, liver, and carcass, but only liver Se concentrations approached levels of concern. Approximately 15% of the total body burden of Se, As, and Cd was sequestered in feathers of older (>5 days) nestlings, whereas only 1% of the total body burden of Sr was sequestered in feathers. Feather concentrations of only three elements (As, Se, and Sr) were correlated with liver concentrations, indicating their value as non-lethal indicators of exposure.

1. Introduction

Impoundments used to store or treat industrial wastewater often create habitats attractive to many species of wildlife (Rowe et al., 2002) including birds. Landscape features of these impoundments often include wooded edges, open herbaceous areas, and open water and can provide nesting habitat for birds (e.g., shrub and tree edges) as well as abundant and diverse prey populations (e.g., insects, amphibians and fish). However, depending on their location and function, these impoundments may attract wildlife into areas that pose substantial risks to their health. For example, coal combustion waste water impoundments attract amphibians which contain elevated levels of metals, affecting their development, reproduction, and survival (Rowe et al., 2002; Snodgrass et al., 2004, 2005; Hopkins et al., 2006).

Coal and coal combustion by-products, primarily fly ash, are sources of multiple contaminants to both aquatic and terrestrial systems, creating both historic and present-day examples of ecological damage (Skorupa, 1998; Lemly, 2002; NRC, 2006, Rowe et al., 2002; Ruhl et al., 2009). These by-products can contain toxic levels of several bioavailable trace elements such as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), selenium (Se), and strontium (Sr) (Rowe et al., 2002). Early studies of fly ash releases into Belews Lake and Hyco Reservoir (both in North Carolina) and Martin Creek Reservoir (Texas) documented uptake of contaminants by aquatic biota, most frequently reporting adverse effects of Se on the resident fish communities (Lemly, 1996, 2002). Adverse effects have also been reported for amphibians, fish, and reptiles inhabiting settling impoundments receiving slurried ash from a coal-fired power plant located on the U. S. Department of Energy's Savannah River Site (Hopkins et al., 1998, 2003; Nagle et al., 2001; Rowe et al., 1996). The 2008 release of fly ash effluent associated with the Kingston (TVA) plant in Tennessee provides a recent example of how these disposal systems threaten nearby aquatic systems and their resident biota (Ruhl et al., 2009).

Studies of adverse effects of fly ash releases on avian species are limited, but demonstrate maternal transfer of trace elements and provide evidence of reproductive impacts. At the Martin Creek Reservoir, King (1988) and King et al. (1994) documented maternal transfer of Se to eggs by Red-winged Blackbirds (*Agelaius phoeniceus*) and Barn Swallows (*Hirundo rustica*), both insectivorous species, as well as suppressed (>50%) egg hatchability by blackbirds. Bryan et al. (2003) examined maternal transfer of elements to Common Grackle (*Quiscalus quiscala*) eggs in nests associated with aquatic ash disposal sites and documented significantly higher

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concentrations of Se in eggs from the ash basins compared to a reference site (5.9 ug/g Se vs. 2.7 ug/g Se dry wt., respectively). The elevated Se levels were greater than background, but did not exceed concentrations expected to influence hatchability in most birds (Heinz, 1996; Fairbrother et al., 1999; Janz et al., 2010). No other contaminants associated with fly ash were maternally transferred in excessive concentrations. However, all of these studies were limited to maternal transfer of contaminants to eggs and did not examine contaminants accumulated by the nestlings through parental provisioning during the nestling period. Altricial nestlings are generally characterized by very fast and resource-demanding growth (Stark and Ricklefs, 1998), requiring extensive parental provisioning for normal development and fledging (Gebhardt-Henrich and Richner, 1998; Lindström, 1999).

To examine whether parental provisioning provides another pathway of contaminant exposure for Common Grackles nesting around coal ash basins, we analyzed trace elements in nestling diet (crop contents) and nestling tissues to document trophic exposure. We compared tissue concentrations in younger (≤5 days post-hatch) and older (>5 days) nestlings to determine if accumulation varied with age of nestlings. We also examined metal concentrations in feathers of older nestlings to determine if feather

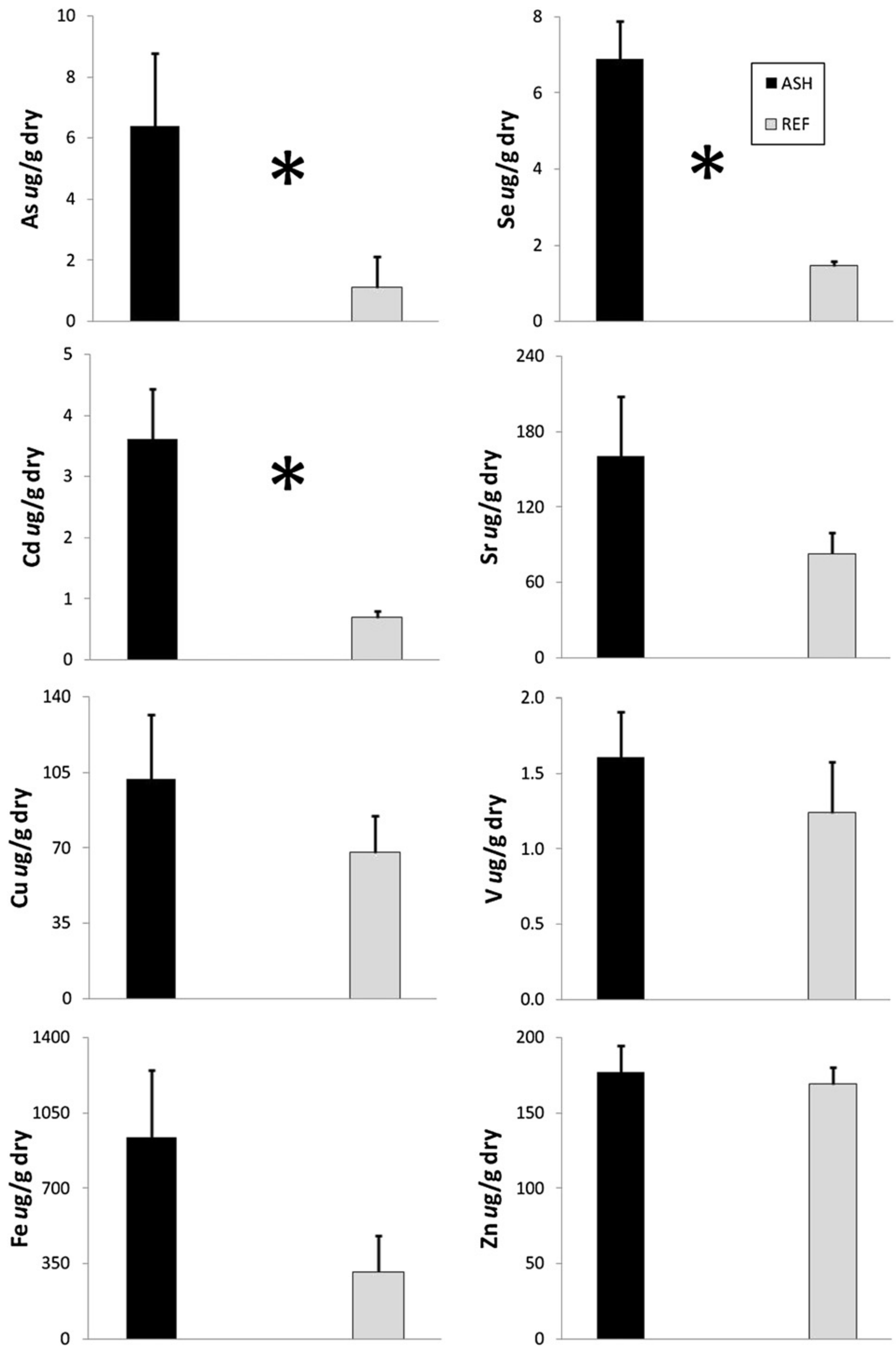

Fig. 1. Mean (±standard error) concentrations (ug/g dry weight) of selected trace elements in crop contents of Common Grackle (*Quiscalus quiscala*) nestlings collected from ash basin and reference sites. Asterisks indicate significant differences (ANOVA $P < 0.05$).

collection could be used as a non-lethal sampling method to assess metal concentrations in other more vital tissues.

2. Methods

2.1. Study species

The Common Grackle is a large blackbird species that is a semi-colonial nester and commonly nests near water. During the breeding season, both parents typically collect insects and seeds to feed their altricial young, although their diet is relatively broad (Peer and Bollinger, 1997). Nestling mass increases from approximately 5.5 g at hatching to 58 g at 11 days post-hatch. Young are fully feathered by day 16. Nestlings typically depart the nest between 12 and 15 days post-hatch, but adults can continue to feed their young for several weeks after fledging (Howe, 1976). Fledgling grackles initially disperse from their natal site distances ranging from only a few feet to 0.5 km (Buckingham, 1976; Peer and Bollinger, 1997).

2.2. Study sites

The D-area coal-fired power plant located on the U. S. Department of Energy's Savannah River Site (SRS) in west-central South Carolina, USA, discharges slurried ash into a series of settling impoundments (two open basins and a drainage swamp) before surface waters enter Beaver Dam Creek and eventually the Savannah River. Grackles nest in shrubs and tall grasses on islands within, and edges around, these impoundments. Studies of contaminant uptake by other wildlife species at these basins confirmed the bioavailability of pollutants to wildlife (Hopkins et al., 1998, 2003; Rowe et al., 1996), including grackles (Bryan et al., 2003). The reference site, a series of small impoundments where grackles nest in bordering dense shrubs, is approximately 16 km from the D-area power plant and has no historical input of coal combustion waste or other industrial by-products.

2.3. Field collections

Grackle nests at both sites were monitored several times weekly to document hatching dates, which were used to estimate age. We collected nestlings from both sites for overall site comparison of trace elements and categorized them relative to their estimated age: young ($\leq$5 days post-hatch) or old ($>$5 days post-hatch). Nestlings were collected from 18 ash basin nests and 12 reference nests from 21 April 2000 through 23 June 2000. In total, 30 nestlings (19 young, 11 old) were collected from the ash basins and 31 nestlings (14 young, 17 old) were collected from the reference site. All nestlings were euthanized by approved methods, weighed (whole nestling), then frozen prior to dissection and elemental analyses. Whole livers were removed from all nestlings. Crop contents also were removed from all nestlings and individual prey items identified to the lowest taxonomic level possible (e.g., Family). All down/feathers were removed from older nestlings ($>$5 days post-hatch). Remaining tissues were analyzed together and classified as carcass.

2.4. Trace element analyses

Grackle nestling tissues and crop contents from the polluted and reference sites were lyophilized and homogenized prior to analysis for trace elements. Grackle feathers were washed in a mild metal-free detergent and rinsed in deionized water prior to this process. Crop contents for individual nestlings were analyzed as composite samples (all individual prey items within a crop were combined for analysis). Homogenates were then digested and analyzed for trace element concentrations (As, Cd, Cu, Fe, Se, Sr, V and Zn) according to the following procedures. Approximately 150 mg dry wt. of sample was used for digestion. Trace-metal grade nitric acid (2.5 ml) was added to samples before digestion in a microwave (Elan 6000 DRC, CEM Corp., Matthews, NC) with heating steps of 60, 60, 70, and 80 percent microwave power for 10, 10, 15, and 20 min, respectively. Next, 1.0 ml of H_2O_2 was added to the samples and microwaved at the same power and duration as the HNO_3 digestion. After digestion, samples were brought to a final volume of 10 ml with 18 MΩ deionized water. Trace element analysis was performed by ICP-MS (Perkin Elmer, Norwalk, CT) on samples diluted 1:1 with deionized water. Calibration standards covering a range of 1–500 μg/L were prepared daily by serial dilution of NIST traceable primary standards. Certified reference material (Tort 2; NRC, Ottawa, Canada) and blanks were included in the digestion and analysis procedure for quality control purposes. Mean percent recoveries for trace elements in tissue certified reference material ranged from 97 to 121%. Variability in mean percent recoveries of certified reference materials among digestion sets ranged from 5 to 15%. Instrument detection limits for As, Cd, Cu, Fe, Se, Sr, V, and Zn were 0.21, 0.30, 1.70, 9.92, 0.73, 0.71, 0.09, and 2.37 μg/kg dry mass, respectively. All concentration data are presented on a dry weight (DW) basis in text, tables and figures.

2.5. Statistical analyses

Elemental concentrations in crop contents were compared between sites for individual elements by one-way ANOVA.

To determine whether age or body mass influenced trace element accumulation in liver or carcass of grackles at each either site, we conducted a series of regression analyses. Age and body mass were highly correlated ($r = 0.94$; $p < 0.0001$) and produced similar results in the regressions with trace element concentrations. Therefore, only body mass is discussed in further analyses. Because accumulation of several elements was influenced by body mass but others were not (see results), we analyzed each element separately using a series of 2-way ANOVAs with site and tissue (liver and carcass) as main effects in the models. In cases where body mass explained a significant portion of the variance, it was included as a covariate in the model. The exception to our approach was Cd, which was below instrument detection limits (BDL) in >50% of liver samples from the reference site. Because of the large number of non-detects, we did not statistically compare liver concentrations of Cd. However, Cd concentrations of carcasses were compared between sites using one-way ANOVA. Body mass and trace element concentrations were log-transformed to better approximate assumptions of parametric statistics. Because none of the elements quantified in grackle tissue were independent of one another, we applied a sequential Bonferroni adjustment to maintain an experiment wide error rate of $\alpha = 0.05$.

Because feathers can be a useful nondestructive index of exposure to certain pollutants (Burger et al., 1993), we examined the relationship between concentrations of elements in feathers and in carcass and liver using Pearson correlation coefficients calculated from log-transformed data. In some cases, feathers can be a significant route of elimination of pollutants (Burger et al., 1993). To examine the importance of feathers in this regard, we reconstructed tissue (carcass, liver, feather) burdens (μg) and total body burdens (μg) for each element using methods similar to those presented by Hopkins et al. (2005). We examined the influence of size (for age)

Table 1
Concentrations of trace elements in Common Grackle (*Quiscalus quiscala*) nestlings relative to site (ash basin vs. reference), tissue type (liver and carcass) and nestling mass.

Element		*F*	*P*	Element		*F*	*P*
As	Overall Model	17.3	<0.0001	Se	Overall Model	109.4	<0.0001
	Site	22.4	<0.0001		Site	411.6	<0.0001
	Tissue	13.1	<0.0004		Tissue	20.5	<0.0001
	Site*Tissue	0.2	0.6780		Site*Tissue	0.5	0.4827
	log Mass	33.4	<0.0001		log Mass	4.9	0.0290
Cd[a]	Overall Model	45.0	<0.0001	Sr	Overall Model	236.0	<0.0001
	Site	52.4	<0.0001		Site	77.4	<0.0001
	log Mass	37.5	<0.0001		Tissue	849.7	<0.0001
					Site*Tissue	4.0	0.0478
					log Mass	10.6	0.0015
Cu	Overall Model	65.0	<0.0001	V	Overall Model	3.0	0.0205
	Site	3.0	0.0874		Site	1.4	0.2336
	Tissue	255.0	<0.0001		Tissue	2.7	0.1043
	Site*Tissue	2.0	0.2231		Site*Tissue	1.3	0.2488
	log Mass	1.0	0.4539		log Mass	6.6	0.0117
Fe	Overall Model	66.1	<0.0001	Zn	Overall Model	5.6	0.0004
	Site	0.1	0.9541		Site	0.6	0.4334
	Tissue	249.1	<0.0001		Tissue	4.8	0.0305
	Site*Tissue	1.7	0.1939		Site*Tissue	0.6	0.4539
	log Mass	12.9	<0.0005		log Mass	16.4	<0.0001

[a] High numbers of BDL liver concentrations of Cd prevented inclusion of tissue within the model.

on total body burden using linear regression. To determine whether birds from the two sites partitioned elements differently among their tissues, we compared the % of an individual's total trace element burden that was partitioned within liver and carcass using a series of 3-way ANOVAs on arcsin square root-transformed data. In addition to site and tissue, size was included as a class variable in the model. Because only larger/older nestlings had feathers, contaminant burdens within feathers could not be directly compared statistically between young and old birds.

3. Results

3.1. Concentrations in crop contents

Examination of crop contents of 28 ash basin nestlings and 30 reference site nestlings revealed the dominant prey items to be insects, comprising 60% and 48% of diet (by frequency) for ash and reference nestlings, respectively. Insect matter consisted of a multitude of taxa including Coleoptera, Hemoptera, Hymenoptera, Lepidoptera, Odonata, and Orthoptera. Plant material was the second highest dietary component by frequency, making up approximately 18% of the items for both sites. Additional items found in crop contents at both sites but with reduced frequency were arachnids, reptiles (i.e., skink), amphibians, and unidentified animal matter. Concentrations of As, Cd, and Se were significantly elevated in ash basin crop contents compared to reference site contents by a factor of approximately 5 ($P < 0.03$, Fig. 1). Strontium and Fe concentrations also appeared higher in ash basin crop contents, but were highly variable at both sites and not significantly different ($P \geq 0.11$).

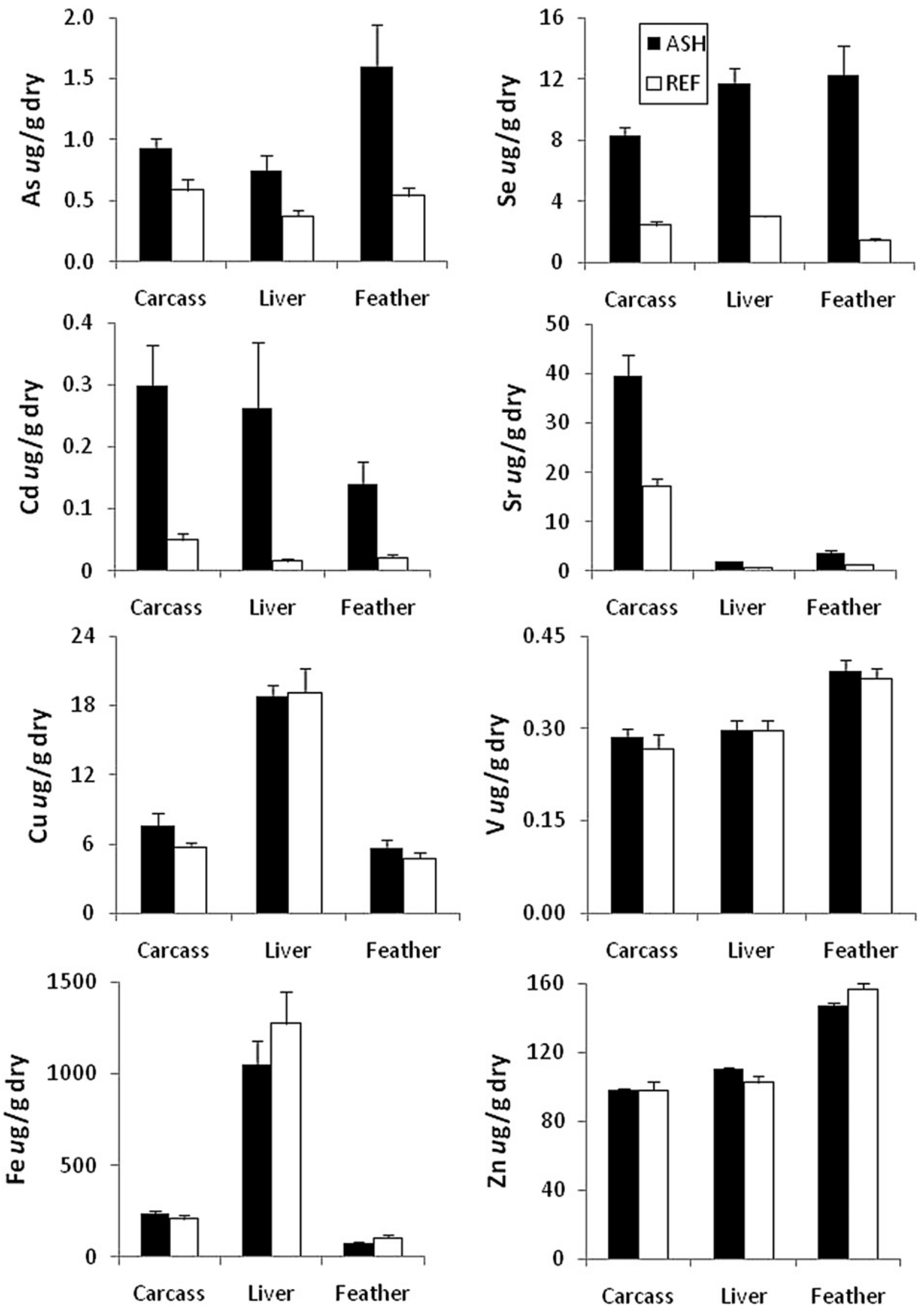

Fig. 2. Mean (±standard error) concentrations (ug/g dry weight) of selected trace elements in tissues of Common Grackle (*Quiscalus quiscala*) nestlings collected from ash basin and reference sites.

3.2. Concentrations in nestling tissues

Arsenic, Cd, Se, and Sr concentrations in grackle nestling tissues (liver & carcass; Table 1) were significantly higher at the ash site compared to the reference site (Fig. 2). Concentrations of all elements except V varied significantly between tissue types (liver & carcass; Cd was not included in analyses), although the degree of differentiation varied considerably. Liver had the highest concentrations for Se, Fe, Cu, and Zn, and carcass had higher concentrations for Sr and As. All elements except Cu varied relative to nestling mass (Table 1), with slightly higher concentrations found in heavier (older) nestlings.

Pearson correlation analyses demonstrated strong positive relationships ($r > 0.82$) between feather and liver concentrations of As, Se, and Sr (Table 2). These same three elements and Cd exhibited moderate to strong positive relationships ($r > 0.57$) between feather and carcass concentrations.

Total body burdens and the percentage of body burdens in individual tissues of each element varied widely among tissues and nestling mass/age (Table 3 and Fig. 3). Total body burdens also varied between sites, but partitioning (% body burden) of these elements among tissues did not vary by site (Ps = 0.209–0.962). Percent body burden of trace elements in liver remained relatively constant between ages for all elements except Cd, which was higher for old nestlings at both sites. When we examined only those metals elevated in ash basin birds (As, Cd, Se, and Sr), partitioning of As, Cd, and Se into nestling feathers ranged from 15% to 18%. In contrast, <1% of the total body burden of Sr was partitioned into feathers (Table 4). The partitioning of As, Cd, and Se into feathers was generally associated with a 7–17.9% reduction of carcass burden compared to younger, relatively un-feathered birds (Fig. 3).

4. Discussion

The development and fitness of avian offspring can be influenced by a multitude of dietary factors including the quantity, nutritional quality, and contaminant content of food (Kitayski et al., 2006; Brasso and Cristol, 2008). Our study demonstrates that avian offspring developing around coal ash settling basins face risks because their food is laden with trace elements that could influence their health. The effects of dietary exposure for nestlings could be further compounded by earlier embryonic exposure to maternally transferred elements (Bryan et al., 2003).

Dietary items fed to grackle nestlings were diverse, but primarily included insects, and represented a significant source of exposure to Se, As, and Cd for nestlings developing around ash settling basins. Concentrations of Se in ash basin crop contents averaged approximately 7 μg/g, >4 times the levels documented in reference food. Crop contents of 5 ash area nestlings (18%) had Se concentrations > 10 μg/g, a dietary level known to result in negative physiological effects (Stanley et al., 1994). Average Sr concentrations were twice as high from the ash basins, but were not significantly different from reference crop contents. The diversity of prey within ash basin crop contents suggests that other insectivores and/or predators foraging near ash basins may also be at risk.

Four elements, Se, As, Cd, and Sr, were accumulated in tissues of nestlings associated with the D-Area ash basins, although only Se approached any reported levels of concern. Selenium concentrations were elevated in ash basin nestlings by a factor of 2–5 in the three tissues examined (carcass, feather, liver) and average tissue concentrations ranged between 8 and 12 μg Se/g DW. Selenium was also the only element elevated in grackle eggs (Bryan et al., 2003). Stanley et al. (1994) reported a diet containing 10 μg Se/g resulted in mallard liver concentrations of 20 μg/g and lower duckling body weights, decreased growth, and lower liver weights. These ducklings had also received embryonic exposure to Se caused by maternal transfer to eggs. Liver concentrations of several individual grackle nestlings were between 19 and 22 μg Se/g. Heinz et al. (1988) found no effect of 10 μg Se/g in diet on mallard duckling growth, so the effects reported above (Stanley et al., 1994) may have been in response to a combination of both dietary and embryonic exposure (as in Bergeron et al., 2011). Although average Se concentrations found in diet and liver for grackles in this study were approaching, but did not meet or exceed, the concentrations resulting in adverse effects in those studies, these birds were exposed to both maternal and dietary elements and the interactive effects of these two routes in grackles remain unknown.

Concentrations of As, Cd, and Sr were elevated in tissues of nestlings from ash basins, but were generally relatively low. Arsenic and Cd concentrations (<2 μg/g) were far below the levels of concern recommended for either element (Furness, 1996; Eisler, 1994). Mallard ducklings exposed to As had lower body weights and reduced growth and liver weights, but only when fed As at levels resulting in considerably higher liver concentrations (5–33 μg/g DW: Stanley et al., 1994). Cadmium concentrations in livers of grackle nestlings were far below the suggested threshold level of 40 μg Cd/g WW (= ~ 160 μg Cd/g DW) (Furness, 1996). Strontium concentrations in ash basin feathers (<5 μg/g DW) were at or below those reported for healthy regional populations of night-herons (Golden et al., 2003). Mobilization of Sr is closely associated with mobilization of calcium, hence the link of Sr to carcass (Table 4), which included the skeleton.

Table 2
Pearson correlation coefficients of feather concentrations of various elements with liver and carcass concentrations from Common Grackle (*Quiscalus quiscala*) nestlings from the ash basin ($n = 11$) and reference ($n = 17$) sites. All concentrations were log-transformed prior to analyses. Underlined probabilities indicate significance at the 0.05 level.

	Feather * Liver		Feather * Carcass	
	r	Prob>|r|	r	Prob>|r|
As	0.8264	<0.0001	0.5700	<0.0001
Cd	0.4371[a]	0.2395	0.7136	<0.0001
Cu	0.3475	0.0700	0.1653	0.4006
Fe	−0.0551	0.7807	−0.1245	0.5278
Se	0.9630	<0.0001	0.9101	<0.0001
Sr	0.9989	0.0001	0.7952	<0.0001
V	0.1144	0.5620	−0.1980	0.3125
Zn	−0.0855	0.6654	0.0626	0.7515

[a] $N = 9$, due to 19 BDL values for liver concentrations.

Table 3
Percent body burdens of elements in Common Grackle (*Quiscalus quiscala*) nestlings relative to tissue and age[a].

Element		F	P	Element		F	P
As	Overall Model	1604	<0.0001	Se	Overall Model	2675	<0.0001
	Tissue	4650	<0.0001		Tissue	7857	<0.0001
	Age	27	<0.0001		Age	53	<0.0001
	Tissue*Age	35	<0.0001		Tissue*Age	13	0.0006
Cd	Overall Model	283	<0.0001	Sr	Overall Model	22823	<0.0001
	Tissue	668	<0.0001		Tissue	68059	<0.0001
	Age	2	0.1767		Age	34	<0.0001
	Tissue*Age	128	<0.0001		Tissue*Age	4	0.0452
Cu	Overall Model	378	<0.0001	V	Overall Model	948	<0.0001
	Tissue	1121	<0.0001		Tissue	2791	<0.0001
	Age	9	0.0030		Age	45	<0.0001
	Tissue*Age	4	0.0415		Tissue*Age	2	0.1535
Fe	Overall Model	191	<0.0001	Zn	Overall Model	3287	<0.0001
	Tissue	454	<0.0001		Tissue	9464	<0.0001
	Age	0	0.8083		Age	195	<0.0001
	Tissue*Age	82	<0.0001		Tissue*Age	39	<0.0001

[a] Percent body burdens were not significantly different between sites.

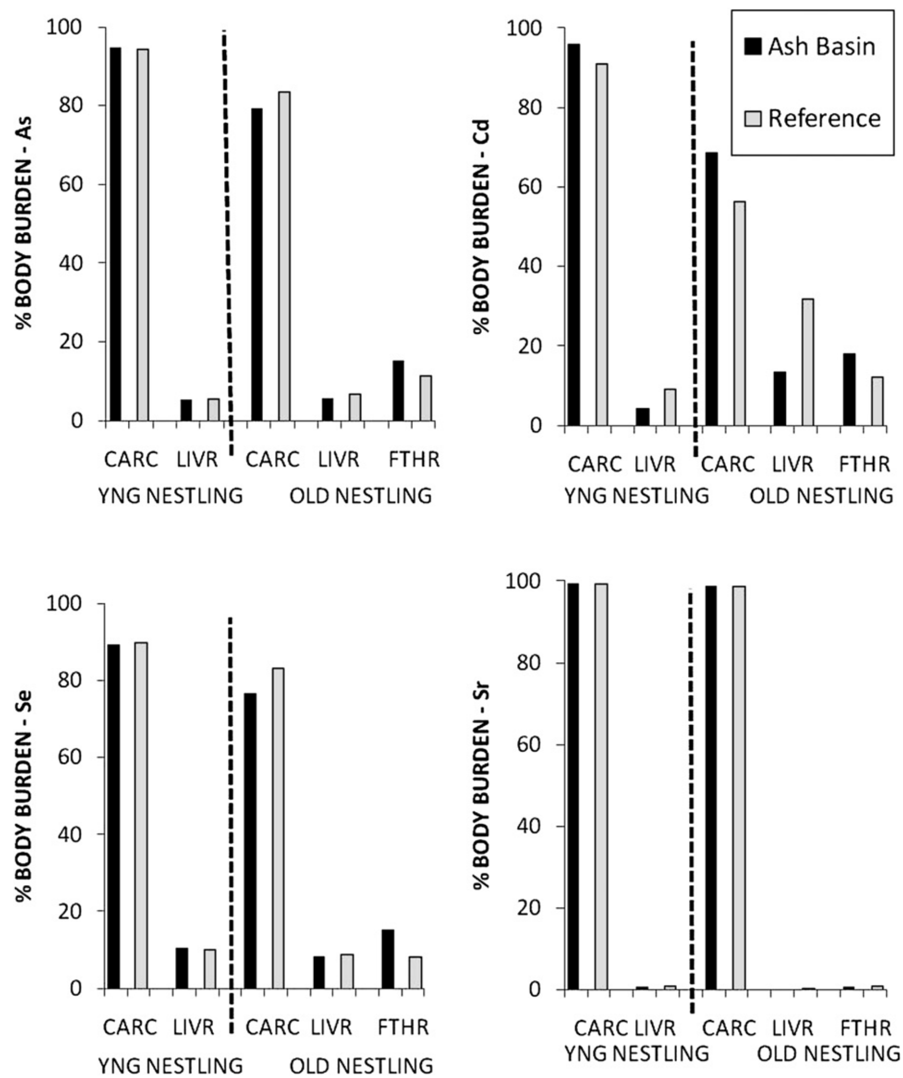

Fig. 3. Mean percent body burdens of selected trace elements in young (≤5 days post-hatch) and old (>5 days) Common Grackle (*Quiscalus quiscala*) nestlings collected from ash basin and reference sites.

Table 4
Body burdens (mean ± SE in μg) of selected elements in Common Grackle (*Quiscalus quiscala*) nestlings relative to age[a], collection site, and tissue (liver, carcass, and feathers)[b].

Element	Tissue	Young nestling		Old nestling	
		Reference	Ash basin	Reference	Ash basin
As	Liver	0.03 ± 0.01	0.10 ± 0.03	0.27 ± 0.03	0.61 ± 0.11
	Carcass	0.52 ± 0.01	1.61 ± 0.25	5.05 ± 0.84	9.07 ± 1.44
	Feathers	–	–	0.65 ± 0.10	1.63 ± 0.25
	Total Burden	0.55 + 0.10	1.71 +0.27	6.13 + 0.80	11.63 + 1.51
Cd	Liver	0.01 ± 0.00	0.03 ± 0.01	0.07 ± 0.01	0.18 ± 0.13
	Carcass	0.10 ± 0.02	0.78 ± 0.18	0.10 ± 0.02	0.83 ± 0.28
	Feathers	–	–	0.03 ± 0.01	0.17 ± 0.04
	Total Burden	0.11 + 0.02	0.81 + 0.19	0.20 + 0.02	1.20 + 0.41
Se	Liver	0.41 ± 0.08	2.24 ± 0.43	1.63 ± 0.11	6.65 ± 0.87
	Carcass	3.58 ± 0.67	18.52 ± 2.94	16.90 ± 2.12	62.63 ± 7.14
	Feathers	–	–	1.69 ± 0.22	13.27 ± 1.87
	Total Burden	3.99 + 0.74	20.77 + 3.31	20.73 + 2.28	85.29 + 9.27
Sr	Liver	0.15 ± 0.07	0.35 ± 0.07	0.24 ± 0.06	1.00 ± 0.19
	Carcass	17.64 ± 3.48	68.17 ± 14.94	163.83 ± 21.28	542.49 ± 115.56
	Feathers	–	–	1.50 ± 0.19	4.82 ± 1.02
	Total Burden	17.79 ± 3.51	68.52 ± 14.99	165.92 ± 21.50	549.63 ± 116.69

[a] Nestling ages: Young (≤5 days post-hatch); Old (>5 days post-hatch).
[b] Feathers were collected only from old nestlings, any feathers present on young nestlings were included in carcass.

4.1. Partitioning into feathers

Feather growth can be a very important excretory pathway for elements in both nestling and adult birds and a by-product of this process is that feathers can be used to predict concentrations of some elements in more vital organs (Gochfeld et al., 1996). For pre-flight nestlings, concentrations of many elements in their growing feathers are indicative of the elements in the diet provided by their parents within the foraging range surrounding the nest (Furness, 1993). Dietary elements are then broadly distributed among the many growing nestling tissues, including growing feathers, and relationships among these tissues are common for many elements. Young birds appear to be at greatest risk from effects of toxicosis from pollutant accumulation after the cessation of feather growth (Spalding et al., 2000). Feather production and nestling "growth dilution" effects may limit accumulation of elements in important organs to toxic levels, but these physiological processes cease during the final stages of development. Fledgling grackles disperse from their natal site distances ranging from only 1 m to 0.5 km (Buckingham, 1976; Peer and Bollinger, 1997) and continue to be fed by their parents for up to several weeks (Howe, 1976), possibly still within a foraging range containing sources of contaminants. Thus, the potential for additional exposure during this critical period when young grackles lack the buffering effects of rapid feather growth remains unexplored, but is an important consideration when attempting to understand the exposure risks of ash basins to young birds.

Percent body burdens found within nestling feathers were relatively consistent for As, Cd, and Se, whereas Sr was considerably lower (see Table 4 and Fig. 3). Percent burden in feathers for As, Cd, and Se ranged from 15 to 18% and 11–12% for the ash basin and reference nestlings, respectively. These concentrations roughly parallel the percentages of total body weight (dry weight) made up by the feathers (mean = 13.2 ± 3.8 SD %; both sites combined). The percent burden for Sr, an element generally associated with calcium-rich tissues such as bone, was reduced in feather and largely present in the carcass. Although the concentrations of As, Cd, and Sr in grackle nestlings in this study were low, the elevated exposure found in ash basin nestlings is still important because they demonstrate that these sites create exposure risks to a complex combination of trace elements for birds and the toxicity of this combination of elements in birds remains unknown. Depending on the type of coal that is burned and the combustion and handling technologies that are used (NRC, 2006), other waste disposal scenarios may produce greater bioavailability of these elements to birds and other wildlife.

5. Conclusions

Common grackles attracted to nest along edges of coal ash basins exposed their developing young to contaminants though both maternal transfer (Bryan et al., 2003) and parental provisioning, and thus experienced a lengthy exposure throughout all phases of nestling development. Specifically, we found that grackle nestlings associated with coal fly ash basins accumulated Se, As, Cd, and Sr via dietary exposure. Of these, only Se accumulation resulted in average tissue concentrations that approached levels associated with negative effects in other studies, and Se tissue concentrations of some individuals exceeded these levels. However, the potential interactive effects of combined exposure to multiple trace elements at lower concentrations remains a major uncertainty that warrants attention. Use of feathers as a non-lethal tissue to predict concentrations in more vital tissues/organs (e.g, liver) was confirmed within the range of Se, As, and Cd tissue concentrations found during this study, but not for 5 other elements, and will be useful for other studies attempting to monitor exposure of birds to multiple trace elements developing around ash basins.

Additional studies are recommended to clarify potential adverse effects of the attraction of nesting birds to coal ash settling basins. Although average concentrations of Se did not exceed suggested levels of concern for the tissues analyzed, tissue concentrations of several individual nestlings did exceed levels of concern. Studies are recommended to examine tissue concentrations in young-of-the-year birds after cessation of feather growth when toxicants may accumulate more rapidly and may result in adverse physiological and behavioral effects in naïve young. Avian immune systems may be sensitive to relatively low exposure to selenium and other trace elements, possibly resulting in reduced survival (Fairbrother and Fowles, 1990; Fairbrother et al., 1994), so examination of immune system effects and post-fledging survival of the grackle young are also recommended. Also, waterfowl, water birds, and shorebirds are also attracted to these basin systems (ALB, WAH pers. obs.) and, given their foraging behaviors (including disturbance of the sediments and increased likelihood of sediment ingestion), could be at greater risk to effects from contaminant exposure.

Disclaimer

The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

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