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Metal and metalloid concentrations in the eggs of threatened Florida scrub-jays in suburban habitat from south-central Florida

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Abstract

Monitoring and assessing changes in contaminants in urban and suburban environments is essential to assessing ecosystem well-being in human-influenced landscapes. We analyzed metal and metalloid levels in the eggs of the threatened Florida scrub-jay (*Aphelocoma coerulescens*), an extremely sedentary and modestly long-lived passerine bird that is federally threatened and endemic only in Florida. Eggs that failed to hatch were collected in a suburban environment to compare with the long-term study of this species at the Archbold Biological Station, located 8 km south in a more rural part of south-central Florida. Florida scrub-jays remain in a permanent territory in scrub oak habitat where they feed mainly on insects and acorns, but in suburban habitats human-provided foods comprise 30% of their diet. From the data previously collected at Archbold, and their low position on the food chain, we expected levels of contaminants to be comparatively low and remain relatively constant over time. Except for the low mercury value, all means were within the range of mean values reported for a wide range of non-passerine species (including those at higher tropic levels), are lower than concentrations associated with abnormalities in birds, and are lower than those previously reported for scrub-jays from Archbold Biological Station. A significant increase in selenium occurred from 1996 to 2001, but did not appear associated with changes in human density.

Keywords: Florida scrub-jay; Metals; Metalloids; Temporal trends; Lead; Mercury; Cadmium; Selenium

1. Introduction

Protecting the environment is a national, regional and local priority, particularly as people concentrate in urban and suburban centers. Maintaining healthy ecosystems that can protect the well-being of organisms living within them, including humans, requires not only environmental planning and management, but also knowledge of how stressors vary in the environment. These stressors can include contaminants, such as metals and pesticides.

Metals are persistent in nature and some readily accumulate in organisms, particularly those that are long-lived and high on the food chain, or in

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those that are close to industrialized areas (Fowler, 1990). Metals can bioaccumulate over time to reach toxic levels that can cause decreases in reproductive success and survival. Because some pollutants undergo biomagnification up the food chain, their concentrations have mainly been studied in top level predators such as raptors and fish-eating birds (Hunter and Johnson, 1982; van Straalen and Ernst, 1991; Burger, 1993; Ohlendorf, 1993; Burger and Gochfeld, 1997; Burger, 2002). Contaminants, such as metals, are generally not examined in birds that are relatively low on the food chain, and short-lived, such as most passerines, because it is assumed their levels are low (Burger, 1993).

In this article, we examine the concentrations of metals and metalloids in eggs of the threatened Florida scrub-jay *Aphelocoma coerulescens* taken at Placid Lake Estates, a residential subdivision about 8 km north of the Archbold Biological Station in south-central Florida, where we had previously studied metal levels in this species (Burger et al., 1999). We were particularly interested in examining temporal differences in eggs collected from 1996 to 2001, in assessing whether housing density affected levels of contaminants, and in assessing whether the levels in a suburban area differed from those of birds residing in the protected biological reserve of the Archbold Biological Station (Burger et al., 1999). We predicted that levels from the suburban area, where birds are potentially exposed to traffic, and to agricultural and lawn chemicals, would have higher levels than those collected previously at Archbold Biological Station, a relatively pristine habitat. Although overall nest success of jays in the two habitats does not differ (Bowman and Woolfenden, 2001), hatching failure in individual nests in the suburbs is twice that of Archbold (Bowman, unpub. data). The present study was undertaken partly to examine whether contaminants were a cause of increased hatching failure in the suburbs.

Florida scrub-jays are relatively sedentary and remain throughout their adult lives in a permanent territory—thus they represent local exposure to contaminants. They feed on a variety of insects (orthopterans and lepidopteran larvae) and in season, on acorns (Woolfenden and Fitzpatrick, 1984, 1996). Acorns constitute about 50% of the diet from September to February, and less than 20% from March to August (DeGange et al., 1989). However, in suburban habitats, human-provided foods such as peanuts, bird seeds and bread comprise 30% of their diet (Fleischer et al., 2003). Average duration as a breeder is 4 or 5 years; maximum longevity is just under 16 years.

Birds take up metals and metalloids mainly by ingestion of prey that have accumulated these substances, but also by drinking and by geophagy (Hui and Beyer, 1998). The absorption rate varies among metals and metalloids depending on intrinsic properties, species physiology, and bioavailability in particular media. Once absorbed through the intestinal tract, metals and metalloids circulate through the body and are deposited in a variety of tissues, are excreted directly, or are sequestered in feathers (Furness et al., 1986; Braune, 1987; Furness et al., 1990; Lewis and Furness, 1991). Females also can excrete some metals in their eggs and eggshells (Fimreite et al., 1982; Burger and Gochfeld, 1991, 1993; Burger, 1994, 2002; Gochfeld and Burger, 1998). For any metal and metalloid, the concentration in eggs can be derived both from recent exposure as well as from mobilization from other tissues.

2. Study area and methods

Under appropriate state and federal collecting permits, non-viable eggs of Florida scrub-jays were salvaged from nests in a suburban population 8 km north of Archbold Biological Station, in south-central Florida. Patches of xeric oak scrub, the habitat of Florida scrub-jays, occur imbedded in the suburban matrix, but the area also is intermixed with unimproved cattle pasture and citrus groves. The eggs came from a color-marked population of scrub-jays, studied for the past 10 years (Bowman and Woolfenden, 2001; Fleischer et al., 2003). Contrary to usual methodology (Burger, 1993), these eggs were not a random sample; instead they were the unhatched eggs from clutches where other eggs had hatched or from clutches that were abandoned and none hatched. In a previous study of scrub-jay eggs, no-significant differences occurred as a function of whether eggs were abandoned or failed to hatch (Burger et al., 1999). Eggs were refrigerated until digested for later analyses. Because of potential weight loss due to storage, we air dried the specimens prior to analyses.

All specimens were analyzed in the Elemental Analysis Laboratory of the Environmental and Occupational Health Sciences Institute in Piscataway. Contents of each egg were digested individually in warm nitric acid mixed with 30% hydrogen peroxide, and subsequently diluted with deionized water. Mercury was analyzed by cold vapor technique, and the other elements were analyzed by graphite furnace atomic absorption (Burger and Gochfeld, 1991).

Instrument detection limits were 0.02 ppb for cadmium, 0.08 ppb for chromium, 0.15 ppb for lead, 0.09 ppb for manganese, 2 ppb for mercury and 0.7 ppb for selenium, but matrix detection levels were up to an order of magnitude higher. All specimens were analyzed in batches with blanks, calibration standards and spiked specimens. Recoveries were 92–105%. The coefficient of variation on replicate, spiked samples ranged up to 10%. All concentrations are expressed in ppb (g/kg) on a dry weight basis using weights obtained from air-dried specimens. Where values were below the detection limit, we used half the detection limit for the calculations (after Clarke, 1998). To convert a dry weight result to an approximate wet weight basis we divided by three (eggs are about 67% water).

We examined the relationship between housing density and contaminant levels by comparing levels in densities of less than 20 houses/40 ha (100 a.c.), 21–40 houses/40 ha, and over 40 houses/ 40 ha, using X^2 tests that indicate the relationship between these two parameters (number of high mercury eggs at each housing level vs. expected number). Both arithmetic and geometric means are given to facilitate comparisons with other studies. Non-parametric Kruskal–Wallis one-way analysis of variance was used to examine differences among years, and Duncan Multiple Range test was used to distinguish these differences. We present arithmetic means as well as geometric means (along with the number of samples that were non-detect) to facilitate comparisons with the literature.

3. Results

Levels of chromium, manganese and selenium varied by year, but arsenic, cadmium, lead and mercury did not (Table 1). Only selenium showed a consistent trend; levels of selenium increased steadily from 1996 to 2001 (Fig. 1).

Only one significant correlation existed among analyte levels in the eggs; lead and manganese levels were significantly correlated ($r=0.22$, d.f. $=$ 74, $P<0.01$). In general, egg size (weight, length or width) did not correlate with metal levels. However, selenium was positively correlated with egg weight ($r=0.17$, $P<0.04$); chromium was negatively correlated with egg weight ($r=-0.31$, $P<0.0002$) and with egg length ($r=-0.21$, $P<$ 0.02).

Density of housing was related to contaminant levels only for mercury. Mercury levels were higher in mid-density (mean of 66 ppb) compared to high-density (mean of 39 ppb) housing areas (Duncan Multiple Range test, $\alpha<0.05$). However, with higher sample sizes, selenium might have shown a significant pattern among the distribution of levels and housing ($X^2=5.0$, d.f. $=2$, $P<0.08$). Significant relationships existed between distributions of housing density and egg length ($X^2=8.0$, d.f. $=2$, $P<0.02$) and weight ($X^2=6.0$, d.f. $=2$, $P<0.05$). Eggs were lighter in the high-density area.

Contrary to our initial prediction, levels of cadmium, lead, manganese and selenium were significantly lower in the eggs collected in this study compared to those collected from the Archbold Biological Station (Table 2). No significant differences occurred in levels of arsenic, chromium and mercury between the two study sites.

4. Discussion

4.1. Yearly variations

Data sets on contaminant levels that span long periods are useful in understanding whether levels are increasing or decreasing in the environment. Such data sets are particularly useful for bioindicator species that are high on the food chain, such as common terns (*Sterna hirundo*, Becker et al.,

Table 1

Metal levels (ppb, dry weight) in scrub-jay eggs collected from 8 km north of Archbold Biological Station 1996–2001. Given are means and standard error. Below are geometric means, Duncan values and number of samples that were non-detects. For the Duncan test, means with same letter are not significantly different

N	1996	1997	1998	1999	2000	2001	$X^2(P)$
	8	21	7	15	10	16	
Arsenic	16 ± 6	11 ± 4	17 ± 6	12 ± 6	11 ± 4	10 ± 4	NS
	3 (A) (3)	1 (A) (11)	4 (A) (2)	1 (A) (8)	2 (A) (4)	1 (A) (7)	
Cadmium	2 ± 1	2 ± 0.5	2 ± 0.8	3 ± 1	2 ± 0.5	2 ± 0.3	NS
	0.3 (A) (3)	0.3 (A) (7)	0.3 (A) (3)	1 (A) (2)	0.5 (A) (3)	1 (A) (0)	
Chromium	49 ± 12	20 ± 3	13 ± 4	48 ± 14	51 ± 24	17 ± 12	13.79(0.02)
	39 (A) (0)	12 (B) (1)	9 (B) (0)	13 (A) (1)	4 (A) (3)	0.6 (B) (6)	
Lead	22 ± 17	3 ± 1	13 ± 9	15 ± 10	8 ± 5	9 ± 4	NS
	0.4 (A) (6)	0.3 (A) (15)	2 (A) (2)	0.7 (A) (9)	0.6 (A) (0)	0.8 (A) (0)	
Manganese	1528 ± 282	998 ± 114	1743 ± 193	1343 ± 166	1242 ± 163	1484 ± 130	12.57(0.03)
	1308 (A, B) (0)	894 (B) (0)	1658 (A) (0)	1144 (A, B) (0)	1142 (A, B) (0)	1348 (A, B) (0)	
Mercury	45 ± 6	55 ± 8	50 ± 8	54 ± 7	42 ± 5	61 ± 14	NS
	42 (A) (0)	48 (A) (0)	45 (A) (0)	48 (A) (0)	39 (A) (0)	50 (A) (0)	
Selenium	606 ± 205	707 ± 67	856 ± 192	1079 ± 108	1165 ± 124	1275 ± 61	27.22(< 0.0001)
	491(C) (0)	645 (C) (0)	778 (B, C) (0)	685 (A, B) (0)	1108 (A, B) (0)	1254 (A) (0)	

NS = not significant.

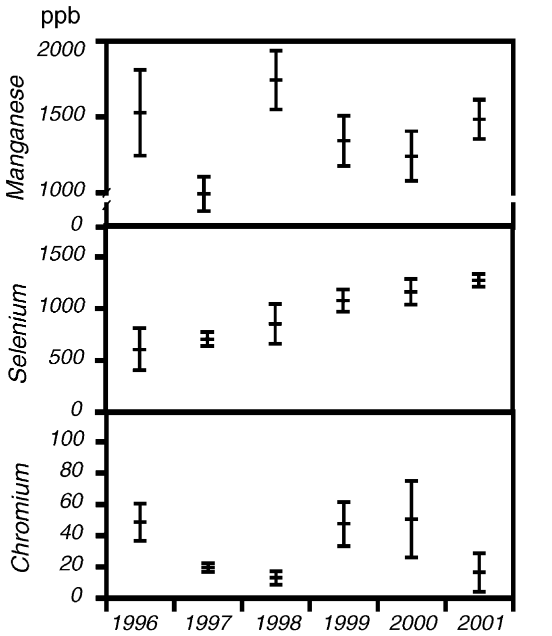

Fig. 1. Metal levels (mean ± ppb) in scrub-jay eggs collected 8 km north of Archbold Biological Station.

1998; Burger and Gochfeld, 2004). However, contaminant levels in passerine birds are seldom examined for temporal trends. Although this is largely because of the assumption that passerines do not have high levels, due to their low position in the food chain and their lack of longevity, the data from this study indicate that they can be used to show temporal trends.

Selenium was the only contaminant that showed a clear and significant temporal trend with levels increasing from 606 ppb in 1996 to 1275 ppb in 2001, a two-fold increase over the six years. During this time period, human-housing density increased, but selenium levels did not appear sensitive to human density. Although these selenium levels are still low compared to those required to cause reproductive deficits (3000 ppb, Heinz, 1996), if the increase continues, there may be cause for concern. However, this level should be considered a conservative estimate of the threshold because it represents the upper range of the mean for selenium in bird eggs from uncontaminated sites (DOI, 1998), and higher levels may be tolerated (Ohlendorf, 2003). However, it is not clear whether scrub-jays are more sensitive to selenium than are other species.

Table 2
Metal levels (ppb, dry weight) in scrub-jay eggs collected in 1997 and 1998 from 2 sites that are 8 km apart. Given are means and standard error; below are geometric means and Duncan values. Means with same letter are not significantly different

	Archbold biological station	8 km north of Archbold	$X^2(P)$
	$n=15$ 1997 + 1998	$n=28$ 1997 + 1998	
Arsenic	34 ± 20 0.8 (A)	12 ± 3 1.5 (A)	NS
Cadmium	25 ± 8 4 (A)	2 ± 0.4 0.3 (B)	10.8(0.001)
Chromium	97 ± 38 17 (A)	18 ± 2 11 (A)	NS
Lead	66 ± 16 20 (A)	6 ± 2 0.4 (B)	16.6(< 0.0001)
Manganese	2330 ± 230 2123 (A)	1199 ± 117 1056 (B)	13.85(0.0002)
Mercury	74 ± 24 23 (A)	54 ± 6 47 (A)	NS
Selenium	1470 ± 95 1425 (A)	737 ± 65 670 (B)	20(< 0.0001)

NS = not significant.

The selenium levels from 2001, from this study are similar to those reported from Archbold from 1997–1998 (1470 ppb, Burger et al., 1999), raising the question of whether the levels at Archbold have also increased. Finally, the data indicate the importance of trend data for a number of years. Only with several years is it possible to determine whether yearly fluctuations occur or whether a clear trend, upward or downward occurs. As is clear from Fig. 1, without continuous sampling during the entire period, other conclusions could have been drawn from the data for chromium and manganese. While it is costly to analyze a sufficient sample from many years, it may be possible to archive specimens to analyze when a problem is detected (such as the increased hatching failure of the scrub-jay population examined in this study).

4.2. Contaminants and housing density

The relationships between contaminant levels and housing densities were not strong, except for mercury. Mercury levels were highest at intermediate housing densities, and lowest at the highest housing density. This is surprising, because we expected that if difference existed, levels would be highest at the highest housing density.

4.3. Comparisons with Archbold Biological Station

We had initially predicted that contaminant levels would be higher in the suburban study area, compared to those in scrub-jay eggs collected at Archbold Biological Station in 1997 and 1998. Archbold has relatively pristine conditions because the land has been managed by the station since the mid-1970s. During this time no pesticides or other contaminants have been applied directly to those lands, although Archbold is surrounded by cattle pastures and citrus groves where a variety of biocides, including some containing metals, have been used over the years (Burger et al., 1999). However, levels of several analytes were higher in the eggs collected at Archbold compared to those collected in this study. Although the differences were not great for most analytes, they were an order of magnitude higher for lead and cadmium. This is surprising, because we expected that lead from previous use of leaded gasoline would have been higher in the suburban jays in the present study. The contaminants in the suburbs (such as mercury and others) may well have come from atmospheric deposition.

Florida scrub-jays have very limited dispersal, usually dispersing within 1–2 territories of their natal territory (Woolfenden and Fitzpatrick, 1996). Dispersal between these two sites appears to be one-way: suburban jays regularly immigrate into the Archbold population but we have never observed an Archbold bird in our suburban site (Bowman, unpubl. data). None of the eggs analyzed in the previous study at Archbold, however, came from suburban birds that had emigrated into that population; thus contaminant levels in eggs should reflect local exposure. Scrub habitats at both sites are similar in plant species composition and occur on the same soil types, but the frequency of fire is lower in the suburbs, so much of the scrub vegetation is taller than at Archbold. Scrub-jay territories are smaller in the suburbs, usually only 3–4 ha, compared to 9 ha at Archbold, but their territories are not restricted to scrub habitats and may include yards, road edges or citrus groves where we might expect the birds to be exposed to potential contaminants. Few of the ecological differences between the sites appear to be consistent with lower levels of contaminants in the suburbs. The higher levels are discussed in Section 4.4.

4.4. Biological significance

Few studies of contaminant levels in passerine exist, largely because they are not high on the food chain (and thus generally do not concentrated contaminants), and are not generally long-lived, which limits the time for bioaccumulation. Most of the data are from seabirds and other fish-eating birds (Table 3). Clearly, the levels of all metals and metalloids found in this study are below or at the low end of those reported for these birds.

However, some data exist for non fish-eating birds. Ormerod and Tyler (1994) reported mercury concentrations of 10–290 ppb from the eggs of dippers *Cinclus cinclus*, a passerine living along rivers in Wales and Ireland. The concentrations of

Table 3
Concentrations of metals (ppb, wet weight) in eggs of raptors, seabirds and other fish-eating birds (adapted from Burger 1994; Hothem et al., 1995; Mora, 1996; Barrett et al., 1996; Burger and Gochfeld 1996; Mason et al., 1997; Gochfeld and Burger 1998). These data include no metal concentrations from passerines. Since most literature reports egg results on a wet weight basis, we converted the Florida scrub-jay data by dividing the dry weight results (Table 1) by 3 (an approximate conversion factor based on average moisture content)

Metal	Number of of studies[a]	Range of concentrations[b] ppb	Median[b] ppb	Scrub-jays this study ppb
Arsenic	too few studies			4
Cadmium	28	2–530[c]	13	0.7
Chromium	20	10–1010	210	10
Lead	27	20–6700	140	3
Manganese	12	350–4000	450	457
Mercury	60	70–7290	220	18
Selenium	10	300–3120	650	323

[a] number of studies or species (some studies include more than one species).
[b] Range and median of the arithmetic mean values reported in the various studies.
[c] Eared grebe (*Podiceps nigricollis*) cadmium concentration of 3470 ppb (Burger and Gochfeld, 1996) is excluded from this analysis.

cadmium (up to 100 ppb) and lead (up to 3160 ppb) were relatively high in the eggs of chickens living near a coal-burning power plant in Brazil (Flores and Martins, 1997). In ducks in Alaska, concentrations of lead ranged up to 4700 ppb (Henny et al., 1995), and mercury concentrations were as high as 3300 ppb (Henny et al., 1995). In contrast, concentrations of all metals from eggs of lesser snow geese (*Anser c. caerulescens*) from Wrangel Island, Russia, were relatively low: cadmium and lead (below detection limit), chromium (410 ppb), mercury (70 ppb), manganese (1780 ppb), and selenium (1900 ppb, Hui et al., 1998). At the selenium-contaminated Kesterson Refuge (California), selenium concentrations in the eggs of a variety of birds ranged up to 69 700 ppb (Ohlendorf et al., 1990; Ohlendorf and Hothem, 1995), well above those reported for the scrub-jays in this study.

From the above comparisons it is clear that the levels of metals and metalloids in the eggs of scrub-jays collected from the suburban study area are generally lower than those otherwise reported in birds. Further, they are below those reported from the scrub-jay eggs collected at Archbold, only 8 km south. The jays at Archbold do not show impaired hatching reproductive success, as do the jays in the population we studied.

The levels reported here are below the range reported to be associated with reproductive deficits for these analytes. For example, Ohlendorf et al. (1986) showed that adverse reproductive effects occur at about 10 000 ppb of selenium in eggs, while Heinz (1996) reported that adverse reproductive effects can occur at selenium concentrations as low as 3000 ppb (wet weight) in eggs. Mercury levels above 3000 ppb cause adverse effects (Heinz, 1979; Eisler, 2000; Burger and Gochfeld, 1997), but the eggs in this study had mercury levels of only 53 ppb. Taken altogether, the data indicate that the contaminants examined in this study are not a cause for the increased hatching failure and lowered reproductive success.

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