Monitoring Potential Cadmium Levels in Avian Tissues Associated with the Savannah Harbor Expansion Project: Year 1 of Construction Annual Report

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INTRODUCTION

The Savannah Harbor Expansion Project (SHEP) involves dredging the Savannah River and will eventually result in deposition of sediment containing potentially high concentrations of Cadmium (Cd) into dredged material containment areas (DMCAs) near Savannah. Cadmium is a toxic metal with both natural and anthropogenic sources and no known nutritional value (Wayland and Scheuhammer 2011). Effects of toxic concentrations of Cd on birds range from organ damage to behavioral changes. The SHEP DMCAs contain upland and aquatic habitats and are bounded by salt marsh and riverine habitats, which tend to attract a wide range of avifauna. Dredged material deposition may be a potential cadmium exposure route for birds attracted to these impoundments. As part of the monitoring to determine potential environmental impacts associated with the SHEP, we examined Cd uptake by avian species associated with containment areas in 2014/2015, a sampling period prior to deposition of dredged materials containing the Cd.

The strategy to examine potential Cd risk to avifauna using the DCMAs was to document Cd uptake in a set of sentinel avian species. These sentinel avian species, which will be monitored during two seasons (summer and winter), were determined by USACE and the US Fish and Wildlife Service (USFWS) and based on long-term monitoring of avian occurrence. Suites of available sentinel species were influenced by the hydrologic condition (wet vs dry) of the DMCAs. In the initial year of this monitoring, we attempted to monitor all sentinel species to provide a baseline for future monitoring. Monitoring in subsequent years, during potential Cd deposition and bioavailability, will likely focus on a reduced number of sentinel species, but a greater number of samples per species.

The primary approach to assess Cd risk, as requested in the SOW, was to analyze blood for Cd from the sentinel resident and migratory species because concentrations of Cd in blood are indicative of recent uptake in adult birds. Cadmium can be removed from blood as quickly as 48-hours (Sell 1975). The use of blood for metals analysis is a nonlethal technique that has little impact on avian populations, but that allows for concomitant assessments of health. As optional monitoring, we opportunistically collected avian prey base samples (invertebrates; e.g., aquatic and terrestrial insects, snails) from the DMCAs and analyzed them for Cd. Such data will provide insights into potential uptake by sentinel and other non-sentinel wildlife.

Our goal in the first year of this project was to capture sentinel avian species and collect blood samples for chemical (primarily cadmium) analyses during the initial Summer (2014) and Winter (2014/2015) seasons. Here we report our captures and the contaminant findings of the avian blood analyses.

METHODS

Study Area

The DMCAs targeted for receiving the sediments potentially contaminated with Cd are 14A and 14B, so our avian collections were originally to be focused within and adjacent to these areas. They are bordered on the north by salt marsh and tidal creeks and to the south by the Savannah River. Dikes around the perimeter will maintain standing water within the DMCA, but the perimeter will still support shrubs and small trees, providing habitat for additional species (Figure 1).

However, construction activities at DMCA 14B during the first year of monitoring prevented us from accessing or collecting any samples from that area. In addition, the impacts of heavy rainfall and large equipment used on the DMCAs occasionally rendered several of the access roads impassable for short periods, which also influenced avian sampling. After discussions with USACE given (1) the lack of access to 14B, (2) the occasional lack of access to 14A due to poor road conditions, and (3) that this was a "control"/pre-Cd deposition year, we attempted to focus sampling effort on 14A and adjacent 13B but agreed to include captures from five DMCAs (12A, 13A, 13B, 14A, 14B) within the Savannah Harbor Navigation Project.

Avian Capture/Blood & Tissue Collection Methods

We employed multiple techniques for capturing DMCA avifauna. Most of the sentinel species (Table 1) were passerines and were captured with mist nets. These nets (30-mm mesh, 2.4m tall X 12m long) were typically deployed in cleared lanes either adjacent to shrubby habitat or through forested habitat during the morning/early afternoon period. Playback equipment broadcasting specific bird songs were often used to attract and capture specific species. Baited enclosure traps were employed to capture mourning doves and occasionally captured other sentinel species (e.g.; red-winged blackbirds). Black-necked stilts were captured by two methods, a WCS NetBlaster and nest traps. The NetBlaster functions like a rocket net but uses compressed air rather than explosives to launch the rockets and deploy the net. We set up the NetBlaster on shore edges where we observed stilts foraging and typically captured single stilts with this method. We later employed nest traps, which involved flushing an attending parent off a nest with eggs and then covering the nest with a "funnel trap" made of light-weight fencing (1m tall, 1.2m diameter). After deploying the trap, the parent would return to the nest and enter the trap through the funnel to continue incubating the eggs.

We had no success live-capturing three species: Mottled Ducks (summer species), Northern Shovelers (winter species), and American Avocets (winter species). We attempted using the NetBlaster to capture both duck species but the ducks either did not use shoreline habitats where the NetBlaster can function or were wary of the NetBlaster set-up. We also attempted baited (corn) enclosure/funnel traps with decoys which will occasionally capture many species of waterfowl, but these traps were not effective possibly due to both species being largely insectivorous. We requested and received permission from USACE (January 2015) to collect these species lethally (e.g.; shotgun) and collected 8 Northern Shovelers in February of 2015. American Avocets were also present on the DMCAs during the winter months but, due to hydrologic conditions in the DMCAs, were not observed in locations accessible with the NetBlaster (e.g.; avocets were typically observed feeding on top of soft sediments below the dredge input pipe). We also received permission from USACE to collect avocets and Mottled Ducks lethally (e.g.; shotgun), however we (UGA-SREL) did not have permission from USFWS (scientific collecting permit) to collect mottled ducks and avocets during the sampling periods (the Northern Shovelers were collected under an existing SREL permit). The request to lethally-collect Mottled Ducks and avocets was submitted to USFWS in January of 2015, but is still under review.

Finally, House Wrens were listed as a "winter" sentinel species. We only captured a single wren during our sampling and the small size of this species (~10 g) precluded us from collecting a sufficient volume of blood for chemical analysis.

Sentinel Species & Potential Alternative Species

The sentinel species collection SOW (provided by USACE) targeted collecting blood from a minimum of 10 individuals of each sentinel species during each season (summer vs winter). To the extent possible, the within-season collections were to be split between early and late periods: Summer – April & August; Winter – October/November & March/April. However, the availability of certain target species was influenced by existing hydrological conditions and/or the behavior of the species. As mentioned above, we had varied success capturing the project sentinel species. As a result of this, during each field season we banded and collected blood samples from some potential alternative avian species in case capturing the sentinel species proved problematic. These potential "alternate" species included Common Ground Doves (for Mourning Doves), Northern Cardinals, Swamp Sparrows, Yellow-rumped Warblers (for House Wrens), and American Coots (for Northern Shovelers). These species were often more easy to capture than the sentinel species and we include their Cd concentrations in this report for comparison and additional background information.

<u>Avian Blood/Tissue Collections</u>

For all live-captures, we collected blood samples from either the jugular or brachial vein with a syringe. Volumes of blood collected ranged from < 0.05 ml to 0.80 ml, depending on bird

condition and size (we were permitted to collect blood volume NTE 1% of the bird's weight). Blood samples were archived (frozen) prior to chemical analysis. Captured individuals received appropriately-sized USGS aluminum leg bands prior to release to allow potential observations of marked birds and/or recaptures (and resampling) of known individuals. Resampling (blood) from recaptured birds will allow for interesting between/among year comparisons. These blood collection/banding activities were conducted under SREL's bird banding permit (BBL 22002).

Northern Shovelers were collected by lethal methods (shotgun) in the winter of 2015. After collection, these birds were immediately dissected to access the heart and blood was drawn from the organ with a syringe and archived as with the other blood live-capture collections. The carcasses were stored in ice and eventually frozen. After returning to SREL, kidney, liver, and gizzard contents were removed from the carcasses for eventual analyses for contaminants and comparison to the blood concentrations. These activities were conducted under SREL's federal migratory bird scientific collecting permit (MB65214A-0) as well as state of South Carolina scientific collecting permits.

Optional nestling tissue collections (e.g.; blackbird nestlings) did not occur in the initial year of the project.

Optional Prey Base Collections

Preliminary collections of potential prey base (for avian species) samples within and/or adjacent to the DMCAs did occur. Collections of aquatic and terrestrial insects and snails involved use of sweep nets and other devices. Due to the small size/mass of many potential prey items, we combined many items into composite samples prior to analyses.

Chemical Analyses

Biological samples (e.g., blood, tissues, prey) were analyzed for Cd as well as a suite of other metals (As, Co, Cr, Cu, Fe, Ni, Pb, Se, Sr, Zn) at the University of Georgia's Savannah River Ecology Laboratory. Samples were digested in multiple batches of 12, which included two sample replicates, a reagent blank, and a certified standard reference material, following EPA method 3052. After digestion, trace element analyses were performed according to EPA method 6020, utilizing an ICP-MS Nex ION 300X, (Perkin-Elmer Sciex Instruments, Toronto, Canada). Tissue concentrations of elements were reported in ppm (µg/g) wet weight for blood and ppm (µg/g) dry weight for avian tissues and potential prey items.

Sample-specific method detection limits (MDLs – Cd concentrations below these levels could not be accurately determined given the instrumentation, volumes of samples, and Cd concentrations within the samples) ranged from 0.00129 – 0.07166 Cd ppm wet weight for avian blood, and was 0.03 µg/g dry weight for avian tissues and 0.31 µg/g dry weight for potential prey items. MDLs for avian blood and tissues were far below the Cd concentrations listed as potential levels resulting in toxic effects (see Discussion).

Concentrations of elements other than Cd in blood, avian tissues, and prey are documented in Appendices 1, 2, and 3. Concentrations of Co (91.8% blood samples below MDL), Sr (77% blood samples below MDL), and Pb (92.5% blood samples below MDL) were not included in Appendix 1 (avian blood) due to low frequency of accurate concentrations.

RESULTS

Blood Concentrations

Of 134 avian blood samples associated with the DMCAs in the first year of sampling, only 39 (29.1%) were above the MDLs (0.00129 - 0.07166 ppm wet wt.) for Cd (Table 3). These above detection results included 7 sentinel species, most of which are generally terrestrial in nature (except Black-necked Stilts). All above-detection findings except one were collected in the Summer period (April-August). Relative to species, Summer samples from Eastern Towhees averaged 0.0075 ppm Cd (n=6, SD=0.0027) and Red-winged Blackbirds averaged 0.0042 ppm Cd (n=11, SD=0.0015) (in these calculations, a <MDL concentrations was replaced by ½ of its MDL). The highest percentage of above-detection findings occurred for Brown Thrashers, where 6 of 9 samples (67%) were > MDL. A single avian blood sample (Brown Thrasher, Winter period) had a Cd concentration (0.41 ppm) greater than the concentration associated with possible toxic effects (0.26 ppm; see Discussion).

Tissue Comparisons

We lethally collected 8 Northern Shovelers to allow for comparison of blood Cd concentrations to other tissues, as well as gizzard contents. Kidney and liver are the primary storage organs for Cd, and we analyzed gizzard contents as an indicator of recent dietary intake. All shoveler blood samples were < MDL for Cd (Table 3) so comparisons to other tissues were not feasible. Kidney concentrations were typically ~ 5 times higher than liver concentrations, although concentrations in both tissues were correlated (Spearman Rank, r=0.7381, Prob > $|r|$ = 0.0366). Kidney Cd concentrations in males were 4 times greater than those in females (Wilcoxon Rank Sum Test, Z=-2.1651, Pr>Z=0.0304). Liver concentrations did not differ between genders (Wilcoxon Rank Sum Test, Z=-1.2990, Pr>Z=0.1939). None of the tissue concentrations of Cd were greater than the concentrations reported to impact avian wildlife (see Discussion). Gizzard contents were largely below the MDL (Table 3).

Potential Prey Base

Cadmium concentrations in potential prey items collected on the DMCAs were highly variable (Table 4). Adult and larval potato beetles (Family Chrysonelidae) had the highest average Cd concentrations (> 10 ppm), followed by aquatic invertebrates (2-7 ppm). Two largely terrestrial insects (katydids and bees) did not accumulate Cd at levels above MDLs.

DISCUSSION

Cadmium (Cd) concentrations in birds vary widely according to ecosystem use, diet, age, and physiological status (Wayland and Scheuhammer 2011). Relative to ecosystem use, seabirds typically have > Cd than coastal birds, which typically have > Cd than freshwater wetland birds, which typically have > Cd than terrestrial birds. Dietary exposure to Cd tends to be greatest with insectivores, which includes several monitored seabird species such as albatrosses, petrels, and storm petrels (Wayland and Scheuhammer 2011), as opposed to piscivores or scavengers, but this varies. Cadmium does not "biomagnify" throughout trophic levels like some elements (e.g.; mercury), but can biomagnify in lower trophic levels (e.g.; water or sediment to lower invertebrates) (Eisler 1985, Scheuhammer 1987). Insects and their larvae, which are often more-closely associated with potentially-contaminated sediments, may provide the more likely pathway for Cd exposure.

Within avian tissues, concentrations of Cd in kidney and liver reflect chronic exposure whereas blood concentrations reflect recent dietary exposure. The majority of Cd in birds is found in the kidney and liver, which typically accounts for 67-97% of the total body burden of Cd. Kidneys are the long-term storage organ for Cd, whereas liver concentrations are generally only 10-70% of kidney concentrations. Cadmium concentrations in blood are generally very low ($\leq$ 0.50 µg/g Cd wet wt). Age and diet are the two most important factors influencing Cd accumulation, with older/adult birds typically having considerably higher Cd concentrations than younger, developing birds.

Avian tissue concentrations of Cd associated with potential toxic effects (e.g.; organ damage, reduced breeding success, altered behaviors, etc.) are largely based on laboratory uptake studies and vary widely among species. Kidney concentrations > 65 µg/g Cd (wet wt) are associated with a 50% likelihood of negative effects, although 100 µg/g Cd (wet wt) is a more liberal level of potential effects (Wayland and Scheuhammer 2011). Liver concentrations greater than 45-70 µg/g Cd (wet wt) and blood concentrations $\geq$ 0.26 µg/g Cd (wet wt) are suggested to be associated with toxic effects.

Concentrations of Cd in blood of avian sentinel species from the Savannah Harbor DMCAs were generally low, with approximately 70% being below the minimum detection limit range of 0.00129-0.07166 µg/g Cd (wet wt), and 0.7% (N=1) of all samples were greater than the concentration (0.26 µg/g Cd (wet wt)) suggested to be associated with toxic effects . Unexpectedly, primarily terrestrial birds had concentrations of blood Cd > than the MDLs. This is contrary to expectations that birds utilizing aquatic habitats should have higher Cd concentrations (Wayland and Scheuhammer 2011). Analyses of a limited set of potential avian invertebrate prey types collected on-site also documented highly variable Cd bioavailability in the current DMCA environment, including the finding that selected terrestrial insects (potato beetles and their larva) averaged higher Cd concentrations than potential aquatic prey. Some plants (e.g.; willows) are known to bioaccumulate Cd more so than others (Eisler 1985, Rodrigue

et al. 2007) and it is possible that the potato beetles were consuming these types of plants. Brown Thrashers, which had the highest occurrence of above-detection level Cd concentrations in blood, are typically insectivores and often specialize in beetles (Cavitt and Haas 2014). Thrashers are typically ground feeders that often feed by sweeping their bill through leaf litter to expose insects, so incidental sediment ingestion could also be a Cd exposure pathway. All blood samples above the MDL except one came from the interior of DMCA 14A, although the vast majority of all captures came from that DMCA. The lone blood sample greater than the level of concern came from a Brown Thrasher captured in the thin strip of forested habitat between DMCA 12A and the salt marsh to the north.

Analyses of potential within season (early vs. late) and between season (summer vs. winter) differences in blood Cd levels was limited by detection levels and sample sizes. So few of the blood samples were above the MDLs that statistical comparison within and between seasons were not feasible. Coarse comparison of the numbers of above minimum detection level samples (all species) suggests greater exposure in the summer months. This may be linked to greater insect abundance and/or larvae emergence during the spring/summer months. These within and between season comparisons may be more informative in the future sampling when the number of sentinel species are reduced to two per season and the number of individuals per species per season increases from a maximum of 10 to 30.

Analyses of Cd concentrations among lethally-collected Northern Shoveler blood and tissue samples were not feasible due to < MDL Cd concentrations for shoveler blood. Other tissue concentrations indicated Cd accumulation primarily in kidneys, as expected. Liver concentrations were also all above detection limits, but considerably lower than kidney concentrations. As expected, kidney concentrations were correlated with liver concentrations. The majority of shoveler gizzard content samples were below Cd detection limits, which suggests a general lack of Cd in the aquatic habitats/prey utilized by shovelers in the current DMCAs, as was also suggested by the blood concentrations. However, concentrations of Cd in selected aquatic potential prey items indicate that Cd is bioavailable within these habitats. Apparent gender differences may be confounded by the low samples sizes and lack of ability to age individual waterfowl (e.g.; the 4 males could have been older than the 4 females). As with the blood sampling effort, these findings will be enhanced by increased sample sizes and analysis of a greater number of potential prey items.

SUMMARY

The majority of avian blood samples (70%) collected from the Savannah Harbor DMCAs in the first year of monitoring was below the range of instrument detection levels (0.00129-0.07166 µg/g Cd wet wt). A single blood sample was found to be above the level of concern for potential toxic effects. The majority of the above-MDL samples were collected during the summer months, possibly due to the greater availability of certain species of insects (a food source) during that period that bioaccumulate Cd. We will likely expand our examination of Cd in

potential prey to include additional invertebrates and seeds/fruit. Analyses of kidney and liver tissues from lethally-collected Northern Shovelers on the DMCAs indicate that this species is accumulating Cd and that it is likely accumulating Cd from other locations since blood and gizzard content concentrations were below the MDLs.

Lethal collections were employed to obtain blood/tissue samples from Northern Shovelers, a species which we could not capture by non-lethal methods (e.g.; traps, Net Blaster, etc.). This method may need to be used to obtain other difficult-to-obtain avian samples, pending acquisition of appropriate scientific collecting permits.

ACKNOWLEDGEMENTS

Chris Depkin, Brigette Haram, and Elizabeth Kurimo of the University of Georgia, and Tim Keyes (GDNR) assisted with field collections. Dr. Karen Sughrue and Chris Coppella of the USFWS also assisted with field captures. Dr. John Seaman and Brian Croft of the SREL analyzed the blood, tissue and prey base samples for Cd and other metals. We received administrative and logistic support and cooperation from many agencies/personnel associated with the Savannah Harbor Expansion Project, particularly the following USACE personnel: William Bailey, Ellie Covington, Margarett Mackenzie, and Mary Richards. This project was funded by a grant from the U.S. Army Corps of Engineers (Cooperative Agreement W912HZ-14-2-0003) and received additional support from the Department of Energy, Office of Environmental Management under Award Number DE-FC09-07SR22506.

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Table 1. Sentinel and Alternative Birds Captured and Sampled on the Savannah Dredge Material Containment Areas (DMCA) in the Summer (S) and Winter (W) Periods.

Sentinel Species	Sentinel Season	Spring-Summer	Fall-Winter
Black-necked Stilt[a]	S	10	-
Brown Thrasher	Both	6	4
Eastern Towhee	Both	6	6
Mourning Dove	S	10	-
Northern Mockingbird	Both	13	13
Red-winged Blackbird	S	13	-
Mottled Duck[a]	S	0	-
Savannah Sparrow	W	7[a]	13
House Wren	W	1[a]	-
American Avocet[a]	W	-	0
Northern Shoveler[a]	W	-	8
Song Sparrow	W	-	11
Alternative Species			
Common Ground Dove	S	5	-
Northern Cardinal	Both	8	8
Swamp Sparrow	S	7	7
Yellow-rumped Warbler	W	-	12
American Coot[a]	W	-	4

[a]These species are typically associated with wet conditions/aquatic habitats, although all species utilize edge habitat between aquatic and terrestrial habitats.

[b]Winter sentinel species captured in early Spring.

Table 2. Avian Blood Concentrations (µg/g wet) of Cadmium From Birds Captured on the Savannah Harbor DMCAs Relative to the Method Detection Limits in 2014-2015 (Year 1 of Construction).

SPECIES	SEASON	N	# (%) < MDL	Max Concentration	MDL Range[a]
Sentinel					
Black-necked Stilt	Summer	10	8 (80%)	0.005	0.00360-0.03450
Brown Thrasher	Summer	6	1 (17%)	0.029	0.00131-0.01310
	Winter	3	2 (67%)	0.414	0.00764-0.02583
Eastern Towhee	Summer	6	0 (0%)	0.011	0.00129-0.01000
	Winter	4	4 (100%)	-	0.00823-0.07166
Northern Mockingbird	Summer	12	10 (83%)	0.017	0.00148-0.02040
	Winter	3	3 (100%)	-	0.00858-0.01759
Red-winged Blackbird	Summer	11	3 (27%)	0.006	0.00129-0.01022
Mourning Dove	Summer	10	5 (50%)	0.016	0.00520-0.01090
Northern Shoveler	Winter	8	8 (100%)	-	0.00185-0.00276
Savannah Sparrow	Summer[b]	9	6 (67%)	0.161	0.00147-0.01326
	Winter	10	10 (100%)	-	0.00186-0.02049
Song Sparrow	Winter	11	11 (100%)	-	0.00556-0.02084
Alternate[c]					
American Coot	Winter	4	4 (100%)	-	0.01472-0.02286
Common Ground Dove	Summer	4	4 (100%)	-	0.00590-0.00940
Northern Cardinal	Summer	8	6 (75%)	0.004	0.00133-0.02210
	Winter	11	11 (100%)	-	0.00716-0.01411

[a]Sample specific Method Detection Limits (MDLs) factoring in sample volume, etc..

[b]Savannah Sparrows are a “winter” species, but several were captured during the early Summer sampling in April.

[c]Alternate species were captured/sampled in case other sentinel species proved difficult to capture.

Table 3. Cadmium Concentrations (µg/g dry wt) in Tissue Samples and Gizzard Contents of Northern Shovelers Lethally Collected on the Savannah Harbor DMCAs in 2014/2015 (Year 1 of Construction).

	Tissue	N	Mean	StDev	StErr	Max
All	Kidney	8	10.71	7.84	2.77	21.94
Male		4	17.44	3.19	1.60	21.94
Female		4	3.97	3.48	1.74	8.92
All	Liver	8	1.75	0.83	0.29	2.72
Male		4	2.14	0.71	0.36	2.72
Female		4	1.36	0.82	0.41	2.49
All	Gizzard	8	< MDL[a]	-	-	0.10
Male		4	< MDL[a]	-	-	0.10
Female		4	< MDL	-	-	-
All	Blood	8	< MDL[b]	-	-	-
Male		4	< MDL[b]	-	-	-
Female		4	< MDL[b]	-	-	-

[a]Gizzard contents were below detection limits for 6 of 8 samples, with only gizzard contents from 2 males (0.10 and 0.06 ppm Cd) being above the MDL of 0.03 µg/g dry wt.

[b]All Cd concentrations in shoveler blood samples were below the MDL of 0.07 µg/g wet wt.

Table 4. Concentrations (µg/g Cd dry wt) of Cadmium Found in Potential Avian Prey Items Collected on the Savannah Harbor DMCAs in 2014/2015 (Year 1 of Construction).

			Cadmium Concentrations			
Prey Type	DMCA	N[a]	Mean	SD	SE	Max
Aquatic Beetles	13B	2	4.5	1.1	0.8	5.3
Aquatic Snails	14A	4	6.8	1.7	0.8	8.7
Shrimp	14A	2	2.7	0.2	0.1	2.9
Bees	14A	2	[b]			[b]
Katydid/grasshopper	13B	3	[b]			[b]
Katydid/grasshopper	14A	2	[b]			1.4
Potato Beetle-Adults	14A	3	11.1	1.6	1.0	12.5
Potato Beetle-Larva	14A	3	15.2	0.6	0.4	15.9

[a]N=number of composite samples analyzed for Cd.

[b]Most, if not all, of the samples were below the Method Detection Limit of 0.312 µg/g Cd.

Figure 1. Dredge material containment areas (DMCAs) associated with the Savannah Harbor Expansion Project.

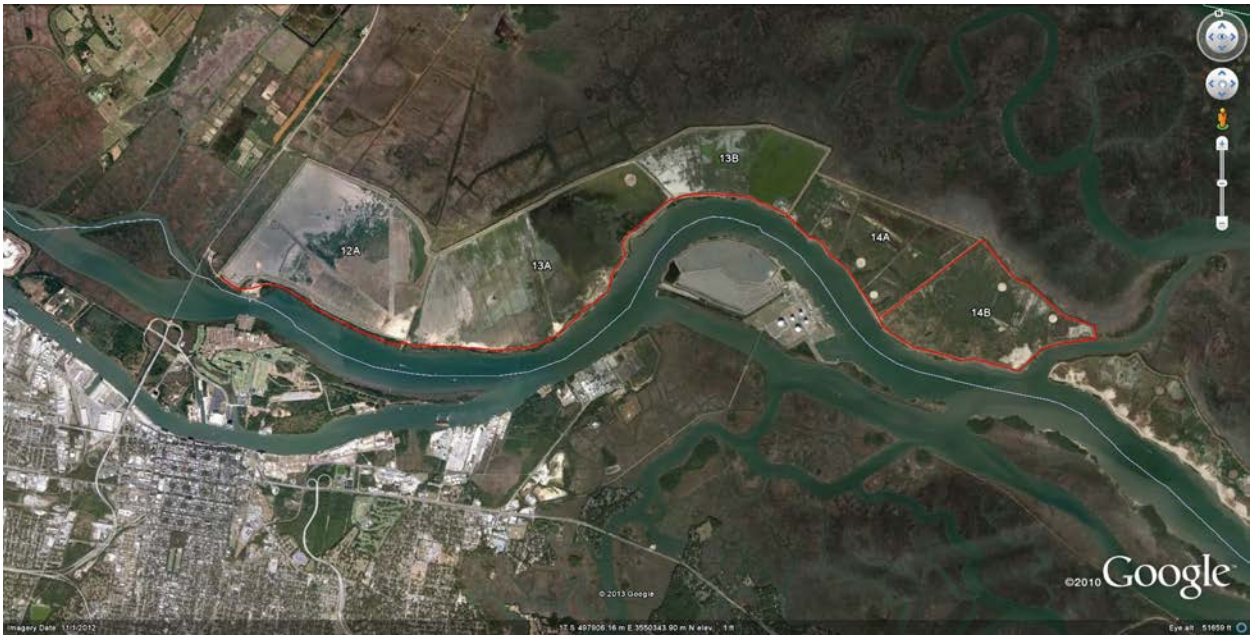


Figure 2. Year one avian sample collection sites in (A) DMCA 14A, (B) DMCA 13B, and (C) DMCA 12A.

A. DMCA 14A

B. DMCA 13B

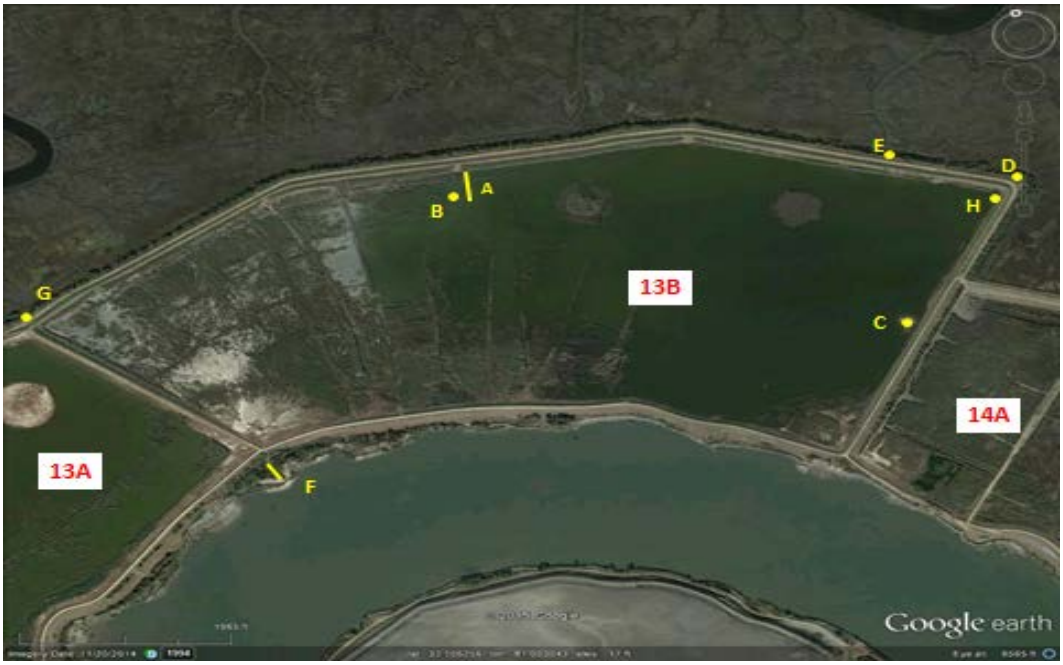
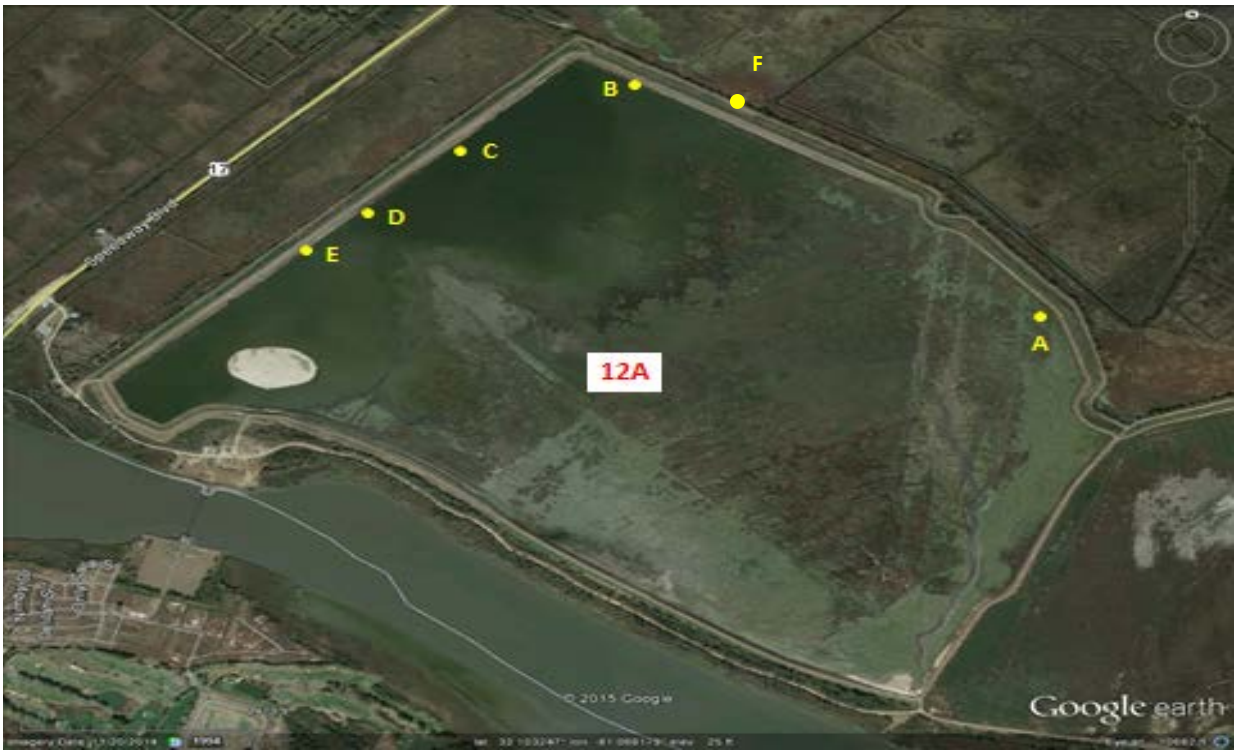


Figure 2 (continued)

C. DMCA 12A



APPENDIX 1. Metal Concentrations (ppm wet wt) in Avian Blood Samples Collected on the Savannah Harbor DMCAs in Year 1 (Summer 2014-2015)[a].

Species	Season	N		Cr	Fe	Ni	Cu	Zn	As	Se
SENTINEL SPECIES										
Black-necked Stilt	Summer	10	Mean	0.19	353.27	0.07	0.53	5.03	0.07	1.50
			SD	0.06	64.08	0.07	0.14	1.34	0.02	0.59
Brown Thrasher	Summer	6	Mean	0.19	392.20	0.04	0.47	4.84	0.05	0.87
			SD	0.09	60.97	0.03	0.17	1.32	0.04	0.48
	Winter	3	Mean	0.97	776.33	0.50	1.49	10.68	0.33	2.12
			SD	1.14	625.34	0.63	1.20	8.04	0.40	2.32
Eastern Towhee	Summer	6	Mean	0.17	384.71	0.04	0.39	5.05	0.03	0.53
			SD	0.02	37.86	0.03	0.08	0.85	0.01	0.16
	Winter	4	Mean	0.33	444.24	< MDL	0.74	6.35	< MDL	< MDL
			SD	0.06	54.19	-	0.27	1.83	-	-
Mourning Dove	Summer	10	Mean	0.201	428.796	0.059	0.446	5.101	0.029	0.305
			SD	0.076	60.831	0.015	0.058	0.744	0.010	0.160
Northern Mockingbird	Summer	12	Mean	0.58	429.06	0.30	0.62	5.61	0.04	0.93
			SD	0.67	75.52	0.44	0.15	1.30	0.01	0.31
	Winter	3	Mean	0.32	518.46	0.10	0.71	5.91	< MDL	< MDL
			SD	0.09	75.93	0.01	0.06	1.04	-	-
Northern Shoveler	Winter	8	Mean	< MDL	359.26	< MDL	< MDL	4.74	0.12	1.33
			SD	-	30.67	-	-	0.51	0.02	0.31

Species	Season	N		Cr	Fe	Ni	Cu	Zn	As	Se
SENTINEL SPECIES	(cont'd)									
Red-winged Blackbird	Summer	13	Mean	0.24	433.81	0.05	0.40	3.77	0.03	1.05
			SD	0.18	73.62	0.04	0.10	1.12	0.02	0.27
Savannah Sparrow	Summer	9	Mean	0.45	750.37	4.40	0.99	13.48	0.09	1.75
			SD	0.39	640.36	11.97	1.14	15.85	0.12	1.40
	Winter	10	Mean	0.34	465.93	0.14	0.53	5.01	< MDL	0.75
			SD	0.26	147.82	0.14	0.03	1.64	-	0.15
Song Sparrow	Winter	11	Mean	0.37	412.33	0.20	0.57	5.01	< MDL	0.66
			SD	0.10	25.80	0.14	0.08	0.57	-	0.18
ALTERNATE SPECIES										
American Coot	Winter	4	Mean	0.43	452.56	< MDL	0.98	6.62	< MDL	< MDL
			SD	0.26	161.80	-	0.22	2.07	-	-
Common Ground Dove	Summer	5	Mean	0.18	424.68	0.05	0.45	5.24	0.03	0.53
			SD	0.03	22.20	0.04	0.05	1.58	0.01	0.06
Northern Cardinal	Summer	8	Mean	0.24	403.45	0.07	0.58	4.76	0.03	0.64
			SD	0.10	39.08	0.07	0.27	1.43	0.01	0.15
	Winter	11	Mean	0.29	422.29	0.08	0.67	5.19	0.06	0.51
			SD	0.04	47.07	0.02	0.09	1.17	0.01	0.09
Method Detection Limits				Cr	Fe	Ni	Cu	Zn	As	Se
(range of MDLs in ppm)				0.029-0.236	3.316-6.968	0.017-0.341	0.213-0.716	0.093-0.413	0.018-0.097	0.341-0.977

[a]Cobalt (Co), Lead (Pb), and Strontium (Sr) were omitted from this table due to their high percentage of <MDL concentrations.

APPENDIX 2. Metal Concentrations (ppm dry wt) in Tissues From Lethally-collected Northern Shovelers From the Savannah Harbor DMCAs in Year 1 (Summer 2014-Winter 2015).

Tissue	Gender	N		Cr	Fe	Co	Ni	Cu	Zn	As	Se	Sr	Pb
Kidney	Male	4	Mean	0.63	627.18	0.43	0.23	21.56	95.45	1.23	6.74	9.57	0.37
			SD	0.24	195.94	0.12	0.17	3.61	7.04	0.32	0.21	10.99	0.18
	Female	4	Mean	0.60	544.12	0.51	0.12	19.83	82.82	1.11	8.18	1.42	0.35
			SD	0.32	141.38	0.13	0.04	2.63	8.08	0.37	1.63	0.45	0.24
Liver	Male	4	Mean	0.39	5232.45	0.13	0.12	83.21	122.83	0.78	5.78	0.76	0.15
			SD	0.16	4668.67	0.04	0.03	46.18	22.78	0.28	0.84	0.48	0.06
	Female	4	Mean	0.49	7276.25	0.17	0.09	70.64	115.47	0.82	7.23	0.70	0.24
			SD	0.12	3868.74	0.02	0.01	23.13	15.83	0.36	1.67	0.27	0.24
Gizzard Contents	Male	4	Mean	0.54	421.61	0.28	0.37	1.68	4.74	0.65	0.43	25.44	1.48
			SD	0.55	439.10	0.30	0.44	1.22	1.89	0.67	0.14	36.37	1.95
	Female	4	Mean	0.62	380.85	0.14	0.30	0.83	6.50	0.27	0.41	2.41	0.29
			SD	0.30	221.55	0.08	0.03	0.32	5.65	0.14	0.21	2.98	0.15
Method Detection Limits (in ppm)				0.05	2.92	0.04	0.03	0.03	0.06	0.02	0.13	0.03	0.03

APPENDIX 3. Metal Concentrations (ppm dry wt) in Potential Avian Prey Items Collected From the Savannah Harbor DMCAs in Year 1 (Summer 2014-Winter 2015).

Tissue	DMCA	N		Cr	Fe	Co	Ni	Cu	Zn	As	Se	Sr	Pb
Aquatic Beetles	13B	2	Mean	5.86	1136.28	0.56	1.67	19.52	179.14	2.04	3.10	153.34	0.90
			SD	2.20	833.80	0.39	0.17	1.24	52.55	1.92	1.24	146.51	0.62
Aquatic Snails	14A	3	Mean	1.25	2232.15	2.88	13.67	3.89	21.06	1.07	2.10	561.75	0.35
			SD	0.06	138.68	0.44	0.50	0.77	2.88	0.17	0.33	72.54	0.03
Shrimp	14A	2	Mean	6.23	464.63	0.43	1.93	56.21	74.50	0.93	4.49	309.33	<MDL
			SD	3.69	66.18	0.12	0.15	14.52	10.66	0.38	0.68	15.55	
Bees	14A	3	Mean	5.74	196.34	0.40	0.46	15.86	89.26	0.41	0.64	1.85	0.28
			SD	3.12	37.51	0.12	0.11	3.82	7.30	0.60	0.09	1.40	0.08
Katydids	13B	3	Mean	1.32	130.00	<MDL	0.56	20.97	141.18	0.21	<MDL	3.79	<MDL
			SD	0.36	22.04	-	0.08	2.85	6.10	0.04	-	0.75	-
Katydids	14A	2	Mean	1.38	114.74	<MDL	1.06	42.25	170.83	<MDL	<MDL	3.00	<MDL
			SD	0.12	30.58		0.70	3.09	31.46	-	-	1.86	-
Potato Beetle Adults	14A	3	Mean	1.91	241.37	0.14	1.26	67.97	89.30	0.65	0.67	41.25	0.28
			SD	0.22	52.65	0.03	0.08	12.13	12.08	0.17	0.22	9.12	0.03
Potato Beetle Larva	14A	3	Mean	9.77	595.17	0.52	5.07	45.35	82.37	0.53	0.69	29.40	0.52
			SD	3.55	145.80	0.11	1.37	4.56	12.96	0.04	0.07	16.37	0.28
Method Detection Limits (in ppm)				0.13	4.88	0.11	0.10	0.07	0.10	0.05	0.52	0.38	0.21