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Trace Element Concentrations in Great Blue Heron and Osprey: 2009-2010

Tennessee Valley Authority
Ash Recovery Project
Kingston, Tennessee

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Acronyms

ANOVA	Analysis of Variance
cm	centimeters
cm^3	cubic centimeters
COPECs	constituents of potential ecological concern
CRM	Clinch River Mile
cy	cubic yard
dw	dry weight
ERM	Emory River Mile
KIF	Kingston Fossil Plant
km	kilometers
mg/kg	milligram per kilogram
Pace	Pace Analytical Services, Inc.
TRM	Tennessee River Mile
TVA	Tennessee Valley Authority

1. Introduction

The Tennessee Valley Authority (TVA) Kingston Fossil Plant (KIF), one of TVA's larger fossil plants, is located at the confluence of the Emory and Clinch Rivers on Watts Bar Reservoir in Roane County, Tennessee. Ash, a by-product of a coal-fired power plant, is stored in unlined containment areas, including a former Dredge Cell. Failure of the Dredge Cell dike released about 5.4 million cubic yards (cy) of coal ash covering approximately 300 acres. Fly ash also entered the channel and overbank areas of the riverine section of the Emory River. While the released fly ash itself is primarily composed of fine silica particles very similar to sand, it also contains trace amounts of arsenic, chromium, copper, lead, mercury, nickel, selenium, thallium, vanadium, zinc, and other metals which occur naturally in the coal.

Evaluations of the spatial extent of ash deposition indicate that ash may have traveled upstream as far as Emory River Mile (ERM) 6.0, and as far downstream as Tennessee River Mile (TRM) 566 (Jacobs 2010). In the upstream direction, the depth of ash appeared to diminish quickly beyond about ERM 3.5. In the downstream direction, ash deposition generally diminishes quickly below about ERM 1.0, with pockets of greater depth occurring in depositional areas in the lower Emory River and Clinch River. Downstream of Clinch River Mile (CRM) 2.0, ash deposits generally vary from trace amounts to 2 inches. Ash deposition of 0.5 to 1 inch was observed in the Tennessee River at TRM 566 (south of the Clinch River). Only trace amounts of ash have been observed further downstream (Jacobs 2010).

Dredging efforts in the Emory River began on March 20, 2009 and continued until roughly May 29, 2010. Hydraulic dredging in the river began during an initial dredging pilot program on March 20, 2009. This pilot study continued until July 20, 2009 (during the time-critical removal action). Phase I production dredging began in August 2009 and focused on removing the greatest volume of ash in the quickest time frame to reduce the potential for upstream flooding by clearing the river channel and to minimize downriver migration risk. At the end of the pilot and Phase I dredging, approximately 1.96 million cy of ash had been removed from the river. Phase II dredging began in February 2010 in order to further minimize the potential future ash migration down river. This period of dredging was considered "precision" dredging and was focused on returning the river channel to its original (pre-spill) depths while minimizing disturbance of legacy sediment. An estimated 780,000 cy of ash was removed during the Phase II dredging. During dredging operations, turbidity was expected to increase in the immediate area of the dredging. Engineering controls (silt curtains) and operational controls (i.e., reduce cutter head speed, reduce rate of advance, and reverse cutter head rotation) were implemented to minimize suspending solids during the dredging operations.

As an initial assessment of the ash-related contaminant exposure in avian species, eggs of great blue heron (*Ardea herodias*) and osprey (*Pandion haliaetus*) nesting near the TVA Kingston fly ash spill were analyzed for metals and metalloids found in coal ash to determine accumulation and extent of maternal transfer of pollutants. It was hypothesized that birds foraging and breeding in ash-contaminated areas would transfer more metals and metalloids to their offspring than birds in reference areas, and that metal and metalloid concentrations would be higher in 2010 than in 2009 as these elements bioconcentrated and accumulated

in prey items for both birds. Furthermore, it was hypothesized that increases in metals and metalloids would in turn decrease egg dimensions and weight.

2. Methods

The methods used for selecting piscivorous bird species are described below, along with a description of the study sites, field collections, trace element analysis, and statistical comparisons made.

2.1 Species Selection

Great blue heron and osprey were selected for this study because they are present throughout the study area and feed on fish and other aquatic organisms that may be in direct contact with ash in the sediment or water column.

Great blue herons (hereafter, “herons”) are the largest member of the heron group that inhabit a variety of freshwater and marine areas, including freshwater ponds, lakes and rivers, brackish marshes, and lagoons. They are a common permanent resident in Tennessee, typically nesting in colonies ranging in size from a few solitarily nesting pairs to several hundred pairs (Nicholson 1997; Robinson 1990). Herons build their nests in the top of the canopy at heights of 90 to 100 feet, with nesting sites typically used for more than 1 year (USEPA 1993). Colonies in Tennessee have been found in pines, upland and bottomland hardwoods, and on transmission line towers. Nests are comprised of a platform of sticks with a shallow bowl lined with twigs and green leaves or pine needles. Eggs are usually laid in March, with average clutch sizes of three or four eggs. Eggs are incubated by both adults for approximately 28 days and nestlings are fed by both adults for approximately 2 months before they fledge. Herons prey on a variety of aquatic animals such as fish, crustaceans, birds, mammals, amphibians, and reptiles that they catch while wading in shallow waters and along river banks (Nicholson 1997; Robinson 1990). Foraging distances from nesting sites typically range from 2.3 to 6.5 kilometers (km) (Vennesland and Butler 2011). Herons may be exposed to constituents of potential ecological concern (COPECs) through bioaccumulation of trace elements in prey, as well as through incidental surface water and sediment ingestion when foraging.

Ospreys are usually found near lakes and rivers. As a breeding species, they are common on Watts Bar Reservoir as spring and summer residents, but are uncommon elsewhere in the state. They arrive in early spring, building their nests close to the water, in areas with good visibility. Osprey nests in Tennessee have been found on human-made structures over water, including navigation markers, transmission towers, silos, and pole-mounted nest platforms, as well as in trees near bodies of water. Nests are made up of large sticks and lined with bark, grasses, vines, and other available materials. Often times, pairs will return to the same nesting sites used in previous years. Eggs are usually laid in the second half of March, with average clutch sizes of two or three eggs. Eggs are incubated by both adults for approximately 5 to 6 weeks and nestlings are fed by both adults for approximately 7 to 8 weeks before they fledge. Ospreys feed almost exclusively on fish, catching their prey by plunging their feet into the water (Nicholson 1997; Robinson 1990). Foraging distances from nesting sites typically range from 0.7 to 1.7 km (Dunstan 1973, as cited in USEPA 1993). Osprey may be exposed to COPECs through bioaccumulation of trace elements in prey, as well as through incidental ingestion of surface water when foraging.

2.2 Study Sites

In 2009 and 2010, great blue herons occupied two colonies near KIF. These colonies were situated in tree tops at ERM 3.0 and on a tall, steel transmission line structure upstream of KIF at TRM 569.5 (Figure 1). The colony at ERM 3.0 has approximately 50 nests, and the colony at TRM 569.5 has approximately 25 nests. Both colonies were sampled in 2009 and 2010, when dredging activities were still in progress on the Emory River.

Osprey nests were found both upstream and downstream of the KIF facility. These nests occurred in trees, as well as on man-made nestling structures built over the water or on river channel markers. The number of osprey nests sampled increased from 2009 to 2010 as barges and aerial lifts were enlisted to assist in accessing nests that were previously inaccessible (Figure 1). All collections in 2009 and 2010 were made while dredging activities were still in progress on the Emory River.

2.3 Field Collections

Great blue heron and osprey egg sampling efforts began in April 2009, approximately 4 months after the spill, and were continued in April 2010. When possible, nests located around the ash-impacted area near the KIF, downstream of the ash-impacted area, and upstream of the ash-impacted area (reference site) were sampled. One egg was collected from each occupied, accessible nest.

Heron nests were accessed by Harriman Utility Board tree climbers and by TVA transmission lineman (Figure 2). Osprey nests were accessed by field and river operation crews, using a barge and aerial lift (Figure 3).

Egg collections for each species followed the same sampling procedures (Figure 4). One egg was randomly selected from each nest, sealed in a labeled plastic bag, placed in a labeled plastic container for transport, and cooled on ice. Clutch size was recorded at the time of collection. Eggs were weighed, measured (length and width), and labeled with a designated identification code. Each egg was then repackaged in a labeled plastic bag, placed in a labeled glass jar and custody sealed, and then frozen. Samples were shipped to the lab on dry ice for chemical analysis (TVA 2011). Crews also collected quality control samples. Since a true field duplicate is not feasible for biological sampling, co-located samples were collected for each species by collecting two eggs from one nest. These eggs were analyzed as part of the data set. A summary of the egg collections by year and location is presented in Table 1.

2.4 Trace Element Analysis

Heron and osprey egg contents from the impacted and reference sites were separated from shells and the egg contents were analyzed for trace elements. Egg content samples were homogenized prior to analysis. Egg homogenates were then digested and analyzed for 26 trace element concentrations (aluminum, antimony, arsenic, barium, beryllium, boron, calcium, cadmium, chromium, cobalt, copper, iron, potassium,

lead, magnesium, manganese, mercury, molybdenum, nickel, sodium, selenium, strontium, silver, thallium, vanadium, and zinc) according to Method SW-846 6020. Results were reported in milligrams per kilogram (mg/kg) wet weight. Percent moisture was also calculated. All trace element and percent moisture analysis was conducted at Pace Analytical Services, Inc. (Pace), Green Bay, Wisconsin.

Percent recoveries of spiked samples and certified reference materials were within the Quality Assurance Project Plan-specified or laboratory-derived acceptance limits in most cases. Data associated with recoveries outside these limits were qualified as estimated (J flagged). These values were considered estimated because they were below the reporting limit but above the project method detection limit.

Percent moisture was performed according to Pace standard operating procedures. In some instances for heron eggs, sample volumes were too small or were held too long to accurately measure percent moisture (ESI 2011). As a result, a default percent moisture value was calculated by averaging percent moistures in all valid heron egg samples. When necessary, a default percent moisture value of 81 percent was used for heron egg samples without valid percent moisture values.

2.5 Statistical Comparisons

Statistical analyses were conducted in order to determine if spatial and temporal trends were occurring for either species. Heron sampling locations included one reference colony at TRM 569.5 and one impacted colony at ERM 3.0. Due to the small number of nests and eggs available near the site, osprey sampling locations were grouped into reference nests and two sets of impacted nests for statistical comparisons. Reference nests included any eggs collected from the upstream Tennessee River (above TRM 568). Impacted nests were divided into eggs collected on the Emory and Clinch Rivers (ERM 0.0 to ERM 6.0 and CRM 0.0 to CRM 4.5), and eggs collected on the downstream Tennessee River (TRM 564 and TRM 568).

Summary statistics were calculated for heron and osprey (sample size, frequency of detection, minimum and maximum detection and detection limits) for each year and location for the 26 metals and metalloids and for egg biometrics (Appendices A and B). Spatial and temporal trends were evaluated for all metals, metalloids, and egg biometrics. For all statistical tests, the null hypothesis was rejected when p-values were less than 0.05. Statistical evaluations of calcium, magnesium, potassium, and sodium were not included as these elements are essential nutrients with little to no information available for toxicity in birds.

For all constituents detected in heron and osprey eggs with normal or lognormal distribution, two-way analysis of variance (ANOVA) tests were conducted using Statistical Analysis Software (v. 9.3), evaluating year, location, and the interaction of year and location. Lognormal variables were transformed before the analyses. ANOVAs were then followed by a post-hoc test using Tukey-Kramer for unequal sample sizes. In addition, a one-tailed Dunnett's test was performed on location in order to compare impacted sites to reference sites. For constituents with no discernable distribution, non-parametric ANOVA tests (Kruskal Wallis with a Sheirer-Ray-Hare extension) were used to further identify differences among sites and years.

Finally, Pearson correlation analyses were conducted for heron and osprey eggs in order to determine if any relationships were evident among trace elements and/or among trace elements and egg biometrics. Pearson correlations were evaluated with raw or log transformed data, as appropriate. Spearman rank correlations were performed if data did not meet parametric test assumptions.

3. Results

The frequency of detection, range of detected concentrations, and range of sample-specific detection limits for all analytes in heron and osprey eggs are presented in Appendices A and B, respectively. Metals that were all non-detects or mostly non-detects in heron and osprey eggs were excluded from the statistical analyses. All analytical results for heron and osprey eggs can be found in Appendices C and D, respectively.

In heron eggs, copper, mercury, selenium, strontium, and zinc were found above detection limits in all samples. Datasets for two metals (barium and manganese) contained only a few non-detects in 2009 samples. For the purposes of statistical testing, sample-specific detection limits were substituted for these non-detects. Iron was detected in only 2010 samples; as a result, comparisons for this analyte were made by comparing ranges and means among locations. Heron egg concentrations of aluminum, antimony, arsenic, beryllium, barium, cadmium, chromium, lead, silver, thallium, and vanadium were below detection limits and were not included in further analysis. In addition, concentrations of cobalt, molybdenum, and nickel were detected in only a few samples or were only detected in 2010 with estimated values (J flagged), and therefore were also not included in further analysis.

In osprey egg contents, mercury and selenium were the only trace elements found above detection limits in all samples. Datasets for two metals (strontium and zinc) contained only a few non-detects in 2009 and 2010 samples. These datasets were evaluated using the full sample-specific detection limits for non-detects. Osprey egg concentrations of aluminum, arsenic, beryllium, barium, cadmium, cobalt, molybdenum, silver, and thallium were below detection limits and were not included in further statistical analysis. In addition, a number of constituents were detected in 2010 but not in 2009 (antimony, barium, chromium, copper, iron, lead, manganese, nickel, and vanadium). Given the small sample sizes and low frequency of detection, these constituents were also not included in further statistical analysis.

A summary of the metal and metalloid concentrations carried forward into further statistical testing for heron and osprey eggs are presented in Tables 2 and 3, respectively. The data for each of these constituents were tested for normality. In heron eggs, manganese, selenium, zinc, egg length, egg width, egg volume, and egg weight all had normal distributions. Copper and mercury had lognormal distributions, while barium and clutch size did not have a discernable distribution. In osprey eggs, zinc, egg length, egg width, and egg volume all had a normal distribution, while mercury, selenium, strontium, and egg weight all had lognormal distributions. Clutch size did not have a discernable distribution. Spatial and temporal evaluations of metal concentrations in heron and osprey eggs are presented in the subsections below and in Figures 5 through 18.

3.1 Great Blue Heron

Result of the spatial and temporal trend analysis for heron eggs are presented in Table 4 and discussed in the subsections below.

3.1.1 Spatial Trends

Significant differences in heron eggs evaluated by location were only found for copper and selenium; however, the p-value for mercury was close to the level of significance and is therefore also discussed below. No significant differences were found between locations for barium, manganese, strontium, zinc, clutch size, egg length, egg width, egg volume, or egg weight.

- Copper concentrations were significantly different between locations, with higher concentrations in impacted eggs than in reference eggs (Table 4). Mean concentrations of impacted eggs had approximately 4.5 mg/kg dry weight (dw) more copper than reference eggs in 2009, but copper concentrations were only 0.35 mg/kg dw higher in impacted eggs than reference eggs in 2010 (Table 2, Figure 13). The differences seen between locations appear to be driven by one of five samples collected in 2009 from ERM 3.0, with a concentration of 18.5 mg/kg dw (Figure 6). The median concentrations which are between 5 and 6 mg/kg in the impacted site are similar to the reference site (especially in 2010, Figure 6), but the concentrations are skewed high by some eggs in the impacted sites, particularly one that exceeded 18 mg/kg.
- Mercury concentrations were close to being significantly higher in impacted eggs than in reference eggs (Table 4). Mean concentrations of impacted eggs were less than 0.1 mg/kg dw higher in mercury than reference eggs in 2009, while 2010 impacted eggs were approximately 0.4 mg/kg dw higher in mercury concentrations than reference eggs. The ranges of mercury concentrations in 2009 were similar between locations; however, in 2010 mercury concentrations shifted up in impacted eggs (Table 2, Figure 15). The highest mercury concentration from the impacted area (1.989 mg/kg dw) did not have a valid percent moisture concentration (Figure 7). As a result, an average percent moisture concentration was used to determine dw concentrations, and could have possibly influenced the maximum concentration of mercury in this sample.
- Selenium concentrations were significantly different between locations, with higher concentrations in impacted eggs than in reference eggs (Table 4). Mean concentrations of impacted heron eggs had less than 1 mg/kg dw more selenium than reference eggs in 2009 and in 2010 (Table 2, Figure 16). Ranges of concentrations were similar; however, the range of selenium concentrations in impacted eggs in 2010 was shifted slightly higher than all other locations and years (Figure 8).

3.1.2 Temporal Trends

Evaluations by year found significant differences for manganese and selenium in heron eggs, and p-values were close to the level of significance for zinc as discussed below. No significant differences in year were found for barium, copper, mercury, strontium, clutch size, egg length, egg width, egg volume, or egg weight.

- Barium concentrations were significantly different between years, with higher concentrations in 2010 eggs than in 2009 eggs (Table 4). Mean concentrations of 2010 reference eggs had approximately 0.36 mg/kg dw more barium than reference eggs in 2009, and approximately 0.85 mg/kg dw more

barium in 2010 impacted than 2009 impacted eggs (Table 2, Figure 12). Most eggs, whether in 2010 or 2009, had barium concentrations equal to or below 1.0 mg/kg, but two of nine eggs collected in 2010 had concentrations between 2 and 4 mg/kg. Because barium did not significantly differ among locations and the interaction term was not significant, differences in barium concentrations seen between years is unlikely attributed to potential effects of the ash release and could possibly be caused by a regional change or the inherent variability in analytical procedures.

- Manganese concentrations were significantly different between years, with higher concentrations in 2010 eggs than in 2009 eggs (Table 4). In 2010 impacted eggs, the mean manganese concentration was approximately 0.5 mg/kg dw higher than 2009 impacted eggs. However, manganese concentrations in reference locations in 2010 had approximately 1.6 mg/kg dw more than reference eggs in 2009 (Table 2). The range of manganese concentrations shifted higher in reference eggs from 2009 to 2010, with the maximum concentration of manganese (5.7 mg/kg dw) detected in 2010 at the reference location (Figures 7 and 14). As a result, the differences in manganese concentrations seen between years is unlikely attributed to potential effects of the ash release and could possibly be caused by a regional change or the inherent variability in analytical procedures.
- Selenium concentrations were significantly different between years, with higher concentrations in 2010 eggs than in 2009 eggs (Table 4). Differences between years were seen when comparing eggs collected from the impacted site in 2010 to eggs collected from the reference site in 2009. Mean concentrations of 2010 impacted heron eggs had approximately 1 mg/kg dw more selenium than reference eggs in 2009 (Table 2; Figure 16). Ranges of concentrations were similar; however, the range of selenium concentrations in impacted eggs in 2010 was shifted slightly higher than all other locations and years (Figure 8).
- Zinc concentrations were close to the level of significance, with higher concentrations in 2010 (Table 4). No specific sites and years were identified as significantly different; however, mean zinc concentrations increased by approximately 9 mg/kg dw in reference eggs from 2009 to 2010 and by approximately 13 mg/kg dw in impacted eggs from 2009 to 2010 (Table 2, Figure 18). Ranges of concentrations for both locations overlapped between years but both ranges shifted higher in 2010 (Figure 9). As a result, the differences in zinc concentrations seen between years is unlikely attributed to potential effects of the ash release and could possibly be caused by a regional change or the inherent variability in analytical procedures.

3.2 Osprey

Results of spatial and temporal trend analysis for osprey eggs are presented in Table 5 and are discussed in the subsections below.

3.2.1 Spatial Trends

No significant differences were identified in metal or metalloid concentrations in osprey eggs evaluated by location; however, egg lengths did indicate a significant difference when using the one-tailed Dunnett's test in Emory and Clinch River eggs compared to reference eggs, and clutch size also showed a significant difference using a non-parametric 2-way ANOVA (Kruskall-Wallis with Sheirer-Ray-Hare extension) (Table 5). In addition, egg volume was close to the level of significance and is also discussed below.

- Clutch size was significantly different in Emory and Clinch River osprey eggs compared to reference eggs. However, the means were higher in the most impacted Emory/Clinch River reach than the reference or more downstream Tennessee River. Consequently, these differences were not attributed to potential effects of the ash release.
- Egg lengths were significantly different in Emory and Clinch River osprey eggs compared to reference eggs, with shorter lengths in impacted eggs than in reference eggs. In 2009, impacted egg lengths were approximately 0.3 centimeters (cm) shorter than reference egg lengths; however, in 2010 impacted egg lengths were less than 0.1 cm shorter than reference eggs (Table 3). Differences of 0.1 cm are unlikely to be biologically meaningful, and as a result, these differences are probably an artifact of natural variability among eggs and habitats.
- Egg volumes were almost significantly different in Emory and Clinch River eggs compared to reference eggs, with smaller volumes in impacted eggs than in reference eggs. In 2009, impacted egg volumes were less than 4 cubic centimeters (cm^3) smaller than reference egg volumes. Similarly, in 2010 impacted egg volumes were about 4 cm^3 smaller than reference egg volumes (Table 3). Given the small number of samples for osprey eggs, these differences are likely an artifact of natural variability among eggs and habitats.

3.2.2 Temporal Trends

Evaluations by year found significant differences for mercury, selenium, strontium, and p-values were close to the level of significance for zinc as discussed below. No significant differences in year were found for clutch size, egg length, egg width, egg volume, or egg weight.

- Mercury concentrations in osprey eggs were significantly different between years, with higher concentrations in 2010 eggs than in 2009 eggs (Table 5; Figure 15). When differences between years were evaluated further, concentrations were close to the level of significance only when comparing eggs collected from the reference site in 2010 to downstream Tennessee River eggs in 2009 (Figure 10). Given that mercury concentrations were higher in reference eggs than in impacted eggs, these differences were not attributed to potential effects of the ash release.
- Selenium concentrations in osprey eggs were significantly different between years, with higher concentrations in 2010 eggs than in 2009 eggs (Table 5; Figure 16). When differences between years

were evaluated further, significant differences were only seen when comparing eggs collected from the reference site in 2010 to reference eggs in 2009. Ranges of selenium concentrations in the impacted rivers were all similar (Table 3; Figure 10). Given that selenium concentrations were different only in reference eggs for both years, these differences were not attributed to potential effects of the ash release.

- Strontium concentrations in osprey eggs were significantly different between years, with higher concentrations in 2010 eggs than in 2009 eggs (Table 5; Figure 17). However, when these differences were evaluated further, no specific year and location comparisons were identified as significant. Ranges of strontium concentrations were similar for the Emory and Clinch Rivers between years, as well as for the downstream Tennessee River (Figure 11). In the reference eggs, however, strontium was below the detection limits in all 2009 eggs, but was detected in all 2010 eggs (Table 3). As a result, differences in strontium concentrations between years were likely attributed to changes in concentrations within the reference eggs and were not attributed to potential effects of the ash release.
- Zinc concentrations in osprey eggs were significantly different between years, with higher concentrations in 2010 eggs than in 2009 eggs (Table 5; Figure 18). Specific differences were identified between zinc concentrations in 2010 reference eggs and 2009 reference eggs. Zinc was below the detection limits in all 2009 eggs, but was detected in all 2010 eggs (Table 3). As a result, differences in zinc concentrations between years were likely attributed to changes in concentrations within the reference eggs and were not attributed to potential effects of the ash release.

3.3 Correlation Analysis

Pearson and Spearman's correlation tests were conducted for both heron and osprey in order to evaluate relationships among metal concentrations and egg metrics. These tests assess how well the relationship between two variables can be described as well as indicating the degree of linear dependence between the two variables. The sign of the correlation coefficient indicates the direction of association between the two variables, with positive coefficients indicating a positive correlation and negative coefficients indicating a negative correlation.

In heron eggs, while several metals indicated a significant positive correlation with each other, manganese, mercury, strontium, and zinc were the metals that showed a significant or almost significant correlation with the egg biometric data (Table 6), but the effect of the metal was positive on egg size. The positive correlations between manganese and clutch size, strontium and clutch size, mercury and egg length (almost significant), and zinc and egg width and volume (almost significant) indicated that as the analyte increased, the biometric data also increased.

Similarly in osprey eggs, while several of the metals detected indicated positive correlations with other metals, none of the metals had a significant correlation with egg biometric data (Table 7), despite the finding that eggs were shorter or smaller than the reference reach.

4. Discussion of Findings

No trace elements evaluated were associated with adverse effects on osprey egg size or clutch size in the study area, nor were they elevated above reference levels. However, for great blue heron, copper and selenium concentrations in eggs significantly differed between impacted and reference sites. In addition, mercury was almost significantly higher in impacted than reference sites. Temporal differences were limited to barium, manganese and selenium; however, differences between years in manganese were only in the reference locations and barium did not significantly differ between impacted and reference sites. Egg concentrations in impacted sites that are higher than reference sites are compared with literature-based effects values, as presented below for each metal.

Mercury effects have been documented in many literature studies. Ranges of concentrations causing effects have been reviewed and summarized by Thompson et al. (1996), who concluded that mercury concentrations in eggs up to 2.5 mg/kg dw appear to have little detrimental effect on reproduction. Means of mercury in impacted heron eggs were 0.41 and 0.79 mg/kg dw, which are below the suggested threshold level of mercury concentrations in egg tissue. Even the maximum concentration of mercury of 1.99 mg/kg dw was below the effects value of 2.5 mg/kg dw.

A literature review of copper hazards to fish, wildlife, and invertebrates by Eisler (1998) found no lowest adverse effects values for egg concentrations in avian wildlife. Toxicity studies have been conducted on domesticated birds. Ridgway and Karnofsky (1952) evaluated the effects of copper sulfate on chicken embryos through injection into the yolk sac. Using data in that study and assumptions of a 55 gram egg and 80 percent moisture, a median lethal injected dose would be 20 mg/kg dw; however, there is a high uncertainty of this concentration as an effects value because the route of exposure (injection) can overestimate effects of some chemicals (Heinz et al. 2009) and the egg weights and percent moistures were not reported. Mean copper concentrations in heron eggs in impacted reaches ranged from 5.9 to 7.84 mg/kg dw, with a maximum concentration of 18.5 mg/kg dw. Both of the impacted means as well as the maximum concentration are below the median lethal threshold for copper concentrations in egg tissue.

Selenium is an essential nutrient at low doses; however, it readily accumulates in birds and can be transferred to developing offspring (Heinz 1996). When accumulated above the required amount, studies have shown effects of selenium on bird reproduction through teratogenesis and offspring mortality, as well as other kinds of sublethal effects. Teratogenic deformaties in birds include anophthalmy (missing eyes), spinal and bill deformations, defects in internal organs, and histological abnormalities (Harding et al. 2005; Heinz 1996; Hoffman 2002). Selenium has been evaluated in various field and laboratory studies. Maternal transfer of selenium to avian offspring has been well documented in various species of wild aquatic birds from both Kesterson National Wildlife Refuge (Ohlendorf et al. 1986) and Martins Reservoir (King 1988; King et al. 1994). These field studies have also been corroborated by several laboratory studies using dietary exposures of selenium-dosed food in mallards (Heinz et al. 1987 and 1989).

Selenium concentrations known to cause reproductive or teratogenic effects in birds vary, possibly due to differences in each species' ability to maternally transfer selenium to their young or from species-specific differences in responses to maternally transferred selenium (Fairbrother et al. 1999; Ohlendorf et al. 1986). As a result of this variability, background concentrations and known levels of selenium causing adverse effects in birds also differs. While selenium has been studied for a number of years and there are many reviews in relation to exposure and effects of selenium in birds, the most recent compilation of selenium effects data in avian eggs (Ohlendorf and Heinz 2011) was used in this evaluation of tissue concentrations. Mean background concentrations of selenium in eggs are generally thought to be below 3 mg/kg dw, with individual egg concentrations of less than 5 mg/kg dw (Ohlendorf and Heinz 2011). Ohlendorf et al. (1986) found that selenium concentrations of 5 mg/kg dw in black-necked stilt (*Himantopus mexicanus*) eggs resulted in 20 percent mortality or deformity in embryos, but a re-analysis of the stilt field data indicated 10 percent mortality results at 21 to 31 mg/kg (Adams et al. 2003). Studies on other species recently have been reviewed and suggest threshold effects (EC10) concentrations ranging from 7.7 to 60 mg/kg dw in various species of avian eggs (Janz et al. 2010). The piscivore, black-crowned night heron *(Nycticorax nycticorax)* had a no adverse effect level of >16.5 mg/kg, which may be similar to the great blue heron and osprey, which are also piscivores.

Mean concentrations of selenium from ERM 3.0 were 2.9 mg/kg dw (2009) and 3.64 mg/kg dw (2010), both of which fall around the suggested background concentrations (Ohlendorf and Heinz 2011) (Table 2). When evaluating individual selenium concentrations, only two concentrations were above the background values and both of these concentrations were less than or equal to 5 mg/kg dw (Appendix C). Consequently, none of the eggs collected during this study surpassed reported threshold effects concentrations of selenium in avian eggs.

4.1 Summary and Conclusions

A total of 26 metals and metalloids were measured in great blue heron and osprey eggs. No differences in trace element concentrations between impacted and reference reaches were observed for osprey. Spatial differences in metal concentrations potentially caused by the ash spill included copper, mercury, and selenium in heron eggs, while temporal differences were limited to barium and selenium in heron eggs. In addition, slight differences in egg biometrics were identified for osprey eggs; however, these differences are likely attributed to natural variability because none of the trace elements were negatively correlated to egg biometrics.

Consistent with other field surveys, uncertainties exist when evaluating species that have the ability to migrate, or in systems of complex analyte mixtures. The evaluations in this study focused on comparisons among sites, between years, and with literature-derived concentrations in order to assess the relationship between the ash release and trace elements in heron and osprey egg contents. Natural variability or historical contamination associated with the sample sites may have potentially contributed to the differences found among sites. Overall, the results of this study indicate that some locational differences in selenium and other metals detected in heron eggs collected from rookeries at ERM 3.0 and TRM 569.5 exist. These

metals are all below the ranges of concentrations thought to cause adverse effects to populations. A comprehensive evaluation of heron and osprey will be completed in the Baseline Ecological Risk Assessment using additional lines of evidence in order to interpret the differences seen between locations and years.

4.2 Future Studies

Monitoring efforts for heron were continued at the same two colonies in March 2011. A total of 20 heron eggs (ten from ERM 3.0 and ten from TRM 569.5) were collected and analyzed for the same suite of 26 metals. Results are currently being evaluated. These efforts may be repeated in 2012 as well.

Osprey monitoring efforts were put on hold due to the limited number of nests in the impacted areas of the river and the small clutch size for each nest. Evaluations of heron eggs in 2011 and 2012 will serve as indicators for potential problems in piscivorous birds and will likely inform the decisions made for protecting osprey populations in the vicinity of the ash spill.

5. Acknowledgements

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Table 1. Summary of Great Blue Heron and Osprey Egg Collections for 2009 and 2010
Tennessee Valley Authority Kingston, Tennessee

Location		Species			
Site Name	**Type**	**2009 Great Blue Heron**	**2010 Great Blue Heron**	**2009 Osprey**	**2010 Osprey**
Upstream Tennessee River	Reference Sites [1]	5	4	2	5
Emory River	Potentially Affected Sites	5	9	2	1
Clinch River	Potentially Affected Sites	NC	NC	2	1
Downstream Tennessee River	Potentially Affected Sites	NC	NC	3	3

[1] Reference Sites = Sampling locations above Tennessee River Mile 568.

NC - Not collected.

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Table 2. Great Blue Heron Egg Summary Statistics for 2009 and 2010

Tennessee Valley Authority **Kingston, Tennessee**

Analyte	Site	2009 Great Blue Heron Egg Results (mg/kg dw)				2010 Great Blue Heron Egg Results (mg/kg dw)			
		Number of Detects	Number of Samples	Mean ± SD[1]	Range	Number of Detects	Number of Samples	Mean ± SD[1]	Range
Aluminum	Reference	0	5	NC ± NC	84.3 – 138	0	4	NC ± NC	14.7 – 23
	Emory River	0	5	NC ± NC	126 – 166	0	9	NC ± NC	19 – 26.2
Antimony	Reference	0	5	NC ± NC	0.34 – 0.55	0	4	NC ± NC	0.05 – 0.08
	Emory River	0	5	NC ± NC	0.51 – 0.67	0	9	NC ± NC	0.07 – 0.10
Arsenic	Reference	0	5	NC ± NC	0.34 – 0.55	0	4	NC ± NC	0.1 – 0.16
	Emory River	0	5	NC ± NC	0.51 – 0.67	0	9	NC ± NC	0.13 – 0.18
Barium	Reference	4	5	0.54 ± 0.11	0.36 – 0.66	4	4	0.72 ± 0.12	0.57 – 0.83
	Emory River	2	5	0.69 ± 0.19	0.51 – 1	9	9	1.36 ± 1.12	0.53 – 3.7
Beryllium	Reference	0	5	NC ± NC	0.34 – 0.55	0	4	NC ± NC	0.11 – 0.17
	Emory River	0	5	NC ± NC	0.51 – 0.67	0	9	NC ± NC	0.14 – 0.19
Boron	Reference	0	5	NC ± NC	6.7 – 11	0	4	NC ± NC	1.5 – 2.4
	Emory River	0	5	NC ± NC	10.1 – 13.3	0	9	NC ± NC	2 – 2.7
Cadmium	Reference	0	5	NC ± NC	0.34 – 0.55	0	4	NC ± NC	0.03 – 0.04
	Emory River	0	5	NC ± NC	0.51 – 0.67	0	9	NC ± NC	0.04 – 0.05
Chromium	Reference	0	5	NC ± NC	0.34 – 0.55	0	4	NC ± NC	0.47 – 0.73
	Emory River	0	5	NC ± NC	0.51 – 0.67	0	9	NC ± NC	0.6 – 0.83
Cobalt	Reference	0	5	NC ± NC	0.34 – 0.55	2	4	0.07 ± 0.01	0.06 – 0.08
	Emory River	0	5	NC ± NC	0.51 – 0.67	0	9	NC ± NC	0.07 – 0.14
Copper	Reference	5	5	3.38 ± 1.14	1.7 – 4.6	4	4	5.55 ± 1.72	3.2 – 7.1
	Emory River	5	5	7.84 ± 6.11	3.1 – 18.5	9	9	5.9 ± 1.81	3.8 – 9.6
Iron	Reference	0	5	NC ± NC	84.3 – 138	4	4	105.83 ± 8.72	95.3 – 113
	Emory River	0	5	NC ± NC	126 – 166	9	9	122.26 ± 25.84	94 – 163
Lead	Reference	0	5	NC ± NC	0.34 – 0.55	0	4	NC ± NC	0.1 – 0.16
	Emory River	0	5	NC ± NC	0.51 – 0.67	0	9	NC ± NC	0.13 – 0.18
Manganese	Reference	3	5	2.7 ± 0.72	1.7 – 3.5	4	4	4.3 ± 1.52	2.5 – 5.7
	Emory River	2	5	3 ± 0.3	2.5 – 3.3	9	9	3.47 ± 0.93	2 – 4.6
Mercury	Reference	5	5	0.35 ± 0.37	0.11 – 0.99	4	4	0.43 ± 0.36	0.21 – 0.96
	Emory River	5	5	0.41 ± 0.13	0.26 – 0.6	9	9	0.79 ± 0.54	0.2 – 1.99
Molybdenum	Reference	0	5	NC ± NC	3.4 – 5.5	4	4	0.57 ± 0.1	0.48 – 0.69
	Emory River	0	5	NC ± NC	5.1 – 6.7	0	9	NC ± NC	0.6 – 1.7
Nickel	Reference	0	5	NC ± NC	0.34 – 0.55	0	4	NC ± NC	0.36 – 0.56
	Emory River	1	5	NC ± NC	0.51 – 3	0	9	NC ± NC	0.46 – 0.64

[1] Mean calculations include reporting limits substituted for non-detects.
cm - Centimeter.
g - Gram.
mg/kg dw - milligrams per kilogram dry weight.
NA - not applicable.
NC - Not calculated; not enough detections to calculate mean. Range includes reporting limits.
SD - standard deviation.
TN - Tennessee.

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Table 2. Great Blue Heron Egg Summary Statistics for 2009 and 2010

Tennessee Valley Authority **Kingston, Tennessee**

Analyte	Site	2009 Great Blue Heron Egg Results (mg/kg dw)				2010 Great Blue Heron Egg Results (mg/kg dw)			
		Number of Detects	Number of Samples	Mean ± SD[1]	Range	Number of Detects	Number of Samples	Mean ± SD[1]	Range
Selenium	Reference	5	5	2.52 ± 0.61	1.6 – 3.2	4	4	2.78 ± 0.17	2.6 – 3
	Emory River	5	5	2.9 ± 0.34	2.4 – 3.3	9	9	3.64 ± 0.69	2.6 – 5
Silver	Reference	0	5	NC ± NC	0.17 – 0.28	0	4	NC ± NC	0.01 – 0.02
	Emory River	0	5	NC ± NC	0.25 – 0.33	0	9	NC ± NC	0.01 – 0.03
Strontium	Reference	5	5	1.5 ± 1.25	0.61 – 3.7	4	4	2.28 ± 1.83	1.1 – 5
	Emory River	5	5	1.78 ± 1.42	0.8 – 4.2	9	9	1.74 ± 0.77	1 – 3.1
Thallium	Reference	0	5	NC ± NC	0.34 – 0.55	0	4	NC ± NC	0.05 – 0.08
	Emory River	0	5	NC ± NC	0.51 – 0.67	0	9	NC ± NC	0.07 – 0.09
Vanadium	Reference	0	5	NC ± NC	0.67 – 1.1	0	4	NC ± NC	0.17 – 0.26
	Emory River	0	5	NC ± NC	1 – 1.3	0	9	NC ± NC	0.22 – 0.3
Zinc	Reference	5	5	51.94 ± 14.48	30.3 – 68.8	4	4	60.8 ± 9.87	46.1 – 67.2
	Emory River	5	5	47.38 ± 20.46	28.5 – 77.9	9	9	60.7 ± 8.31	53.1 – 76.3
Clutch Size	Reference	NA	4	3.75 ± 0.96	3 – 5	NA	3	4.33 ± 1.5	3 – 6
	Emory River	NA	5	3 ± 0.71	2 – 4	NA	9	3.89 ± 0.33	3 – 4
Egg Length (cm)	Reference	NA	5	6.27 ± 0.63	5.76 – 7.25	NA	4	6.40 ± 0.42	5.97 – 6.97
	Emory River	NA	5	6.34 ± 0.19	6.16 – 6.56	NA	9	6.45 ± 0.29	6.05 – 6.90
Egg Width (cm)	Reference	NA	5	4.60 ± 0.19	4.4 – 4.903	NA	4	4.59 ± 0.06	4.53 – 4.68
	Emory River	NA	5	4.50 ± 0.19	4.196 – 4.67	NA	9	4.54 ± 0.10	4.36 – 4.68
Egg Volume (cm^3)	Reference	NA	5	68.19 ± 12.66	56.90 – 88.93	NA	4	68.9 ± 5.21	62.4 – 74.5
	Emory River	NA	5	65.73 ± 7.14	55.55 – 72.53	NA	9	67.8 ± 4.72	58.6 – 73.2
Egg Weight (g)	Reference	NA	5	66.8 ± 9.09	58 – 81	NA	4	67.7 ± 5.75	62.6 – 74.5
	Emory River	NA	5	64 ± 5.05	58 – 68	NA	9	67.9 ± 5.68	54.8 – 74.3

[1] Mean calculations include reporting limits substituted for non-detects.
cm - Centimeter.
g - Gram.
mg/kg dw - milligrams per kilogram dry weight.
NA - not applicable.
NC - Not calculated; not enough detections to calculate mean. Range includes reporting limits.
SD - standard deviation.
TN - Tennessee.

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Table 3. Osprey Egg Summary Statistics for 2009 and 2010

Tennessee Valley Authority Kingston, Tennessee

Analyte	Site	2009 Osprey Egg Results (mg/kg dw)				2010 Osprey Egg Results (mg/kg dw)			
		Number of Detects	Number of Samples	Mean ± SD[1]	Range	Number of Detects	Number of Samples	Mean ± SD[1]	Range
Aluminum	Reference	0	2	NC ± NC	141 – 162	0	5	NC ± NC	20.8 – 27.7
	Emory/Clinch Rivers	0	4	NC ± NC	106 – 174	0	2	NC ± NC	23.3 – 24.3
	Downstream TN River	0	3	NC ± NC	98.4 – 165	0	3	NC ± NC	25 – 27.7
Antimony	Reference	0	2	NC ± NC	0.56 – 0.65	1	5	NC ± NC	0.08 – 0.43
	Emory/Clinch Rivers	0	4	NC ± NC	0.42 – 0.7	0	2	NC ± NC	0.08 – 0.09
	Downstream TN River	0	3	NC ± NC	0.39 – 0.66	0	3	NC ± NC	0.09 – 0.1
Arsenic	Reference	0	2	NC ± NC	0.56 – 0.65	0	5	NC ± NC	0.15 – 0.19
	Emory/Clinch Rivers	0	4	NC ± NC	0.42 – 0.7	0	2	NC ± NC	0.16 – 0.34
	Downstream TN River	0	3	NC ± NC	0.39 – 0.66	0	3	NC ± NC	0.18 – 0.19
Barium	Reference	0	2	NC ± NC	0.56 – 0.65	1	5	NC ± NC	0.24 – 0.32
	Emory/Clinch Rivers	0	4	NC ± NC	0.42 – 0.7	1	2	NC ± NC	0.27 – 0.28
	Downstream TN River	0	3	NC ± NC	0.39 – 0.66	1	3	NC ± NC	0.29 – 0.33
Beryllium	Reference	0	2	NC ± NC	0.56 – 0.65	0	5	NC ± NC	0.15 – 0.2
	Emory/Clinch Rivers	0	4	NC ± NC	0.42 – 0.7	0	2	NC ± NC	0.17 – 0.36
	Downstream TN River	0	3	NC ± NC	0.39 – 0.66	0	3	NC ± NC	0.18 – 0.2
Boron	Reference	0	2	NC ± NC	11.3 – 12.9	0	5	NC ± NC	2.2 – 2.9
	Emory/Clinch Rivers	0	4	NC ± NC	8.5 – 13.9	0	2	NC ± NC	2.4 – 2.5
	Downstream TN River	0	3	NC ± NC	7.9 – 13.2	0	3	NC ± NC	2.6 – 2.9
Cadmium	Reference	0	2	NC ± NC	0.56 – 0.65	0	5	NC ± NC	0.04 – 0.05
	Emory/Clinch Rivers	0	4	NC ± NC	0.42 – 0.7	0	2	NC ± NC	0.04 – 0.05
	Downstream TN River	0	3	NC ± NC	0.39 – 0.66	0	3	NC ± NC	0.05 – 0.05
Chromium	Reference	0	2	NC ± NC	0.56 – 0.65	1	5	NC ± NC	0.66 – 1.5
	Emory/Clinch Rivers	0	4	NC ± NC	0.42 – 0.7	0	2	NC ± NC	0.74 – 0.77
	Downstream TN River	0	3	NC ± NC	0.39 – 0.66	0	3	NC ± NC	0.79 – 0.88
Cobalt	Reference	0	2	NC ± NC	0.56 – 0.65	0	5	NC ± NC	0.07 – 0.1
	Emory/Clinch Rivers	0	4	NC ± NC	0.42 – 0.7	0	2	NC ± NC	0.08 – 0.09
	Downstream TN River	0	3	NC ± NC	0.39 – 0.66	0	3	NC ± NC	0.09 – 0.1
Copper	Reference	0	2	NC ± NC	2.8 – 3.2	5	5	2.6 ± 1.03	1.8 – 4.4
	Emory/Clinch Rivers	0	4	NC ± NC	2.1 – 3.5	2	2	1.85 ± 0.49	1.5 – 2.2
	Downstream TN River	0	3	NC ± NC	2 – 3.3	3	3	2.17 ± 0.15	2 – 2.3
Iron	Reference	0	2	NC ± NC	141 – 162	4	5	126.48 ± 48.29	73.3 – 197
	Emory/Clinch Rivers	1	4	153.75 ± 20.61	127 – 174	1	2	81.2 ± 15.41	70.3 – 92.1
	Downstream TN River	1	3	152 ± 19.97	129 – 165	3	3	125.03 ± 62.46	85 – 197

[1] Mean calculations include reporting limits substituted for non-detects.

cm - Centimeter.

g - Gram.

mg/kg dw - milligrams per kilogram dry weight.

NA - not applicable.

NC - Not calculated; not enough detections to calculate mean. Range includes reporting limits.

SD - standard deviation.

TN - Tennessee.

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Table 3. Osprey Egg Summary Statistics for 2009 and 2010

Tennessee Valley Authority Kingston, Tennessee

Analyte	Site	2009 Osprey Egg Results (mg/kg dw)				2010 Osprey Egg Results (mg/kg dw)			
		Number of Detects	Number of Samples	Mean ± SD[1]	Range	Number of Detects	Number of Samples	Mean ± SD[1]	Range
Lead	Reference	0	2	NC ± NC	0.56 – 0.65	1	5	NC ± NC	0.15 – 0.57
	Emory/Clinch Rivers	0	4	NC ± NC	0.42 – 0.7	0	2	NC ± NC	0.16 – 0.17
	Downstream TN River	0	3	NC ± NC	0.39 – 0.66	0	3	NC ± NC	0.17 – 0.19
Manganese	Reference	0	2	NC ± NC	2.8 – 3.2	4	5	1.78 ± 0.68	1 – 2.8
	Emory/Clinch Rivers	1	4	NC ± NC	2.4 – 3.5	2	2	1.6 ± 0.28	1.4 – 1.8
	Downstream TN River	0	3	NC ± NC	2 – 3.3	2	3	1.7 ± 0.78	1.2 – 2.6
Mercury	Reference	2	2	0.34 ± 0.04	0.31 – 0.36	5	5	0.58 ± 0.28	0.21 – 0.89
	Emory/Clinch Rivers	4	4	0.24 ± 0.03	0.2 – 0.28	2	2	0.35 ± 0.01	0.34 – 0.36
	Downstream TN River	3	3	0.19 ± 0.06	0.16 – 0.26	3	3	0.39 ± 0.26	0.18 – 0.68
Molybdenum	Reference	0	2	NC ± NC	5.6 – 6.5	0	5	NC ± NC	0.18 – 0.24
	Emory/Clinch Rivers	0	4	NC ± NC	4.2 – 7	0	2	NC ± NC	0.21 – 0.21
	Downstream TN River	0	3	NC ± NC	3.9 – 6.6	0	3	NC ± NC	0.22 – 0.24
Nickel	Reference	0	2	NC ± NC	0.56 – 0.65	1	5	NC ± NC	0.51 – 0.9
	Emory/Clinch Rivers	0	4	NC ± NC	0.42 – 0.7	0	2	NC ± NC	0.57 – 0.59
	Downstream TN River	0	3	NC ± NC	0.39 – 0.66	0	3	NC ± NC	0.61 – 0.68
Selenium	Reference	2	2	1.55 ± 0.07	1.5 – 1.6	5	5	3.02 ± 1.12	1.9 – 4.7
	Emory/Clinch Rivers	4	4	2.28 ± 0.25	2 – 2.6	2	2	2.75 ± 0.35	2.5 – 3
	Downstream TN River	3	3	1.8 ± 0.17	1.7 – 2	3	3	2.53 ± 0.23	2.4 – 2.8
Silver	Reference	0	2	NC ± NC	0.28 – 0.32	0	5	NC ± NC	0.02 – 0.02
	Emory/Clinch Rivers	0	4	NC ± NC	0.21 – 0.35	0	2	NC ± NC	0.02 – 0.02
	Downstream TN River	0	3	NC ± NC	0.2 – 0.33	0	3	NC ± NC	0.02 – 0.02
Strontium	Reference	0	2	NC ± NC	0.56 – 0.65	5	5	0.96 ± 0.22	0.73 – 1.2
	Emory/Clinch Rivers	3	4	0.7 ± 0.11	0.6 – 0.8	2	2	0.75 ± 0.22	0.59 – 0.9
	Downstream TN River	2	3	0.85 ± 0.23	0.66 – 1.1	3	3	0.99 ± 0.18	0.89 – 1.2
Thallium	Reference	0	2	NC ± NC	0.56 – 0.65	0	5	NC ± NC	0.07 – 0.1
	Emory/Clinch Rivers	0	4	NC ± NC	0.42 – 0.7	0	2	NC ± NC	0.08 – 0.08
	Downstream TN River	0	3	NC ± NC	0.39 – 0.66	0	3	NC ± NC	0.09 – 0.1
Vanadium	Reference	0	2	NC ± NC	1.1 – 1.3	1	5	NC ± NC	0.24 – 0.51
	Emory/Clinch Rivers	0	4	NC ± NC	0.85 – 1.4	0	2	NC ± NC	0.27 – 0.28
	Downstream TN River	0	3	NC ± NC	0.79 – 1.3	0	3	NC ± NC	0.29 – 0.32
Zinc	Reference	1	2	NC ± NC	13.2 – 29.4	5	5	59.64 ± 20.23	34 – 86.2
	Emory/Clinch Rivers	4	4	45.65 ± 22.5	24.4 – 76.8	2	2	40.7 ± 13.86	30.9 – 50.5
	Downstream TN River	3	3	48.7 ± 15.24	36 – 65.6	3	3	51.87 ± 19.43	37.2 – 73.9

[1] Mean calculations include reporting limits substituted for non-detects.

cm - Centimeter.

g - Gram.

mg/kg dw - milligrams per kilogram dry weight.

NA - not applicable.

NC - Not calculated; not enough detections to calculate mean. Range includes reporting limits.

SD - standard deviation.

TN - Tennessee.

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Table 3. Osprey Egg Summary Statistics for 2009 and 2010

Tennessee Valley Authority Kingston, Tennessee

Analyte	Site	2009 Osprey Egg Results (mg/kg dw)				2010 Osprey Egg Results (mg/kg dw)			
		Number of Detects	Number of Samples	Mean ± SD[1]	Range	Number of Detects	Number of Samples	Mean ± SD[1]	Range
Clutch Size	Reference	NA	2	3 ± 0	3 – 3	NA	4	2.75 ± 0.50	2 – 3
	Emory/Clinch Rivers	NA	3	3.33 ± 0.58	3 – 4	NA	2	3.5 ± 0.71	3 – 4
	Downstream TN River	NA	3	2.33 ± 1.15	1 – 3	NA	3	2.67 ± 0.58	2 – 3
Egg Length (cm)	Reference	NA	2	6.22 ± 0.16	6.11 – 6.33	NA	5	6.07 ± 0.18	5.84 – 6.33
	Emory/Clinch Rivers	NA	4	5.90 ± 0.06	5.81 – 5.95	NA	2	6.00 ± 0.10	5.93 – 6.07
	Downstream TN River	NA	3	6.16 ± 0.12	6.09 – 6.30	NA	3	6.16 ± 0.24	5.89 – 6.35
Egg Width (cm)	Reference	NA	2	4.54 ± 0.06	4.49 – 4.58	NA	5	4.60 ± 0.06	4.55 – 4.68
	Emory/Clinch Rivers	NA	4	4.52 ± 0.04	4.48 – 4.57	NA	2	4.46 ± 0.05	4.42 – 4.49
	Downstream TN River	NA	3	4.65 ± 0.18	4.5 – 4.85	NA	3	4.60 ± 0.19	4.40 – 4.77
Egg Volume (cm^3)	Reference	NA	2	65.2 ± 3.48	62.7 – 67.6	NA	5	65.4 ± 1.77	63.5 – 67.5
	Emory/Clinch Rivers	NA	4	61.3 ± 1.07	60.2 – 62.7	NA	2	60.7 ± 2.36	59.1 – 62.4
	Downstream TN River	NA	3	68.0 ± 5.15	62.9 – 73.2	NA	3	66.8 ± 7.90	58.2 – 73.8
Egg Weight (g)	Reference	NA	2	69 ± 5.66	65 – 73	NA	5	67.2 ± 1.41	65.4 – 68.7
	Emory/Clinch Rivers	NA	4	64 ± 1.83	62 – 66	NA	2	65.0 ± 2.91	63.0 – 67.1
	Downstream TN River	NA	3	70.7 ± 5.51	67 – 77	NA	3	71.2 ± 9.27	61.4 – 79.8

[1] Mean calculations include reporting limits substituted for non-detects.

cm - Centimeter.

g - Gram.

mg/kg dw - milligrams per kilogram dry weight.

NA - not applicable.

NC - Not calculated; not enough detections to calculate mean. Range includes reporting limits.

SD - standard deviation.

TN - Tennessee.

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Table 4. Great Blue Heron Egg ANOVAs – Comparisons Between Years and Locations

Tennessee Valley Authority **Kingston, Tennessee**

Analyte	Number of Samples	R^2	Location	Year	Location*Year	ER vs. REF Post-hoc Comparisons [1]	Location by Year Post-hoc Comparisons [2]
Barium [3]	23	–	0.23	0.04	0.80	0.12	0.04-0.06 (ER, REF 2010 > REF 2009)
Copper	23	0.30	0.05	0.32	0.10	0.03 (ER > REF)	0.07 (ER 2009 > REF 2009)
Manganese	23	0.28	0.52	0.02	0.18	0.74	0.08 (REF 2010 > REF 2009)
Mercury	23	0.29	0.07	0.17	0.75	0.03 (ER > REF)	0.07 (ER 2010 > Ref 2009)
Selenium	23	0.46	0.02	0.05	0.33	0.009 (ER > REF)	0.009 (ER 2010 > REF 2009) 0.08 (ER 2010 > REF 2010)
Strontium	23	0.068	0.97	0.30	0.53	0.49	–
Zinc	23	0.18	0.69	0.07	0.71	0.66	–
Clutch Size [3]	21	–	0.30	**0.07**	0.36	0.30	0.02 (ERM 2010 > ERM 2009)
Egg Length	23	0.04	0.72	0.49	0.99	0.64	–
Egg Width	23	0.08	0.23	0.83	0.76	0.11	–
Egg Volume	23	0.02	0.60	0.68	0.84	0.30	–
Egg Weight	23	0.06	0.65	0.41	0.60	0.33	–

Note: Comparisons between years and locations were conducted using 2-way ANOVAs.

[1] Significant differences from the post-hoc Dunnett's one-tailed test, except barium, which used Wilcoxon rank sum test for pairwise comparisons.

[2] Significant differences from the post-hoc Tukey-Kramer two-tailed test, except for barium, which used Wilcoxon rank sum test for pairwise comparisons.

[3] Analyte did not have a discernable distribution; therefore, a non-parametric 2-way ANOVA (Kruskall-Wallis with Sheirer-Ray-Hare extension) was used to compare location and year.

Shading denotes statistical significance ($p<0.05$).

BOLD denotes potential statistical significance ($0.05 \leq p \leq 0.1$)

– - Indicates no statistical differences.

ANOVA - Analysis of Variance.

ER - Emory River.

NC - Not calculated.

R^2 - Correlation coefficient; indicates the proportion of the variation accounted for by location, year, and interaction between location and year.

REF - Sampling location above Tennessee River Mile 568.

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Table 5. Osprey Egg ANOVAs – Comparisons Between Years and Locations

Tennessee Valley Authority **Kingston, Tennessee**

Analyte	Number of Samples	R^2	Location	Year	Location*Year	ER/CR vs. REF Comparisons [1]	TR vs. REF Comparisons [1]	Location by Year Comparisons [2]
Mercury	19	0.49	0.17	0.05	0.93	0.97	0.99	0.06 (REF 2010 > TR 2009)
Selenium	19	0.57	0.39	0.003	0.30	0.19	0.63	0.05 (REF 2010 > REF 2009)
Strontium	19	0.47	0.17	0.05	0.33	0.82	0.14	–
Zinc	19	0.45	0.32	0.10	**0.07**	0.33	0.12	0.07 (REF 2010 > REF 2009)
Clutch Size[3,4]	17	0.31	0.02	0.89	0.49	–	–	–
Egg Length	19	0.41	**0.08**	0.80	0.43	0.05	0.75	–
Egg Width	19	0.30	0.14	0.78	0.60	0.20	0.92	–
Egg Volume	19	0.37	**0.06**	0.79	0.96	**0.09**	0.92	–
Egg Weight	19	0.32	0.11	0.97	0.86	0.19	0.94	–

Note: Comparisons between years and locations were conducted using 2-way ANOVAs.

[1] Significant differences from the post-hoc Dunnett's one-tailed test.

[2] Significant differences from the post-hoc Tukey-Kramer two-tailed test.

[3] Analyte did not have a discernable distribution; therefore, a non-parametric 2-way ANOVA (Kruskall-Wallis with Sheirer-Ray-Hare extension) was used to compare location and year.

[3] Sample sizes for individual pairwise comparisons were too small for pairwise comparisons.

Shading denotes statistical significance ($p<0.05$).

BOLD denotes potential statistical significance ($0.05 \leq p \leq 0.1$)

– - Indicates no statistical differences.

ANOVA - Analysis of Variance.

ER/CR - Emory and Clinch Rivers.

R^2 - Correlation coefficient; indicates the proportion of the variation accounted for by location, year, and interaction between location and year.

REF - Sampling location above Tennessee River Mile 568.

TR - Downstream Tennessee River (below Tennessee River Mile 568).

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Table 6. Great Blue Heron Egg Pearson Correlation Coefficients

Tennessee Valley Authority **Kingston, Tennessee**

Analyte		Barium[1]	Copper	Manganese	Mercury	Selenium	Strontium	Zinc
Clutch Size[1,2]	**R^2**	0.20	0.17	0.37	0.24	0.15	0.37	0.17
	p-value	0.37	0.43	**0.09**	0.27	0.51	**0.08**	0.43
Egg Length[2]	**R^2**	0.12	0.14	0.08	0.44	0.17	0.17	0.29
	p-value	0.60	0.53	0.72	0.03	0.43	0.45	0.18
Egg Width[2]	**R^2**	-0.12	0.17	0.24	-0.01	0.15	0.26	0.40
	p-value	0.59	0.44	0.28	0.97	0.49	0.23	**0.06**
Egg Volume[2]	**R^2**	0.06	0.16	0.17	0.23	0.17	0.22	0.38
	p-value	0.79	0.48	0.44	0.29	0.45	0.32	**0.07**
Egg Weight[2]	**R^2**	0.12	0.02	0.21	0.24	0.29	0.04	0.26
	p-value	0.59	0.95	0.34	0.26	0.19	0.84	0.24

Note: All analytes are log transformed unless otherwise noted.

[1] Correlations were evaluated using Spearman rank correlations since data did not meet parametric test assumptions.

[2] Correlations were evaluated with untransformed data.

Shading denotes statistical significance ($p<0.05$).

BOLD denotes potential statistical significance ($0.05 \leq p \leq 0.1$)

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Table 7. Osprey Egg Pearson Correlation Coefficients

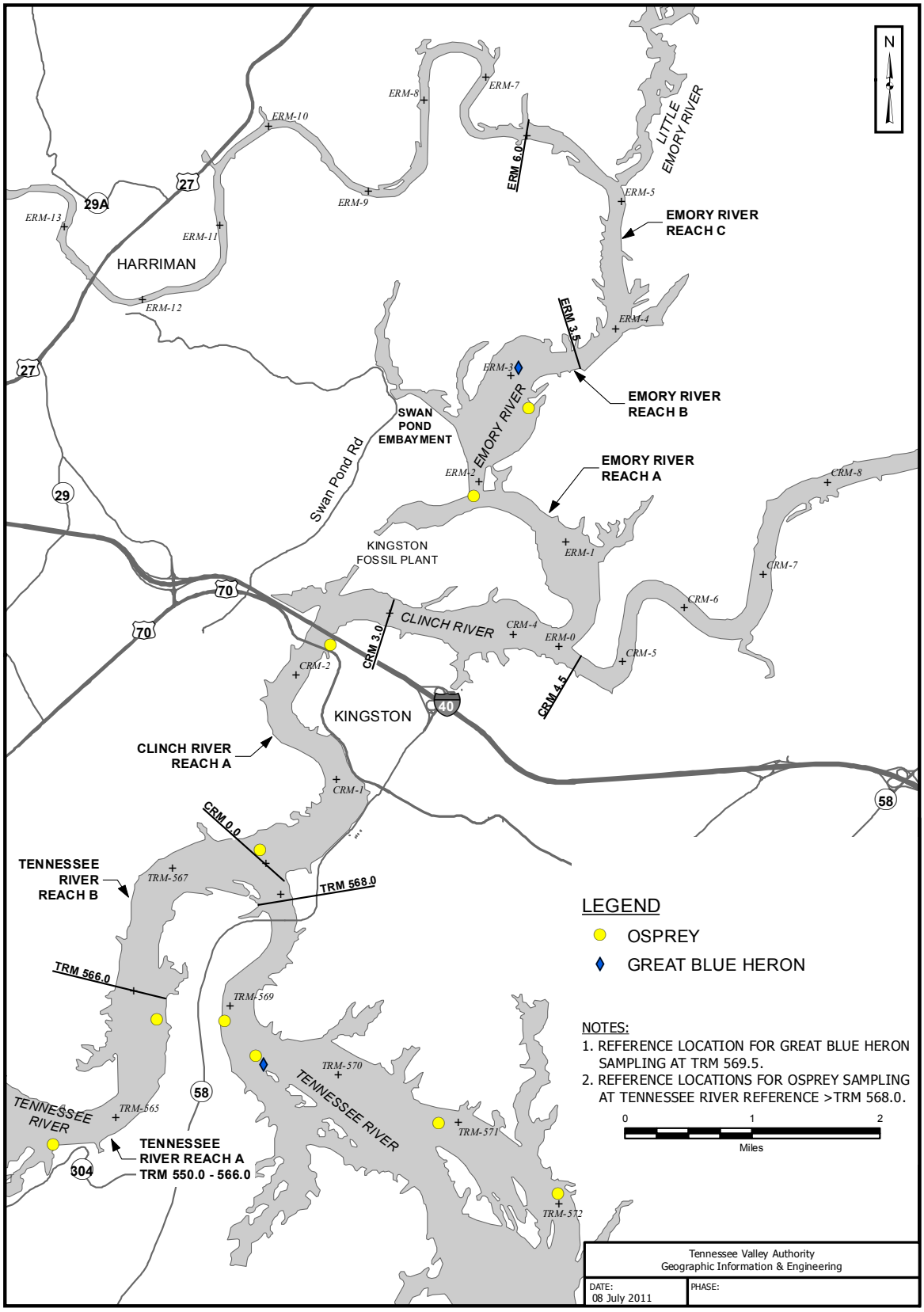
Tennessee Valley Authority **Kingston, Tennessee**

Analyte		Mercury	Selenium	Strontium	Zinc
Clutch Size[1,2]	R^2	-0.22	0.26	-0.25	0.02
	p-value	0.37	0.29	0.31	0.94
Egg Length[2]	R^2	0.30	-0.03	0.13	-0.11
	p-value	0.22	0.89	0.59	0.65
Egg Width[2]	R^2	-0.06	-0.15	0.07	0.01
	p-value	0.81	0.55	0.78	0.97
Egg Volume[2]	R^2	0.07	-0.12	0.11	-0.03
	p-value	0.77	0.62	0.66	0.89
Egg Weight[2]	R^2	0.05	-0.18	0.01	-0.14
	p-value	0.85	0.46	0.97	0.58

Note: All analytes are log transformed unless otherwise noted.

[1] Correlations were evaluated using Spearman rank correlations since data did not meet parametric test assumptions.

[2] Correlations were evaluated with untransformed data.



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TENNESSEE VALLEY AUTHORITY
KINGSTON, TENNESSEE

TRACE ELEMENT CONCENTRATIONS IN GREAT BLUE HERON AND OSPREY: 2009-2010

HERON AND OSPREY SAMPLING LOCATIONS

ARCADIS

FIGURE
1

CITY: KNX DIV/GROUP: ENV/GIS DB: C.SMITH PIC: B.ILGNER PM: D.JONES TM: S.YOUNG
PROJECT: TNTVAKIP.ECA1.00003 PATH: G:\GIS\TVA\KIF\Amphibians-Bird data\Heron & Osprey\F1_Heron&OspreySamplingLocs.pdf

Harriman Utility Board tree climbers collecting great blue heron eggs

TVA transmission linemen collecting great blue heron eggs from power line structure.

TENNESSEE VALLEY AUTHORITY
KINGSTON, TENNESSEE
TRACE ELEMENT CONCENTRATIONS IN
GREAT BLUE HERON AND OSPREY: 2009-2010

HERON EGG COLLECTIONS

ARCADIS

FIGURE
2

Field crews using barge and airlift to access osprey eggs

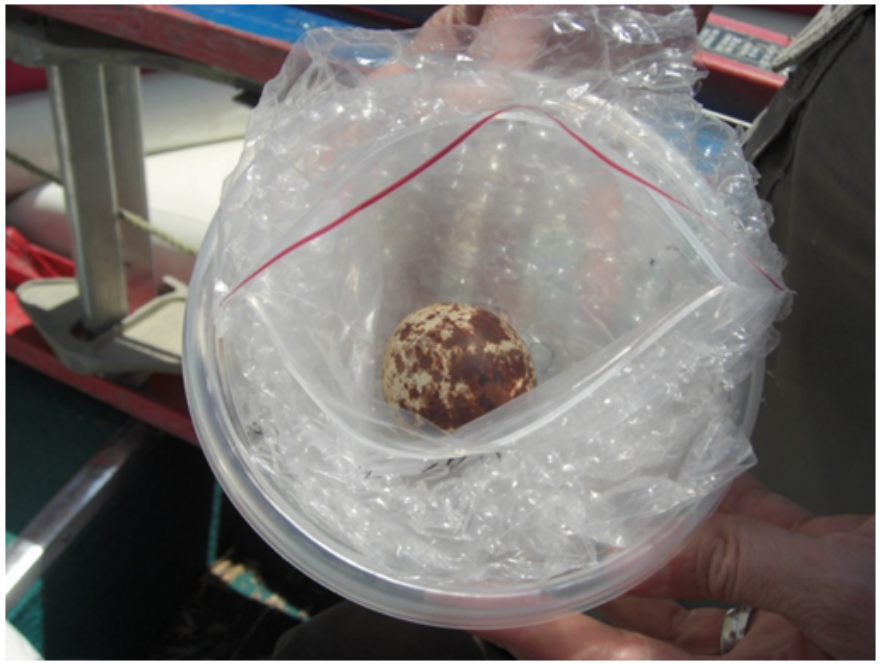
TENNESSEE VALLEY AUTHORITY
KINGSTON, TENNESSEE
TRACE ELEMENT CONCENTRATIONS IN
GREAT BLUE HERON AND OSPREY: 2009-2010

OSPREY EGG COLLECTIONS

ARCADIS

FIGURE
3

Great blue heron egg collection.



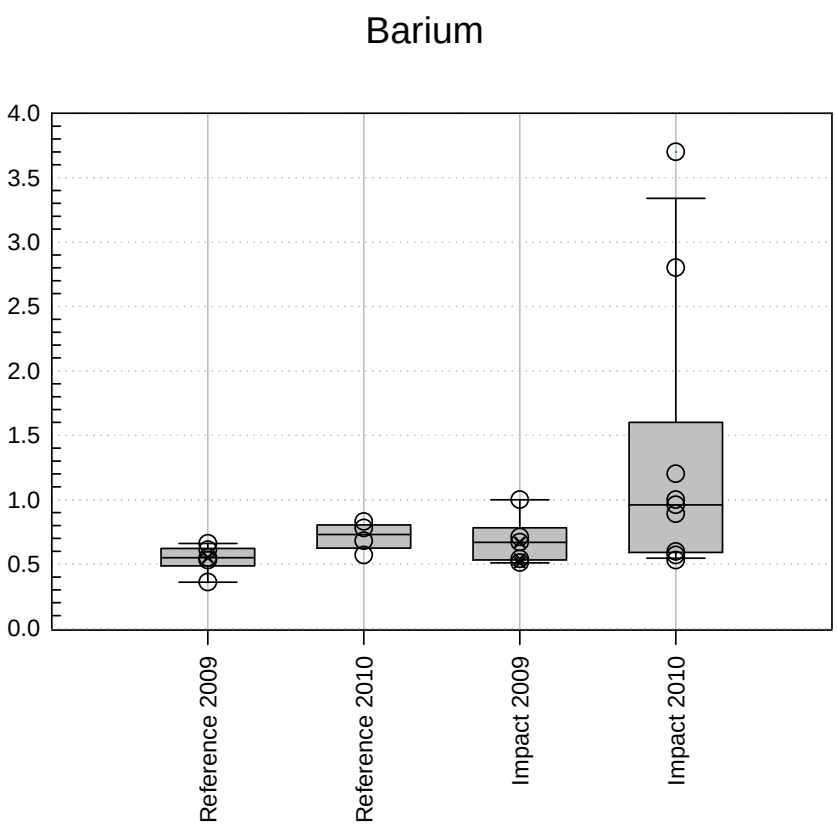
Osprey egg collection.

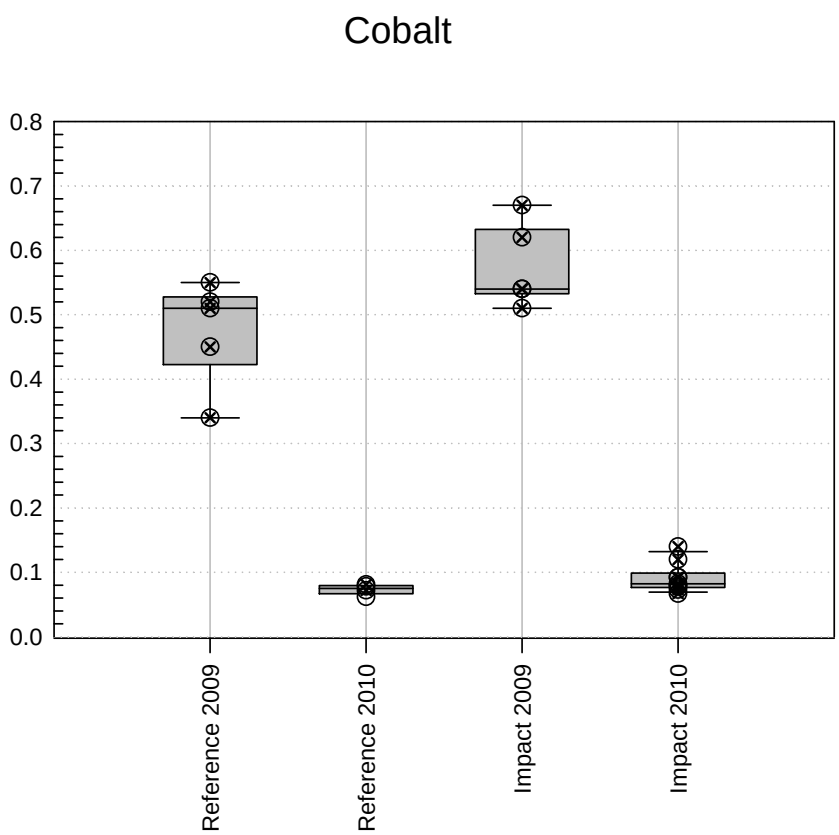
TENNESSEE VALLEY AUTHORITY
KINGSTON, TENNESSEE
TRACE ELEMENT CONCENTRATIONS IN
GREAT BLUE HERON AND OSPREY: 2009-2010

HERON AND OSPREY EGG SAMPLES

ARCADIS

FIGURE
4





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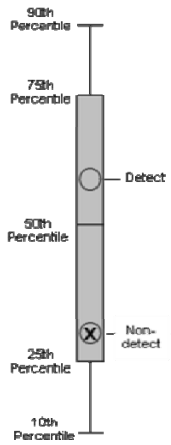


Note:
Egg content concentrations in mg/kg (dw) = milligrams per kilogram (dry weight).
Reference = Tennessee River Mile 569.5.

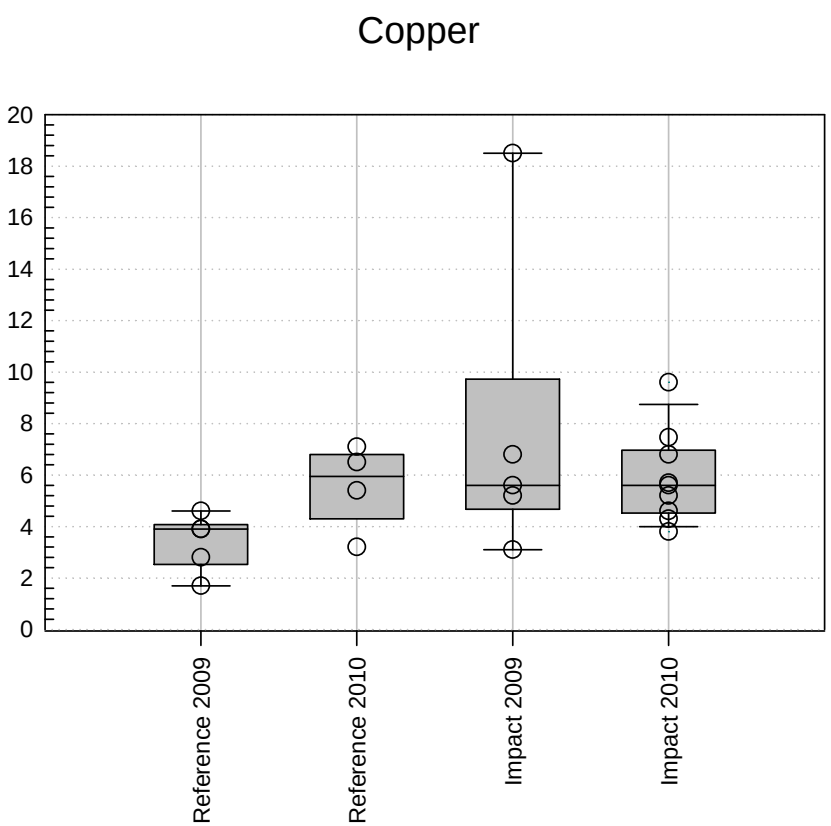
TENNESSEE VALLEY AUTHORITY
KINGSTON, TENNESSEE

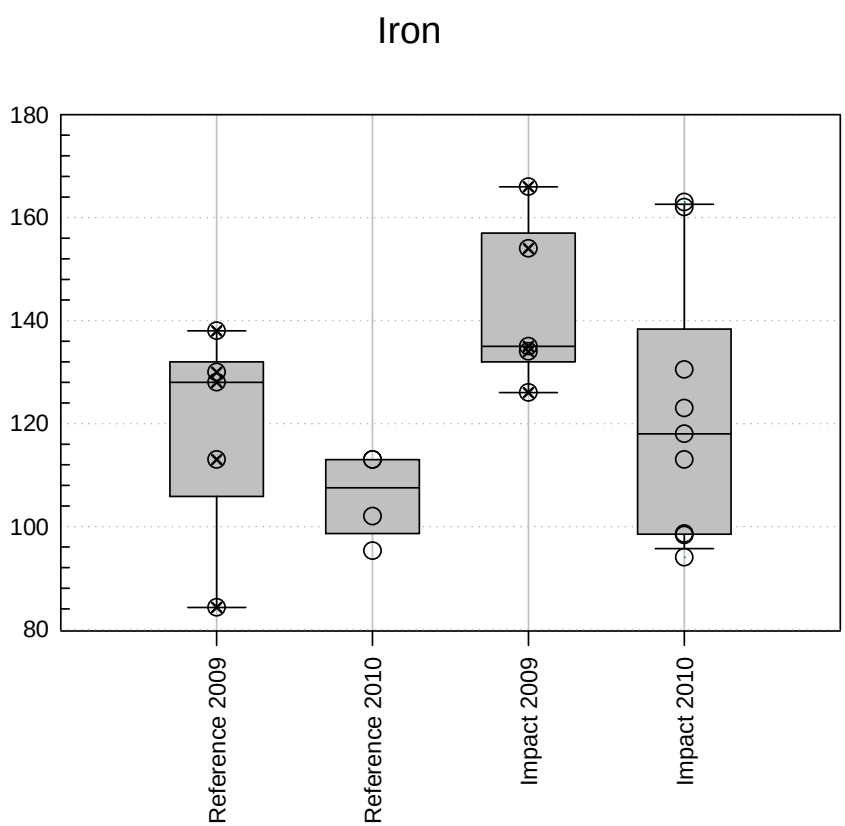
TRACE ELEMENT CONCENTRATIONS IN GREAT BLUE HERON: 2009-2010

TRACE ELEMENT CONCENTRATIONS IN HERON – BARIUM AND COBALT

ARCADIS

FIGURE
5





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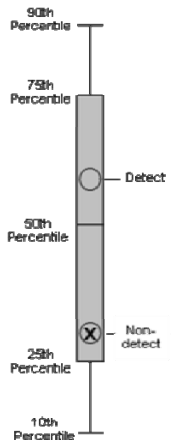


Note:
Egg content concentrations in mg/kg (dw) = milligrams per kilogram (dry weight).
Reference = Tennessee River Mile 569.5.

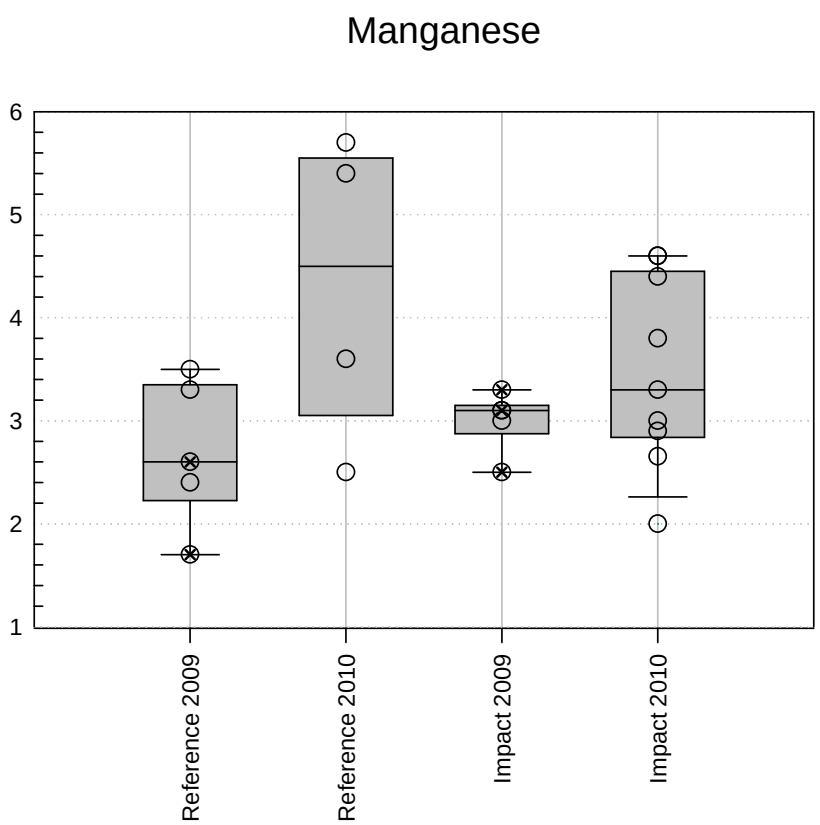
TENNESSEE VALLEY AUTHORITY
KINGSTON, TENNESSEE

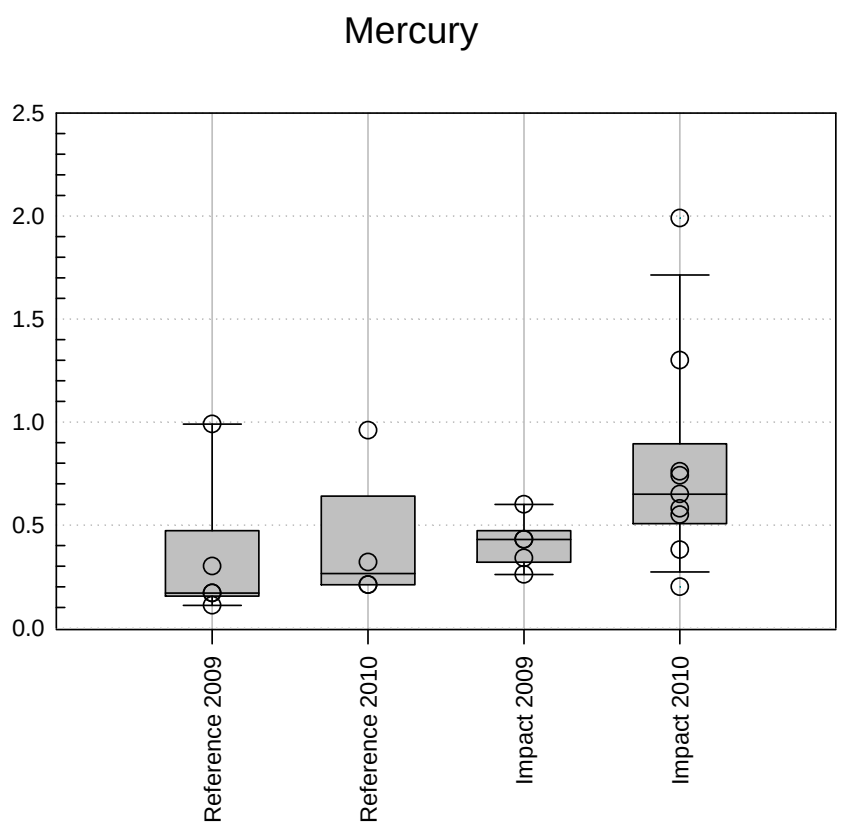
TRACE ELEMENT CONCENTRATIONS IN GREAT BLUE HERON: 2009-2010

TRACE ELEMENT CONCENTRATIONS IN HERON – COPPER AND IRON

ARCADIS

FIGURE
6





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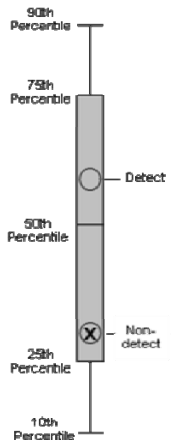


Note:
Egg content concentrations in mg/kg (dw) = milligrams per kilogram (dry weight).
Reference = Tennessee River Mile 569.5.

TENNESSEE VALLEY AUTHORITY
KINGSTON, TENNESSEE

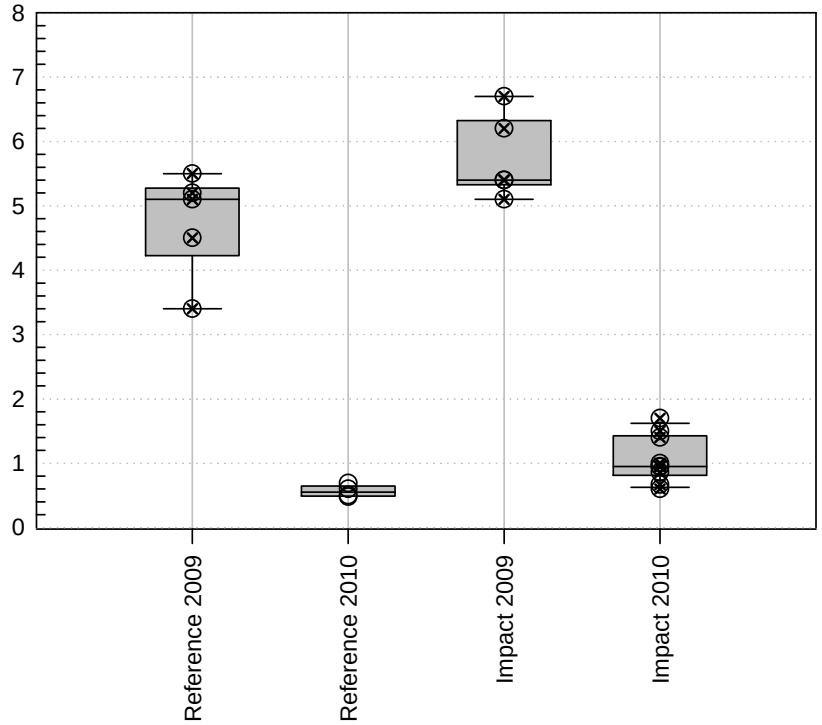
TRACE ELEMENT CONCENTRATIONS IN GREAT BLUE HERON: 2009-2010

TRACE ELEMENT CONCENTRATIONS IN HERON – MANGANESE AND MERCURY

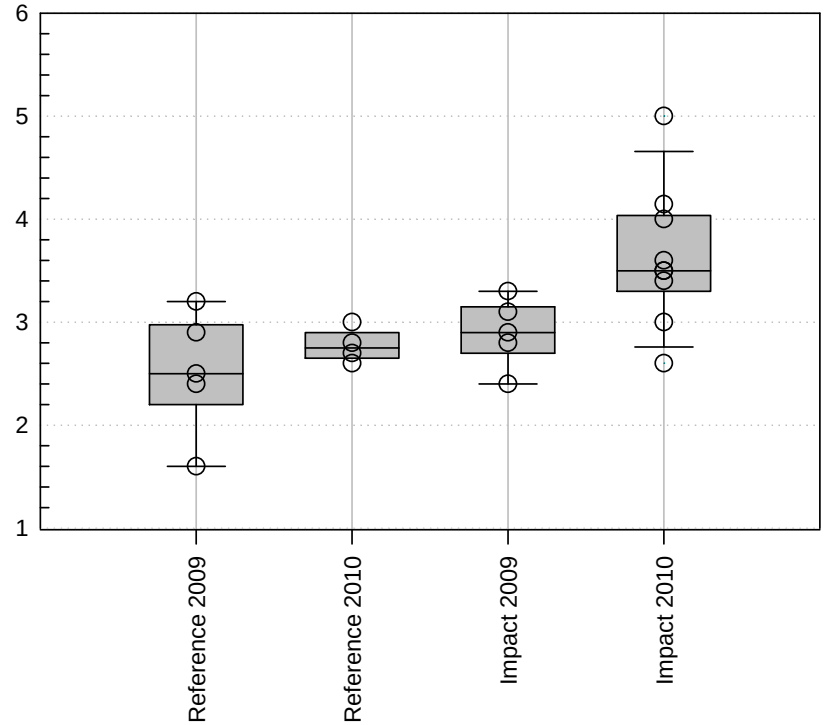
ARCADIS

FIGURE
7

Molybdenum



Selenium



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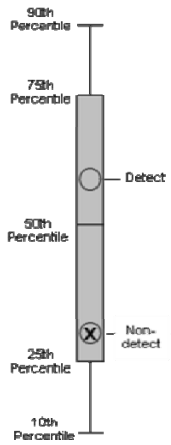


Note:
Egg content concentrations in mg/kg (dw) = milligrams per kilogram (dry weight).
Reference = Tennessee River Mile 569.5.

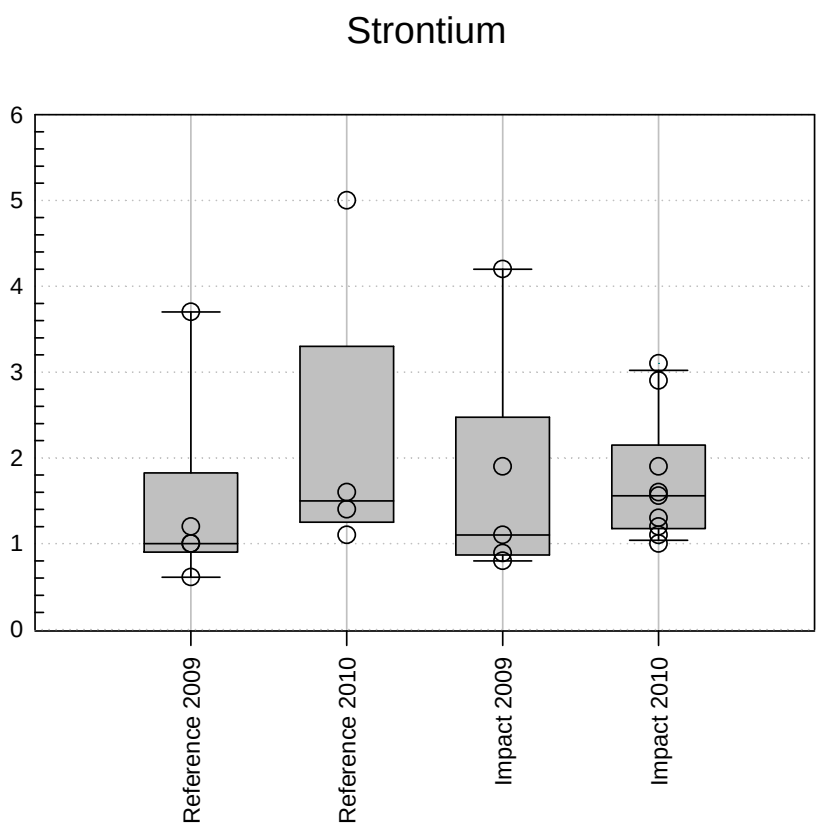
TENNESSEE VALLEY AUTHORITY
KINGSTON, TENNESSEE

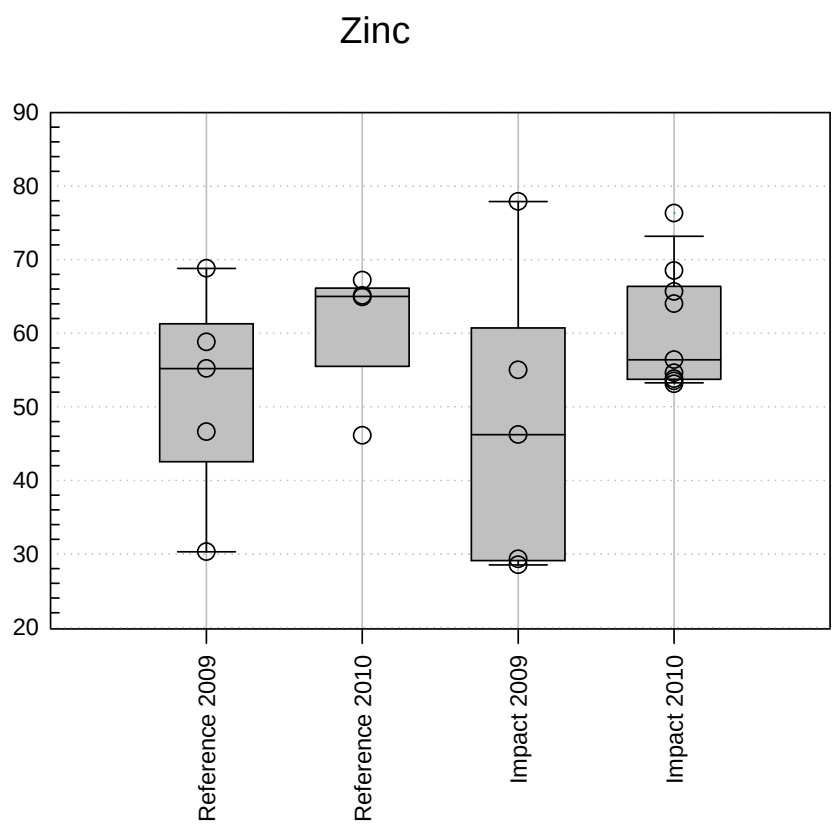
TRACE ELEMENT CONCENTRATIONS IN GREAT BLUE HERON: 2009-2010

TRACE ELEMENT CONCENTRATIONS IN HERON – MOLYBDENUM AND SELENIUM

ARCADIS

FIGURE
8





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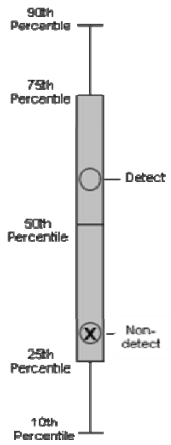


Note:
Egg content concentrations in mg/kg (dw) = milligrams per kilogram (dry weight).
Reference = Tennessee River Mile 569.5.

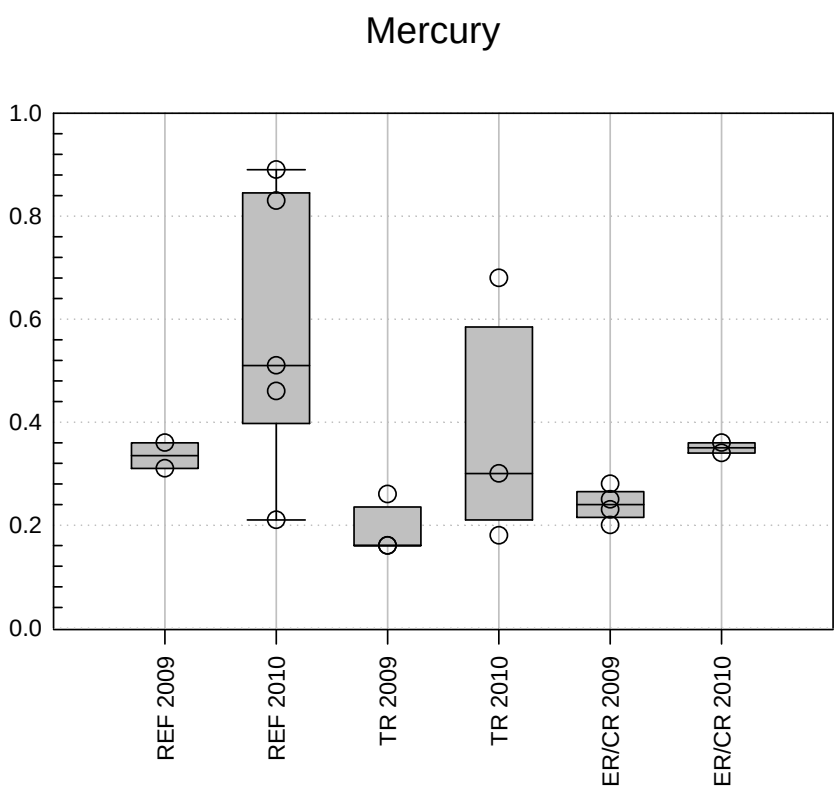
TENNESSEE VALLEY AUTHORITY
KINGSTON, TENNESSEE

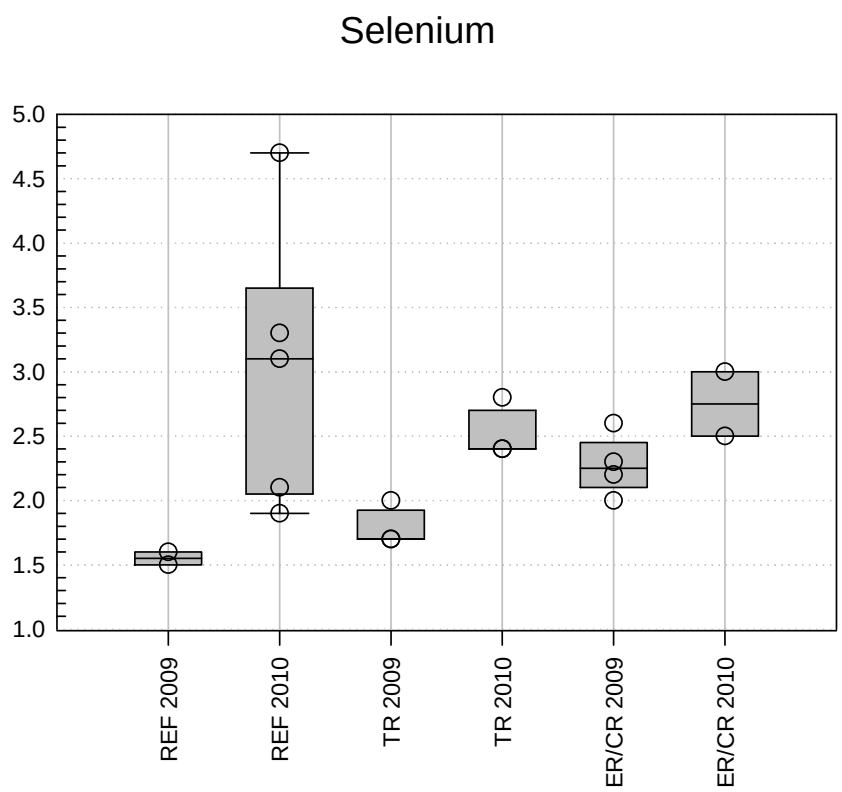
TRACE ELEMENT CONCENTRATIONS IN GREAT BLUE HERON: 2009-2010

TRACE ELEMENT CONCENTRATIONS IN HERON – STRONTIUM AND ZINC

ARCADIS

FIGURE
9





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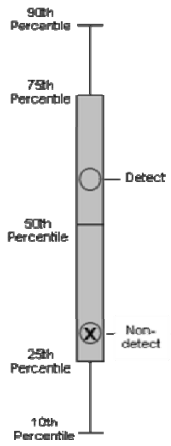


Note:
Egg content concentrations in mg/kg (dw) = milligrams per kilogram (dry weight).
ER/CR = Emory and Clinch Rivers.
REF = Reference; Tennessee River Mile 569.5.
TR = Downstream Tennessee River (below Tennessee River Mile 568(.

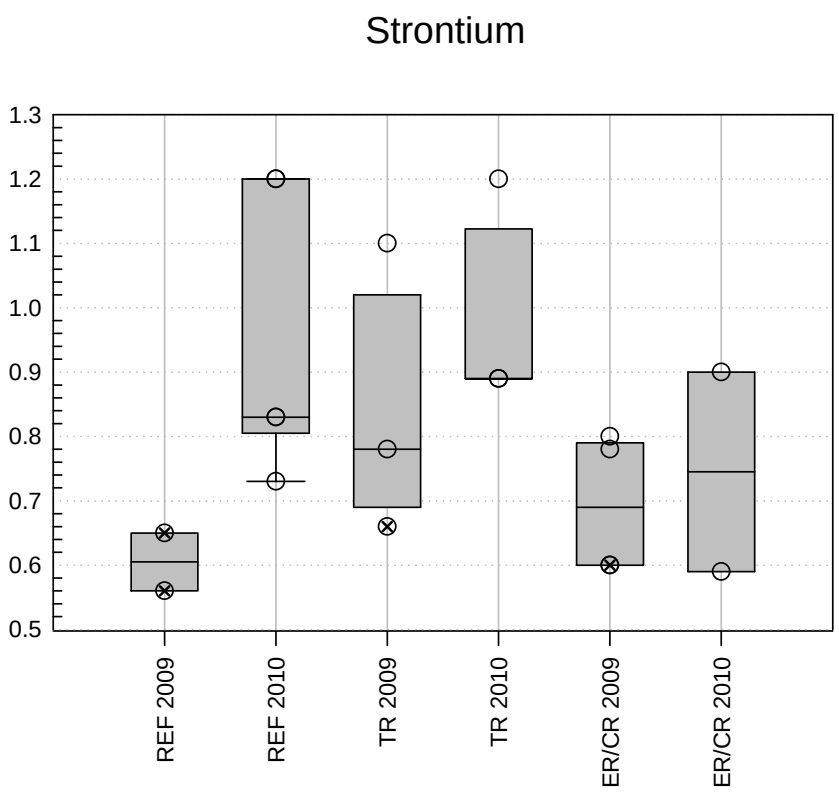
TENNESSEE VALLEY AUTHORITY
KINGSTON, TENNESSEE

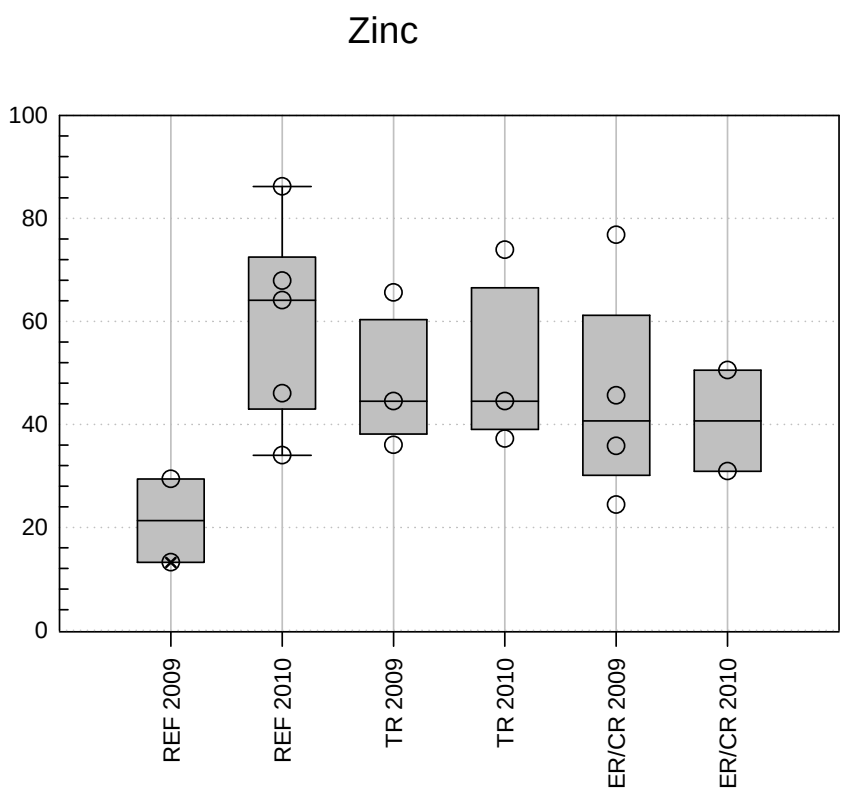
TRACE ELEMENT CONCENTRATIONS IN OSPREY: 2009-2010

TRACE ELEMENT CONCENTRATIONS IN OSPREY – MERCURY AND SELENIUM

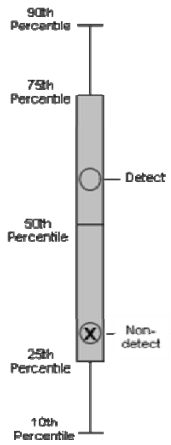
ARCADIS

FIGURE
10





Box Plot Legend



Note:
Egg content concentrations in mg/kg (dw) = milligrams per kilogram (dry weight).
ER/CR = Emory and Clinch Rivers.
REF = Reference; Tennessee River Mile 569.5.
TR = Downstream Tennessee River (below Tennessee River Mile 568(.

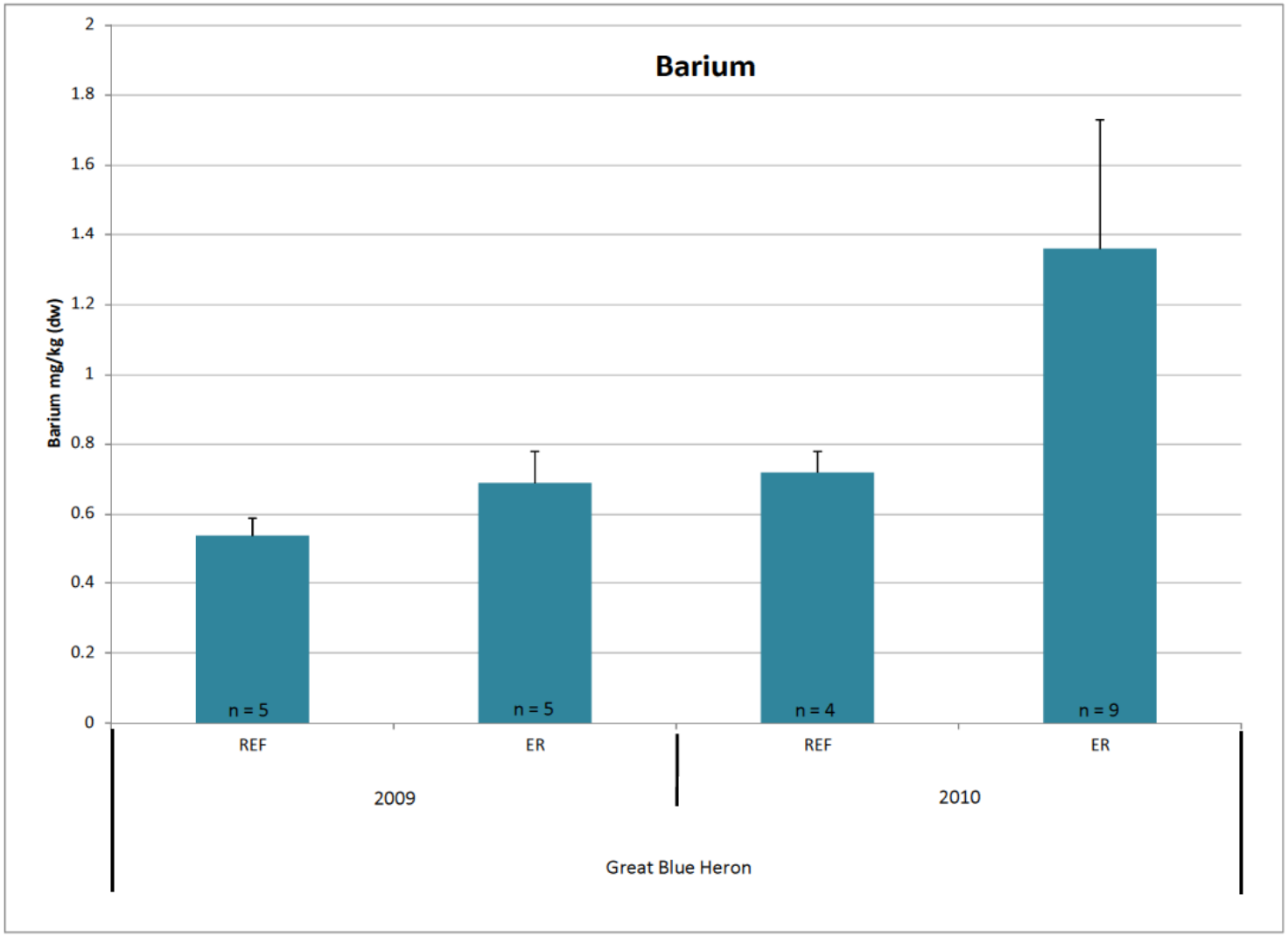
TENNESSEE VALLEY AUTHORITY
KINGSTON, TENNESSEE

TRACE ELEMENT CONCENTRATIONS IN OSPREY: 2009-2010

TRACE ELEMENT CONCENTRATIONS IN OSPREY – STRONTIUM AND ZINC

ARCADIS

FIGURE
11



Note: Mean ± standard error.
Egg content concentrations in mg/kg (dw) = milligrams per kilogram (dry weight).
ER = Emory River.
n = Number of samples.
REF = Reference; Tennessee River Mile 569.5.

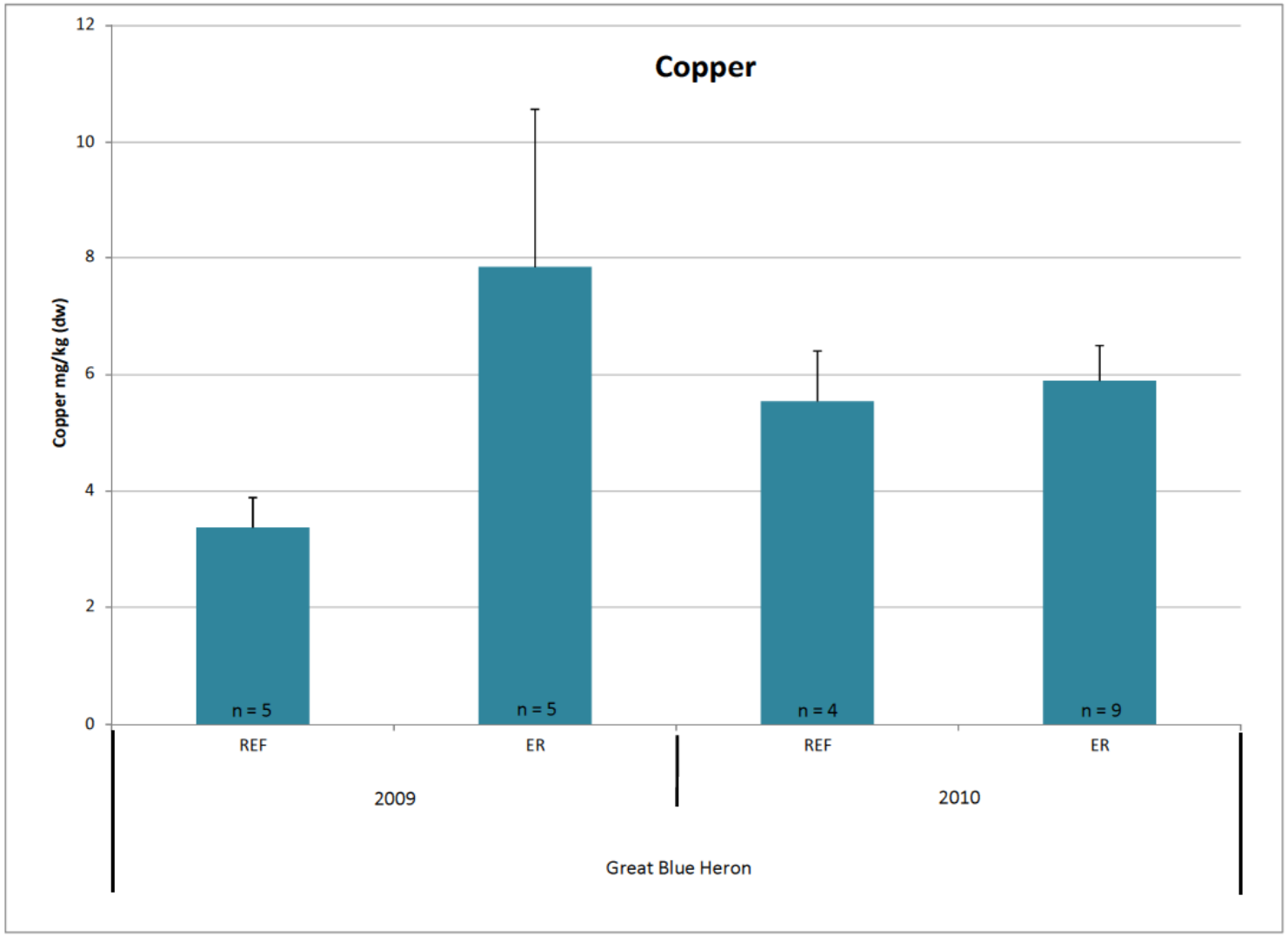
TENNESSEE VALLEY AUTHORITY
KINGSTON, TENNESSEE

TRACE ELEMENT CONCENTRATIONS IN GREAT BLUE HERON: 2009-2010

MEAN CONCENTRATIONS IN BARIUM

ARCADIS

FIGURE
12



Note: Mean ± standard error.
Egg content concentrations in mg/kg (dw) = milligrams per kilogram (dry weight).
ER = Emory River.
n = Number of samples.
REF = Reference; Tennessee River Mile 569.5.

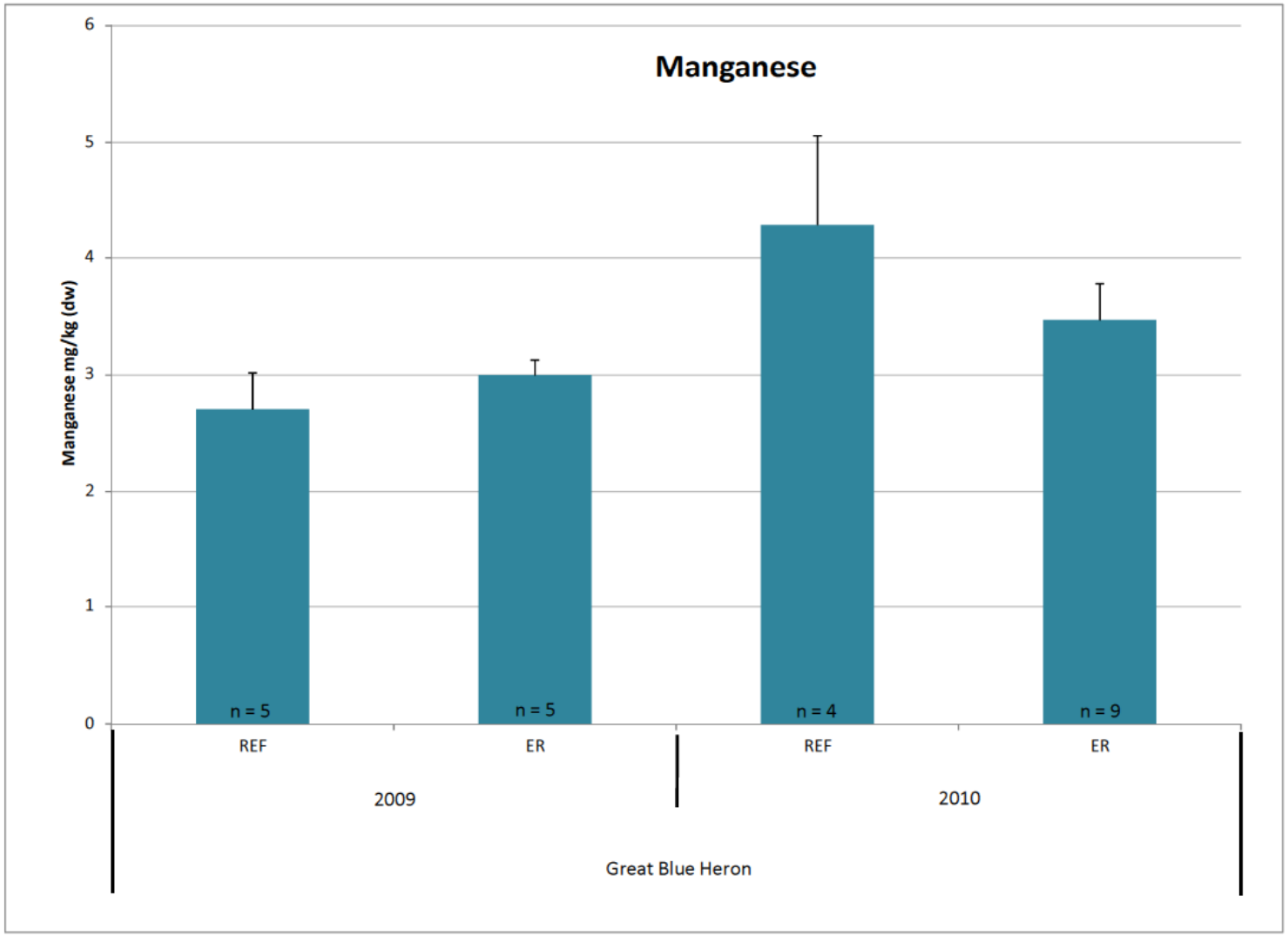
TENNESSEE VALLEY AUTHORITY
KINGSTON, TENNESSEE

TRACE ELEMENT CONCENTRATIONS IN GREAT BLUE HERON: 2009-2010

MEAN CONCENTRATIONS IN COPPER

ARCADIS

FIGURE
13



Note: Mean ± standard error.
Egg content concentrations in mg/kg (dw) = milligrams per kilogram (dry weight).
ER = Emory River.
n = Number of samples.
REF = Reference; Tennessee River Mile 569.5.

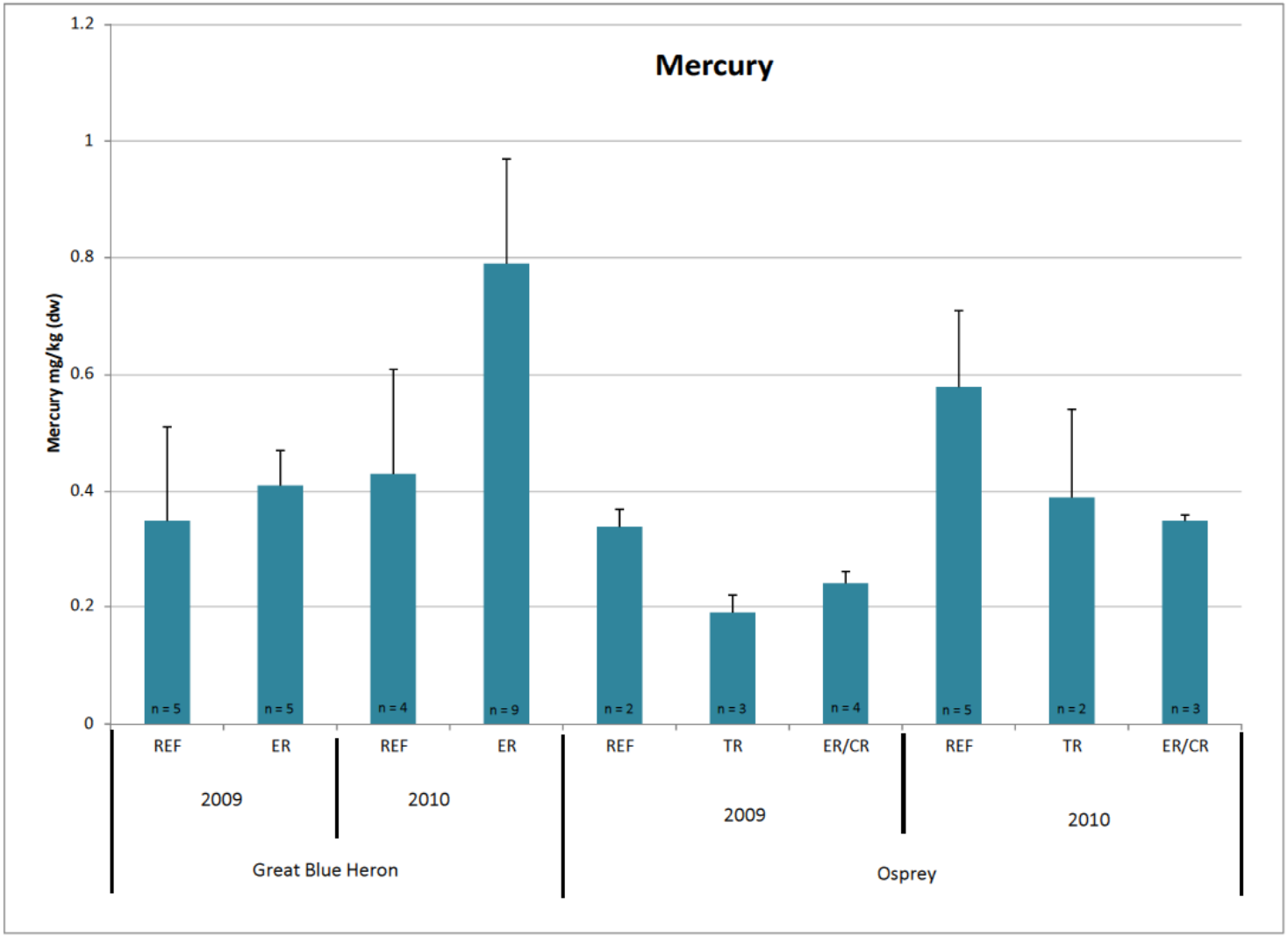
TENNESSEE VALLEY AUTHORITY
KINGSTON, TENNESSEE

TRACE ELEMENT CONCENTRATIONS IN GREAT BLUE HERON: 2009-2010

MEAN CONCENTRATIONS IN MANGANESE

ARCADIS

FIGURE
14



Note: Mean ± standard error.
Egg content concentrations in mg/kg (dw) = milligrams per kilogram (dry weight).
ER = Emory River.
ER/CR = Emory and Clinch Rivers.
n = Number of samples.
REF = Reference; Tennessee River Mile 569.5.
TR = Downstream Tennessee River (below Tennessee River Mile 568(.

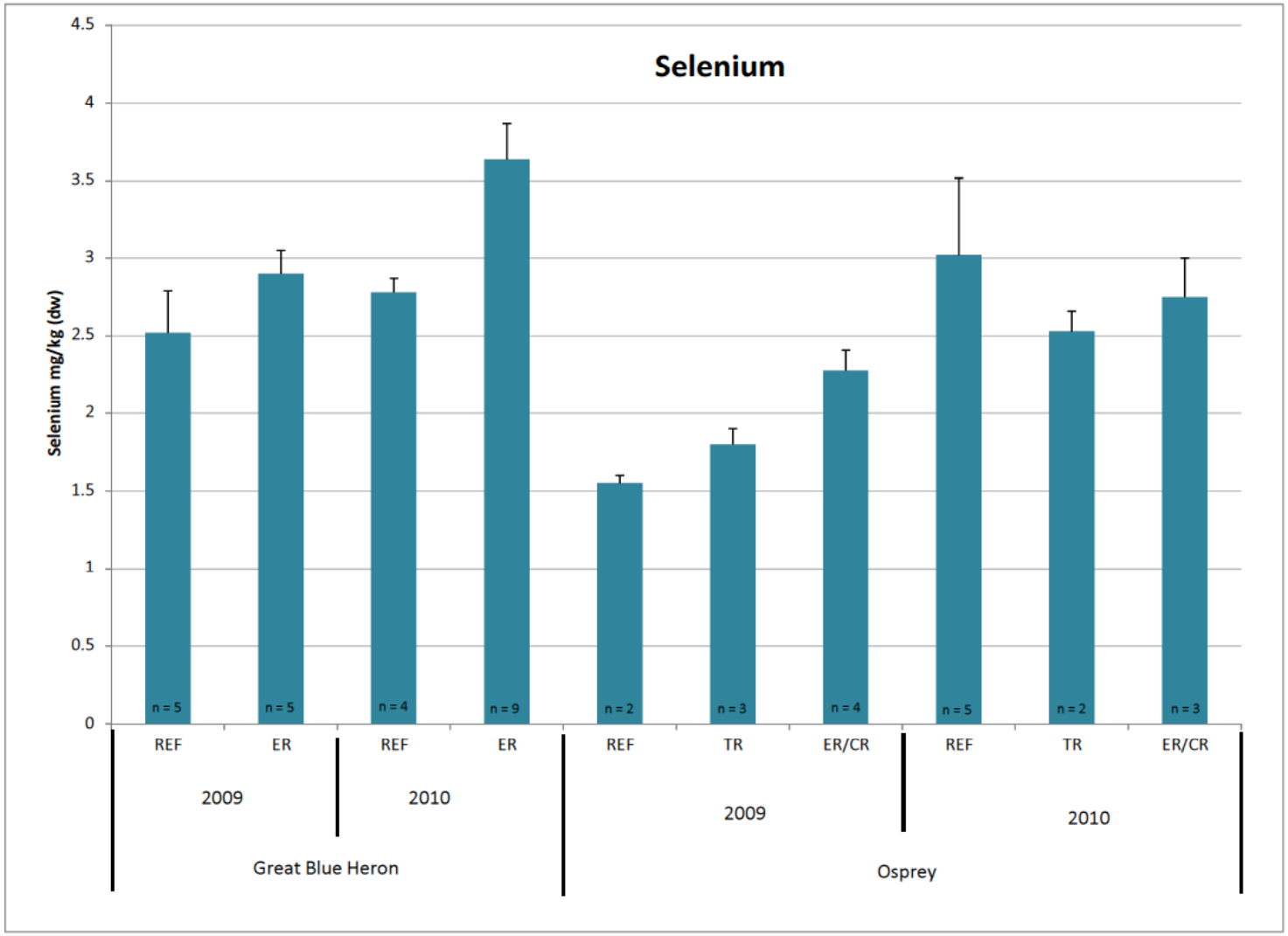
TENNESSEE VALLEY AUTHORITY
KINGSTON, TENNESSEE

TRACE ELEMENT CONCENTRATIONS IN GREAT BLUE HERON & OSPREY: 2009-2010

MEAN CONCENTRATIONS IN MERCURY

ARCADIS

FIGURE
15



Note: Mean ± standard error.
Egg content concentrations in mg/kg (dw) = milligrams per kilogram (dry weight).
ER = Emory River.
ER/CR = Emory and Clinch Rivers.
n = Number of samples.
REF = Reference; Tennessee River Mile 569.5.
TR = Downstream Tennessee River (below Tennessee River Mile 568(.

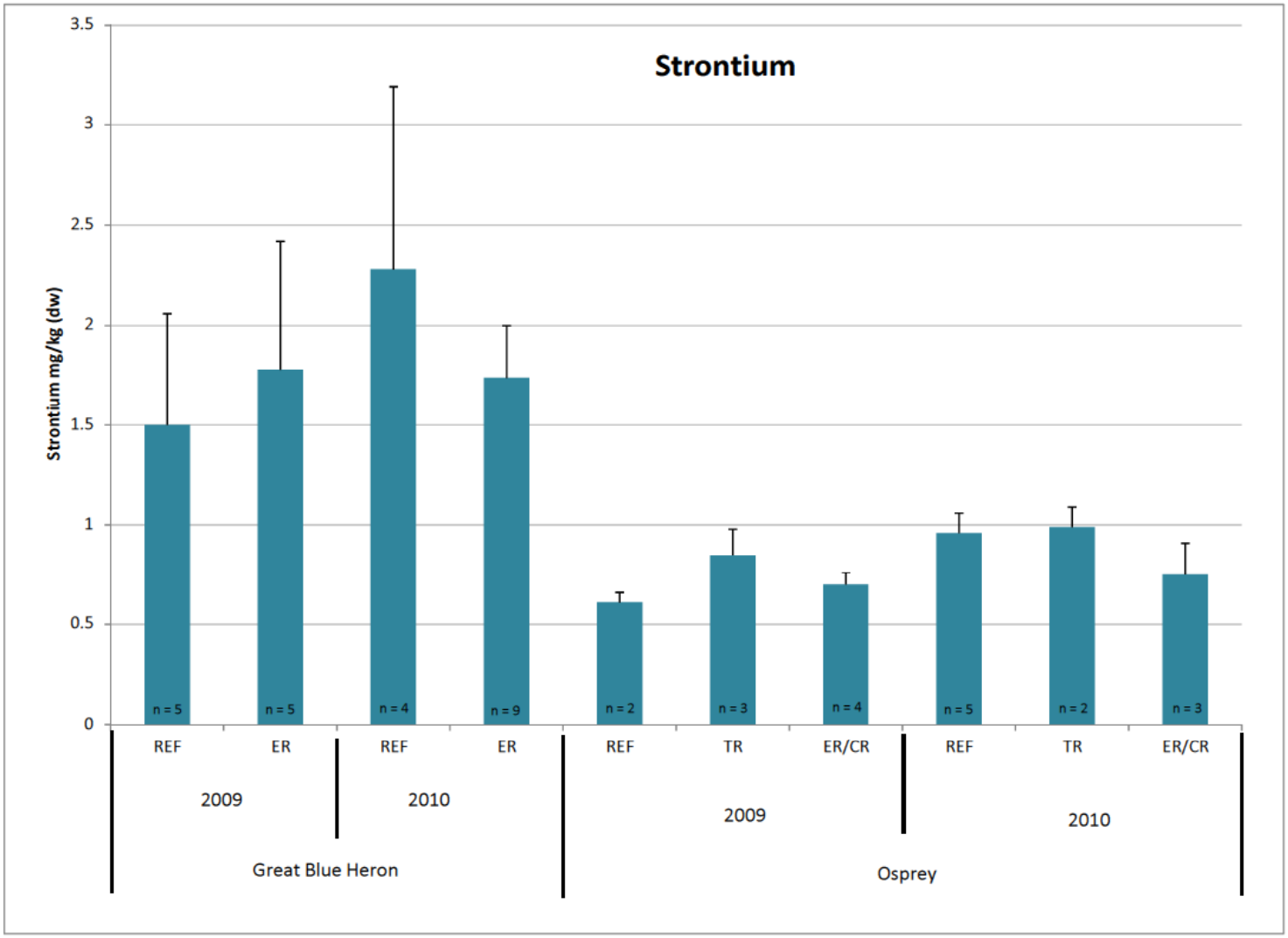
TENNESSEE VALLEY AUTHORITY
KINGSTON, TENNESSEE

TRACE ELEMENT CONCENTRATIONS IN GREAT BLUE HERON & OSPREY: 2009-2010

MEAN CONCENTRATIONS IN SELENIUM

ARCADIS

FIGURE
16



Note: Mean ± standard error.
Egg content concentrations in mg/kg (dw) = milligrams per kilogram (dry weight).
ER = Emory River.
ER/CR = Emory and Clinch Rivers.
n = Number of samples.
REF = Reference; Tennessee River Mile 569.5.
TR = Downstream Tennessee River (below Tennessee River Mile 568(.

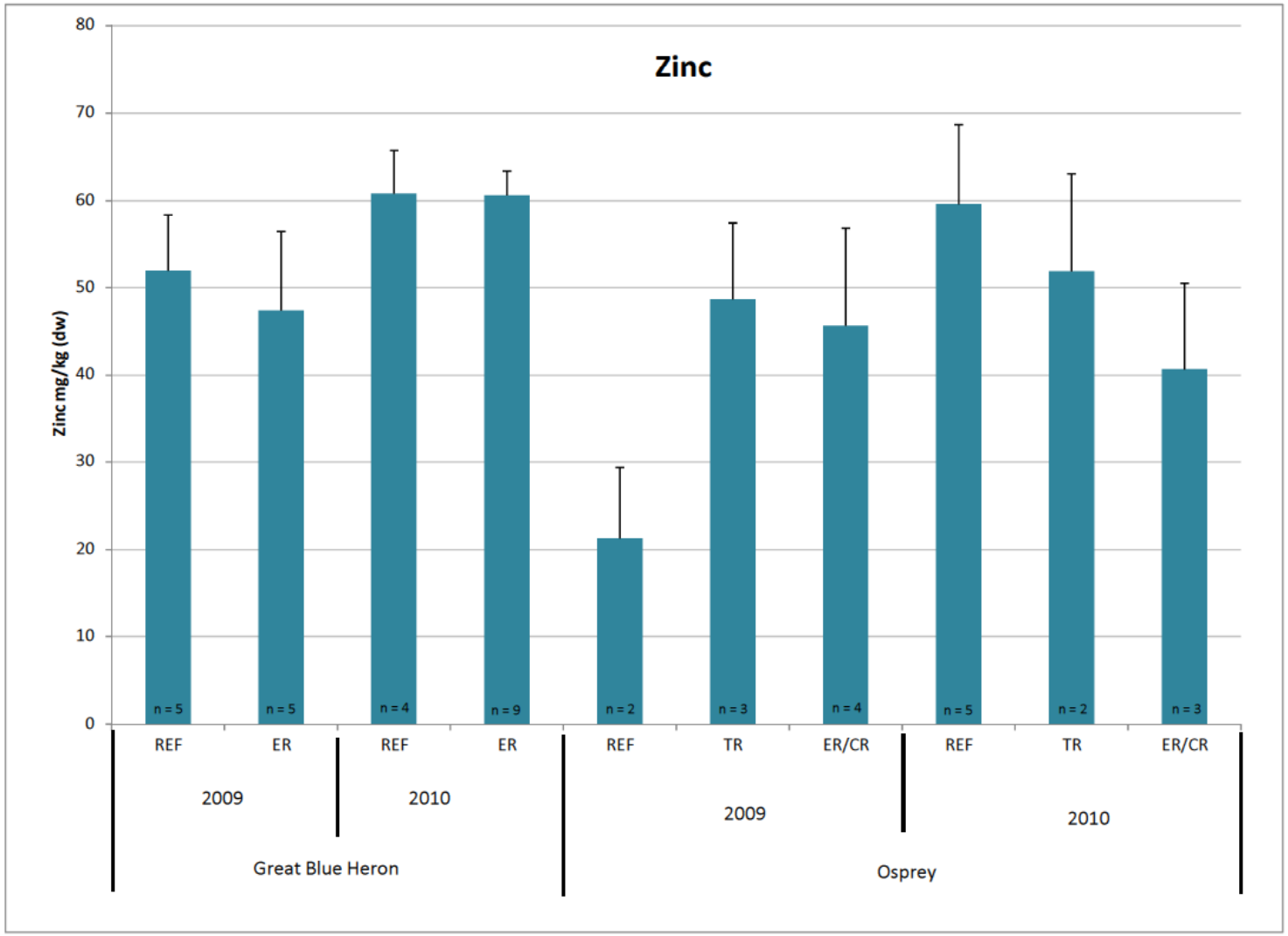
TENNESSEE VALLEY AUTHORITY
KINGSTON, TENNESSEE

TRACE ELEMENT CONCENTRATIONS IN GREAT BLUE HERON & OSPREY: 2009-2010

MEAN CONCENTRATIONS IN STRONTIUM

ARCADIS

FIGURE
17



Note: Mean ± standard error.
Egg content concentrations in mg/kg (dw) = milligrams per kilogram (dry weight).
ER = Emory River.
ER/CR = Emory and Clinch Rivers.
n = Number of samples.
REF = Reference; Tennessee River Mile 569.5.
TR = Downstream Tennessee River (below Tennessee River Mile 568(.

TENNESSEE VALLEY AUTHORITY
KINGSTON, TENNESSEE

TRACE ELEMENT CONCENTRATIONS IN GREAT BLUE HERON & OSPREY: 2009-2010

MEAN CONCENTRATIONS IN ZINC

ARCADIS

FIGURE
18

ARCADIS

Appendix A

Great Blue Heron Egg Occurrence Tables

Table A-1
Great Blue Heron Egg Dataset
Reference Site - Upstream Tennessee River - 2009
Tennessee Valley Authority (TVA)
Kingston Ash Recovery Project

Constituent	Frequency of Detection (FOD) [a]			Detected Concentrations (mg/kg dw)		Detection Limits (mg/kg dw)	
	number of detects / number of samples		FOD %	(mg/kg dw)	(mg/kg dw)	(mg/kg dw)	(mg/kg dw)
Aluminum	0	5	0	–	–	84.3	138
Antimony	0	5	0	–	–	0.34	0.55
Arsenic	0	5	0	–	–	0.34	0.55
Barium	4	5	80	0.36	0.66	0.55	0.55
Beryllium	0	5	0	–	–	0.34	0.55
Boron	0	5	0	–	–	6.7	11
Cadmium	0	5	0	–	–	0.34	0.55
Calcium	5	5	100	1,480	16,800	–	–
Chromium	0	5	0	–	–	0.34	0.55
Cobalt	0	5	0	–	–	0.34	0.55
Copper	5	5	100	1.7	4.6	–	–
Iron	0	5	0	–	–	84.3	138
Lead	0	5	0	–	–	0.34	0.55
Magnesium	2	5	40	564	637	337	519
Manganese	3	5	60	2.4	3.5	1.7	2.6
Mercury	5	5	100	0.11	0.99	–	–
Molybdenum	0	5	0	–	–	3.4	5.5
Nickel	0	5	0	–	–	0.34	0.55
Potassium	5	5	100	4,930	6,310	–	–
Selenium	5	5	100	1.6	3.2	–	–
Silver	0	5	0	–	–	0.17	0.28
Sodium	5	5	100	6,850	9,280	–	–
Strontium	5	5	100	0.61	3.7	–	–
Thallium	0	5	0	–	–	0.34	0.55
Vanadium	0	5	0	–	–	0.67	1.1
Zinc	5	5	100	30.3	68.8	–	–

– - Not detected/ not analyzed/ not applicable.
mg/kg dw - Milligram per kilogram dry weight.
[a] - Frequency of detection (FOD) = number of detects / total number of samples analyzed.

Table A-2
Great Blue Heron Egg Dataset
Impacted Site - Emory River - 2009
Tennessee Valley Authority (TVA)
Kingston Ash Recovery Project

Constituent	Frequency of Detection (FOD) [a]			Detected Concentrations (mg/kg dw)		Detection Limits (mg/kg dw)	
	number of detects / number of samples		FOD %	(mg/kg dw)	(mg/kg dw)	(mg/kg dw)	(mg/kg dw)
Aluminum	0	5	0	–	–	126	166
Antimony	0	5	0	–	–	0.51	0.67
Arsenic	0	5	0	–	–	0.51	0.67
Barium	2	5	40	0.71	1	0.51	0.67
Beryllium	0	5	0	–	–	0.51	0.67
Boron	0	5	0	–	–	10.1	13.3
Cadmium	0	5	0	–	–	0.51	0.67
Calcium	5	5	100	1,600	10,700	–	–
Chromium	0	5	0	–	–	0.51	0.67
Cobalt	0	5	0	–	–	0.51	0.67
Copper	5	5	100	3.1	18.5	–	–
Iron	0	5	0	–	–	126	166
Lead	0	5	0	–	–	0.51	0.67
Magnesium	3	5	60	542	691	505	665
Manganese	2	5	40	3.0	3.1	2.5	3.3
Mercury	5	5	100	0.26	0.6	–	–
Molybdenum	0	5	0	–	–	5.1	6.7
Nickel	1	5	20	3	3	0.51	0.67
Potassium	5	5	100	5,420	7,720	–	–
Selenium	5	5	100	2.4	3.3	–	–
Silver	0	5	0	–	–	0.25	0.33
Sodium	5	5	100	7,490	12,200	–	–
Strontium	5	5	100	0.8	4.2	–	–
Thallium	0	5	0	–	–	0.51	0.67
Vanadium	0	5	0	–	–	1	1.3
Zinc	5	5	100	28.5	77.9	–	–

– - Not detected/ not analyzed/ not applicable.
mg/kg dw - Milligram per kilogram dry weight.
[a] - Frequency of detection (FOD) = number of detects / total number of samples analyzed.

Table A-3
Great Blue Heron Egg Dataset
Reference Site - Upstream Tennessee River - 2010
Tennessee Valley Authority (TVA)
Kingston Ash Recovery Project

Constituent	Frequency of Detection (FOD) [a]			Detected Concentrations (mg/kg dw)		Detection Limits (mg/kg dw)	
	number of detects / number of samples		FOD %	(mg/kg dw)	(mg/kg dw)	(mg/kg dw)	(mg/kg dw)
Aluminum	0	4	0	–	–	14.7	23
Antimony	0	4	0	–	–	0.053	0.083
Arsenic	0	4	0	–	–	0.1	0.16
Barium	4	4	100	0.57	0.83	–	–
Beryllium	0	4	0	–	–	0.11	0.17
Boron	0	4	0	–	–	1.5	2.4
Cadmium	0	4	0	–	–	0.028	0.044
Calcium	4	4	100	2,500	23,400	–	–
Chromium	0	4	0	–	–	0.47	0.73
Cobalt	2	4	50	0.062	0.078	0.072	0.081
Copper	4	4	100	3.2	7.1	–	–
Iron	4	4	100	95.3	113	–	–
Lead	0	4	0	–	–	0.1	0.16
Magnesium	4	4	100	546	1,010	–	–
Manganese	4	4	100	2.5	5.7	–	–
Mercury	4	4	100	0.21	0.96	–	–
Molybdenum	4	4	100	0.48	0.69	–	–
Nickel	0	4	0	–	–	0.36	0.56
Potassium	4	4	100	7,030	8,680	–	–
Selenium	4	4	100	2.6	3.0	–	–
Silver	0	4	0	–	–	0.011	0.017
Sodium	4	4	100	8,450	12,300	–	–
Strontium	4	4	100	1.1	5	–	–
Thallium	0	4	0	–	–	0.051	0.079
Vanadium	0	4	0	–	–	0.17	0.26
Zinc	4	4	100	46.1	67.2	–	–

– - Not detected/ not analyzed/ not applicable.
mg/kg dw - Milligram per kilogram dry weight.
[a] - Frequency of detection (FOD) = number of detects / total number of samples analyzed.

Table A-4
Great Blue Heron Egg Dataset
Impacted Site - Emory River - 2010
Tennessee Valley Authority (TVA)
Kingston Ash Recovery Project

Constituent	Frequency of Detection (FOD) [a]			Detected Concentrations (mg/kg dw)		Detection Limits (mg/kg dw)	
	number of detects / number of samples		FOD %	(mg/kg dw)	(mg/kg dw)	(mg/kg dw)	(mg/kg dw)
Aluminum	0	9	0	–	–	19	26.2
Antimony	0	9	0	–	–	0.069	0.095
Arsenic	0	9	0	–	–	0.13	0.18
Barium	9	9	100	0.53	3.7	–	–
Beryllium	0	9	0	–	–	0.14	0.19
Boron	0	9	0	–	–	2	2.7
Cadmium	0	9	0	–	–	0.036	0.05
Calcium	9	9	100	2,400	7,020	–	–
Chromium	0	9	0	–	–	0.6	0.83
Cobalt	0	9	0	–	–	0.067	0.14
Copper	9	9	100	3.8	9.6	–	–
Iron	9	9	100	94	163	–	–
Lead	0	9	0	–	–	0.13	0.18
Magnesium	9	9	100	462	967	–	–
Manganese	9	9	100	2.0	4.6	–	–
Mercury	9	9	100	0.2	1.989	–	–
Molybdenum	0	9	0	–	–	0.6	1.7
Nickel	0	9	0	–	–	0.46	0.64
Potassium	9	9	100	6,590	9,420	–	–
Selenium	9	9	100	2.6	5.0	–	–
Silver	0	9	0	–	–	0.014	0.025
Sodium	9	9	100	8,590	15,800	–	–
Strontium	9	9	100	1	3.1	–	–
Thallium	0	9	0	–	–	0.065	0.09
Vanadium	0	9	0	–	–	0.22	0.3
Zinc	9	9	100	53.1	76.3	–	–

– - Not detected/ not analyzed/ not applicable.
mg/kg dw - Milligram per kilogram dry weight.
[a] - Frequency of detection (FOD) = number of detects / total number of samples analyzed.

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Appendix B

Osprey Egg Occurrence Tables

Table B-1
Osprey Egg Dataset
Reference Site - Upstream Tennessee River - 2009
Tennessee Valley Authority (TVA)
Kingston Ash Recovery Project

Constituent	Frequency of Detection (FOD) [a]			Detected Concentrations (mg/kg dw)	Detection Limits (mg/kg dw)
	number of detects / number of samples		FOD %	Min - Max	Min - Max
Aluminum	0	2	0	– - –	141 - 162
Antimony	0	2	0	– - –	0.56 - 0.65
Arsenic	0	2	0	– - –	0.56 - 0.65
Barium	0	2	0	– - –	0.56 - 0.65
Beryllium	0	2	0	– - –	0.56 - 0.65
Boron	0	2	0	– - –	11.3 - 12.9
Cadmium	0	2	0	– - –	0.56 - 0.65
Calcium	2	2	100	1120 - 1650	– - –
Chromium	0	2	0	– - –	0.56 - 0.65
Cobalt	0	2	0	– - –	0.56 - 0.65
Copper	0	2	0	– - –	2.8 - 3.2
Iron	0	2	0	– - –	141 - 162
Lead	0	2	0	– - –	0.56 - 0.65
Magnesium	0	2	0	– - –	563 - 646
Manganese	0	2	0	– - –	2.8 - 3.2
Mercury	2	2	100	0.31 - 0.36	– - –
Molybdenum	0	2	0	– - –	5.6 - 6.5
Nickel	0	2	0	– - –	0.56 - 0.65
Potassium	2	2	100	6010 - 6020	– - –
Selenium	2	2	100	1.5 - 1.6	– - –
Silver	0	2	0	– - –	0.28 - 0.32
Sodium	2	2	100	9560 - 9800	– - –
Strontium	0	2	0	– - –	0.56 - 0.65
Thallium	0	2	0	– - –	0.56 - 0.65
Vanadium	0	2	0	– - –	1.1 - 1.3
Zinc	1	2	50	29.4 - 29.4	13.2 - 13.2

– - Not detected/ not analyzed/ not applicable.
mg/kg dw - Milligram per kilogram dry weight.

[a] - Frequency of detection (FOD) = number of detects / total number of samples analyzed.

Table B-2
Osprey Egg Dataset
Impacted Site - Emory and Clinch Rivers - 2009
Tennessee Valley Authority (TVA)
Kingston Ash Recovery Project

Constituent	Frequency of Detection (FOD) [a]			Detected Concentrations (mg/kg dw)	Detection Limits (mg/kg dw)
	number of detects / number of samples		FOD %	Min - Max	Min - Max
Aluminum	0	4	0	– - –	106 - 174
Antimony	0	4	0	– - –	0.42 - 0.7
Arsenic	0	4	0	– - –	0.42 - 0.7
Barium	0	4	0	– - –	0.42 - 0.7
Beryllium	0	4	0	– - –	0.42 - 0.7
Boron	0	4	0	– - –	8.5 - 13.9
Cadmium	0	4	0	– - –	0.42 - 0.7
Calcium	4	4	100	1330 - 2690	– - –
Chromium	0	4	0	– - –	0.42 - 0.7
Cobalt	0	4	0	– - –	0.42 - 0.7
Copper	0	4	0	– - –	2.1 - 3.5
Iron	1	4	25	165 - 165	127 - 174
Lead	0	4	0	– - –	0.42 - 0.7
Magnesium	0	4	0	– - –	424 - 696
Manganese	1	4	25	2.4 - 2.4	2.5 - 3.5
Mercury	4	4	100	0.2 - 0.28	– - –
Molybdenum	0	4	0	– - –	4.2 - 7
Nickel	0	4	0	– - –	0.42 - 0.7
Potassium	4	4	100	3870 - 6620	– - –
Selenium	4	4	100	2 - 2.6	– - –
Silver	0	4	0	– - –	0.21 - 0.35
Sodium	4	4	100	5120 - 10100	– - –
Strontium	3	4	75	0.6 - 0.8	0.6 - 0.6
Thallium	0	4	0	– - –	0.42 - 0.7
Vanadium	0	4	0	– - –	0.85 - 1.4
Zinc	4	4	100	24.4 - 76.8	– - –

– - Not detected/ not analyzed/ not applicable.
mg/kg dw - Milligram per kilogram dry weight.

[a] - Frequency of detection (FOD) = number of detects / total number of samples analyzed.

Table B-3
Osprey Egg Dataset
Impacted Site - Downstream Tennessee River - 2009
Tennessee Valley Authority (TVA)
Kingston Ash Recovery Project

Constituent	Frequency of Detection (FOD) [a]			Detected Concentrations (mg/kg dw)	Detection Limits (mg/kg dw)
	number of detects / number of samples		FOD %	Min - Max	Min - Max
Aluminum	0	3	0	– - –	98.4 - 165
Antimony	0	3	0	– - –	0.39 - 0.66
Arsenic	0	3	0	– - –	0.39 - 0.66
Barium	0	3	0	– - –	0.39 - 0.66
Beryllium	0	3	0	– - –	0.39 - 0.66
Boron	0	3	0	– - –	7.9 - 13.2
Cadmium	0	3	0	– - –	0.39 - 0.66
Calcium	3	3	100	1840 - 2420	– - –
Chromium	0	3	0	– - –	0.39 - 0.66
Cobalt	0	3	0	– - –	0.39 - 0.66
Copper	0	3	0	– - –	2 - 3.3
Iron	1	3	33.3	129 - 129	162 - 165
Lead	0	3	0	– - –	0.39 - 0.66
Magnesium	0	3	0	– - –	394 - 662
Manganese	0	3	0	– - –	2 - 3.3
Mercury	3	3	100	0.16 - 0.26	– - –
Molybdenum	0	3	0	– - –	3.9 - 6.6
Nickel	0	3	0	– - –	0.39 - 0.66
Potassium	3	3	100	3510 - 7460	– - –
Selenium	3	3	100	1.7 - 2	– - –
Silver	0	3	0	– - –	0.2 - 0.33
Sodium	3	3	100	5200 - 11200	– - –
Strontium	2	3	66.7	0.78 - 1.1	0.66 - 0.66
Thallium	0	3	0	– - –	0.39 - 0.66
Vanadium	0	3	0	– - –	0.79 - 1.3
Zinc	3	3	100	36 - 65.6	– - –

– - Not detected/ not analyzed/ not applicable.
mg/kg dw - Milligram per kilogram dry weight.

[a] - Frequency of detection (FOD) = number of detects / total number of samples analyzed.

Table B-4
Osprey Egg Dataset
Reference Site - Upstream Tennessee River - 2010
Tennessee Valley Authority (TVA)
Kingston Ash Recovery Project

Constituent	Frequency of Detection (FOD) [a]			Detected Concentrations (mg/kg dw)	Detection Limits (mg/kg dw)
	number of detects / number of samples		FOD %	Min - Max	Min - Max
Aluminum	0	5	0	– - –	20.8 - 27.7
Antimony	1	5	20	0.43 - 0.43	0.075 - 0.1
Arsenic	0	5	0	– - –	0.15 - 0.19
Barium	1	5	20	0.31 - 0.31	0.24 - 0.32
Beryllium	0	5	0	– - –	0.15 - 0.2
Boron	0	5	0	– - –	2.2 - 2.9
Cadmium	0	5	0	– - –	0.04 - 0.053
Calcium	5	5	100	1720 - 3900	– - –
Chromium	1	5	20	1.5 - 1.5	0.66 - 0.79
Cobalt	0	5	0	– - –	0.073 - 0.097
Copper	5	5	100	1.8 - 4.4	– - –
Iron	4	5	80	91.1 - 197	73.3 - 73.3
Lead	1	5	20	0.57 - 0.57	0.15 - 0.19
Magnesium	5	5	100	436 - 1050	– - –
Manganese	4	5	80	1.4 - 2.8	1 - 1
Mercury	5	5	100	0.21 - 0.89	– - –
Molybdenum	0	5	0	– - –	0.18 - 0.24
Nickel	1	5	20	0.9 - 0.9	0.51 - 0.61
Potassium	5	5	100	5780 - 17100	– - –
Selenium	5	5	100	1.9 - 4.7	– - –
Silver	0	5	0	– - –	0.015 - 0.02
Sodium	5	5	100	9460 - 25800	– - –
Strontium	5	5	100	0.73 - 1.2	– - –
Thallium	0	5	0	– - –	0.072 - 0.095
Vanadium	1	5	20	0.51 - 0.51	0.24 - 0.28
Zinc	5	5	100	34 - 86.2	– - –

– - Not detected/ not analyzed/ not applicable.
mg/kg dw - Milligram per kilogram dry weight.

[a] - Frequency of detection (FOD) = number of detects / total number of samples analyzed.

Table B-5
Osprey Egg Dataset
Impacted Site - Emory and Clinch Rivers - 2010
Tennessee Valley Authority (TVA)
Kingston Ash Recovery Project

Constituent	Frequency of Detection (FOD) [a]			Detected Concentrations (mg/kg dw)	Detection Limits (mg/kg dw)
	number of detects / number of samples		FOD %	Min - Max	Min - Max
Aluminum	0	2	0	– - –	23.3 - 24.3
Antimony	0	2	0	– - –	0.084 - 0.088
Arsenic	0	2	0	– - –	0.16 - 0.34
Barium	1	2	50	0.27 - 0.27	0.28 - 0.28
Beryllium	0	2	0	– - –	0.17 - 0.36
Boron	0	2	0	– - –	2.4 - 2.5
Cadmium	0	2	0	– - –	0.044 - 0.046
Calcium	2	2	100	1270 - 2270	– - –
Chromium	0	2	0	– - –	0.74 - 0.77
Cobalt	0	2	0	– - –	0.082 - 0.086
Copper	2	2	100	1.5 - 2.2	– - –
Iron	1	2	50	92.1 - 92.1	70.3 - 70.3
Lead	0	2	0	– - –	0.16 - 0.17
Magnesium	2	2	100	362 - 574	– - –
Manganese	2	2	100	1.4 - 1.8	– - –
Mercury	2	2	100	0.34 - 0.36	– - –
Molybdenum	0	2	0	– - –	0.21 - 0.21
Nickel	0	2	0	– - –	0.57 - 0.59
Potassium	2	2	100	5540 - 7110	– - –
Selenium	2	2	100	2.5 - 3	– - –
Silver	0	2	0	– - –	0.017 - 0.018
Sodium	2	2	100	8650 - 9150	– - –
Strontium	2	2	100	0.59 - 0.9	– - –
Thallium	0	2	0	– - –	0.08 - 0.084
Vanadium	0	2	0	– - –	0.27 - 0.28
Zinc	2	2	100	30.9 - 50.5	– - –

– - Not detected/ not analyzed/ not applicable.
mg/kg dw - Milligram per kilogram dry weight.

[a] - Frequency of detection (FOD) = number of detects / total number of samples analyzed.

Table B-6
Osprey Egg Dataset
Impacted Site - Downstream Tennessee River - 2010
Tennessee Valley Authority (TVA)
Kingston Ash Recovery Project

Constituent	Frequency of Detection (FOD) [a]			Detected Concentrations (mg/kg dw)	Detection Limits (mg/kg dw)
	number of detects / number of samples		FOD %	Min - Max	Min - Max
Aluminum	0	3	0	– - –	25 - 27.7
Antimony	0	3	0	– - –	0.09 - 0.1
Arsenic	0	3	0	– - –	0.18 - 0.19
Barium	1	3	33.3	0.33 - 0.33	0.29 - 0.32
Beryllium	0	3	0	– - –	0.18 - 0.2
Boron	0	3	0	– - –	2.6 - 2.9
Cadmium	0	3	0	– - –	0.048 - 0.053
Calcium	3	3	100	2180 - 3120	– - –
Chromium	0	3	0	– - –	0.79 - 0.88
Cobalt	0	3	0	– - –	0.088 - 0.098
Copper	3	3	100	2 - 2.3	– - –
Iron	3	3	100	85 - 197	– - –
Lead	0	3	0	– - –	0.17 - 0.19
Magnesium	3	3	100	641 - 705	– - –
Manganese	2	3	66.7	1.3 - 2.6	1.2 - 1.2
Mercury	3	3	100	0.18 - 0.68	– - –
Molybdenum	0	3	0	– - –	0.22 - 0.24
Nickel	0	3	0	– - –	0.61 - 0.68
Potassium	3	3	100	7230 - 8780	– - –
Selenium	3	3	100	2.4 - 2.8	– - –
Silver	0	3	0	– - –	0.018 - 0.02
Sodium	3	3	100	11100 - 13500	– - –
Strontium	3	3	100	0.89 - 1.2	– - –
Thallium	0	3	0	– - –	0.086 - 0.096
Vanadium	0	3	0	– - –	0.29 - 0.32
Zinc	3	3	100	37.2 - 73.9	– - –

– - Not detected/ not analyzed/ not applicable.
mg/kg dw - Milligram per kilogram dry weight.

[a] - Frequency of detection (FOD) = number of detects / total number of samples analyzed.

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Appendix C

Great Blue Heron Egg 2009 and 2010 Sample Results

Table C-1. Great Blue Heron Eggs 2009 and 2010 Sample Results, Reference Location (mg/kg dw)
Tennessee Valley Authority **Kingston, Tennessee**

Analyte / Location: / Sample Date:	TRM569.5 4/15/2009	TRM569.5 4/15/2009	TRM569.5 4/15/2009	TRM569.5 4/15/2009	TRM569.5 4/15/2009	TRM569.5 4/9/2010	TRM569.5 4/9/2010	TRM569.5 4/9/2010	TRM569.5 4/9/2010
Aluminum	<113	<138	<84.3	<130	<128	<19.6	<20.4	<23	<14.7
Antimony	<0.45	<0.55	<0.34	<0.52	<0.51	<0.071	<0.074	<0.083	<0.053
Arsenic	<0.45	<0.55	<0.34	<0.52	<0.51	<0.14	<0.14	<0.16	<0.1
Barium	0.61	<0.55	0.36	0.53	0.66	0.68 J	0.57	0.83 J	0.78 J
Beryllium	<0.45	<0.55	<0.34	<0.52	<0.51	<0.14	<0.15	<0.17	<0.11
Boron	<9	<11	<6.7	<10.4	<10.3	<2	<2.1	<2.4	<1.5
Cadmium	<0.45	<0.55	<0.34	<0.52	<0.51	<0.037	<0.039	<0.044	<0.028
Calcium	3000 J	16800 J	1480 J	3030 J	2790 J	3080	2500	23400	3120
Chromium	<0.45	<0.55	<0.34	<0.52	<0.51	<0.62	<0.65	<0.73	<0.47
Cobalt	<0.45	<0.55	<0.34	<0.52	<0.51	0.078 J	<0.072	<0.081	0.062 J
Copper	3.9	4.6	1.7	2.8	3.9	7.1	5.4	3.2	6.5
Iron	<113	<138	<84.3	<130	<128	113 J	102 J	113 J	95.3
Lead	<0.45	<0.55	<0.34	<0.52	<0.51	<0.14	<0.14	<0.16	<0.1
Magnesium	<452	637	<337	<519	564	704	546	1010	685
Manganese	2.4	3.3	<1.7	<2.6	3.5	5.4	2.5	3.6	5.7
Mercury	0.17 J	0.99 J	0.11 J	0.17 J	0.3 J	0.21	0.96	0.32	0.21
Molybdenum	<4.5	<5.5	<3.4	<5.2	<5.1	0.6 J	0.5 J	0.69 J	0.48 J
Nickel	<0.45	<0.55	<0.34	<0.52	<0.51	<0.48	<0.5	<0.56	<0.36
Potassium	5560	6310	4930	5360	6010	7510	7380	8680	7030
Selenium	2.5	3.2	1.6	2.4	2.9	2.8 J	2.6 J	3 J	2.7 J
Silver	<0.23	<0.28	<0.17	<0.26	<0.26	<0.014	<0.015	<0.017	<0.011
Sodium	7220	9280	6850	7520	8930	12300 J	9840	11900	8450 J
Strontium	1.2	3.7 J	0.61	1	1	1.6	1.1	5	1.4
Thallium	<0.45	<0.55	<0.34	<0.52	<0.51	<0.068	<0.07	<0.079	<0.051
Vanadium	<0.9	<1.1	<0.67	<1	<1	<0.22	<0.23	<0.26	<0.17
Zinc	55.2	46.6	30.3 J	58.8 J	68.8	64.9	46.1	67.2	65.1

mg/kg dw - Milligrams per kilogram dry weight.
< - Not detected at sample quantitation limit indicated.
J - Estimated value.
TRM - Tennessee River Mile.

Table C-2. Great Blue Heron Eggs 2009 and 2010 Sample Results, Emory River (mg/kg dw)
Tennessee Valley Authority Kingston, Tennessee

Analyte / Location: Sample	ERM3.0 4/23/2009	ERM3.0 4/23/2009	ERM3.0 4/23/2009	ERM3.0 4/23/2009	ERM3.0 4/23/2009	ERM3.0 4/12/2010	ERM3.0 4/12/2010	ERM3.0 4/12/2010	ERM3.0 4/12/2010	ERM3.0 4/12/2010	ERM3.0 4/12/2010	ERM3.0 4/12/2010	ERM3.0 4/12/2010	ERM3.0 4/12/2010
Aluminum	<134	<135	<154	<126	<166	<20.56	<22.3	<23.7	<26.2	<19	<21.1	<23.1	<21.2	<22.1
Antimony	<0.54	<0.54	<0.62	<0.51	<0.67	<0.07461	<0.081	<0.086	<0.095	<0.069	<0.076	<0.083	<0.077	<0.08
Arsenic	<0.54	<0.54	<0.62	<0.51	<0.67	<0.1442	<0.16	<0.17	<0.18	<0.13	<0.15	<0.16	<0.15	<0.16
Barium	0.71	<0.54	1	<0.51	<0.67	0.5968	3.7	1.2	0.53 J	1	2.8	0.89	0.96 J	0.57
Beryllium	<0.54	<0.54	<0.62	<0.51	<0.67	<0.1509	<0.16	<0.17	<0.19	<0.14	<0.16	<0.17	<0.16	<0.16
Boron	<10.7	<10.8	<12.3	<10.1	<13.3	<2.155	<2.3	<2.5	<2.7	<2	<2.2	<2.4	<2.2	<2.3
Cadmium	<0.54	<0.54	<0.62	<0.51	<0.67	<0.03979	<0.043	<0.045	<0.05	<0.036	<0.04	<0.044	<0.04	<0.042
Calcium	3990 J	2260 J	10700 J	1600 J	1890 J	3780 J	2520 J	2630 J	7020 J	4390 J	3280 J	2890 J	2520 J	2400 J
Chromium	<0.54	<0.54	<0.62	<0.51	<0.67	<0.6466	<0.71	<0.75	<0.83	<0.6	<0.67	<0.73	<0.67	<0.7
Cobalt	<0.54	<0.54	<0.62	<0.51	<0.67	<0.07295	<0.079	<0.092	<0.092	<0.067	<0.12	<0.14	<0.082	<0.078
Copper	6.8	5.2	18.5	3.1	5.6	7.461	4.6	5.6	9.6	5.7	5.2	3.8	6.8	4.3
Iron	<134	<135	<154	<126	<166	130.5	94 J	123 J	98.3 J	98.6 J	162	163	118 J	113 J
Lead	<0.54	<0.54	<0.62	<0.51	<0.67	<0.1426	<0.16	<0.17	<0.18	<0.13	<0.15	<0.16	<0.15	<0.15
Magnesium	542	629	691	<505	<665	792.5	574	523 J	967	751	569	568	776	462 J
Manganese	3.1	3	<3.1	<2.5	<3.3	2.653	4.6	4.4	3.3	4.6	2.9	3.8	3	2 J
Mercury	0.26 J	0.6 J	0.34 J	0.43 J	0.43 J	1.989	0.65	0.2	1.3	0.38	0.74	0.58	0.76	0.55
Molybdenum	<5.4	<5.4	<6.2	<5.1	<6.7	<0.945	<0.95	<0.67	<0.86	<1	<1.7	<0.6	<1.4	<1.5
Nickel	<0.54	<0.54	3 J	<0.51	<0.67	<0.4974	<0.55	<0.58	<0.64	<0.46	<0.51	<0.56	<0.52	<0.54
Potassium	6340	7020	7720	5420	7310	8157	8000	9420	8630	6590	6950	6970	8310	6670
Selenium	2.9	3.1	2.8	2.4	3.3	4.145	3.6	5	3.4	2.6	4	3.5	3.5	3
Silver	<0.27	<0.27	<0.31	<0.25	<0.33	<0.01492	<0.016	<0.017	<0.02	<0.014	<0.015	<0.025	<0.015	<0.016
Sodium	10100	10500	12000	7490	12200	10975	9820	12600	15300	11000	8590	10600	15800	8840
Strontium	1.9	1.1	4.2	0.8	0.89	1.558	1.2	1.6	3.1	2.9	1.9	1	1.1	1.3
Thallium	<0.54	<0.54	<0.62	<0.51	<0.67	<0.07129	<0.077	<0.082	<0.09	<0.065	<0.073	<0.08	<0.073	<0.076
Vanadium	<1.1	<1.1	<1.2	<1	<1.3	<0.2321	<0.26	<0.27	<0.3	<0.22	<0.24	<0.26	<0.24	<0.25
Zinc	55	46.2	77.9	28.5	29.3	65.65	53.5	56.4	53.1	64	76.3	68.5	53.8	54.6

mg/kg dw - Milligrams per kilogram dry weight.
< - Not detected at sample quantitation limit indicated.
J - Estimated value.
ERM - Emory River Mile.

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Appendix D

Osprey Egg 2009 and 2010
Sample Results

Table D-1. Osprey Eggs 2009 and 2010 Sample Results Reference Location (mg/kg dw)
Tennessee Valley Authority **Kingston, Tennessee**

Analyte	Location: Sample Date:	TRM569.0 4/23/2009	TRM569.5 4/15/2009	TRM569.0 4/12/2010	TRM569.5 4/12/2010	TRM569.5 4/12/2010	TRM571.0 4/12/2010	TRM571.9 4/12/2010
Aluminum		<141	<162	<24.3	<27.7	<24.9	<20.8	<20.9
Antimony		<0.56	<0.65	<0.088	<0.1	<0.09	<0.075	0.43 J
Arsenic		<0.56	<0.65	<0.17	<0.19	<0.17	<0.15	<0.15
Barium		<0.56	<0.65	<0.28	<0.32	<0.29	<0.24	0.31 J
Beryllium		<0.56	<0.65	<0.18	<0.2	<0.18	<0.15	<0.15
Boron		<11.3	<12.9	<2.5	<2.9	<2.6	<2.2	<2.2
Cadmium		<0.56	<0.65	<0.046	<0.053	<0.047	<0.04	<0.04
Calcium		1120 J	1650 J	1720 J	3180 J	3900 J	2740 J	2470 J
Chromium		<0.56	<0.65	<0.77	1.5 J	<0.79	<0.66	<0.66
Cobalt		<0.56	<0.65	<0.086	<0.097	<0.088	<0.073	<0.074
Copper		<2.8	<3.2	1.8 J	4.4	2.4 J	2.2 J	2.2 J
Iron		<141	<162	<73.3	143 J	197	128	91.1 J
Lead		<0.56	<0.65	<0.17	<0.19	<0.17	<0.15	0.57
Magnesium		<563	<646	436 J	1050	772	669	614
Manganese		<2.8	<3.2	<1	2 J	2.8 J	1.4 J	1.7 J
Mercury		0.31 J	0.36 J	0.46 J	0.83 J	0.51 J	0.89 J	0.21 J
Molybdenum		<5.6	<6.5	<0.21	<0.24	<0.22	<0.18	<0.18
Nickel		<0.56	<0.65	<0.59	0.9 J	<0.61	<0.51	<0.51
Potassium		6010	6020	5780	17100 J	9690 J	9550	6880
Selenium		1.6	1.5	1.9 J	4.7 J	3.3 J	3.1 J	2.1 J
Silver		<0.28	<0.32	<0.018	<0.02	<0.018	<0.015	<0.015
Sodium		9800	9560	9460 J	25800 J	16200 J	14800 J	9520 J
Strontium		<0.56	<0.65	0.83	1.2	1.2	0.83	0.73
Thallium		<0.56	<0.65	<0.084	<0.095	<0.086	<0.072	<0.072
Vanadium		<1.1	<1.3	<0.28	0.51 J	<0.28	<0.24	<0.24
Zinc		<13.2	29.4	34 J	64.1 J	86.2 J	67.9 J	46 J

Note: Reference Location = Upstream Tennessee River (above TRM 568).
mg/kg dw - Milligrams per kilogram dry weight.
< - Not detected at sample quantitation limit indicated.
J - Estimated value.
TRM - Tennessee River Mile.

Table D-2. Osprey Eggs 2009 and 2010 Sample Results Emory and Clinch Rivers (mg/kg dw)
Tennessee Valley Authority **Kingston, Tennessee**

Analyte / Location: / Sample Date:	CRM2.5 4/15/2009	CRM2.5 4/15/2009	ERM1.8.OS.04 4/15/2009	ERM2.7 4/23/2009	CRM2.5 4/12/2010	ERM2.8 4/21/2010
Aluminum	<174	<127	<106	<149	<23.3	<24.3
Antimony	<0.7	<0.51	<0.42	<0.6	<0.084	<0.088
Arsenic	<0.7	<0.51	<0.42	<0.6	<0.16	<0.34
Barium	<0.7	<0.51	<0.42	<0.6	0.27 J	<0.28
Beryllium	<0.7	<0.51	<0.42	<0.6	<0.17	<0.36
Boron	<13.9	<10.2	<8.5	<12	<2.4	<2.5
Cadmium	<0.7	<0.51	<0.42	<0.6	<0.044	<0.046
Calcium	1830 J	1670 J	2690 J	1330 J	1270 J	2270
Chromium	<0.7	<0.51	<0.42	<0.6	<0.74	<0.77
Cobalt	<0.7	<0.51	<0.42	<0.6	<0.082	<0.086
Copper	<3.5	<2.5	<2.1	<3	1.5 J	2.2 J
Iron	<174	<127	165 J	<149	<70.3	92.1 J
Lead	<0.7	<0.51	<0.42	<0.6	<0.16	<0.17
Magnesium	<696	<509	<424	<598	362 J	574 J
Manganese	<3.5	<2.5	2.4	<3	1.4 J	1.8 J
Mercury	0.23 J	0.25 J	0.28 J	0.2 J	0.34 J	0.36
Molybdenum	<7	<5.1	<4.2	<6	<0.21	<0.21
Nickel	<0.7	<0.51	<0.42	<0.6	<0.57	<0.59
Potassium	5680	4800	3870	6620	5540	7110
Selenium	2	2.2	2.3	2.6	2.5 J	3
Silver	<0.35	<0.25	<0.21	<0.3	<0.017	<0.018
Sodium	10100	7530	5120	9930	8650 J	9150
Strontium	0.8	0.6	0.78	<0.6	0.59	0.9
Thallium	<0.7	<0.51	<0.42	<0.6	<0.08	<0.084
Vanadium	<1.4	<1	<0.85	<1.2	<0.27	<0.28
Zinc	45.6	35.8	76.8	24.4	30.9 J	50.5

CRM - Clinch River Mile.
ERM - Emory River Mile.
mg/kg dw - Milligrams per kilogram dry weight.
< - Not detected at sample quantitation limit indicated.
J - Estimated value.

Table D-3. Osprey Eggs 2009 and 2010 Sample Results Downstream Tennessee River (mg/kg dw)
Tennessee Valley Authority **Kingston, Tennessee**

Analyte / Location: / Sample Date:	TRM564.5 4/23/2009	TRM564.6 4/15/2009	TRM567.6 4/15/2009	TRM564.6 4/12/2010	TRM566.0 4/12/2010	TRM567.6 4/12/2010
Aluminum	<162	<98.4	<165	<27.7	<25	<25.6
Antimony	<0.65	<0.39	<0.66	<0.1	<0.09	<0.093
Arsenic	<0.65	<0.39	<0.66	<0.19	<0.18	<0.18
Barium	<0.65	<0.39	<0.66	<0.32	<0.29	0.33 J
Beryllium	<0.65	<0.39	<0.66	<0.2	<0.18	<0.19
Boron	<13	<7.9	<13.2	<2.9	<2.6	<2.7
Cadmium	<0.65	<0.39	<0.66	<0.053	<0.048	<0.049
Calcium	1980 J	2420 J	1840 J	2180 J	2200 J	3120 J
Chromium	<0.65	<0.39	<0.66	<0.88	<0.79	<0.81
Cobalt	<0.65	<0.39	<0.66	<0.098	<0.088	<0.09
Copper	<3.2	<2	<3.3	2.2 J	2 J	2.3 J
Iron	<162	129 J	<165	85 J	93.1 J	197
Lead	<0.65	<0.39	<0.66	<0.19	<0.17	<0.18
Magnesium	<648	<394	<662	705	672	641
Manganese	<3.2	<2	<3.3	<1.2	1.3 J	2.6 J
Mercury	0.26 J	0.16 J	0.16 J	0.3 J	0.68 J	0.18 J
Molybdenum	<6.5	<3.9	<6.6	<0.24	<0.22	<0.23
Nickel	<0.65	<0.39	<0.66	<0.68	<0.61	<0.63
Potassium	7460	3510	6180	8540	8780	7230
Selenium	2	1.7	1.7	2.4 J	2.8 J	2.4 J
Silver	<0.32	<0.2	<0.33	<0.02	<0.018	<0.019
Sodium	11200	5200	10500	12800 J	13500 J	11100 J
Strontium	1.1	0.78	<0.66	0.89	0.89	1.2
Thallium	<0.65	<0.39	<0.66	<0.096	<0.086	<0.088
Vanadium	<1.3	<0.79	<1.3	<0.32	<0.29	<0.29
Zinc	44.5	65.6	36	37.2 J	44.5 J	73.9 J

mg/kg dw - Milligrams per kilogram dry weight.
< - Not detected at sample quantitation limit indicated.
J - Estimated value.
TRM - Tennessee River Mile.