So What Does It Mean? What Ecological Effects Has the Kingston Ash Spill Caused?

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ABSTRACT

Immediately following the TVA Kingston fly ash spill, on the basis of a few hastily-collected samples several researchers predicted calamitous effects on the aquatic ecology in the Emory, Clinch, and Tennessee Rivers as a result of bioaccumulation of ash-related constituents.

This poster describes the extent of ecological effects observed during the first two years following the ash spill and possible relationships with bioaccumulation results that are presented in a companion poster. Information is presented on observations of ecological effects at the cellular, organ, organism, and population levels. Results are presented on species abundance and diversity, reproductive success, early life stage effects and survival, and other potential ecological effects.

Because selenium is a significant contaminant in fly ash that in other studies has been shown to have adverse effects on animal reproduction, particular emphasis has been placed on evaluating potential reproductive effects that could have cascading effects on populations of the affected organisms and their predators.

OBJECTIVES

Ecosystem-wide monitoring is an ongoing process at TVA Kingston. Assessments at all levels of ecosystem organization offer a comprehensive way to assess whether adverse effects have occurred because of the spill. The purpose of the monitoring is not only to evaluate communities and populations potentially exposed to impacted areas, but also to assess the individuals comprising these groups, individual organ and tissue health, and reproduction success, as these endpoints are potential indicators of ash related effects.

SUB-ORGANISM: An organism's internal make-up of cells, blood, enzymes, tissues, organs, and organ systems

INDIVIDUAL: An organism within the area of study interacting with the abiotic environment around it

POPULATION: A group of organisms of the same species, occupying a defined area during a specific time

COMMUNITY: An assemblage of different species interacting with one another

SUB-ORGANISM

- Measure metal concentrations in fish reproductive organs and other tissues.
- Evaluate ovaries of fish for reproductive condition.
- Measure components in blood indicative of fish kidney and gill function.
- Measure feathers and tarsus length of tree swallows nestlings.
- Relate effects seen at the sub-organism level to higher levels of organization.

NDIVIDUAL

- Measure metal concentrations in whole fish/fish fillets and eggs from tree swallow, great blue heron, Canada goose, and osprey and compare each with literature-derived effects values.
- Evaluate anomalies in individuals through sport fish surveys.
- Relate effects seen at the organism level to higher levels of organization.

POPULATION

- Evaluate clutch size, hatching, and fledgling success in tree swallows.
- Measure reproductive success of fish in laboratory exposures to ash.
- Measure changes in sport fish population class size distributions.
- Relate effects seen at the population level to higher levels of organization.

COMMUNITY

- Measure fish and benthic macroinvertebrate community richness and density.
- Evaluate the fish and benthic macroinvertebrate community condition using specific indices for each.
- Relate effects in one community to those seen throughout the river-system.

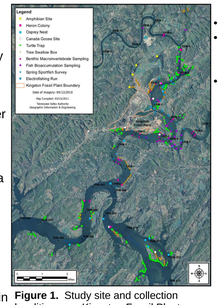

Figure 1. Study site and collection localities near Kingston Fossil Plant, Roane County, Tennessee. Sampling sites: Emory (ERM), Clinch (CRM) and Tennessee (TRM) Rivers.

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SUB-ORGANISM LEVEL

Fish Health and Reproduction:

- Five locations were sampled for female fish during the start of their respective breeding seasons.
  - Metal bioaccumulation was analyzed in ovaries and other tissues.
  - Batch fecundity and egg development were additional measurement endpoints.
  - Target sample sizes were 8 or more females of 3-5 fish species (bluegill, largemouth bass, white crappie, channel catfish, redear sunfish) .
- Selenium concentrations in fish ovaries from the Emory and Clinch Rivers were elevated in redear sunfish (Figure 2) but remained lower than EPA's proposed Tier 2 assessment threshold (10 mg/kg) for all other fish.

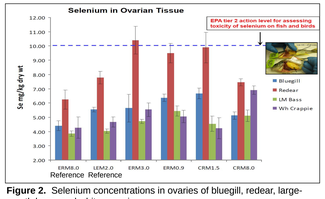

Figure 2. Selenium concentrations in ovaries of bluegill, redear, large-mouth bass, and white crappie.

- Bluegill collected at the beginning of the 2009 breeding season at the spill site experienced a slight delay in ovarian development as evidenced by smaller ovaries and fewer and less developed vitellogenic oocytes compared with other sites (Figure 3).
- Bluegill at the spill site showed an absence of a significant increase in oocyte atresia (one indicator of direct toxicity to the immature eggs), and considering the relative size-distributions of developing oocytes at study sites (Figure 3), suggests a probable bioenergetic rather than direct toxicity explanation for the reproductive delay at the spill site during the spring 2009 breeding season.
- Bluegill both upstream and downstream of the spill site showed no significant differences in the reproduction condition at the beginning of the 2010 breeding season (data not shown).
- Largemouth bass fecundity was similar among all the study sites in 2009 (Figure 4).
- Largemouth bass at the spill site experienced higher occurrences of atresia compared to the upstream Emory River reference site in spring 2009, however were not elevated compared to other study sites (Figure 4).
- Pathological differences in some major fish organs (e.g., gill and kidney) at the lower Emory River site as compared to reference (Figure 5) indicated lower health condition.

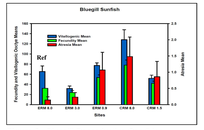

Figure 3. Bluegill Reproductive Condition.

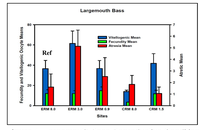

Figure 4. Largemouth Bass Reproductive Condition.

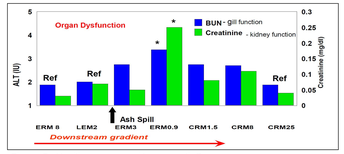

Figure 5. Health responses of Largemouth Bass.

Tree Swallow Health:

- Impacted and reference locations were sampled for 15-day post hatching tree swallow nestlings in 2009 and 2010 to assess potential teratogenesis from maternal transfer of selenium.
  - Third primary feathers were measured.
  - Tarsus length was measured.
- There were no significant differences betweens sites for feather or tarsus length (Figure 6).

Measuring length of third primary feather of 15 day old nestling .

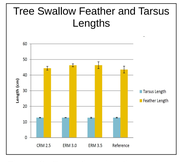

Figure 6. Evaluation of feather and tarsus lengths for 15-day nestlings.

INDIVIDUAL LEVEL

Sport Fish Surveys - Physical Anomalies:

- Black bass population sampled at CRM 2.5 as part of TVA's Valley-Wide Monitoring Program in 2002, 2003, 2004, and 2005.
- CRM 2.5 and an additional site at ERM 2.5 sampled in 2009 and 2010.
  - All bass were measured, weighed, enumerated, and visually inspected for physical anomalies.
- A total of 695 and 661 black bass were collected during 2009 and 2010 surveys, respectively (Table 1).
- Anomalies observed in 1.3 to 2.8% of bass collected in 2009 and 2010 were lower than 2002-2005 average of 3.7% for CRM 2.5.

Table 1. Spring sport fish survey of anomalies in the Emory and Clinch Rivers

River	Year	Total # of Bass	Catch Rate (no./hr.)	Lesions	Emaciated/ Skinny	Scoliosis	Fin rot	Fungus	Blind-eye	Cancer-ous growth	Popeye	Deformed	Total Anomalies*
EMORY 2.5	2010	304	50.7	2		1	3	1	1				8 (2.6%)
	2009	319	53.2	1			1	2					4 (1.3%)
CLINCH 2.5	2010	357	59.7	2	4	1		2		1			10 (2.8%)
	2009	376	62.7	6		2			1				9 (2.4%)
	2005	252	42.0	2		1		3	1	1			8 (3.2%)
	2004	256	42.7	5	1			7	1				14 (5.5%)
	2003	289	48.1	2	1			6	1		1		11 (3.8%)
	2002	311	51.8	3				3	1				7 (2.3%)

*Percent of total number of black bass collected

Selenium Concentrations in Individuals Compared with Threshold Levels:

Whole Body Fish

- EPA (2004) chronic criteria for selenium concentrations in whole-body fish is 7.91 mg/kg dw (dry weight). In addition, if whole-body fish tissue concentrations exceed 5.85 mg/kg dw during summer or fall, fish tissue should be monitored during the winter to determine whether selenium concentrations exceeds 7.91 mg/kg dw.
- No sites had concentrations exceeding these thresholds (Figure 7).

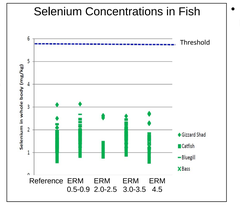

Figure 7. Concentration of selenium from fish collected at reference areas and Emory River miles in 2009 and 2010.

Bird Eggs

- Eggs include: Goose, heron, osprey, and tree swallow.
- Selenium concentrations in eggs differed among sites. Reference sites (Ft. Loudoun Dam, Tellico Dam, Upstream Tennessee River) had significantly lower Se concentrations than impacted sites (ash spill area, downstream Clinch and Tennessee Rivers) (Kruskal-Wallis, $p<0.001$, Figure 8).
- Potential effects range is between 6 and 12 mg/kg for bird eggs (Skorupa and Ohlendorf 1991).
  - Only 3 tree swallow eggs had selenium concentrations within this range.
  - Only one tree swallow egg exceeded the threshold concentration of 12 mg/kg (concentration= 13.04)(Figure 8).
  - Continued monitoring of tree swallows is in progress by other agencies.

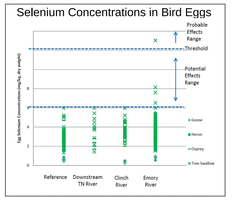

Figure 8. Concentration of selenium from all bird eggs collected at reference areas, downstream Tennessee River, and Clinch and Emory Rivers in 2009 and 2010.

POPULATION LEVEL

Fish Population Metrics:

Field Measurements -

- Bass populations were measured at 2 locations (CRM 2.5 and ERM 2.5) during Spring Sport Fish Surveys (Figure 9A-B).
  - Pre-spill surveys conducted on the Clinch River provide a baseline for comparison.
  - Six years of data available from CRM 2.5 and catch rates were higher in 2009 and 2010.
  - Catch rates at ERM 2.5 in 2009 and 2010 similar to Clinch River's long-term average of 51.2 fish/hr.
  - Length frequency histograms for largemouth bass at both locations illustrate typical distributions observed at CRM 2.5 prior to the spill (Figures 9A-B).

Laboratory Tests - Effects of direct exposure to fly ash on fish early development:

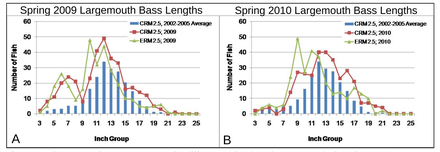

Figure 9. Fish population assessments for differences in A) Spring 2009 and B) Spring 2010 population length frequency histograms for largemouth bass.

- The 7-day embryo-larval toxicity tests and long-term tests consisted of fathead minnows exposed to impacted sediment from the Emory and filtered Emory River water from ERM 8.0.
- No differences were observed between controls and fly-ash exposed embryos (Figure 10A) during short-term 7-day tests.
- Preliminary results of long-term exposures indicate no effects on egg production (Figure 10B).

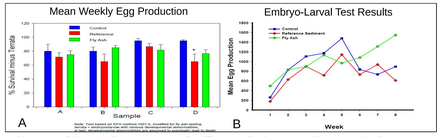

Figure 10. Fish population assessments for differences in A) Mean weekly egg production per treatment in long-term fathead minnow exposures and B) Results of the 7-day fathead minnow embryo-larval tests.

Tree Swallow Population Metrics:

- Clutch sizes ranged from 2-7 eggs (mean clutch size=4.33, n=155).
- Average hatching success was similar among sites, ranging from 84.39% to 93.24% among the sites (Kruskal-Wallis, $p=0.25$, Figure 11).
- There was no relationship between egg selenium concentrations and hatching success (linear regression, $r^2=0.002$, $p=0.73$).
- Nestling survival to day 15 did not differ between sites (Kruskal-Wallis, $p=0.27$), however, trends suggest that the reference site had higher survival rates than all other sites (see Figure 12).
- There was no relationship between day 15 nestling survival and selenium concentrations (linear regression, $r^2=0.008$, $p=0.48$).

Tree swallow eggs and hatchlings.

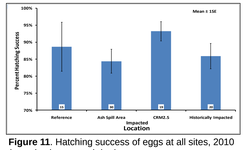

Figure 11. Hatching success of eggs at all sites, 2010 (sample size on each bar).

Tree swallow nestling approximately 15 days old.

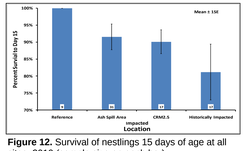

Figure 12. Survival of nestlings 15 days of age at all sites, 2010 (sample size on each bar).

COMMUNITY LEVEL

Fish Community:

- Fifteen 300-meter electrofishing runs and ten, overnight gill net sets per site.
  - Total of 5,198 fish and 38 species collected in 2009; a total of 5,366 fish and 46 species collected in 2010.
- Species richness in 2009 and 2010 similar to pre-spill results (Figure 13A)
  - Greatest richness (40) was near the ash -impacted site, ERM 2.5 in 2010.
  - Differences observed were "incidental" species with historic median catch rates of 0 to 1.
- Community data evaluated with multi-metric scoring method (Reservoir Fish Assemblage Index or RFAI) developed by TVA in early 1990s as part of TVA's Valley-wide Reservoir Vital Signs Monitoring Program (Figure 13B).
- RFAI scores ranged from Fair to Good; highest scores nearest spill area.
- In 2009, ERM 2.5 scored higher in number of native species, number of benthic invertivores, and % non-native species.
- In 2010, RFAI scores and individual metric scores similar among sites.

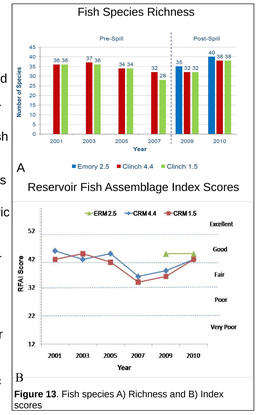

Figure 13. Fish species A) Richness and B) Index scores

Benthic Macroinvertebrate Community

- No historical data exist for benthic macroinvertebrate communities.
- Ten equally-spaced Ponar grabs collected across the width of the reservoir at each site.
- Sites nearest the spill had population densities and taxa richness similar to –and often greater than– the Clinch and Tennessee Rivers.
- Reference site ERM 6.0 and site ERM 5.0 had the lowest densities (Figure 14A-B).
  Population density graph is not included in poster.
- Greatest temporal variation in densities at reference sites on the Clinch (CRM 8.7 and 6.0), a likely result of scouring from storm flow events during 2009, which resulted in lower composition of fines (silt/clay); no obvious effect at downstream locations as cross-sectional area increases up to three-fold.
- The mayfly *Hexagenia* are generally most abundant in the Clinch River downstream of the Emory River and least abundant in the upper Emory River (ERM 6.0, ERM 5.0, and ERM 4.1) (Figure 14B).
- Highest taxa richness observed at spill sites ERM 2.2 and 4.1 in December 2009 (Figure 14C).
- Variation in taxa richness between sample periods at each site was primarily "incidental" species; those represented by fewer than 3 or 4 individuals throughout a transect (i.e., 10 grab samples).
- Differences in benthos appear to be primarily related to variations in channel morphology and the complexity of converging river systems with different hydrological, physical and chemical characteristics.

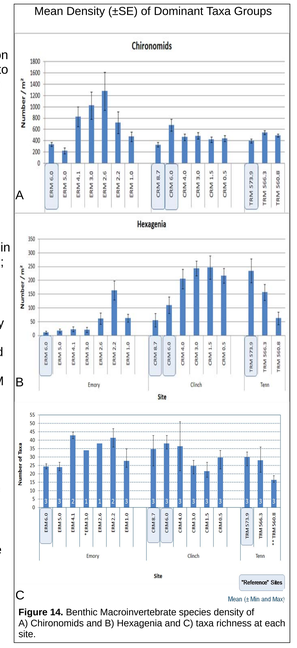

Figure 14. Benthic Macroinvertebrate species density of A) Chironomids and B) Hexagenia and C) taxa richness at each site.

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