Environmental Research 138 (2015) 38–48

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Reproduction and hatchling performance in freshwater turtles associated with a remediated coal fly-ash spill ☆

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ARTICLE INFO

Article history:
Received 16 August 2014
Received in revised form
28 January 2015
Accepted 30 January 2015
Available online 14 February 2015

Keywords:
Coal combustion wastes
Ecotoxicology
Reptile
Selenium
Trace element
Wildlife

ABSTRACT

In 2008 an impoundment retaining wall failed at the Tennessee Valley Authority's coal burning plant in Kingston, Tennessee, releasing large quantities of coal-fly ash into the Emory River. Following extensive remediation of the spill, we captured (in 2011 and 2012) gravid turtles of multiple species in three rivers (two impacted and one reference) within the vicinity of the spill to determine whether there was evidence of the spill influencing reproduction. There was little evidence that river of origin affected reproductive output, hatching success, hatchling size, or hatchling locomotor performance. Although hatching success and hatchling righting ability of pond sliders, *Trachemys scripta*, was higher in our reference river than in the Emory or Clinch River, respectively, these differences could not be attributed to differences in individual element concentrations in turtle tissues and effect sizes were relatively small. For example, hatching success was reduced by 11% in the spill zone compared to the reference river, an effect that is unlikely substantial enough to influence local population dynamics in light of turtle life history. Our results suggest that residual contamination that remains in the Emory–Clinch system after its remediation poses low risk of excessive element exposure and limited adverse reproductive effects to freshwater turtles. Future monitoring could reveal whether the observed reduction in hatching success gradually attenuates with time, or whether any long-term effects of chronic exposure to low-level contamination emerge over time.

1. Introduction

Coal combustion is a widespread source of global energy, accounting for approximately 30% of the world's power in 2011 (British Petroleum, 2012). A notable byproduct of coal combustion is fly ash; in the United States alone, over 140 million tons of fly ash were produced in 2005 (US EPA, 2010). Depending on the composition of the coal and the combustion technologies used, fly ash may contain a wide variety of elements, including arsenic (As), mercury (Hg), and selenium (Se; Izquierdo and Querol, 2012). Approximately 40% of the fly ash annually produced in the United States is stored in aquatic surface impoundments (ACAA, 2010). Ash-derived elements within these impoundments may contaminate surrounding bodies of water through leaching, discharge and spills or after the failure of impoundment retaining walls or dikes (Benito et al., 2001; Rowe et al., 2002; Ugurlu 2004; National Research Council, 2002, 2006; Lemly, 2015).

The release of elements from coal fly ash and other industrial processes into aquatic systems can negatively affect aquatic organisms and ecological processes (Rowe et al., 2002; National Research Council, 2006; Rowe, 2014). Certain elements are of particular concern because they can influence reproduction and/or survival at high concentrations (e.g., Sorensen, 1986; Lemly, 2002; Hopkins et al., 2013a). In addition, females may maternally transfer elements to their young during reproduction and post-hatching provisioning, potentially resulting in compromised physiology of offspring (Nagle et al., 2001), increased malformation prevalence (Ohlendorf et al., 1986; Rowe et al., 1996) and altered offspring behavior (Bergeron et al., 2011; Chin et al., 2013).

Turtles are good organisms to study element accumulation from coal fly ash and associated reproductive effects (e.g., Nagle et al., 2001; Yu et al., 2011; Hopkins et al., 2013a) because they live long lives (Congdon et al., 1993, 1994) and have relatively small

☆Capsule Abstract: We captured gravid turtles to determine if environmental contamination at a remediated coal-fly ash spill influenced reproduction. There was little evidence of adverse effects.

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http://dx.doi.org/10.1016/j.envres.2015.01.024
0013-9351/

home ranges (e.g., Obbard and Brooks, 1981); as a result, turtles may be exposed to local contaminants over a long period of time. In addition, turtles possess attributes that make them logistically tractable for study such as high population densities (Iverson, 1982) and inducible oviposition (Ewert and Legler, 1978). Turtles also allocate similar quantities of elements to all eggs within a clutch, reducing the variability of embryonic exposure to contaminants among siblings (Van Dyke et al., 2013b); therefore, entire clutches do not need to be sacrificed to obtain representative samples for toxicological studies. Negative effects of environmental contamination on freshwater turtles are particularly important to study because their populations are sensitive to anthropogenic sources of mortality and many species are highly imperiled (Rhodin et al., 2010). Negative reproductive effects observed among turtles associated with environmental contaminants could include reduced clutch sizes or decreased hatching success (e.g., Bishop et al., 1991; Hopkins et al., 2013a). In addition, hatchlings exposed to contaminants may develop abnormalities (Bishop et al., 1998) or altered locomotor behavior (i.e., speed, Burger et al., 1998), which may affect their survival because the speed of a hatchling is thought to be positively associated with its ability to avoid predation (Janzen et al., 2000a, 2000b, but see Congdon et al. (1999)).

In 2008, a retaining wall of a fly-ash impoundment failed at the Tennessee Valley Authority (TVA) coal-burning plant in Kingston, Tennessee, USA, resulting in over 4.1 million cubic meters of fly ash being released into the Emory River. Following the 2008 spill, TVA instituted an intensive remediation effort that included mechanical/hydraulic dredging and off-site disposal of ~2.5 million cubic meters of fly ash by August 2010 (TVA, 2009, 2011). Despite remediation efforts, residual ash remains in some areas of the system (Carriker et al., 2011) and element concentrations in the area may be sufficiently elevated to be of environmental concern (e.g., Jackson, 2011; Ruhl et al., 2010). Thus, it is important to determine whether remaining ash poses any risks to wildlife. In 2011 and 2012, we sampled turtles in two rivers (i.e., the Clinch and Emory Rivers) downstream of the spill and also the Tennessee River upstream of its confluence with the Clinch River, where turtles were unlikely to be affected by the spill (Fig. 1). Initial work suggested that females in the area near the remediated spill were maternally transferring some elements (i.e., As, Hg, Se, Sr, and Zn) to their offspring (Van Dyke et al., 2014). Therefore, the goal of our study was to determine whether gravid female turtles inhabiting the impacted area experienced adverse reproductive effects.

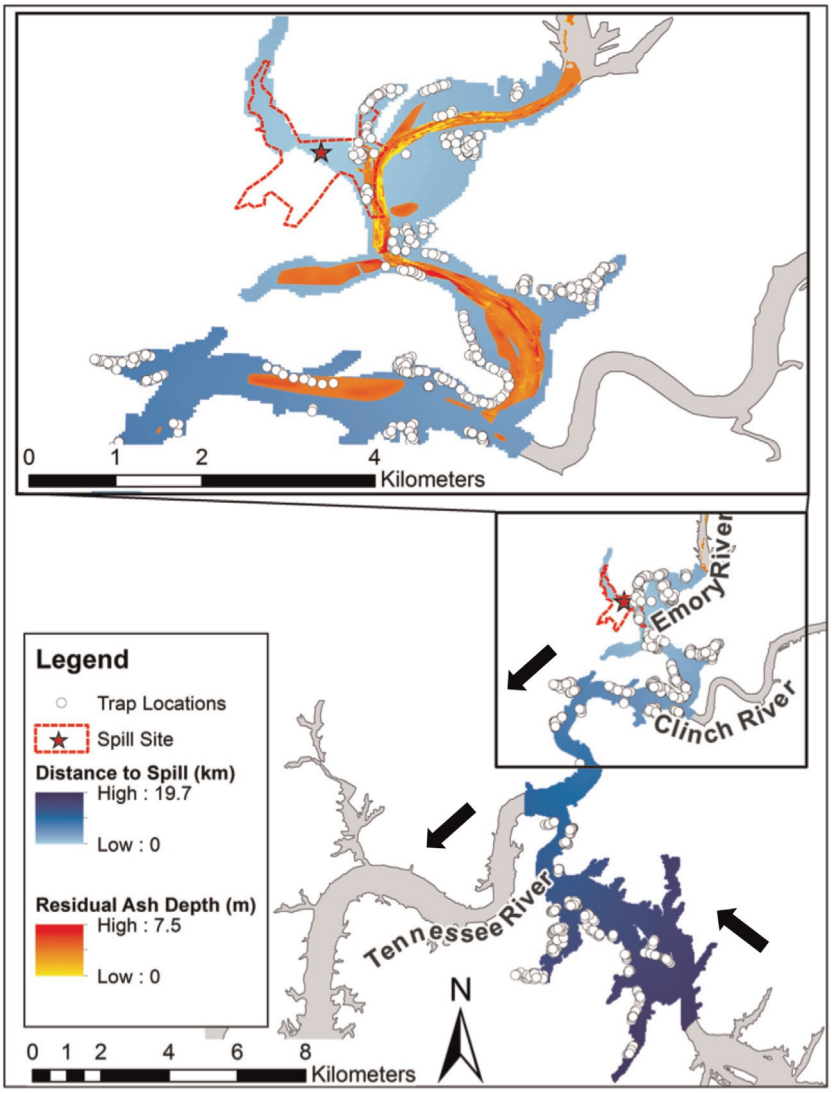

Fig. 1. Segments of the Clinch, Emory, and Tennessee Rivers trapped for turtles in 2011 and 2012. The Emory and Clinch rivers were impacted by the spill, but trap locations on the Tennessee River were upstream of the confluence with the Clinch River and thus served as an unimpacted reference river. Arrows indicate flow direction.