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Teratogenic effects and monetary cost of selenium poisoning of fish in Lake Sutton, North Carolina

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ABSTRACT

Selenium pollution from coal ash wastewater was investigated in Lake Sutton, NC. This lake has been continuously used as a cooling pond for a coal-fired power plant since 1972. Historic and recent levels of contamination in fish tissues (14–105 μg Se/g dry weight in liver, 24–127 in eggs, 4–23 in muscle, 7–38 in whole-body) exceeded toxic thresholds and teratogenic effects were observed in fish collected in 2013. A high proportion (28.9 percent) of juvenile Lepomis spp. exhibited spinal and craniofacial malformations that were consistent with selenium poisoning. Teratogenic Deformity Index values indicated population-level impacts on the fishery. The partially monetized cost of resultant fishery losses was calculated at over $US 8.6 million annually, and over $US 217 million for the entire period of damage, which dates back to 1987 when chemical and biological monitoring began.

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1. Introduction

Duke Energy Progress (Progress, formerly Progress Energy Carolinas, Inc.), a subsidiary of Duke Energy, constructed Lake Sutton as a cooling reservoir for the L.V. Sutton Steam Plant, a coal-fired electric generating facility. Water is withdrawn from the Cape Fear River and used to cool steam condensers in the power plant, after which this now-heated water is discharged into the reservoir to allow heat dissipation before the return flow enters the river. Construction of Lake Sutton was authorized by statute and deed from the State of North Carolina in 1971 and included an easement signed by the Governor of NC and by Progress stipulating that the lake is required to be managed as a public fishery (SELC, 2013). Although Progress holds deed to the land, the Office of the Attorney General of NC has concluded that Lake Sutton is a water of the State because it impounded Catfish Creek, which was a navigable water of the State and the United States (SELC, 2013). Thus, while impoundment of the reservoir created lacustrine aquatic habitat, it also destroyed lotic habitat and a navigable water of the State that was owned by the public. As a water of the State, the lake's natural resource values are held in trust to the public by the State.

Lake Sutton is an extremely popular fishing location both for sport anglers and for subsistence fishermen. The fishery is managed by the North Carolina Wildlife Resources Commission with financial support from the U.S. Fish and Wildlife Service's Sport Fish Restoration Program. These entities encourage the public to fish at Lake Sutton through fishing education and they facilitate public access through construction and maintenance of boat ramps, parking lots, fishing piers, and shore-fishing access points. Through their cooperative efforts, the State, federal programs, and Progress created a highly valued and highly utilized natural resource in Lake Sutton.

Located adjacent to the Cape Fear River about 8 km northwest of Wilmington, NC (Fig. 1) the 445 ha lake is used as a disposal site for wastewater discharged from the power plant's coal ash settling ponds. As a result, Lake Sutton is polluted by the trace element selenium, which is a well-documented contaminant in coal ash wastewater and it can cause developmental abnormalities and reproductive failure in fish and wildlife (Lemly, 2002a). The reservoir and power plant were put into operation in 1972 and Lake Sutton has been receiving elevated concentrations of selenium (>2 μg/L) in ash wastewater more or less continuously since that time. Fish populations and chemical contamination (Se, As, and heavy metals) have been monitored in Lake Sutton since the late 1980s (NCDIF, 2010, 2013). Waterborne selenium enters Lake Sutton in ash wastewater and then bioaccumulates in the aquatic food chain, where it becomes a source of increased dietary selenium to fish, resulting in elevated concentrations in their tissues. Although monitoring results have long indicated that the concentrations of selenium in fish equal or exceed diagnostic toxic levels (Table 1) there has been no detailed biological investigation to determine if impacts are actually occurring. This study was conducted to answer that question.

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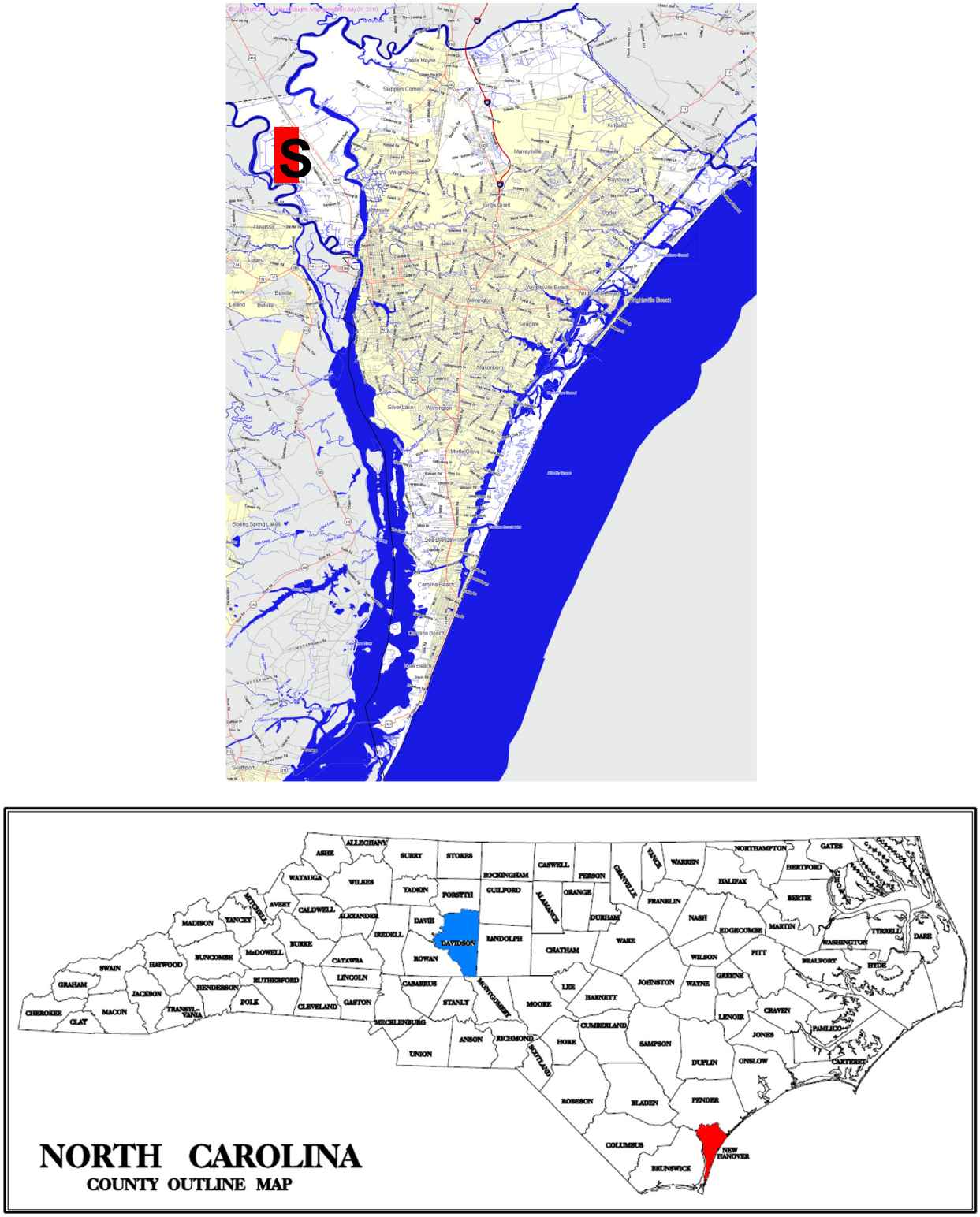

Fig. 1. Location of Lake Sutton (letter S over red marker) in New Hanover County, North Carolina. This county borders the Atlantic Ocean and is shown in red on the NC State map. Davidson County, location of the reference High Rock Lake, is in central NC, and is shown in blue on the NC State map. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2. Methods

2.1. Assessment technique

The assessment method was developed through the author's work on other selenium-polluted lakes in NC and is published in the peer-reviewed scientific literature (Lemly, 1993a, 1997a). It consists of examining young fish for the presence of selenium-induced defects and then applying the Teratogenic Deformity Index to evaluate impacts on fish populations.

2.2. Fish collection and examination

Juvenile fish were collected from Lake Sutton during May–September 2013 using small mesh seines (4 mm^2 mesh size) and examined for deformities. Only

Table 1
Historical and recent concentrations of selenium in bluegill (*Lepomis macrochirus*) from Lake Sutton[a] relative to known toxic thresholds.

Year	*n*	Mean tissue Se μg/g dw			Whole-body	Toxic thresholds[b]
		Liver	Egg	Muscle		
1987	**6**	105.5	86.5	15.7	26	Liver = 12 μg/g dw
1989	**6**	NA	24	4.4	7.5	Egg = 10 μg/g dw
1991	**6**	14.5	59	10.7	18	Muscle = 8 μg/g dw
1993	**6**	28.5	102	18.5	31	Whole-body = 4 μg/g dw
1995	**6**	69	99	18	30	
1997	**6**	75.5	124	22.5	37.5	
1999	**6**	30	127	23	38.5	
2001	**6**	30	104.5	19	31.5	
2003	**6**	30	77	15.5	23	
2005	**6**	25.5	91	16.5	27.5	
2007	**6**	27	79	18	27.5	
2010	**6**	24	NA	17.5	NA	
2011	**6**	24	NA	17	NA	

NA = not analyzed.

[a] 1987–2007 data were extracted from NC Division of Inland Fisheries summary for selenium in Lake Sutton (NCDIF, 2013); 2010–2011 data are from Progress Energy (Progress Energy, 2011, 2012).

[b] Toxic thresholds for induction of post-hatch deformities and reproductive failure in bluegill/Lepomis spp. as reported in Lemly (1993b, 2002b).

Lepomis spp. (primarily bluegill, *Lepomis macrochirus*) were obtained in sufficient numbers ($\geq$500), proper age (young-of-the-year), and correct size ($<$6 cm total length) to perform valid teratogenic assessment (Lemly, 1997a). A total of 529 Lepomis from Lake Sutton were examined under magnification and any physical abnormalities were noted and recorded. Types of abnormalities investigated included spinal curvature (kyphosis, lordosis, scoliosis), craniofacial defects (including mouth, jaws, and gill cover), fin irregularities (missing, misshaped, vestigial), eye abnormalities (including lens cataracts and exopthalmus), and edema (fluid accumulation and associated swelling). Photographic records were made of representative individuals that exhibited abnormalities.

For comparison, 553 juvenile Lepomis (predominantly bluegill, *Lepomis macrochirus*) $<$6 cm total length were also collected from a reference lake (also using 4 mm^2 mesh seines) that does not have elevated levels of selenium (High Rock Lake, Davidson County, NC) and examined under magnification for morphological abnormalities.

3. Results and discussion

3.1. Selenium concentrations

Historic and recent concentrations of selenium in fish tissues indicate that levels consistently exceeded toxic thresholds by a wide margin. Measured concentrations were 14–105 μg Se/g dry weight in liver, 24–127 in eggs, 4–23 in muscle, 7–38 in whole-body; toxic thresholds are 12 μg Se/g dry weight for liver, 10 for eggs, 8 for muscle, and 4 for whole-body (Table 1).

3.2. Morphological abnormalities

Lepomis spp. from Lake Sutton exhibited a high incidence of abnormalities (28.9 percent). Deformities included major skeletal and craniofacial defects characterized by spinal curvature (kyphosis, lordosis, and scoliosis) and malformation of the head and mouth (Figs. 2–5; Table 2). In combination with elevated concentrations of selenium (Table 1), these hard tissue abnormalities are diagnostic biomarkers of selenium poisoning (Lemly, 1993a, 1997a, 1997b). Of the 553 Lepomis spp. examined from the reference lake, only 3 exhibited abnormalities (0.5 percent), and all of those were minor fin deformities which did not involve axial skeletal malformations. Studies of other lakes in North Carolina show that the types and prevalence of deformities seen in Lake Sutton fish are quite typical of power plant lakes that receive selenium-laden coal ash wastewater. For example, in Belews Lake, where selenium poisoning eventually eliminated most species, deformity rates were often in the 20–30 percent range, and reached a high of 70 percent (Lemly, 1993a). Studies of nearby Hyco Reservoir revealed that early post-hatch deformities in larval centrarchids frequently ranged above 50 percent (Gillespie and Baumann, 1986; Woock et al., 1987). Reservoirs in Texas have also experienced selenium pollution from coal ash wastewater. Fish at those sites displayed similar spinal and craniofacial malformations and other physiological toxic effects which were expressed in 10–50 percent of the fish, depending on species and age (Sorensen et al., 1982; Sorensen, 1988).

Fig. 2. An abnormal bluegill (*Lepomis macrochirus*, top) from Lake Sutton, NC, with deformities that result from teratogenic effects of selenium poisoning. This individual has multiple defects of the mouth (which is less than 20 percent of its normal size and permanently distended) and other craniofacial structures including "gaping" permanently deformed gill cover. Bottom individual is normal.

3.3. Teratogenic deformity index (TDI)

Applying the method prescribed by Lemly (1997a) yields a TDI of 7.20 percent teratogenic mortality (28.9 percent deformed $\times$ 25 percent mortality of the juvenile fish exhibiting deformities). It should be noted that a mortality rate of 25 percent is used because only severe deformities of the spine and craniofacial structure are considered to be lethal (due to their impact on respiration, feeding and nutrition, and ability to evade predators), which on average, amounts to about 25 percent of total deformities in a selenium-impacted fish population. Other, less severe deformities such as minor fin abnormalities may generally not be lethal and are not factored into teratogenic mortality. TDI thus yields a conservative estimate of mortality and resultant population effects. The final assessment is 71.19 percent surviving normal fish + 21.61 percent surviving teratogenic fish = 92.8 percent total survivors.

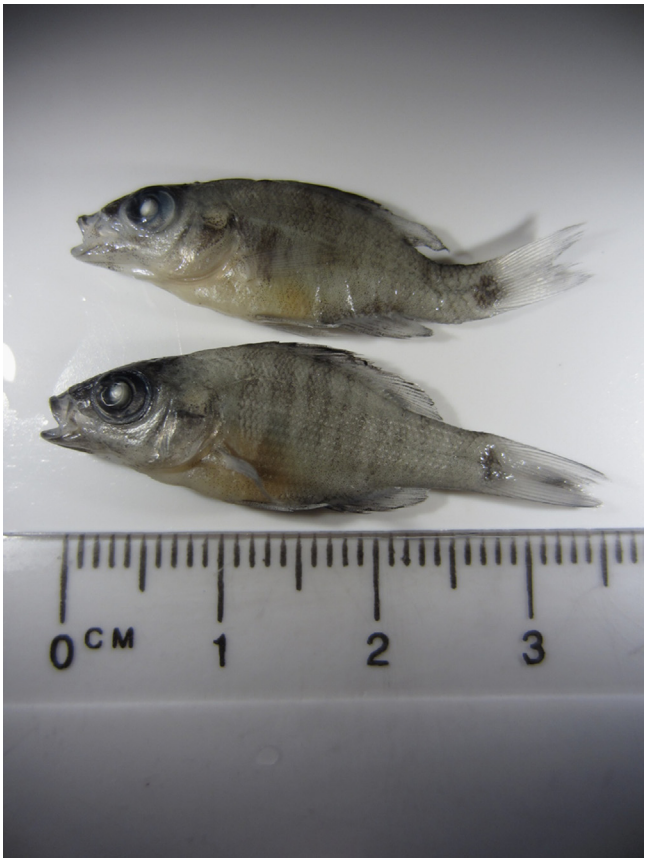

Fig. 3. A deformed bluegill (*Lepomis macrochirus*, top) from Lake Sutton, NC, exhibiting spinal curvature (kyphosis and lordosis) due to teratogenic effects of selenium poisoning. Bottom individual is normal.

Fig. 4. Abnormal bluegill (*Lepomis macrochirus*, top) from Lake Sutton showing the craniofacial defect known as "pugnose". This condition is characterized by deformed "underbite" mouth and jaws, and compressed or shortened head and mouth due to distorted cranial skeletal structure and gill cover. The bottom individual is normal.

Total teratogenic mortality is thus estimated at 7.2 percent, a Level 2 TDI rating (Lemly, 1997a, 2002b), which means that population-level impacts are expected. A Level 2 TDI rating implies that a sufficient number of individuals are being removed by selenium poisoning to depress normal population levels and reproductive output to the point that long-term persistence of bluegill and other Lepomis spp. in Lake Sutton are seriously threatened. In ecotoxicology, population-level effects are generally considered to be impacts that reduce the standing crop through depression of adult numbers and/or chronic reduction in reproductive output (Sindermann, 1994). Pollution-induced reduction of numbers by as little as 5 percent per year can negatively affect persistence of a viable fish population when the reductions are recurring (meaning that 5 percent each year is additive and over several years will result in cumulative losses that far exceed 5 percent) and the time span of poisoning equals or exceeds the life expectancy of the species (Munns and Mitro, 2006). This situation is likely at Lake Sutton, as evidenced by the 10–50 percent depression of large-mouth bass (*Micropterus salmoides*) and other species during the last decade (NCDIF, 2010). However two factors make clear demonstration of population-level effects in Lake Sutton difficult: (1) hydrological connections constructed between Lake Sutton and the Cape Fear River to allow circulation of cooling water, as well as occasional river flooding, allow movement of fish into the lake, and (2) fish have been stocked occasionally by the State.

3.4. Monetized value of toxic impacts

Loss of fish due to toxic effects of water pollution imparts several well recognized and calculable economic costs. These costs may include ecological, recreational, commercial, subsistence, property, and esthetic value components (Kopp and Smith, 1993). Each fish carries multiple values and when that fish is lost, all of those values are lost. Thus, one must calculate and add all the value components together to arrive at the true and full monetized negative cost impact (Gentner and Bur, 2009). For the present investigation, three of the principal components of cost were calculated and added: (1) replacement cost, (2) recreational sport value, and (3) food/subsistence value. Replacement cost can be determined by multiplying the number of fish poisoned times the monetized value of an individual fish in terms of its physical replacement cost, that is, the cost to spawn and grow (via hatchery), collect (via field sites), or otherwise obtain and stock a replacement fish. That cost was calculated for lost bluegill/Lepomis spp. in Lake Sutton. The first step in this process was to use catch records from the two most recent Progress Energy monitoring reports (Progress Energy, 2011, 2012) to determine the relative abundance of bluegill/Lepomis spp. in the total fish population, which indicates an average of 63.5 percent. The next step was to estimate the total fish standing crop, which was done using catch per unit effort electrofishing results from Lake Sutton (Progress Energy, 2011, 2012) combined with fisheries monitoring information from other NC lakes that have experienced coal ash pollution and selenium levels similar to Lake Sutton (Lemly and Skorupa, 2012). Total fish standing crop estimates for Lake Sutton ranged from 34,050 individuals/ha to 54,470/ha, or an average of $44{,}260 \times 63.5$ percent $= 28{,}105$ bluegill/Lepomis spp. per hectare. For comparison, NC lakes of similar size and trophic status that are unpolluted by coal ash typically have total fish standing crops in excess of 60,000/ha (Rodriguez and Olmsted, 1993; Duke Power,

2005). The total standing crop of the bluegill/Lepomis species group in Lake Sutton is thus estimated at 28,105 individuals/ha × 445 ha = 12,506,725. A teratogenic mortality rate of 7.2 percent translates to a loss of 900,484 individuals from the bluegill/Lepomis species group annually. The replacement cost for these lost fish is calculated from inflation-adjusted numbers using 1993 NC Department of Environment and Natural Resources figures as the basis ("Sunfish – All Sizes – $5/fish"; NCAC, 1993) which yields a dollar amount of $8.10 for each individual bluegill/Lepomis spp. The resultant dollar replacement cost of poisoned fish amounts to $7,293,920 for the 2013 sampling year. It is scientifically and toxicologically reasonable to expect that poisoning rates were similar in preceding years when tissue selenium concentrations were at or above current levels. Monitoring data shows that those levels were present in all but 2 (1989 and 1992) of the previous 26 years for which records are available, going back to 1987 (NCDIF, 2013; Table 1). The cumulative replacement cost of selenium poisoning on the bluegill/Lepomis spp. group in Lake Sutton is calculated to be $7,293,920 per year (using the inflation-adjusted value of $8.10 per fish) × 25 years, or $182,348,000.

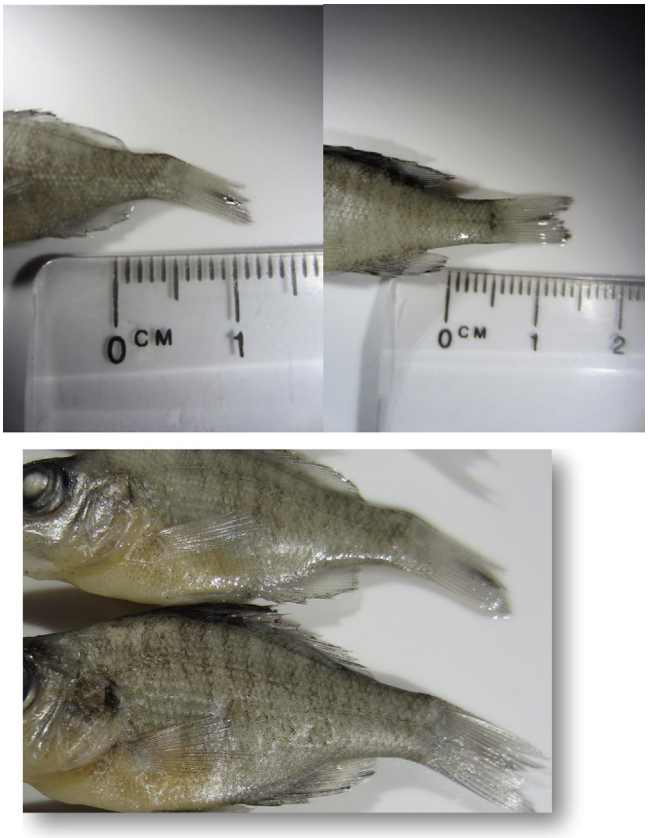

Fig. 5. Examples of deformities in bluegill (*Lepomis macrochirus*) from Lake Sutton, NC, that cause downturned tails due to malformed spine vertebrae and caudal fin rays. Individual in upper right is normal.

The two other aspects of cost that are included here are the recreational sport value and the food value of fish that have been poisoned, but would have been present and reached catchable size for sport enjoyment by recreational anglers and potential consumption by both anglers and subsistence fishermen (there is significant subsistence use of Lake Sutton fish, SELC, 2013). Those costs are calculated by combining the recreational value of lost harvestable size fish with the food value of those harvestable size fish (Lemly and Skorupa, 2012). Approximately 10 percent of the estimated standing crop of a fish population is expected to mature to harvestable/edible size (Carlander, 1997), which results in a catchable/edible population of bluegill/Lepomis spp. in Lake Sutton of 1,250,672 (12,506,725 × 10 percent). A total of 90,048 harvestable/edible individuals would be expected to be missing from the population due to teratogenic mortality (1,250,672 × 7.2 percent). The dollar value of missing angler/sport fish in 2013 is set at $8.10 per fish, which is a baseline value equal to 1993 replacement cost adjusted for inflation. This amount is conservative because it must capture the value of lost sport angling opportunity and also the recreational expenditures associated with the "fishing trip", which would include travel, camping, lodging, food/provisions, clothing, tackle, bait, gasoline, etc. The sport angling cost is likely to be well in excess of replacement cost. Applying that number yields $8.10 × 90,048 = $729,388. The dollar value of missing food/subsistence fish in 2013 is set at $7.50 (1 fish per meal, price based on current restaurant prices for "fish sandwich" fast-food meals, Roston, 2012) × 90,048 = $675,360; total for both = $1,404,748. As with replacement cost, adding the damage costs from recreational and consumptive losses expected in previous years using the inflation-adjusted number ($8.10) yields a total of $1,404,748 × 25 = $35,118,700 in cumulative monetized losses.

Some readers may have reservations concerning my inclusion of "uneaten" food/subsistence fish and "uncaught" sport fish by calculating values using all possible individuals rather than using a subset based on catch statistics or creel samples, or an estimate of the percentage that is actually being "taken". On the surface, restricting valuation to a subset of fish seems reasonable since it is unlikely that all "catchable" fish will be caught, or that all "edible" fish will be consumed. There are often difficulties grasping the many value components that enter into a full valuation of poisoned fish and wildlife. However, with careful thought, it becomes evident that assigning value to all chemically-lost fish, rather than a subset, must be done because each fish carries the same inherent value based on its potential to provide the valued asset for food or sport, regardless of whether or not that individual is actually utilized. For example, even though it is highly unlikely that all of the potentially available sport/recreation-size fish could possibly be caught, the value of each fish is inherent in its survival, and thus is lost in its mortality…that is why all chemically-lost individuals must be included in valuation.

The total monetized value for fishery losses due to teratogenic mortality caused by selenium poisoning in Lake Sutton is calculated to be $8,698,668 in 2013 for the bluegill/Lepomis species group, and the total cumulative losses for this group are valued at $217,466,700 for the period 1987–2013. However, it is not correct to interpret/infer that morphological abnormalities and resultant

Table 2
Summary of deformities in Lepomis spp. (primarily bluegill, *Lepomis macrochirus*) collected May–September 2013 from Lake Sutton and reference High Rock Lake.

Lake	*n*	Number with abnormality (percent)						
		Spinal	Craniofacial	Fin	Eye	Edema	Multiple	Total
Lake Sutton	529	146 (27.6)	16 (3.0)	1 (0.2)	0	0	10 (1.9)	153 (28.9)
High Rock Lake	553	0	0	3 (0.5)	0	0	0	3 (0.5)

mortality is the "total impact". Externally visible deformities are reliable biomarkers of selenium poisoning but they are just a symptom of a much larger underlying problem. Only impacts resulting from teratogenic mortality can be estimated by TDI, not total mortality/impacts. This is because a large part of selenium's toxicity is expressed just before or soon after hatching as the selenium contained in egg yolk is metabolized. These effects have been well studied in NC lakes and are reported in the scientific literature (Gillespie and Baumann, 1986; Woock et al., 1987). Embryo mortality and post-hatch toxicity prior to swim-up of larval bluegill typically range from 25 to 100 percent for individual spawns when the selenium concentration in eggs is at the levels reported from Lake Sutton (Table 1). This pre-swim-up mortality could easily quadruple the observed teratogenic mortality (7.2 percent) assessed from deformities that persist in the 2–5 cm length stage. Therefore, it is scientifically and toxicologically reasonable to estimate that the total selenium impact on the bluegill/Lepomis spp. group in Lake Sutton is currently in the range of 25–30 percent total population mortality per year. The resultant value of losses would be correspondingly increased, which would mean that annual monetary losses under existing pollution levels could amount to as much as $34,794,672 (4 × teratogenic mortality costs) and the 25-year losses for the bluegill/Lepomis spp. group would be approximately $869,866,800. However, this is only a partially monetized damage figure because it does not include the value of losses to other important sport and food species such as largemouth bass (*Micropterus salmoides*), catfish (Ictalurus spp.), crappie (Pomoxis spp.), and carp (*Cyprinus carpio*), which were not collected in sufficient numbers to reliably assess toxic impacts.

4. Conclusions

The findings of this study show that Lake Sutton is experiencing environmental damage caused by wastewater from surface impoundment disposal of coal ash. The biological assessment indicates that discharges from the L.V. Sutton Steam Plant are causing selenium poisoning and reducing survival of young fish in Lake Sutton. Selenium is not the only toxic chemical pollutant emanating from coal ash wastewater discharges to Lake Sutton; among the mix there is also arsenic and a variety of heavy metals including mercury, which bioaccumulates in fish similar to selenium. However, only selenium is known to produce teratogenic deformities in fish. The presence of terata (hard-tissue deformities) in combination with elevated tissue levels of selenium is a reliable cause-effect bioindicator of selenium poisoning (Lemly, 1993a). This combination was present in Lake Sutton.

It should be noted that Lake Sutton is hydrologically connected to the Cape Fear River by man-made canals. The river is the final receiving water for coal ash discharges that first circulate through the lake. The electric utility company augments circulation by discharging heated water from the cooling process and by pumping water from the Cape Fear River into Lake Sutton (NCDIF, 2010; Progress Energy, 2011). Occasionally, the river may also overflow naturally into the lake during flood stage. Two-way movement of fish (into and out of the lake and river) and one-way movement of coal ash contaminants (out of the lake and into the river) are possible. This can introduce "clean" fish to Lake Sutton and polluted water into the Cape Fear River. The connection and associated fish movement may contribute to the persistence of fish populations in the lake by allowing recruitment from the river (Progress Energy, 2012; Marsh, 2012). Fish have also been stocked in the lake by the State on several occasions (Hotz, 2009; Marsh, 2013). The combination of immigration and stocking could obscure effects of selenium poisoning by offsetting reproductive failure and creating a false sense of "healthy populations", which to some might suggest that there is no "net" environmental damage. This is certainly not the case because maintaining a poisoned fishery with stocking or natural immigration does not restore ecosystem health because the system is still contaminated and those contaminants continue to bioaccumulate and poison fish. Moreover, in addition to the observed lacustrine toxicity, riverine impacts of selenium discharged from the lake are probably occurring. For example, Mallin et al. (2011) found concentrations of selenium in river bowfin (*Amia calva*) collected at sites near the power plant that were unexpectedly high…up to 3 times the threshold for toxic effects (12 μg Se/g dry weight liver toxicity threshold; 36 μg/g measured).

The type of pollution and associated fishery impacts in Lake Sutton results in diminished natural resource values that have the potential for both short and long-term negative economic effects at the local, state and regional levels. Similar toxicity of coal ash discharges to fish populations and negative economic effects took place in North Carolina in the 1970s and 1980s (Cumbie and Van Horn, 1978; Lemly, 1985; Gillespie and Baumann, 1986; Woock et al., 1987; Lemly and Skorupa, 2012). Adding the partially monetized cost of fishery losses determined for Lake Sutton during the period 1987–2013 ($US 217,466,700) to the damage value calculated for other coal-ash impacted reservoirs in North Carolina (Belews Lake, damage = $US 531,153,873; Hyco Reservoir, damage = $US 864,742,344; Mayo Reservoir, damage = $US 80,825,500; Lemly and Skorupa, 2012) yields a total damage value of $US 1,694,188,417. Documented fishery losses therefore exceed $US 1.69 billion in damage costs from the electric utilities currently operating in this state.

North Carolina presents an extreme irony with respect to coal ash disposal and associated wastewater impacts on fish. The most costly environmental damage cases ever documented took place in the 1970s and 1980s at Belews Lake and Hyco Reservoir (Lemly and Skorupa, 2012) respectively. These lakes were studied intensely and the results were presented at workshops convened by the Electric Power Research Institute in the early 1980s to inform the utility industry and state about the environmental dangers of selenium and coal ash disposed in surface impoundments (EPRI, 1984). Actions were taken and those two sites were largely remedied by changes in ash handling practices that eliminated surface impoundment disposal (switch to dry-landfilling) and, thereby, the release of contaminated ash–slurry wastewater. Ecosystem recovery at those sites, while slow due to the continued movement of sediment-associated selenium into benthic food chains and fish, has been substantial (Lemly, 1997b; Crutchfield, 2000). The lessons provided from Belews Lake and Hyco Reservoir are powerful, and illustrate the benefits to aquatic life of eliminating selenium discharges by changing ash handling practices. Unfortunately, those lessons were not heeded at other locations in the form of progressive ash disposal (landfilling) to prevent additional episodes of wildlife poisoning. Now, four decades later, the same surface-impoundment pollution issues are emerging across North Carolina at sites managed by the same electric utility companies, most recently involving a major surface impoundment coal ash spill on the Dan River in February 2014 (NCDENR, 2014). With respect to Lake Sutton, the practice of using a public fishery water of the State as a disposal site for coal–ash drainage is currently under litigation on charges that it is in direct violation of the Clean Water Act (SELC, 2013). Also, circumstances surrounding the Dan River spill, including risks to wildlife from surface impoundment ash disposal, are being examined by a Federal grand jury (Lehmert, 2014).

In December 2013 the L.V. Sutton Steam Plant began phasing out coal-based operations, switching to natural gas as a fuel (Duke Energy, 2013). Termination of coal combustion will stop production of ash and eliminate the need for surface impoundment disposal. However, management of the existing impounded ash will be critical for future lake conditions and health of fish.

Selenium inputs from the decommissioned ash ponds into Lake Sutton will still continue as a result of precipitation and plant-site storm drainage that collects in the ponds. While total wastewater flows and selenium loading to Lake Sutton may be reduced once active ash disposal ceases, selenium inputs will not stop as long as there is conveyance of water from the ash basins into the lake. Little improvement in environmental conditions would be expected as long as this continues. When and if this link is severed, there is still the residual sediment selenium load that will continue to move into water, food-chain organisms and fish (Lemly and Smith, 1987). The legacy effect of this selenium may be substantial and protracted. For example, given the magnitude of sediment-associated selenium contamination currently in Lake Sutton relative to the toxic threshold for bioaccumulation and reproductive effects in fish (21–28 μg/g reported in 2011 samples, Progress Energy, 2012; toxic threshold=2 μg/g, Lemly, 2002b) there is a huge repository of selenium in the lake bottom. Once incorporated into the aquatic food chain, sediment-associated selenium is no different toxicologically, and is of no less biological hazard to fish, than the waterborne source which initially carried selenium into the lake. Thus, biological impacts can persist as if the power plant was still operating. Natural sedimentation rates combined with microbial volatilization and biological removal into macroorganisms (insects, annelids, crustaceans, mollusks, etc.) typically results in about a 1–2 percent attenuation of sediment selenium concentrations per year (Frankenberger and Engberg, 1998; Lemly, 2002b). Taking the upper limit of this range means that, at best, the sediment associated selenium in Lake Sutton would continue to equal or exceed the fish toxicity threshold for another 46 years following complete termination of waterborne selenium inputs. Associated negative impacts on the fishery, recreational anglers, and subsistence fishermen would also be expected to persist for that length of time as well.

Management actions that accelerate the natural attenuation rate (volatilization) of selenium in Lake Sutton are advisable. Removing the contaminated sediments by dredging or covering them with new soil to isolate selenium are not preferable options because they pose significant risk of additional negative impacts to resident biota. Dredging would resuspend large amounts of fine sediment and associated contaminants, which may increase selenium bioaccumulation in the lake, and would also transport pollutants into the Cape Fear River. Dredging would also destroy virtually all of the existing benthic community and other animals that cannot “flee the dredge”. Soil addition would blanket and kill benthic macroorganisms and many small, vulnerable vertebrates such as the eggs and early-life-stages of fish, amphibians, and reptiles. An ecologically preferable alternative would be to augment natural circulation and outflow by pumping low-selenium water from the Cape Fear River into the lake in combination with stimulation of in-lake circulation and mixing by placement of aeration pods (linked to shore-based air compressors) within the lake.

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