

SELENIUM FROM COAL MINING IN THE ELK RIVER VALLEY

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ABSTRACT

Coal mining in the Elk River Valley, B.C. enhances natural release of selenium (Se), resulting in elevated concentrations of selenium downstream of the mines. Studies to determine the extent and significance of Se in Valley waters began in 1996. Selenium concentrations downstream of the five coal mines have increased in some areas. However, the same magnitude of increases has not occurred in lotic (flowing water) fauna, and Se concentrations in fish from lotic areas have not increased from 1996 to 2003. Although Se concentrations in cutthroat trout and some of their eggs were above concentrations shown to be toxic in other areas with other fish species, a laboratory effects study found that fry hatched and developed normally. Both cutthroat and bull trout populations have increased since 1986. A study of two common waterfowl (American dippers and spotted sandpipers) living in lotic areas found no discernable adverse effects, and Se concentrations in eggs were below thresholds at which adverse effects have been documented in other areas. Although lotic areas are most common in the Elk River Valley, lentic (still water) areas may represent the worst case because there is more likelihood of inorganic Se being converted into the much more toxic organic Se. A reconnaissance study in 2002 examined lentic areas (a screening level sampling strategy) to identify “worst-case” lentic areas, to select appropriate reference areas comparable to key mine-exposed areas of interest and to identify receptor species that are at risk in these areas. For instance, the most contaminated lentic area was also the most productive area. However, more detailed studies are required before any definitive conclusions are reached. Ongoing and planned studies include determinations of aquatic food webs in both lentic and lotic areas, further monitoring in both areas, and fish and waterfowl effects studies in lentic areas. A human health risk assessment found that there was negligible risk to humans eating fish from the Valley, and benefits from consuming moderate quantities of fish.

INTRODUCTION

The soils of the Elk River Valley naturally contain elevated concentrations of selenium (Se). Coal mining in the Valley first occurred in 1897; large-scale coal mining began in 1970 and has since expanded to five major coal mining operations producing over 25 million metric tons of coal each year. The Valley presently contains the largest producing coalfield in British Columbia.

In 1998, BC Environment published a report on concentrations of Se in water, sediment and biota in the Elk River Valley (McDonald and Stroscher, 1998), which indicated that Se concentrations exceeded levels at which adverse effects had been shown to occur in some other (primarily warm water) areas. To further address the potential for impact of Se in the Elk River Valley, the Elk Valley Selenium Task Force (EVSTF) was formed. Membership of the EVSTF presently includes

the Elk Valley coal mines, the BC Ministry of Water, Land and Air Protection, the BC Ministry of Energy and Mines, and Environment Canada.

The EVSTF is addressing two primary questions; the answers to these questions will be used to manage the issue of elevated Se concentrations: (1) Is there evidence that any adverse ecological impact(s) have or will occur related to discharges of Se associated with the Elk River Valley coal mining? (2) What are the trends in Se concentrations in both standing (lentic) and flowing (lotic) water areas and biota of the watershed?

Studies conducted to date, though not yet definitive, do not provide indications of adverse effects on aquatic biota or waterfowl in the Elk River Valley. Further studies into this issue continue, with an increasing focus on effects-based studies. This paper briefly summarizes findings to date. More detailed information is provided by EVMEMC (2003).

PAST AND CURRENT STUDIES

Water, Sediment, Periphyton and Fish

An initial survey of Se contamination and bioaccumulation (uptake into organisms) in the Elk River by McDonald and Strosher (1998) found elevated concentrations of Se in water, sediment and fish tissues but no evidence of an unhealthy ecosystem. Se concentrations in sediments, algae, invertebrates and fish were not as elevated as water column concentrations.

Routine monitoring by Environment Canada of Se and other substances at a station downstream of the five mines indicates a trend of increasing concentrations over the last 10 years (from <1 :g/L to about 3 :g/L). Based on Se water monitoring conducted by each of the five mines (EVS Environment Consultants, 2003a): Se concentrations tend to decrease with distance downstream away from the mines and are highest during low flow periods; Se release is highest during high flow periods (highest run-off), but concentrations in the water are lower due to dilution. Selenium is released naturally, however generation of waste rock enhances natural selenium release processes (Ryan et al., 2001; Lussier, 2001).

Waterfowl

Harding and Paton (2003) studied American dippers and spotted sandpipers living in lotic areas of the Elk River Valley and exposed to elevated concentrations of Se. The focus was on: eggs laid, eggs hatched, hatchlings fledged, and any abnormalities. This study found that the eggs of these two bird species, even from areas with elevated concentrations of Se, contained Se concentrations below those at which adverse effects would be expected (based on studies in other areas). In addition, there were no discernable adverse effects attributable to Se on adult or juvenile birds (Figs 1 and 2).

Differences in Se accumulation were noted between the two birds that may relate to their diets (Figs 1 and 2). Sandpipers feed mainly on adult insects at the water's edge, while dippers feed mostly underwater on a variety of prey.

The study concluded that there is no risk to either of these waterfowl unless Se concentrations in the eggs increase or if limnological conditions change (increasing the conversion of biologically available Se). Such increases would not occur unless Se water concentrations increased; the level of increase that would result in risk to these waterfowl, if any, is presently unknown.

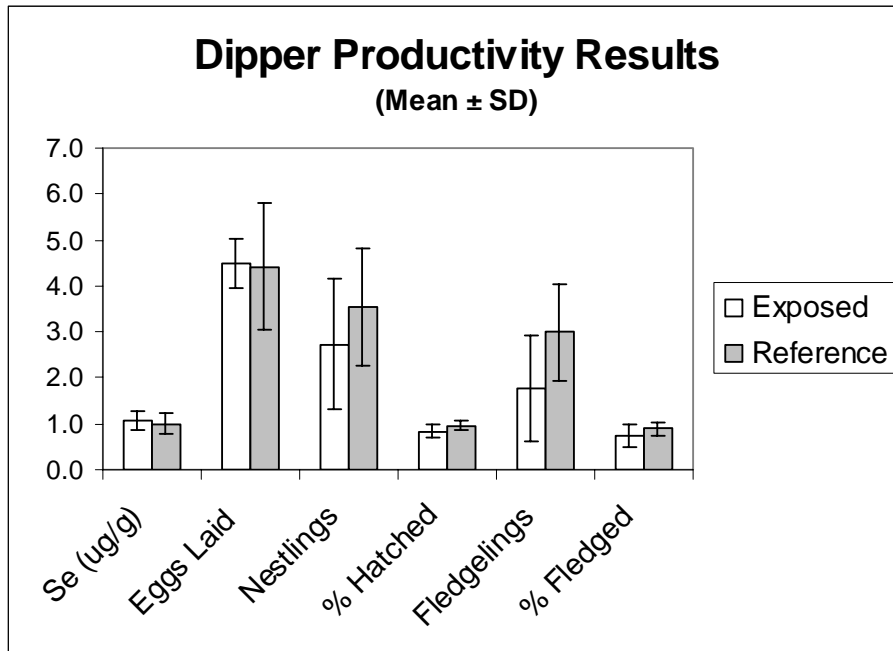


Figure 1. American dipper productivity and egg Se concentrations (wet weight) in areas with elevated Se concentrations compared to areas with background Se concentrations. Values for % hatched and % fledged are shown as decimal fractions. From Harding and Paton (2003).

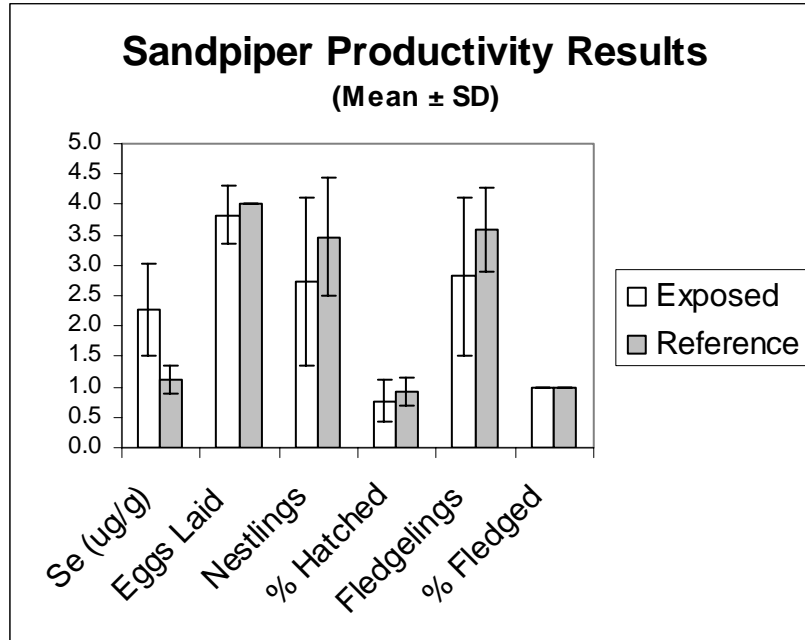


Figure 2. Spotted sandpiper productivity and egg Se concentrations (wet weight) in areas with elevated Se concentrations compared to areas with background Se concentrations. Values for % hatched and % fledged are shown as decimal fractions. From Harding and Paton (2003).

Lotic Areas

Lotic systems are by far the most common in the Elk River Valley. EVS Consultants (2003b) assessed Se concentrations in water and fish (cutthroat trout and mountain whitefish), invertebrate and plant tissues collected from various locations in the Elk River Valley in 2001 (three times for water – April, June, October, once in April for cutthroat trout and once in October for all other biota), 2002 (three times for water - May, July, October and once in April for cutthroat trout) and 2003 (three times for water – May, August, October).

The most variable and highest Se concentrations in waters were found below mine inputs. Downstream water Se concentrations did not always show a trend of increasing concentrations over time. Se fish tissue concentrations measured in 1996 (McDonald and Strosher, 1998), 1998 (Kennedy et al., 2000), 2001 and 2002 were not appreciably different, indicating no clear trend of increasing concentrations. There is “no indication of adverse effects occurring at the population level”.

Lentic Areas

Although lentic systems are less common than lotic systems in the Elk River Valley, they may represent the worst case in terms of Se toxicity because conversion of inorganic Se to organic Se most commonly occurs in lentic systems. Accordingly a reconnaissance survey of Se

concentrations and bioaccumulation in lentic areas compared six lentic sites exposed to high concentrations of waterborne Se to four suitable lentic reference areas (Minnow Environmental, 2003). Se concentrations were measured in water, sediment, fish and amphibians. The structure of communities of bottom-dwelling organisms (benthos) and of small animals living in the water column (zooplankton) was evaluated. Waterfowl were assessed qualitatively.

The lentic area with the highest level of Se was Goddard Marsh, located downstream of the Elkview coal mine. An investigation of this marsh by BC Environment in 2001 also found elevated concentrations of Se in water and in the tissues of aquatic plants, invertebrates and fish. However, this was also the most productive of the ten lentic areas examined, including the four reference areas. It had the highest density of fish, high densities of zooplankton and benthos, abundant waterfowl and other species.

All lentic habitats had established, multi-trophic level aquatic food webs. However, the same species were not found in all lentic areas, which is not surprising given habitat differences. There was no correlation between elevated Se concentrations and the consistent absence of particular species. Fish (cutthroat and brook trout, longnose sucker and longnose dace) were found at all locations where they could be found, waterfowl and other birds with a life-cycle associated with aquatic habitats via their diet (e.g., red winged blackbird) were found in all areas, and amphibians were found in two of the six lentic areas contaminated with Se

Investigative Studies

Kennedy et al. (2000) conducted investigative studies to determine whether cutthroat trout from the Valley were able to successfully reproduce. Mature male and female fish were collected from an area in the Valley that was contaminated with Se from the mines and from an area that was not. The fish were spawned, Se concentrations in the fish and eggs were measured, and the viability of both eggs and offspring determined. Although Se concentrations in the mature fish and in some of their eggs were above concentrations shown to be toxic in other areas with other fish species (Table 1), there was no toxicity. Specifically, there was no difference between the following parameters for fish exposed to and accumulating high concentrations of Se in their tissues, and those that did not: fertilization success; percent and time to egg hatch; incidence of mortalities, deformities or abnormalities (for eggs, larvae and fry). In the words of Kennedy et al. (2000), deformities characteristic of “excessive selenium in eggs...did not occur.”

Table 1. Se concentrations ($\mu\text{g/g}$ Se dry weight) in Elk River Valley cutthroat trout eggs compared to Lemly's (2002) suggested threshold toxicity value. Where the suggested threshold was exceeded, the data (from Kennedy et al., 2000), are italicized and bolded.

REFERENCE AREA		ELK RIVER		SUGGESTED THRESHOLD
MEAN	RANGE	MEAN	RANGE	
4.6	2.0 - 8.8	<i>21.0</i>	8.7 - <i>81.3</i>	10

Kennedy et al. (2000) suggested that this lack of effects might be due to an evolved tolerance, since the Elk River Valley is naturally high in Se. Because the results of this study do not conform to similar studies done in other (more southerly, warmer) areas with other species of fish, the study has generated discussion in the scientific literature (Hamilton and Palace, 2001; McDonald and Kennedy, 2002). However, it is clear from this study that there should be no major adverse effects from Se on cutthroat trout populations living in lotic areas of the Elk River Valley. This is an important finding since cutthroat trout are the dominant sport fish in this river system (the other sport fish are bull trout and mountain whitefish).

Status of Elk River Valley Fish Populations

Prior to 1995 the major impact on recreational fisheries in the Elk River Valley, which is dominated by westslope cutthroat trout, was the catch-and-consume fisheries. Over-harvesting caused dramatic declines. From 1931 to 1985 the daily limit for trout decreased progressively from 15 to 2. In 1985, angling was prohibited in some areas. In 1995, in response to the perceived effects of a major flood on fish populations, most of the streams in the basin, including the main stem, were placed under catch-and-release regulations (no harvest). Presently, catch-and-consume fisheries (e.g., one trout or one char) are only allowed in a few areas of the Elk Basin. As a result of the catch-and-release regulations, fish populations have increased, and the Elk River Valley has been featured in fishing magazines and television fishing shows.

A good example of increases in fish populations due to the regulatory change from catch-and-consume to catch-and-release, is provided by the fisheries populations in Line Creek, which were decimated by 1985, at which time all angling was prohibited. Allan (2002) analyzed cutthroat trout and juvenile bull trout populations in Line Creek over time, including data from studies conducted in 1987 and then from 1993 to 2001. Although Line Creek has high levels of Se above BC Environment guidelines for water quality, it still supports a very healthy fishery. In fact, despite natural annual variability, both trout species “exhibited a tendency to increasing numbers since 1987”, and there was evidence for increased reproduction, which would not be occurring if adverse Se-related effects were occurring. Previous fisheries studies in the Elk River Valley (e.g., West Slope Fisheries, 2001) have similarly found no evidence for adverse effects related to Se.

Human Health Risk Assessment

A human health risk assessment (EVS Consultants, 2000) conservatively evaluated the possibility that humans living in the Elk River Valley may be exposed to elevated concentrations of Se from eating fish that have bioaccumulated Se. It also considered positive benefits from both Se and fish consumption to human health. Drinking water containing elevated concentrations of Se or skin contact with such waters do not pose a significant risk of harm to humans.

Data from surveys and investigative studies conducted by BC Environment (McDonald and Stroscher, 1998; Kennedy et al., 2000) were used in plausible but conservative fish ingestion scenarios for both aboriginal fishers and non-aboriginal recreational fishers. Both groups would have greater than average exposure to local freshwater fish. Children were not directly evaluated both because they have a lower daily fish intake than adults, and because children need more Se than adults and thus are less sensitive than adults.

Conservative assumptions included: an aboriginal subsistence fishery although one is not known to exist; a catch-and-consume fishery even though the fishery is primarily catch-and-release for conservation reasons; 100% of fish come from the most contaminated portion of the Elk River; no loss of Se due to cooking; upper bound (i.e., probably unrealistically high) exposure values.

Despite its conservative assumptions, this study concluded that there was “negligible risk of selenosis in human populations consuming Elk River Basin fish, regardless of the exact location of fish capture.” This conclusion did not take into account the benefits of Se and fish consumption to human health: it is an essential element for the maintenance of good health (adequate ingestion prevents deficiency symptoms); it may have anti-carcinogenic properties due to its role as an antioxidant; it may have benefits for cardiovascular health. Fish consumption has its own benefits, including the positive effect of fish oils in preventing cardiovascular disease. When these benefits were considered, it was concluded “moderate quantities of fish consumed from the Elk River Basin (i.e., 2-3 meals per week) would actually have a net positive impact on human health.”

ONGOING STUDIES

Ongoing studies include determination of food webs in lentic and lotic areas using stable isotope analyses and lentic effects studies focused on waterfowl, suckers and frogs. Monitoring of Se concentrations in waters, sediments and biota continues, as does monitoring of resident fish populations.

CONCLUSIONS

Based on studies conducted to date, although current BC Environment (BCMWLAP, 2001) Se guidelines for the protection of aquatic life in freshwater are exceeded in some parts of the Elk River watershed, these exceedances do not appear to result in adverse ecological effects. The development of site-specific water quality objectives for Se in the Elk River Valley has been advocated by BC Environment (McDonald and Strosher, 2000).

There may be several reasons for the apparent lack of adverse effects despite elevated Se concentrations. Aquatic biota may have adapted and/or there may be a relatively steady state between inorganic Se accumulation, sequestering and excretion such that the toxic organic form of Se makes up a very small portion of the total Se, at least in lotic areas where there is very little opportunity for Se to be incorporated into organic forms via microbial action.

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