

ARSENIC POLLUTION ASSOCIATED WITH TAILINGS AT AN ABANDONED GOLD MINE IN HALIFAX COUNTY, NOVA SCOTIA

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Arsenic concentrations have been determined in tailings and vegetation at an abandoned gold mine in Nova Scotia. Arsenic in tailings was very heterogeneous, with concentrations ranging from 0.12% to 7.2%. Several plant species had elevated arsenic concentrations, especially *Juncus tenuis* (834 $\mu\text{g/g}$), *Equisetum fluviatile* (538 $\mu\text{g/g}$), and *Agrostis tenuis* (579 $\mu\text{g/g}$). In laboratory bioassays using tomato, radish, and bean plants, there were significantly lower rates of growth in plants grown in tailings than those grown in sand. The addition of nutrients to the tailings did not alleviate this toxicity. Tolerance to tailings decreased as follows: radish > tomato > beans. Fish caged in a contaminated brook at the tailings site accumulated significantly more arsenic over a four week period than did unexposed fish.

Les concentrations en arsenic ont été mesurées dans les débris de minerai et la végétation sur le site d'une mine d'or abandonnée de la Nouvelle-Ecosse. L'arsenic dans les débris était très hétérogène, les concentrations variant de 0.12% à 7.2%. Plusieurs espèces végétales, particulièrement *Juncus tenuis* (834 $\mu\text{g/g}$), *Equisetum fluviatile* (538 $\mu\text{g/g}$), et *Agrostis tenuis* (579 $\mu\text{g/g}$), avaient des concentrations en arsenic élevées. Au cours d'expériences de laboratoire effectuées sur des tomates, des radis et des haricots, les taux de croissance des plantes cultivées sur les débris de minerai étaient significativement moins élevés que ceux des plantes cultivées sur du sable. L'addition de sels nutritifs aux débris n'a pas allégué cette toxicité. La tolérance aux débris décroît comme suit: radis > tomate > haricot. Des poissons maintenus en cage dans un ruisseau contaminé situé sur le site des débris ont accumulé, d'une façon significative, plus d'arsenic que ne le firent des poissons non exposés.

Introduction

Arsenic is ubiquitous, existing naturally in the atmosphere, soils, rocks, water, and in plants and animals. Inputs of arsenic to the environment occur from many sources, both natural and anthropogenic. Much of this arsenic eventually reaches sinks, such as soils and sediments. Until this final sequestering of arsenic occurs, the biological world can be subjected to its toxic effects.

The mining and processing of various minerals can release arsenic to the environment in large quantities. In Nova Scotia many former gold districts are littered with rock heaps and tailings dumps contaminated by arsenopyrite. Previous studies of these sites have been concerned mainly with possible epidemiological effects and well water contamination. Recently, Brooks et al. (1982) reported a broader study which included the analysis of stream waters, sediments, aquatic organisms, and riverbank vegetation in the Montague Gold Mining District, Nova Scotia. The present report is a continuation of this study, with an emphasis on contamination of terrestrial vegetation, toxicity of tailings, and accumulation of arsenic by fish.

Study Site

The study site was in the Montague Gold District, near the city limits of Dartmouth, Halifax County, Nova Scotia, 7 km from the Atlantic Ocean (44° 42' N, 63° 31' W; 61 m above sea level. Fig 1). Samples were collected at various sites on the tailings disposal area and from Mitchell Brook. This study area was chosen because: i) tailings at this and many other abandoned gold mines in neighbouring

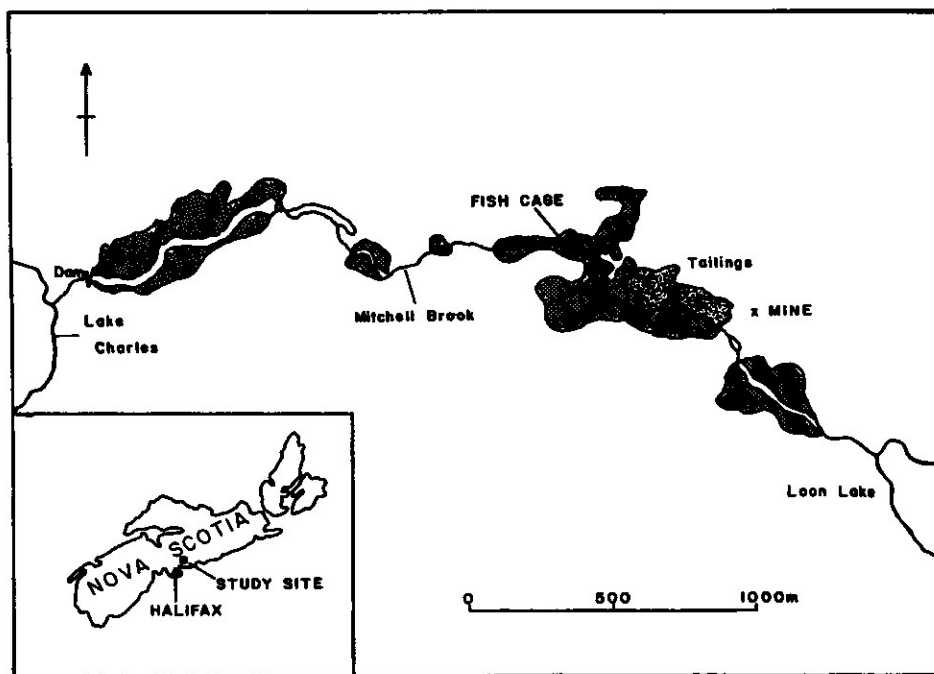


Fig 1 Montague Gold Mine District, Nova Scotia.

gold districts have been linked with arsenic contamination of well water (Briscoe et al. 1976; Grantham and Jones 1976), ii) a previous study at Montague revealed tailings concentrations of up to 1% arsenic, and brook water concentrations that exceeded 0.05 ppm arsenic (Brooks et al. 1982), the value established by Canadian Health officials as the maximum permissible limit for drinking water, iii) fish in Mitchell Brook have been shown to have elevated levels of arsenic (Brooks et al. 1982), and iv) children use the tailings flats as recreational areas.

Geology

The area is underlain by the 9,000 m thick metasedimentary Meguma Series of rocks of Ordovician Age (400 million years old). This triangular-shaped series covers much of southern Nova Scotia, with the apex at Canso and the base running from Shelburne to Yarmouth. It consists of two formations: the upper Halifax Formation (4,000 m) and the lower Goldenville Formation (5,000 m). The Halifax Formation is composed mainly of soft graphitic and ferruginous slates, and minor quartzite. The Goldenville Formation is mainly metagraywacke, with feldspathic quartzite and minor slates (Thompson 1978). It is thought that after the Meguma Group had been deposited and buried, quartz veins formed from silica rich solutions released during regional metamorphism. These veins contain large amounts of arsenopyrite ($AsFeS$) in association with gold. Gold also tended to concentrate near the crests of anticlines in bedding planes and fissures (Grantham and Jones 1976). Subsequent erosion removed the crests exposing the lower Goldenville Formation and the quartz veins (Thompson 1978). In addition to gold and arsenopyrite, these veins contain other minerals, including carbonate, iron pyrite, and pyrrhotite (Anonymous 1978b).

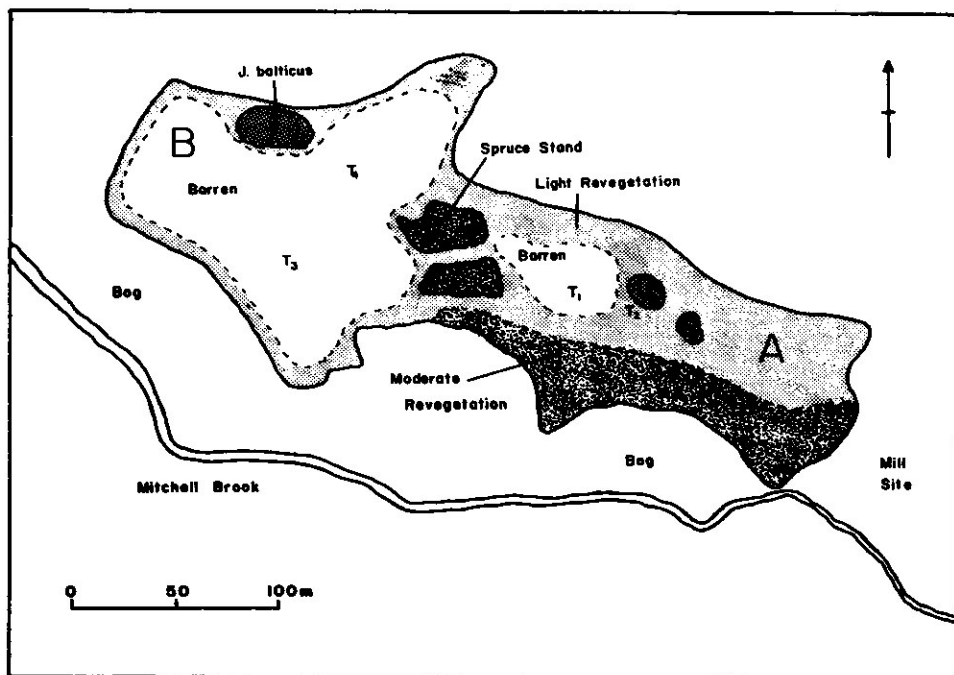


Fig 2 Tailings flats at Montague. Sample sites are indicated.

Topography and Vegetation

Montague is located in the headwater region of the Shubenacadie River, an area with approximately 70 lakes and ponds, and with streams and rivers interlaced between many low hills and ridges (Anonymous 1978c). The mine area is covered by surficial soils derived from glacial till, and generally about 2 m in thickness. This overlies a substrate of either Halifax or Goldenville rocks (Johnson 1978).

Loon Lake (73 ha) is upstream from the mine site, and it drains into Lake Charles via Mitchell Brook (Fig 1). The brook course includes stretches of fast-moving waters, still waters, and diffuse drainages through bogs over its 3.5 km length. The average gradient is 11 m/km.

The study area is surrounded by a mature fir and spruce-dominated forest. Downslope from the old mine shafts and mill the land opens onto a flat area bisected by Mitchell Brook, with the tailings flats (designated A and B, Fig 1) on the north side, and the bog on the south.

The tailings flats (Fig 2) comprise an area of roughly 3.5 ha. Flat B is virtually barren except for a small area of *Juncus balticus*. Flat A is better vegetated, mainly with *Juncus balticus*, *Juncus tenuis*, *Equisetum fluviatile*, *Equisetum arvense*, *Leontodon autumnalis*, *Aster lateriflorus*, *Centaurea nigra*, *Agrostis tenuis*, and several additional grass and herb species.

History of Development

The gold mining industry was established in Nova Scotia during the 1860's, shortly after the California Goldrush infused gold fever into the North American population. A total of 65 official gold districts were proclaimed by the provincial government, and one of the most significant of these was Montague. During the

years 1860 to 1939, 122,000 tonnes of ore were crushed at Montague, yielding 1.9×10^6 g of gold (Anonymous 1978b).

During the mining process the gold-bearing rock was brought to the surface from several mine shafts. At the surface the rock was crushed to a sand size, and this was then subjected to a mercury amalgamation extraction of the gold (Anonymous 1978b). The remaining waste, high in arsenopyrite content, was then sluiced downslope as a slurry into the bog and stream, creating the tailings flats A and B (Fig 2). These two areas resulted from different periods of operation. Area A was created from 1860 until after the turn of the century. During this time the tailings were sluiced directly into the stream as well as adjacent to it, altering the course of the channel. At periods of peak activity the iron released formed a precipitate ($\text{Fe}(\text{OH})_3$), which was deposited on the stream bottom, and also created a froth on the water surface that coursed downstream into Lake Charles. This created a recreational nuisance for bathers and also threatened water quality, until the city of Dartmouth put a halt to the practice. The mining company was then forced to sluice the tailings beyond Area A into Area B and not directly into the stream. This area includes deposits made up until 1939 when the mine ceased operation (personal communication with Gerald Cooper, local resident).

Materials and Methods

(i) *Plant Collections*: Eight different plant species representing the dominant community members on the tailings flats were collected during August, 1981 ($n=5$ plants in all cases) from several designated areas (T_1, T_2, T_3, T_5 ; Fig 2). These were dried at 65°C for 48 h, and dry weights were determined to the nearest 0.1 mg. They were then ground using a Wiley Mill and stored in paper envelopes. Subsamples of 0.5 g were placed in 50 ml acid-washed digestion tubes. They were then predigested in 5.0 ml of concentrated nitric acid for two h at room temperature (21°C). The digestion tubes were then placed into aluminium heating blocks, and digested on a hotplate at 100°C for two h. The digest was vacuum filtered and made up to 20 ml with distilled-deionized water. These samples were then stored in plastic vials for later analysis.

(ii) *Tailings Collections*: Soil pits were dug at sites T_1, T_2, T_3, T_4, T_5 (Fig 2) to the depth of the water table (20-30 cm). Plastic vials (20 cm^3) were pressed horizontally into the sides of the pit (3 per interval) at depths from 0-30 cm at 3 cm intervals. Wet weights and pH were determined in the lab. The samples were then air dried, and dry weights were determined. Subsamples of approximately 0.5 g were digested using the method described above for plants. Filtered digests were diluted to 20 ml and stored in plastic vials for later analysis.

Several filter papers from both the plant and tailings digests were removed after filtration and were digested in the above manner to determine the efficiency of As recovery.

(iii) *Fish Caging Experiments*: The exposure cage was constructed of 0.6 cm mesh galvanized screening coated with polyurethane. The cage was cylindrical, with a height of 80 cm, and a diameter of 60 cm. The cage was open on the bottom, and had a removable screen top.

Approximately 50 Banded Killifish (*Fundulus diaphanus*) were collected with dip nets from Dingle Pond, located 2 miles SW of Halifax. These were immediately transported to the lab in pails of pond water. For later identification the left pelvic fin was removed from each fish. A group of 10 fish was killed, wet weights were determined and then they were frozen. A second group of 10 fish was taken to the study site and placed into a cage. This cage was located in Mitchell Brook down-

stream from tailings area 2 (Fig 1), in a section of the stream previously determined to have the highest As concentration in the water (140 $\mu\text{g/g}$) (Brooks et al. 1982). The cage was sunk into the sediment in a water depth of approximately 30 cm. The caged fish were left for four wk during August, 1981. After this exposure period, the fish were taken to the lab, killed, weighed, and frozen. Later, all fish were thawed and predigested in 100 ml beakers containing 20 ml of a 1:4 nitric-perchloric acid solution. These were fumed to dryness on a hotplate, and the residues were redissolved in 5 ml of 2M nitric acid. These were then analyzed for arsenic content.

(iv) *Arsenic Analysis:* All samples were analyzed for arsenic using a Perkin Elmer 2380 Atomic Absorption Spectrophotometer with an attached MHS-10 hydride generating system and an electrodeless discharge lamp. The 197.3 nm line was monitored, using a slit width of 0.7 nm and an air acetylene flame. A solution of 1% NaOH and 3% NaBH_4 was used as the reductant. Microliter aliquots of sample were introduced into the reaction flask, which contained 10 ml of 1.5% HCl. The arsine (AsH_3) generated was measured in a heated quartz crystal over the flame. A Varian single channel, multispan chart recorder (model G-2010) set at 10 mv was used to measure and record peak height. The range of standards was 10, 20, 25, 50, 75, and 100 μl of a 1 $\mu\text{g/g}$ standard solution of As (made from Fisher AA grade 1000 $\mu\text{g/g}$ As standard). These corresponded to 10, 20, 25, 50, 75, and 100 ng of As. Dilutions were made where appropriate so that all sample peaks fell within this range.

Standard reference orchard leaves (No. 1571, U.S. National Bureau of Standards) were analyzed to check accuracy. In addition, as a further check on accuracy, several samples were analyzed by neutron activation at the Slowpoke facility at Dalhousie University. The results of these analyses are summarized in Appendix 1.

(v) *Plant Bioassays:* Bioassays were made using three crop species; tomato (Beefsteak), radish (Early Scarlet Globe), and beans (Round Pod Kidney Wax). These represented tolerant, intermediate, and intolerant species respectively, in terms of arsenic toxicity (Woolson 1973; Anonymous 1978a). Thirty plants of each species were grown in control sand (C), tailings No. 1 (T_1), and tailings No. 3 (T_3), and each of these was further divided into 10 plants each of no nutrient addition, low nutrient addition, and high nutrient addition.

Six cm plastic pots with filter paper on the bottom were filled with similar volumes of each soil type. These pots were watered with the various nutrient solutions using 25 ml plastic graduated cylinders, and were then allowed to stand for 2 d. Nutrient treatments were as follows: i) no nutrient—25 ml of tap water every day; ii) low nutrient—6 g of a 20-20-20 fertilizer in 4 liters of tap water, 25 ml of this solution every 5 d interspersed with 25 ml of tap water; iii) high nutrient—same as low nutrient except 24 g of fertilizer in 4 litres of tap water.

Three seeds each of tomato and radish or two bean seeds were sown per pot. Pots were randomized to eliminate position effects, and they were placed in a Conviron controlled environment growth chamber with a 16 h photoperiod, a temperature range of 20-22°C, and light intensity of 1000 microeinsteins $\text{m}^{-2} \text{sec}^{-1}$ (cool white fluorescent lamps; intensity was measured at pot height). Seeds were allowed to germinate, and when they were firmly established the smallest plants were cut back leaving one plant per pot. Germination was 100% for controls of all species.

The experiment was terminated at 25 d. Plants were then cut at the soil:air level and were dried for 48 h at 65°C. Dry weights were determined to the nearest 0.1 mg.

Table 1 Arsenic concentration ($\mu\text{g/g}$ d.w.) in various plants collected from tailings flats at Montague Mines (T_1 , T_2 , T_3 , and T_5). Controls from Dingle Park, N.S.. Each value is the mean of 5 composite plant samples

Species	SITE				Control
	T_1	T_2	T_3	T_5	
<i>Leontodon autumnalis</i>	-	211	-	53	6
<i>Centaurea nigra</i>	252	101	-	16	2
<i>Juncus balticus</i>	28	11	20	18	2
<i>Juncus tenuis</i>	108	82	44	-	3
	-	-	59	-	-
	-	-	834	-	-
<i>Aster lateriflorus</i>	65	19	20	34	0.5
<i>Equisetum fluviatile</i>	-	463	-	178	2
	-	538	-	-	-
<i>Equisetum arvense</i>	210	143	131	170	1
<i>Agrostis tenuis</i>	282	578	134	13	1

Results and Discussion

i. *Plant Community*: Table 1 shows the arsenic concentrations of plants collected from up to four sites in the tailings area, and from an uncontaminated site at Dingle Park, N.S. In almost all cases plants from the tailings area were an order of magnitude higher in As concentration than controls, and in most cases two orders of magnitude. All control values are similar to those reported for uncontaminated vegetation in the literature (Porter and Peterson 1975; Girling and Peterson 1978).

These findings of high concentrations of As in plants are not surprising. A number of plant species have been shown to accumulate large amounts of various metals when growing on contaminated sites (e.g. Freedman and Hutchinson 1981). The same has been shown for arsenic by various authors. For example, up to 10,000 $\mu\text{g/g}$ As (ash wt.) has been found in Douglas Fir needles in B.C. (Warren et al. 1964, cited in Porter and Peterson 1975).

Three samples of *Juncus tenuis* (5 plants/sample) from T_3 had arsenic concentrations of 44, 59, and 834 $\mu\text{g/g}$. As well, two samples of *Equisetum fluviatile* (5 plants/sample) from T_2 were determined to have 463 and 538 $\mu\text{g/g}$. These differences within species are likely a reflection of the heterogeneity within the tailings themselves with respect to arsenic.

It has been shown that populations within a species can evolve physiological tolerances to arsenic (Antonovics et al. 1974; Williamson and Johnson 1981). For example, Porter and Peterson (1975) measured arsenic and various other metals in plants growing on mine waste in England. Plants growing on high arsenic sites had an arsenic content that ranged from 460 - 6640 $\mu\text{g/g}$ As (dry wt.), while those on low arsenic sites ranged from 0.28 - 3.0 $\mu\text{g/g}$ (dry wt.). Further investigations demonstrated that material from one of the high arsenic clones of *Agrostis tenuis* was tolerant to levels of arsenic that were lethal to non-tolerant clones.

Other studies have looked at species of *Equisetum* as arsenic tolerators and accumulators (Girling et al. 1978; Brooks et al. 1981). These studies were done with the aim of investigating the contention that the *Equisetaceae* are gold accumulators, as proposed by Nemeč et al. (1936). Species of *Equisetum* are generally found in damp areas, and are common on disturbed sites such as tailings

Table II Arsenic concentrations of tailings at various depths. Mean value of 3 samples. T₁, T₂ and T₅ are located in tailings flat A. T₃ and T₄ are located in tailings flat B

DEPTH (cm)	TAILINGS PIT ARSENIC (X 10 ³ µg/g)				
	T ₁	T ₂	T ₃	T ₄	T ₅
0-3	5.93	1.86	72.1	9.44	7.18
3-6	4.34	-	-	-	-
6-9	3.65	1.48	27.9	3.08	7.09
9-12	3.17	-	-	-	-
12-15	-	2.29	3.21	2.11	6.53
15-18	3.05	-	-	-	-
18-21	5.04	1.75	2.51	1.81	5.96
24-27	-	2.32	-	2.00	-
27-30	-	1.19	-	-	-

disposal areas around mining districts (Smith 1938). Brooks et al. (1981) sampled *Equisetum* from several gold mine tailings sites in Nova Scotia, and found a range of 41-738 µg/g arsenic in *Equisetum* compared with <0.5 µg/g gold. They suggested that species of *Equisetum* are indirect indicators of gold deposits, due to the high levels of arsenic which are often associated with gold deposits.

It can be seen from the data in Table 1 that *Equisetum fluviatile* had a high arsenic concentration (538 µg/g) at T₂, but that in *Agrostis tenuis* from the same site this value was exceeded (578 µg/g). Furthermore, the other values for both species of *Equisetum* were within the range of the other species. Obviously these other species are also quite tolerant of arsenic, and can accumulate large amounts.

ii. *Arsenic Content of Tailings*: The results for the tailings pit samples are in Table 2. Each value represents a mean determination of 3 composite samples from the same depth. The lowest depth in each case marked the height of the water table at that location. Surface concentrations of arsenic at T₃ were anomalously high for the area, but are comparable to tailings values reported elsewhere (eg. 50,000 ppm, Venus Mine, Yukon (Kuja 1979)). The other tailings concentrations are similar to those reported in the literature (Comanor 1974; Kuja 1979; Brooks et al. 1982).

Both T₃ and T₄ from tailings flat B had higher surface concentrations than flat A tailings. This is likely a reflection of: 1) differences in ore composition that are reflected in the tailings arsenic concentrations, 2) age of the tailings, as flat B was formed during the later period of mine operation, and did not experience as long a period of leaching, or 3) downslope leaching of arsenic from flat A to flat B.

In four of the pits there was a decrease in arsenic concentration with increasing depth. T₂ was the only pit which did not show this trend. It had the lowest arsenic concentrations of all five pits, with values averaging approximately 2,000 µg/g. This pit was located in a stand of *Juncus balticus*. It is possible that decaying organic matter from this vegetation altered the chemistry of the arsenic, resulting in no variation in concentration with depth.

The acidity of the tailings does not appear to be a significant toxic factor. For example, pH measurements at T₁ averaged 6.9, 5.9 at T₂, and 5.4 at T₃.

iii. *Fish Caging Experiment*: This experiment was prompted by results of Brooks et al. (1982), who reported that resident fish downstream from the tailings at Mon-

taque had arsenic concentrations five times that of upstream "control" fish. The experiment was designed to exclude possible migration up or downstream in order to determine uptake of arsenic over a set period of time by fish not previously exposed to such high concentrations.

At the end of the experiment the mean arsenic concentrations of the exposed and unexposed fish were significantly different ($0.010 < p < 0.025$). The control fish averaged $0.446 \mu\text{g/g}$, while the fish caged in Mitchell Brook had $0.639 \mu\text{g/g}$ As wet weight. Interestingly, two resident Banded Killifish which entered the experimental cage had values of 4.77 and $4.02 \mu\text{g/g}$ As wet weight. These much higher concentrations (approximately 10x higher) reflect the longer residence times of these two fish in contaminated Mitchell Brook.

The water in the stream at the caging site contained $0.14 \mu\text{g/g}$ As (Brooks et al. 1982). While not lethal, this and lower concentrations have been shown to produce significant behavioural changes in goldfish exposed for 24 to 48 h (Wier and Hine 1970, cited in Anonymous 1978a). However, different fish species have exhibited different tolerances to arsenic. Perch exposed to $0.7 - 1.1 \mu\text{g/g}$ As for 48 d were unaffected. However, when the concentration was raised to $1.1 - 2.2 \mu\text{g/g}$ As the perch showed a toxic response. Similarly, bass tolerated $6.0 \mu\text{g/g}$ As but not $7.6 \mu\text{g/g}$ for 10 d (Luh et al. 1973). While these arsenic test levels are unusually high in comparison with natural waters, the experiments were of relatively short duration. Natural low dose exposures of longer duration will accumulate arsenic in fish tissues as well, as evidenced by the present findings. Here the question of food chain transfer arises. It is probable that some of the arsenic uptake by fish caged in Mitchell Brook occurred by ingestion of lower trophic level organisms. Similarly, larger game fish are known to enter Mitchell Brook (e.g. trout, bass). These could feed on the killifish and they would consume approximately $25 \mu\text{g/g}$ As per fish eaten (assuming an average fish weight of five grams and an arsenic content of $5 \mu\text{g/g}$). It is not generally believed that As biomagnification occurs in aquatic food-chains (Anonymous 1978a). However, fish spending part or all of their lifecycle in

Table III Mean weight (mg d.w.) and standard deviation of vegetable crops on different nutrient treatments in tailings and control sand. N=10 in all treatments

PLANT	NUTRIENT TREATMENT	CONTROL SAND		TAILINGS T ₁		TAILINGS T ₃	
		\bar{X}	S.D.	\bar{X}	S.D.	\bar{X}	S.D.
TOMATO	NO	8.6	3.4	8.3	3.1	5.6	2.2
	LOW	66.0	23.3	3.0	1.8	11.0	3.2
	HIGH	63.9	20.0	<0.1	-	3.8	1.6
RADISH	NO	55.5	11.6	34.6	11.3	21.6	5.5
	LOW	125.3	23.2	57.9	17.9	56.9	16.0
	HIGH	216.7	30.1	28.7	15.1	66.6	12.1
BEAN	NO	421.4	63.5	7.2	10.1	7.6	17.5
	LOW	368.0	48.0		N.E.	4.8	11.8
	HIGH	391.8	92.2		N.E.		N.E.

N.E. no emergence from soil

contaminated streams have increased arsenic contents, and some of these fish may ultimately be consumed by people, with possible long term epidemiological effects if the fish are eaten regularly or in large quantities.

iv. *Plant Bioassay*: Results of the plant bioassay are in Table 3 and Figures 3, 4, and 5. In all cases, the control values for plant production were significantly higher ($p < 0.05$) than T_1 and T_3 tailings, except for tomato on no nutrient and T_1 tailings. The results strongly suggest a toxic element in the tailings, which is presumably arsenic. The data also indicate possible synergism between arsenic and high nutrients, e.g. nutrient additions predispose the plants to As toxicity.

Table 4 lists our data for the relative growth of experimental plants compared with the controls. These data indicate that radish was more tolerant of arsenic than tomato (contrary to Woolson 1973). Beans were the least tolerant, growing little or not at all. The bean cotyledons that managed to emerge were often distorted and shrivelled. This symptom has been observed by other researchers using beans in arsenic bioassays, and it appears to be a toxic response. Woolson (1973) made bioassays with lima beans and showed that toxic amounts of arsenic arrested the germination of the bean seeds and reduced seedling viability. The bean cotyledons which emerged turned brown, shrivelled, and died.

Arsenic lies beneath phosphorus in the periodic table, and resembles it in its chemistry. Arsenic can penetrate the plant cuticle, and it combines with sulfhydryl groups causing inhibition of enzyme activity, resulting in membrane damage (Dickerson 1980; Leonard and Lauwerys 1980). Arsenic also causes chlorosis (Foy et al. 1978). It was noted that many of the experimental radishes and beans developed chlorotic foliage after about two weeks, while only a few tomatoes did so. In addition, some radish developed red margins on the leaves. None of the

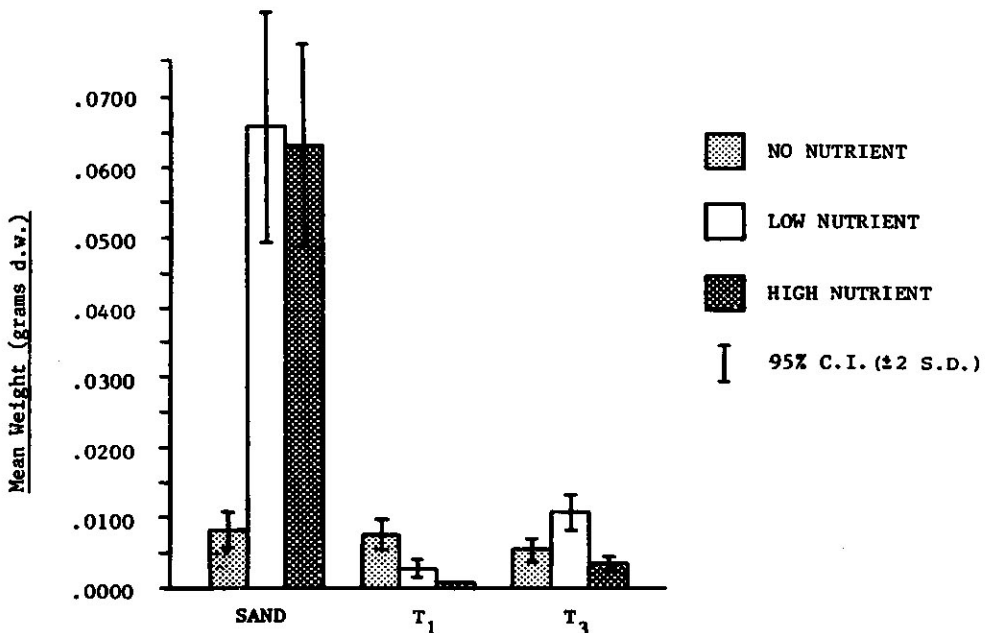


Fig 3 Mean weights (grams dry weight) of tomato bioassays grown in three different soil types with three nutrient treatments.

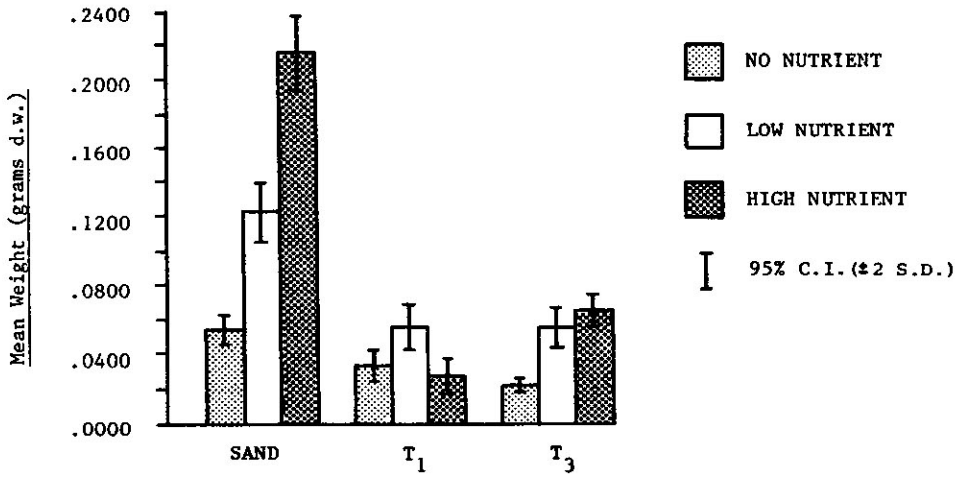


Fig 4 Mean weights (grams dry weight) of radish bioassays grown in three different soil types with three nutrient treatments.

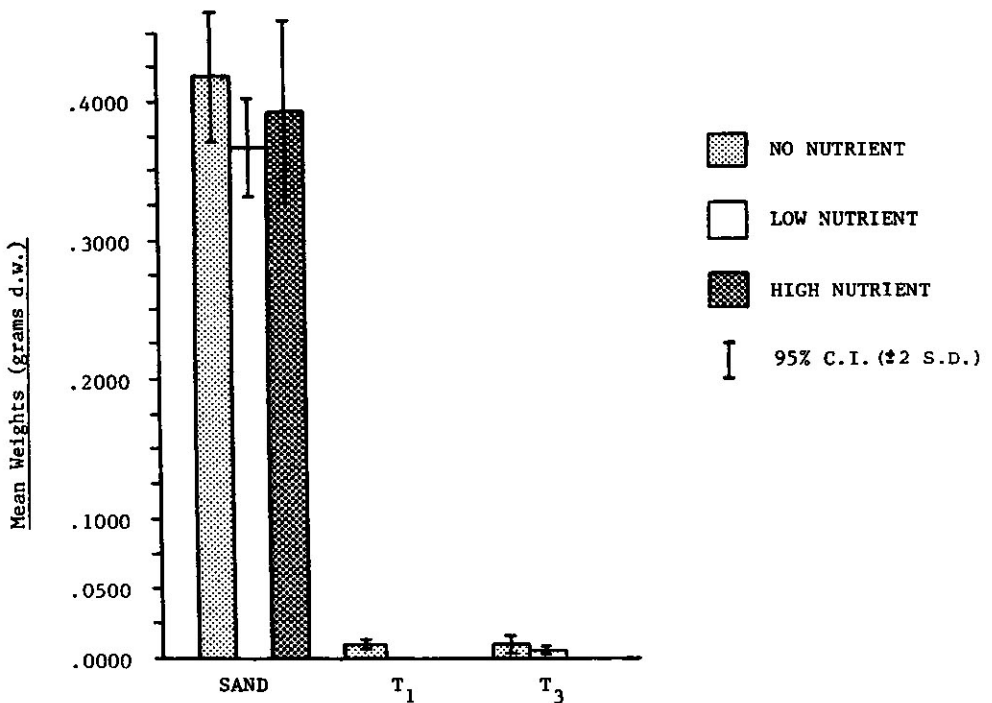


Fig 5 Mean weights (grams dry weight) of bean bioassays grown in three different soil types with three nutrient treatments.

Table IV Growth of plants in tailings, expressed as a percent of growth in control sand

PLANT	NUTRIENT TREATMENT	T ₁	T ₃
TOMATO	NO	97	65
	LOW	5	17
	HIGH	1	6
RADISH	NO	62	39
	LOW	46	45
	HIGH	13	31
BEAN	NO	2	2
	LOW	0	1
	HIGH	0	0

control plants had such coloration of the leaves. If the occurrence of these symptoms are used as criteria for tolerance, then tomatoes were the most tolerant.

In general, the control plants appeared to be more turgid and deeper in colour than the tailings plants. Primary leaf pairs were held more nearly horizontal, and were more similar in size and shape than in the tailings plants, especially for radishes. Also, several experimental beans dropped leaves near the end of the experiment. This decreased turgidity in experimental plants could be due to decreased uptake of water. Woolson (1973) has reported that plants stressed by arsenic are less able to transport water upwards.

Thus, the plant bioassays demonstrate that the tailings at Montague are quite toxic to non-adapted plants. However, different plants vary in their degree of tolerance to the tailings.

Summary and Conclusion

This study has examined several features of an arseniferous tailings disposal area, and some related effects on organisms. There is no doubt that the tailings are highly toxic and that they represent a large quantity of arsenic available for leaching into the ecosystem for years to come.

These tailings may be partially responsible for the wellwater contamination observed in the area (Briscoe et al. 1976). To our knowledge, the 7.2% arsenic value measured at tailings flat B is the highest value reported in the literature. Of 42 gold tailings dumps sampled in Nova Scotia (not including Montague) and analysed by Cochran in 1921 (cited in Fralick 1980), the highest As values were 4.6% and 1.3%, with the remainder less than 1%. Most of these values were, however, based on only one sample. In addition, Murdoch and Sandilands (1978) found that, of 17 streams in the Shubenacadie headwater region, Mitchell Brook had the highest value (10 X) for arsenic in suspended solids at the outflow of Loon Lake above the tailings area. This suggests that the Loon Lake region is underlain with rocks having a higher than usual arsenopyrite content.

Even with such large amounts of arsenic these tailings are being naturally vegetated with As tolerant plants. This process eventually will build up nutrients and organic matter, which will further stabilize the site. However, this natural colonization process is slow. An alternative would be a reclamation program.

Reclamation has been successful in other areas (Williamson and Johnson 1981). If the Montague tailings were reclaimed, human exposure to arsenic would decrease, especially to children who now play in the tailings area. In addition, reclamation would improve the esthetics of the area, and would generally tend to stabilize the tailings with respect to erosion and dust-blown material.

Aside from the direct exposure to tailings and intake of contaminated well water, the possibility of ingestion of contaminated fish exists for local residents. We are unaware of any studies that have investigated the effects on humans of eating fish contaminated with arsenic. However, Utidjian (1974, cited in Anonymous 1978a) reported that humans ingesting lobster tails with high arsenic levels had elevated urine excretion rates of 0.78-1.68 $\mu\text{g As/l}$ of urine, compared to a normal value of 0.01-0.05 $\mu\text{g/l}$, and that 2 d were required for the normal rates to return. Several researchers have reported that as little as 0.15-3.3 mg As ingested per day (long term) caused chronic poisoning (Anonymous 1978a). Thus, ingestion of fish may be important, and game fish from Mitchell Brook should be analysed for arsenic content.

Finally, it would be prudent to control existing or future mining operations in the area with respect to the dumping of tailings, and with particular regard to problems associated with contamination of groundwater. This conclusion has been reached by previous researchers (Arsenic Task Force in Nova Scotia; Grantham and Jones 1976), and is merely reiterated here.

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Appendix

Comparison check on analytical accuracy of Atomic Absorption by Neutron Activation using standard reference material and representative samples. Result of filter paper digestion for check on recovery of arsenic by vacuum filtration

Sample	Atomic Absorption $\mu\text{g/g As}$	Neutron Activation $\mu\text{g/g As}$	
Standard Orchard Leaves	14 (14)*	13 (14)*	
Tailings T ₃ Digested	72000	60000	3000
Undigested		64000	12000
Banded Killifish	0.77	0.5	0.2
E. fluviatile	462	470	
Filter Paper	0		

*certified value for reference material