Arcellinida (Testate Lobose Amoebae) as Sensitive Bioindicators of Arsenic Contamination in Lakes

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Abstract

Arcellinida (testate lobose amoebae) are sensitive to arsenic (As) contamination from historic gold mining in Canadian subarctic lakes. Partial redundancy analysis revealed that As (9.4%) and S1 (labile organic matter, 8.9%) were the most important contributors to variance in faunal distribution. Arcellinida are important intermediary food web components in lacustrine environments. Microbes are their primary food source and elevated As-levels are known to suppress microbial growth (S1). The observed correlations are likely to be related to As-destabilization of Arcellinida microbial food supplies. To assess the utility of arcellinidans as tracers of temporal variation in As, we analyzed a freeze core from Frame Lake in the city of Yellowknife, which requires remediation following a steep decline in water quality through the 1960s that left it dead. Land-use activities in the area of the lake are well documented but little information is available regarding their impact on the lake itself. Geochemical, sedimentological and arcellinidan analysis showed that the system was non-depositional from the mid Holocene until ~1962 when the lake began to rapidly infill with highly As contaminated sediments. Since the early 1990s runoff from the catchment, and reduced lake circulation associated with installation of a causeway with rarely opened sluiceways at the only outlet, has caused eutrophication.

Keywords

Arcellinida • Testate lobose amoebae • Arsenic contamination • Lakes • Subarctic canada

1 Introduction

Due to a strong affinity between gold and As-rich sulfides in mineralized zones, gold mining is a significant source of As contamination in mining districts worldwide. Arsenic contamination of lake systems is of particular concern due to the recreational and aquatic ecosystem services provided by lakes. Lake sediments sequester As, which if physically disturbed, or under altered redox conditions due to climate variability, can remobilize As into the water column causing severe ecological stress and increase human health risks (Galloway et al. 2017). Legacy gold mines (e.g. Giant Mine [GM]; 1948-2004; Fig. 1a, b) near the city of Yellowknife, Northwest Territories, Canada, require considerable remediation of legacy contamination. Mineral processing at GM released As_2O_3 to the atmosphere through roaster stack emissions resulting in extreme contamination of the landscape, including lakes and streams (Galloway et al. 2017). Frame Lake within Yellowknife is of special interest, as it is heavily contaminated due to both urbanization in the lake catchment and mining activities (Nasser et al. 2016). Arcellinida (testate lobose amoebae) are important intermediary food web components in lacustrine environments that rely on bacteria and other microbes as their principle food supply (Patterson et al. 2012). Their agglutinated shells are abundant and preserve well in the sedimentary record making them ideal bioindicators for tracking temporal trophic change. Arcellinida were studied in 90 lakes in the vicinity of the GM to: (1) quantify their sensitivity to As; and (2) use these results to track hydrological changes in Frame Lake resulting from mining and urbanization.

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H. Chenchouni et al. (eds.), *Exploring the Nexus of Geoecology, Geography, Geoarcheology and Geotourism: Advances and Applications for Sustainable Development in Environmental Sciences and Agroforestry Research*, Advances in Science, Technology & Innovation, https://doi.org/10.1007/978-3-030-01683-8_15

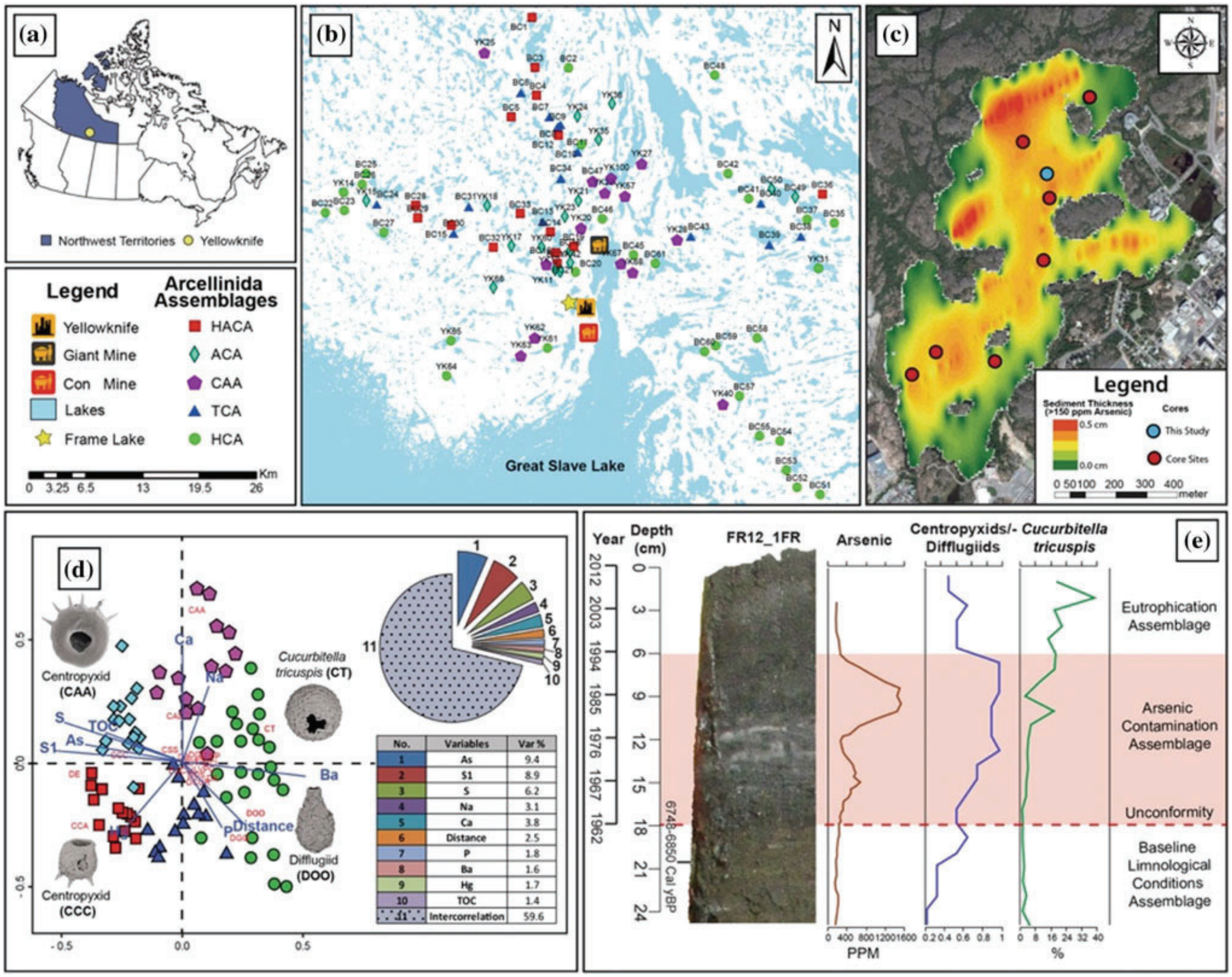

Fig. 1 **a** Map showing Yellowknife, NT. **b** Location of 90 sampled lakes and Frame Lake relative to GM, and distribution of Arcellinida assemblages. **c** Core locations and interpolated thickness of the As-contaminated sediments in Frame Lake. **d** RDA species-environment-sample triplots for sediment-water interface samples having statistically significant values. Partial RDA pie-chart shows variance explained by 10 ecologically significant environmental variables. **e** Paleolimnological reconstruction of Frame Lake Freeze core showing development of As-contaminated conditions post-1962 and the transition to eutrophication conditions in the 1990s

2 Materials and Methods

Ninety-three sediment-water interface samples (SWIS; top 0.5 cm) were collected with a pontoon-equipped helicopter using an Ekman grab from 90 lakes within a ~30 km radius around the site of GM (BC12, YK14; Fig. 1b). Water property data were collected using a YSI Professional Plus multi-parameter instrument at 1-m increments through the water column [pH; temp.; conductivity; oxygen]. A freeze core was collected from Frame Lake and transported frozen to Carleton University. Sub-bottom profiles for Frame Lake were obtained from 14 GPS-positioned transects using a Lowrance HDS-8 sonar and SyQwest Strata Box HD. The profiles were ground-truthed from the stratigraphy observed in 6 gravity cores collected across the lake (Fig. 1c).

The SWIS and Frame Lake samples were characterized by grain size and ICP-MS analysis (Aqua-Regia), Rock Eval (S1), and Arcellinida enumeration. Twenty-five of 30 arcellinidan species and strains observed in 84 SWIS samples had statistically significant populations for Redundancy (RDA) and partial redundancy (pRDA) statistical analysis. The Frame Lake core contained 32 statistically significant species and strains in 30 samples that were statistically significant and retained for subsequent analysis.

3 Results, Discussion and Conclusion

ICP-MS analysis revealed that As concentration is higher than the levels set by the Canadian interim freshwater quality guidelines (5.9 ppm) and probable effect levels (17 ppm) in all samples, particularly in the prevailing downwind area to the west ($\overline{\text{As}}$ = 694 ppm ± 1087.3 SD) and north ($\overline{\text{As}}$ = 674.5 ppm ± 1956.8 SD) of GM. Conversely, mean As levels in lakes to the east ($\overline{\text{As}}$ = 88 ppm ± 136.4 SD) and south ($\overline{\text{As}}$ = 76.3 ppm ± 87.5 SD) of the mine site were much lower [cf. 1]. Results of a Q-mode cluster analysis, corroborated by NMDS and RDA (Fig. 1b, d), revealed five distinct arcellinidan assemblages: (1) "High As Contamination Assemblage (HACA)"; (2) "As contamination Assemblage (ACA)"; (3) "*Centropyxis aculeata* Assemblage (CAA)"; (4) "Transitional Conditions Assemblage (TCA)"; and (5) "Healthy Conditions Assemblage (HCA)". The RDA and pRDA analysis revealed that the arcellinidan assemblages reflected ecological conditions characteristic of stressed (HACA, ACA), transitional (CAA, TCA) and relatively healthy lacustrine systems (HCA).

Ten environmental parameters accounted for ~40% of the variance in arcellinidan distribution with As (9.4%) and S1 (labile organic matter 8.9%) being the most influential. There was a strong correlation between the distribution of arcellinidan contamination assemblages and the higher As typical in proximal downwind lakes to the W and NW of the GM (Fig. 1d). The arcellinidan response to the spatial variability of S1 was similar to that observed for As. S1 provides an organic substrate suitable for microbial growth, which in turn mediates the authigenic precipitation of As sulfides (Galloway et al. 2017). Healthy microbial communities thrive within organic substrates with a readily biodegradable labile fraction (i.e. S1), which in turn provides a food supply for grazing Arcellinida. In contrast As is toxic to most bacteria as it can inhibit basic cellular functions linked to energy metabolism, basal respiration, and enzyme activities. The resultant reduction in microbial biomass may induce sufficient environmental stress that nutrition sensitive arcellinidan taxa (e.g. *Cucurbitella tricuspis* (CT), *Difflugia oblonga* "oblonga" DOO) are negatively impacted and stress tolerant taxa such as centropyxids (e.g. *C. aculeata* "aculeata" (CAA); *C. aculeata* "discoides" CAD) take advantage of the open niche space and increase their populations (Fig. 1d). Reflectors observed in the sub-bottom profiles from throughout the Frame Lake and ground-truthed based on ICP-MS results and sedimentology of core data were used to estimate the distribution and volume of legacy arsenic contamination. The geomatics IDW procedure was used to extrapolate the thickness of sediments with >150 ppm As throughout the lake. Large deposits of highly contaminated sediments (As concentrations of 150–1538 ppm) occurred in both basins with up to 57 cm of highly contaminated sediments found along the NW shore (Fig. 1c). The total amount of highly contaminated sediment is estimated at ~230,000 m^3. Down-core arcellinidan and ICP-MS As concentrations were assessed from a frozen core collected in the north basin of Frame Lake as part of an initiative to assess remediation measures required to rejuvenate the lake following significant degradation in the 1960s. The results showed that the system was non-depositional from the mid-Holocene until ~1962 after which the lake began to rapidly infill with highly As contaminated sediments derived from urban development and mine activities. The apparent sharp peak in As in sediments deposited during the mid-1980s is likely the result of remobilization due to changes in redox conditions. Temporal changes in the ratio between the healthy lake indicating difflugiids and As-tolerant centropyxids better characterizes the interval from ~1962 to early 1990s when arsenic significantly impacted the lake ecosystems. From ~1990 onward the major ecological challenge to the lake has been eutrophication derived from runoff and a reduction in lake circulation associated with the construction of a causeway with rarely opened sluiceways at the only outlet.

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