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Rotifer loricas in second millennium sediment of Crawford Lake, Ontario, Canada

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Abstract

Crawford Lake (43° 28.1′N, 79° 56.9′W, 278 m asl) sediment is unusual because it preserves abundant loricas of *Kellicotia longispina*, *Keratella cochlearis*, *K. earlinae*, *K. quadrata* and *K. hiemalis*. Rotifer abundance covaries with diatoms, both of which indicate eutrophication. Dating is by varves after AD 1867 but before 1867, dating is by AMS (Accelerator Mass Spectrometry) because of irregular varve deposition. Fossil loricas become abundant about AD 1286 when *Zea*, *Cucurbita* and *Helianthus* pollen indicate native Iroquoian settlement and farming; a second rotifer peak begins in 1867 with Canadian settlement. Rotifers reflect nutrient-induced phytoplankton blooms as shown by *Chlorella* cells lodged within a lorica.
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1. Introduction

Rotifers are microscopic herbivores, common in plankton of freshwater habitats, which feed on single-celled algae and bacteria. Where food is abundant, they may exceed 5000 per liter of water (Wallace and Snell, 1991). Their abundance reflects eutrophication; for example, *Keratella cochlearis* and *Kellicottia longispina* increase with enhanced input of phosphorous (Edmondson and Litt, 1982). Except for resting eggs (van Geel, 2001), rotifer fossils are rare although Swadling et al. (2001) report *Notholca* loricas from Holocene mud of an Antarctic lake. In Crawford Lake sediment hundreds of thousands of rotifer loricas are preserved per g sediment. For two genera and four species, abundance covaries with settlement intervals, both prehistoric Iroquoian and historic Canadian, and indicates eutrophication.

2. Physical, biological and cultural setting

Crawford Lake (2.4 ha surface area) located 65 km southwest of Toronto, Ontario, Canada, occupies a small but deep basin in dolostone bedrock. In the deepest part of the basin, 22.5 m of water overlies 4.5 m of postglacial sediment. Water enters the lake mostly by seepage from a catchment of ca. 80 ha (Yu et al., 1997). Limnological measurements indicate the lake is meromictic with anoxic bottom water. In the mixolimnion from 0 to 9 m depth, water temperature (Dickman, 1985) and dissolved oxygen

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(Prepas and Rigler, 1978) vary with the season, whereas in the monimolimnion below 15 m, the anoxic, hydrogen sulfide-rich water is a constant 5 to 6 °C. In the transitional metalimnion at 12 to 14 m, anaerobic green and purple photosynthetic sulfur bacteria form a plate (Moenig et al., 1970); these bacteria die in the autumn to deposit a dark sediment lamina (Dickman, 1979). White calcite laminas deposited in the spring usually separate these dark autumn laminas. In the upper sediment, laminas are distinct to a depth of 60 cm but lamina remnants are visible to at least 70 cm. The laminas form yearly couplets or varves. White laminas are likely missing from intervals marked by unusually wide, dark laminas; this accounts for the 10% missing varves implied by the AMS chronology (Ekdahl et al., 2004). Thus, the AMS chronology is more accurate than the largely obsolete varve chronology of Crawford Lake.

Water analysis (Moenig et al., 1970) shows living *Keratella cochlearis* was the most abundant rotifer, especially in the upper 6 m of the water column. Other species include *K. hiemalis* (most abundant at 6–14 m depth), *K. quadrata* (rare), *Filinia* spp., *Polyarthra* spp., cf. *Notholca* sp. and an unidentified species; *Kellicottia longispina* was not reported. Because the photic zone is only the upper 6-m of water, *K. cochlearis* may be feeding on phytoplankton whereas the deeper *K. hiemalis* appears to feed on detritus and bacteria.

Area climate is humid cool-temperate continental; at nearby Millgrove Climate Station the annual precipitation averages 910 mm; mean temperature for July is 20.3 °C and for January is −6 °C (Environment Canada, 1993). Upland mixed forest (Scott, 1995) is dominated by deciduous trees: *Fagus grandifolia* (beech), *Acer saccharum* (sugar maple), *Quercus rubra* (red oak), *Betula allegheniensis* (yellow birch), *B. papyrifera* (white birch), *Ulmus americana* (white elm) until 1970, *Ostrya virginiana* (ironwood), *Tilia americana* (basswood), *Fraxinus americana* (white ash) and *Populus grandifolia* (large-toothed aspen) together with the evergreen trees *Pinus strobus* (white pine), *Tsuga canadensis* (hemlock) and *Thuja occidentalis* (Eastern white cedar). North of the lake on the deep soil of a drumlin, maize is grown now as it probably was in prehistoric time.

In the first half of the last millennium, native Iroquoian people lived in agricultural villages within 3 km of the lake. Seven Middle Iroquoian village sites were each occupied for up to 30 years with populations ranging 200 to 3000 people (Finlayson, 1998): they date AD 1200–1500 (Dodd et al., 1990). Excavations of these sites yielded charred seeds of domesticated *Zea* (maize), *Cucurbita* (squash), *Phaseolus* (bean), *Helianthus* (sunflower) and *Nicotiana* (tobacco). The Crawford Village site, in the catchment 300-m north of the lake, had two occupations, each with 200 to 250 inhabitants. Between 1500 and the mid 1800s the area was deserted. After Canadian farmers acquired land within 2 km of the lake between 1822 and 1864 (McAndrews and Boyko-Diakonow, 1989), the land was deforested and the deeper soils were tilled while the shallow rocky land surrounding the lake returned to forest. A house and barn stood on the site of the Iroquoian village until 1972, when a reconstructed village and a visitor center replaced them.

Pollen analyses of the lake sediment delimit two zones of human impact on the landscape (Byrne and McAndrews, 1975; McAndrews and Boyko-Diakonow, 1989; Byrne and Finlayson, 1998; Ekdahl et al., 2004). The prehistoric Iroquoian Zone has *Zea*, *Helianthus* and *Cucurbita* pollen together with weedy Poaceae (grass) and *Portulaca* (purslane) pollen while the historic Canadian Zone has *Zea* together with weedy *Ambrosia* (ragweed) and *Rumex acetosella* (sheep sorrel). In addition, in the Canadian Zone a decline in *Pinus strobus* pollen from logging is followed by a rise of *Betula* and *Ulmus* pollen due to forest succession. Diatom analysis revealed corresponding intervals of lake eutrophication from human impact in the lake catchment (Rybak and Dickman, 1988; Ekdahl et al., 2004).

3. Methods

In 2001 we collected the upper 70 cm of sediment with a freezing sampler (Ekdahl et al., 2004), a 1-m long hollow metal wedge filled with dry ice and ethanol. In the laboratory, varves were counted and terrestrial plant samples taken for AMS dating. Only the varve counts back to 1867 were confirmed by the AMS dates. Close-interval samples were freeze-dried for diatom, pollen and rotifer analysis.

Fossil pollen grains, spores and rotifers were concentrated from 133 levels with dilute HCl and KOH followed by sieving to remove particles greater than 150 μm. Percentages of pollen and rotifers were calculated on a sum of 200 tree pollen grains. Because of its large size (400-μm long), some *Kellicottia longispina* loricas failed to pass through the 150-μm sieve to be recorded in the rotifer count. To correct this error, 70 of the 133 levels were reprepared without sieving and analysis found that the *K. longispina* had been underestimated by a factor of 10. Therefore, it is also probable that some large *Keratella cochlearis* are under reported due to sieving.

4. Results

Rotifer fossils are mostly the loricas of female *Kellicottia* and *Keratella* (Plate I)) although other genera are present as eggs or fragmented appendages. *Kellicottia*

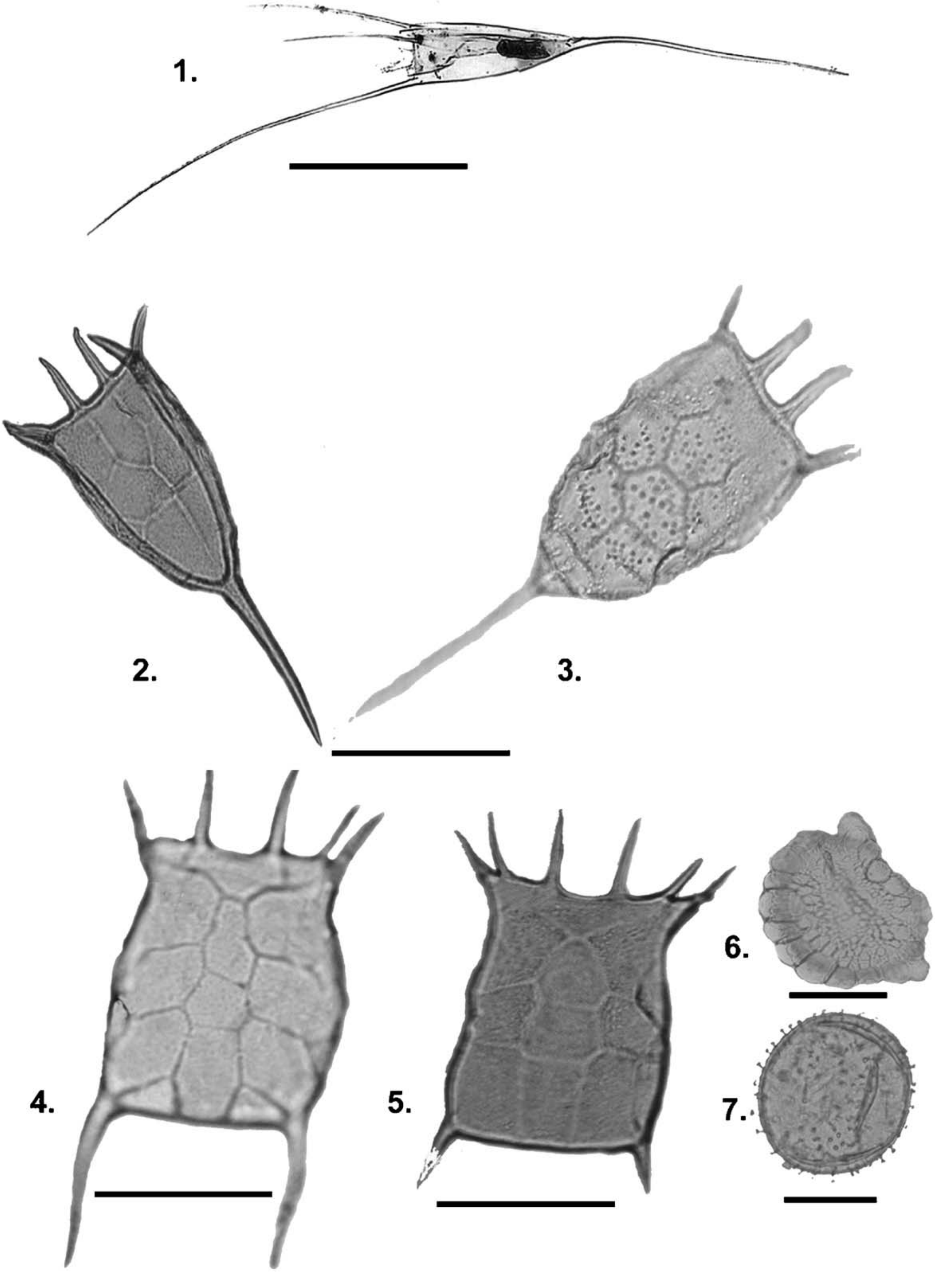

Plate I. Fossil rotifer loricas and resting eggs: (1) *Kellicottia longispina*, (2) *Keratella cochlearis*, (3) *K. earlinae*, (4) *K. quadrata*, (5) *K. hiemalis*, (6) cf. *Filinia* resting egg and (7) cf. *Synchaeta* resting egg. Scale bars for 1 is 90 μm, 2 and 3 is 50 μm, 4 and 5 is 80 μm and for 6 and 7 is 25 μm.

Plate II. Lorica of *Keratella cochlearis* filled with *Chlorella* cf. *fuscus*, a unicellular green alga.

longispina is a slender animal up to 400-μm long including spines (our measurements), with six anterior spines and one long posterior spine (Plate I, 1).

We report four species of fossil *Keratella* distinguished by the number of posterior spines and the pattern, size, shape and ornamentation of facets on the loricas (Edmondson, 1959). The first pair of species is typically 150-μm long and 60-μm wide, each species with one posterior spine; *Keratella cochlearis* (Plate I, 2) has one pair of central facets whereas in *K. earlinae* (Plate I, 3) the upper polygonal facets are not mesially divided, there are three additional pairs of small facets below the main facet and its surface is usually verrucate. On Plate II *Keratella cochlearis*, dating AD 1350, contains the green alga *Chlorella*. We are unaware of other fossil *Chlorella* reports.

The second pair of *Keratella* species usually has two posterior spines. *Keratella quadrata* (Plate I, 4) is ca. 250-μm long with the posterior spines at least half the length of its body and it has two lateral ridges of the posterior median plate that divide toward the posterior. *Keratella hiemalis* (Plate I, 5) is 170-μm long with its two posterior spines are relatively short, barely measuring a quarter of the body's length; its lateral ridges do not divide. Also present are fossil resting eggs of cf. *Filinia* (Plate I, 6), cf. *Synchaeta* (Plate I, 7) and *Keratella* (sensu van Geel, 2001).

The pollen and rotifer diagram (Fig. 1) shows two zones of human impact on the landscape and lake. The

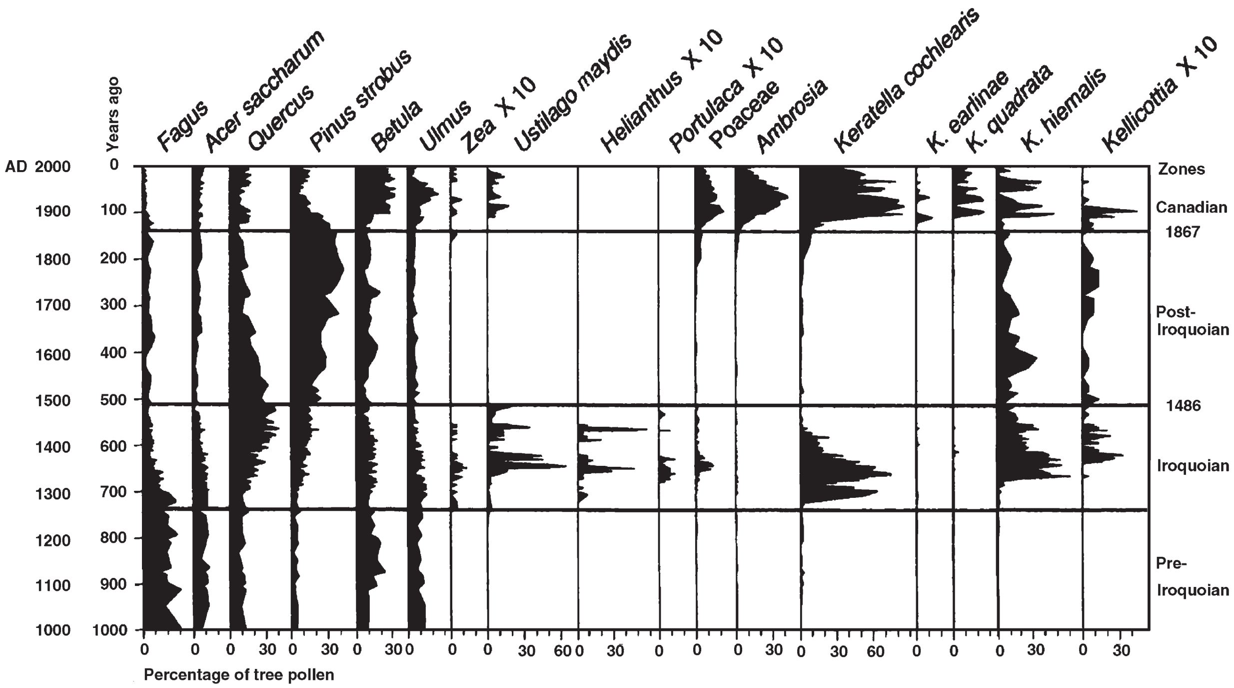

Fig. 1. Diagram showing percentages of selected tree and herb pollen grains, *Ustilago maydis* (smut) spores and rotifer loricas. Percentages are calculated on a sum of 200 tree pollen grains. Pollen identifications follow McAndrews et al. (1973), *Ustilago maydis* follows Kapp et al. (2000) and rotifers follow Edmondson (1959). To increase diagram visibility, the rare pollen of *Zea*, *Helianthus* and *Portulaca* are multiplied by 10 whereas *Kellicottia* loricas were multiplied by 10 to account for loricas lost in sieving.

Iroquoian Zone spans 1268 (oldest *Zea* pollen) to 1486 and features peaks of *Zea*, *Helianthus*, *Portulaca* and Poaceae pollen grains and *Ustilago maydis* spores whereas the Canadian Zone beginning about 1867 is marked by *Zea*, *Ustilago*, Poaceae and *Ambrosia* together with forest pollen succession from *Pinus* to the fast-growing pioneer *Betula* and *Ulmus*. Rotifer loricas, rare in the Pre-Iroquoian Zone, peak in the Iroquoian Zone, persist in the Post-Iroquoian Zone and again peak in the Canadian Zone. *Keratella cochlearis* peaks in both human occupation zones whereas *K. earlinae* and *K. quadrata* peak only in the Canadian Zone. In contrast, *K. hiemalis* (usually lacking spines) and *Kellicottia longispina* have high values in the intervening Post-Iroquoian Zone where there is no pollen or archaeological evidence of human impact on the landscape.

In the Pre-Iroquoian Zone, all rotifer species are rare, about 5000 per g dry sediment. This contrasts with the Iroquoian and Canadian Zones where rotifers are about 400,000 per g, which exceed the density of pollen grains. In the intervening Post-Iroquoian Zone, rotifers are about 150,000 per g.

5. Discussion

The preservation of rotifer loricas is not well understood; perhaps hydrogen sulfide excludes decomposing bacteria. Although pollen preparations typically involve harsh acids and mild oxidizing agents, Crawford Lake rotifers survive the treatment. Pollen grain concentrates prepared with KOH, acetolysis and HF treatments and preserved in silicone oil (McAndrews and Boyko-Diakonow, 1989) retain fossil rotifers, albeit distorted. Other soft tissue fossils, e. g. blade leaves, feathers, and green *Pinus* needles (McAndrews et al., 1971) as well as green *Chlorella* underscore the unusual conditions of preservation.

The succession from *Keratella cochlearis* to *K. hiemalis* to *Kellicottia longispina* in the Iroquoian Zone, and less apparently in the Canadian Zone, suggests initially high and then declining food supply of algae and bacteria. These algae flourish with abundant nutrients such as phosphorus (Makarewicz and Likens, 1979) and thus indicate eutrophication. Perhaps the persistence of *Keratella hiemalis* and *Kellicottia* in the Post-Iroquoian Zone reflects the cool temperatures of the Little Ice Age.

6. Conclusions

Crawford Lake sediment preserves abundant, well-preserved loricas of planktonic rotifers. Lorica abundance covaries with abundance of diatoms and thus they are indicators of eutrophication. Eutrophication began in the 13th century when humans impacted the upland. Since then the eutrophic status of the lake has persisted but the relative paucity of rotifer species AD 1500–1850 may reflect cool water temperatures during the Little Ice Age in addition to reduced nutrient input. In the late 19th and 20th centuries, there was enhanced eutrophication of the lake.

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