

Preface: Cladocera crustaceans: sentinels of environmental change

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Published online: 20 October 2011
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Background

Growing awareness of the negative impacts of global change urges scientists to look for adequate means to assess past and ongoing environmental change. The extent and dynamics of natural ecosystem variability is not yet fully clear, though understanding of this variability is crucial for predicting future trends (IPCC, 2007). Paleolimnological records holding valuable proxy information in the form of sediment features, geochemical records and micro- and macro-fossil assemblages, can complement observational data by extending timescales, integrating sub-annual variability and expanding the range of sites that can be studied (Battarbee et al., 2005). Modern limnological time-series, though limited in space and time, can still add crucial information to these surveys. Similarly, in situ and laboratory experiments can complement paleolimnological approaches by improving our

mechanistic understanding of the relationship between proxy indicators and their environment.

Cladocera (Crustacea: Branchiopoda; water fleas) play a key role in freshwater ecosystems because of their pivotal position in the food web, sandwiched between top-down regulators (fish and invertebrate predators) and bottom-up factors (phytoplankton). The intermediary position occupied by cladocerans underlies their significance for nutrient cycling in freshwaters (Järvinen & Salonen, 1998; Urabe et al., 2002) and as sentinels of environmental change (Jeppesen et al., 2001; Korhola & Rautio, 2001; Kurek et al., 2010). Subfossil cladocerans (typically Bosminidae, Chydoridae and Daphniidae) appear in lake sediments mainly in disarticulated body parts, such as head shields, carapaces and postabdomens, or as ephippia (a structure that protects diapausing eggs). The taxonomic composition of these remains has been used to track past changes in the environment, including eutrophication (Brodersen et al., 1998; Shumate et al., 2002; de Eylo et al., 2003; Davidson et al., 2007; Chen et al., 2010), acidification (Paterson, 1994; Jezierski et al., 2008), lake water calcium decline (Jezierski et al., 2008), lake levels (Korhola et al., 2000, 2005) and climate (Lotter et al., 2000; Kattel et al., 2008). In addition, the taxonomic composition of cladocerans shows a strong response to biotic factors that can vary with lake trophic state, such as fish density (Jeppesen et al., 1996, 2001; Finney et al., 2000) and submerged macrophytes (Davidson et al., 2007). Cladocera-based reconstructions have not remained qualitative only, but the strong link between cladoceran

Guest editors: H. Eggermont & K. Martens / Cladocera as indicators of environmental change.

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distribution and various environmental variables has led to the construction of so-called *inference models* (or transfer functions) now allowing for quantitative reconstruction of total phosphorus (TP) (Brodersen et al., 1998; Amsinck et al., 2005; Chen et al., 2010), lake depth (Korhola et al., 2005; Nevalainen et al., 2011a, b) and temperature (Lotter et al., 1997; Korhola, 1999; Kattel et al., 2008). Resting eggs of the pelagic species of *Daphnia*, then again, have been applied to testing cause and effect relationships between past populations and paleolimnological inferences (Kerfoot et al., 1999; Amsinck et al., 2007). Because subfossil resting eggs are often viable for up to 100 years (Hairston et al., 1993) and provide sufficient quality and quantities of DNA for genetic analyses from even longer periods of time, resting egg banks also represent a unique biological archive to unravel ecological and evolutionary changes (Hairston et al., 1999; Brendonck & De Meester, 2003). As such, paleogenetics of *Daphnia* resting eggs has proven its value in studies on micro-evolutionary changes in cladoceran populations (e.g., Cousyn et al., 2001; Limburg & Weider, 2002), response of populations and communities to environmental change (e.g., Pollard et al., 2003; Brede et al., 2009), and invasion and/or recolonization dynamics (e.g., Duffy et al., 2000; Mergeay et al., 2006, 2007). Hence, over recent years cladoceran paleoecology has clearly grown to a mature research discipline, but significant challenges remain.

Challenges in cladocera paleoecology

Frey (1960) was, in many respects, a pioneer in recognising the utility of cladoceran remains in lake sediments as opposed to sampling extant populations that may show substantial variability in seasonal and annual abundance, in addition to habitat diversity. Methods for sampling Cladocera from lake sediments are now relatively standardised (Frey, 1986; Hann, 1989; Korhola & Rautio, 2001; Szeroczyńska & Sarmaja-Korjonen, 2007), but they are still being updated (e.g. Kurek et al. 2010). Also, available transfer functions are critically evaluated (e.g., Kattel et al., 2008) and new methodologies become available (e.g. Alexander & Hotchkiss, 2010). Interpretation of the sedimentary cladoceran record is not straightforward, however, and the development of techniques for subfossil Cladocera research has clearly lagged behind

other common paleolimnological indicators (e.g. diatoms, chironomids). Indeed, cladoceran paleoecology is still facing limitations related to taxonomic difficulties (Korosi et al., 2011), complex patterns of production and distribution (Kerfoot, 1981; Anneville et al., 2010), differential preservation of species and type of remains (Frey, 1986; Hann, 1989; Rautio et al., 2000; Kattel et al., 2007), and sedimentation dynamics. Efforts to improve the comparability of observational data and the paleolimnological record are therefore still needed (Battarbee, 2005). Furthermore, most of the published literature on (sub)-fossil Cladocera originates from Europe and North America (Korosi & Smol, 2011), and only a small number focuses on tropical regions (e.g. Eggermont et al., 2008; Rull et al., 2008).

One approach to evaluate how well the sediment record reflects the living community is to sample live animals from various habitats within a lake, and to compare the species assemblages (plankton counts) with lake surface sediments (Rautio et al., 2000; Kattel et al., 2007; Nykänen et al., 2009). Such results have addressed the differential preservation of species (Alric & Perga, 2011), as well as biases in a central lake core, attributable to transport processes from littoral source communities (Nykänen et al., 2009). Another approach is to sample less extensively in one lake, but to incorporate data from several lakes (Jeppesen et al., 2000; Davidson et al., 2007). Such studies have illustrated discrepancies as well as similarities between the contemporary community and fossil assemblages (Nykänen et al., 2009). Finally, studies quantifying the relationship between the production of remains and their deposition also yielded very valuable insights (Kerfoot 1981, 1995; Hall & Yan, 1997; Nykänen et al., 2009). Yet, due to the heterogeneity of approaches used, and/or focus on different lake types and time windows, results of studies are not always readily comparable. Clearly, more taphonomic studies are needed to broaden our understanding of the picture provided by cladoceran fossil assemblages.

In light of global change impacts and mitigation, Cladocera-based reconstructions of climate are gaining increased attention. Besides methodological difficulties mentioned above, environmental changes that are not related to climate, such as eutrophication, acidification or habitat modification, can hamper Cladocera-based climate reconstruction (e.g. Sarmaja-Korjonen & Hyvärinen, 1999; Duigan & Birks, 2000; Hofmann,

2003). Similarly, influence of regional temperature change on a local cladoceran fauna may be masked by their biotic response to variation in other (local) limnological factors driven by climate change (Battarbee et al., 2002). It may therefore be difficult or even impossible to separate many of the environmental signals from downcore data, but careful examination of the influence of all parameters on Cladocera-based reconstructions and multi-proxy approaches can bring some solace.

Special issue content

Several papers in this special issue aim at identifying environmental forcing factors affecting cladoceran distribution at various spatial scales, and as such they provide a better delineation of their ecological preferences and indicator value. For example, Nevalainen (2011) assessed the intra-lake variability in fossil cladoceran assemblages to identify habitat specificity of Cladocera in relation to local hydrology-related environmental factors. Similarly, Kultti et al. (2011) showed that the total number of chydorid ephippia increases along a climate gradient, and they used this relationship to create a novel method for paleotemperature reconstruction in Finnish cold-temperate environments. Rumes et al. (2011), then again, analysed the turnover of cladoceran species along several environmental gradients in a large set of Ugandan crater lakes to demonstrate their potential as biological indicators for water quality and ecosystem health in East Africa. Whereas the latter study focused on the Ugandan lowlands, Van Damme & Eggermont (2011) addressed the ecology, biogeography and taxonomy of the Cladocera fauna in the Rwenzori Mountains (Uganda–D. R. Congo).

Taphonomic problems in cladoceran paleoecology are also dealt with in this issue. Alric & Perga (2011) assessed the effect of production, sedimentation and taphonomic processes on the representativeness of fossil assemblages in terms of both species composition and size structure of pelagic communities by comparing fossil assemblages in sediment traps and modern cladoceran source communities in a subalpine lake.

This issue also tackles taxonomical issues. For example, Korosi et al. (2011) performed a detailed analysis of the postabdominal claws from several

Daphnia species in south-central Ontario, Canada (including claw length, width, curvature and spine/spinule length) to determine whether subtle differences exist that can be used to aid taxonomic resolution within species complexes. Such advances in the taxonomic resolution of subfossils will allow researchers to address increasingly nuanced questions, and ultimately help to improve our understanding on how lakes change over time in response to complex multiple environmental stressors.

Aspects of quantitative Cladocera-based reconstructions are also examined here. For example, Davidson et al. (2011a) analysed cladoceran surface sediment assemblages from 53 lakes in Greenland with substantial variation in lake depth and fish abundance, and developed lake-depth transfer functions for various sets of lakes (i.e. with and/or without fish). As such, they were able to assess the degree to which variation in predation pressure can interfere with an empirical model based largely on an indirect relationship. Luoto et al. (2011) investigated the influence of hydrological variables and stream flow on quantitative Cladocera-based air temperature and water depth reconstructions. In doing so, they also addressed the issue of sampling point selection in down core paleolimnological studies. In the same context of lake level reconstruction, Siitonen et al. (2011) provided a Cladocera-based Holocene lake-depth reconstruction of a northern boreal lake in Finnish Lapland, and compared this with reconstructions based on other proxies, in order to evaluate the utility of Cladocera as single-used proxy.

Six papers in this special issue provide actual Cladocera-based reconstructions, and as such, validate the potential of subfossil Cladocera as sentinels of environmental change. Using the so-called ‘top–bottom’ approach, Nevalainen et al. (2011a, b) compared contemporary and pre-industrial age (before 1850 AD) fossil assemblages of Cladocera in sediment cores from 25 lakes in the Italian and Swiss Alps to investigate the impact of mounting anthropogenic stresses over the past 150 years on community composition. Milecka et al. (2011) provided a paleoenvironmental record of lake and catchment changes in northern Poland during the Late Glacial and the beginning of the Holocene. Similarly, Kattel & Sirocko (2011) examined the role of cladocera for reconstruction of the environmental, cultural and archaeological development in the Eifel maar lakes

region (West Germany) during the Late Glacial and Holocene periods; and Korponai et al. (2011a) analysed subfossil cladocera assemblages from Late Glacial/Preboreal sediments of Lake Brazi (a South Carpathian mountain lake) to trace the community response to rapid climatic warming that occurred during this period. Korponai et al. (2011b), then again, provided a Cladocera-based reconstruction of trophic states in Lake Balaton (Hungary) over the last several thousand years; and López-Blanco et al. (2011) presents some interesting data on Cladocera species shifts resulting from hydrological alterations caused by a canal in Lake El Tobar, Spain.

This issue also illustrates the usefulness of combining paleo- and neo-ecological observational studies, as well as short-term experiments in assessing the response of Cladocera to environmental change. Fischer et al. (2011) showed that *Daphnia* abundance can serve as a powerful sentinel to climate change in alpine lakes of the Rocky Mountains.

Finally, using examples from Danish, Estonian and UK lakes, Jeppesen et al. (2011) showed in their review paper that zooplankton (sampled from the sediment and water) have a strong indicator value. As such, the authors plead for including zooplankton in the ecological quality assessment of lakes according to the European Water Framework Directive (WFD; European Union, 2000). Within the same WFD, Davidson et al. (2011b) compared plant macrofossil and subfossil Cladocera assemblages from 21 sediment cores spanning the last two to three centuries, and further confirm the (paleo)indicator value of Cladocera in shallow lakes.

In summary, the articles presented in this Special Issue are intended to explore and highlight the indicator value of Cladocera, using both modern and paleolimnological approaches. Although it is clear that more research is needed to validate results in a geographically larger context, this issue definitely brings out research areas which will prove fruitful for future investigation.

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