The role of plankton, zoobenthos, and sediment in organic matter degradation in oligotrophic and eutrophic mountain lakes

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Abstract
Intensity of organic matter degradation, assessed by the respiratory electron transport system (ETS) activity, was studied in microplankton, zooplankton, chironomid larvae as the dominant group of the macrobenthos, and sediment in mountain lakes of different trophic levels in summer months. The highest ETS activities per unit of surface were observed in sediments. Significantly lower activities were observed in microplankton, and lower still in zooplankton, and chironomids. The total ETS activity m⁻² was higher in eutrophic lakes (Jezero na Planini pri Jezeru and Krnsko jezero) than in oligotrophic ones (Zgornje Kriško jezero, Spodnje Kriško jezero, Jezero v Ledvicah). The contributions of communities investigated to total ETS activity m⁻² differed between lakes of different trophic level. Estimation of respiratory carbon loss through different components revealed that the most of the organic matter was oxidized in sediments of mountain lakes. The respiratory carbon losses were higher through zooplankton than through microplankton in all lakes. Carbon losses through plankton components and sediments were significantly lower in oligotrophic than in eutrophic lakes. The contribution of respiratory carbon loss through chironomids to total carbon loss m⁻² was higher in oligotrophic than in eutrophic lakes. Therefore, it seems that contributions of microplankton and zooplankton to mineralization processes increase, and contributions of chironomids and sediment surface decrease with increasing trophic level of the lakes.

Introduction
To explain the structure and energy flow in an ecosystem, knowledge of population dynamics, production, respiration and feeding of the dominant species at different trophic levels is required. Estimation of the metabolic activities of the consecutive groups of organisms is central in describing the energy flux through the food chain, since most of the energy passes through as respiratory loss. In this approach, respiration is an expression of the metabolic activity. Numerous researchers have investigated metabolic activity of plankton communities (Devol & Packard, 1978; Devol, 1979; G.-Tóth, 1992; G.-Tóth et al., 1995; Rossetti et al., 2001; Simčič & Brancelj, 2001), sediment (G.-Tóth, 1992; Simčič & Brancelj, 2002 a, b), biofilm (G.-Tóth et al., 1995), and benthic communities (Hamburger & Dall, 1990; Lindeggaard, 1994). It was reported that contribution of communities to total metabolic activity m⁻² differs between aquatic ecosystems of different trophic levels (Devol & Packard, 1978; G.-Tóth, 1992, 1993; G.-Tóth et al., 1995). These studies mostly investigated the contribution of plankton, biofilm and sediment to total metabolic activity in lakes, but the contribution of benthic organisms to mineralization processes has been less frequently
investigated (Lindegaard, 1994; Kurashov, 2002). Especially in shallow-water lake systems, the metabolic activity of the benthos as well as its contribution to the total (water column + sediment) mineralization is relatively higher than in deeper ones (Relexans, 1996a).

Slovenian mountain lakes are relatively small and shallow, having short ice-free period of 3–6 months (Muri & Brancelj, 2002). The structures of the pelagic community of the lakes show that Rotifera, Cladocera and Copepoda are presented with few species (Brancelj et al., 1997; Brancelj, 2002), and species of Cyanophyta and Chlorophyceae dominate the phytoplankton (Šiško & Kosi, 2002). Because of the shallowness of the lakes and low temperatures, the major part of oxidation of organic matter presumably occurs on the bottom of mountain lakes. From this point of view macrozoobenthos living on sediment of mountain lakes could contribute essentially to processes of mineralization through respiration. In high-mountain lakes, the metabolically most active zone is focused to the profundal, probably by the intensive UV-B radiation (G.-Tóth et al., 1995).

Oligotrophic mountain lakes are specific aquatic ecosystems, where low metabolic activities of organisms are expected due to low temperature and productivity. As respiration rates in these ecosystems are often below the detection limit of conventional methods, different attempts have been done to find more sensitive methods. Therefore, method based on the measurement of the activity of respiratory electron transport system (ETS) was proposed by Packard (1971). ETS is responsible for more than 90% of the biologically consumed O\textsubscript{2} in the biosphere (Packard, 1985). The ETS assay, based on the reduction of 2-iodo-3-nitrophenyl-5-phenyl-tetrazolium-chloride (INT), has proved to be a good tool for estimating the respiratory potential of zooplankton (Owens & King, 1975; James, 1987), microplankton (Devol & Packard, 1978), benthos (Jones & Simon, 1979; Cammen et al., 1990) and sediment (Trevors, 1984; G.-Tóth et al., 1994), in particular in those cases, when the direct measurement of the respiration rate is difficult. The main reaction is the reduction of INT into formazan instead of the reduction of the natural electron acceptor, oxygen. The activity of a complex enzyme system like ETS must be determined at the rate-limiting step. In the ETS this step is the oxidation of the coenzyme Q-cytochrome B complex (Packard, 1971). Formazan production in ETS assays has been found to be closely correlated to O\textsubscript{2} consumption (Kenner & Ahmed, 1975b; Owens & King, 1975; Bamstedt, 1980; del Giorgio, 1992). As ETS activity measurements show potential respiration rates they need to be converted to \textit{in vivo} respiration rates (R) by empirically determined factors. ETS/R ratios have been published for zooplankton (Owens & King, 1975; Bamstedt, 1980; James, 1987; Simčič & Brancelj, 1997), phytoplankton (Kenner & Ahmed, 1975a), sediment (Simčič & Brancelj, 2002a) and some groups of benthic organisms (Cammen et al., 1990; Muskó et al., 1995), but none for chironomids.

The aims of this study were to determine ETS/R ratios for chironomid larvae, and biological oxidation potentials of microplankton, net zooplankton, chironomids larvae as macrobenthos and sediment surface, in order to compare the contribution of each component to total metabolic activity in mountain lakes of different trophic levels. As macrophytes are absent from lake Jezero v Ledvicah, or present in small abundance in lakes Zgornje Kriško jezero, Spodnje Kriško jezero and Jezero na Planini pri Jezeru (Urbanc-Berc & Gabersčik, 2002), they were not included in the study. Additionally, respiratory carbon loss through each component at \textit{in situ} temperatures, and relationships between respiratory carbon loss and estimation of primary assimilated carbon in the water column in lakes of different trophic levels were estimated.

Materials and methods

Samples were collected from the deepest parts of the five mountain lakes in NW Slovenia (Table 1) in August–September 2001. Water samples were taken using van Dorn water bottles (Wildco), and zoobenthos samples using a van Veen grab (Eijkelkamp). The sediment samples were collected with a Kajak corer with a 6 cm diameter plexiglass tube. Water samples were collected for analyses of chlorophyll \textit{a} and total phosphorous at three to seven depths of the water column. Samples were transported to the laboratory at \textit{in situ} temperature and analysed within 24 h.