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Fine particulate organic matter (FPOM) transport and processing in littoral interstices – use of fluorescent markers

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Abstract

A fluorescent labelling method is presented as a new tool for the investigation of organic particle transport and biogenic carbon cycling processes in sandy littoral interstices at Lake Tegel, Berlin, Germany. Passive particle transport through the pore system was studied by in situ exposition of 2.4 µm monodisperse polymeric resin microparticles stained with 7-amino-4-methylcoumarin (AMC). Uptake of fluorescein-5-isothiocyanate (FITC)-labelled *Chlorella vulgaris* and fine particulate organic matter (FPOM) by the interstitial fauna was investigated in laboratory and field experiments. The major portion (>85%) of the FITC-labelled particles added to sediment cores was recovered from the topmost centimetre of sediment during the study period of 14 days. Uptake of FITC-labelled FPOM was observed in several benthic groups, e.g. chironomids, microcrustaceans, oligochaetes and tardigrads, whereas *C. vulgaris* was ingested by oligochaetes only. There is evidence to suggest that both are suitable materials for investigating the fragmentation and ingestion of organic material by herbivorous and detritivorous fauna. Field experiments with inert microparticles and FITC-labelled FPOM (<1 mm) prepared from dried alder leaves were carried out in plexiglass tubes as in situ whole core technique. Within the investigation period of two weeks, the transport of FPOM was restricted to the topmost 2–3 cm of sediment in conjunction with a distinct fragmentation to finer size classes with respect to increasing sediment depth. Vertical FPOM transport was hindered by a high interstitial concentration of natural POM and an intensive settlement of the interstices by algae (mainly epispammic algae, 65–96% of algae cell number) and extra-cellular polymeric substances (EPS), which formed a dense three-dimensional structure.

Keywords: Fluorescein-5-isothiocyanate (FITC); Fluorescence marker; Littoral sediment; Particulate organic matter (POM); Groundwater recharge; Interstices; Interstitial

Introduction

The transition between streams or lakes and groundwater, the hyporheic biotope or interstitial zone, is a focus of interest in water management, applying the process of water infiltration for groundwater recharge and bank filtration for drinking water supply. Many investigations of the riverine bank filtration zone and slow sand filtration describe the interstitial flora and fauna, and verify self-purification processes during infiltration (Higgins and Thiel, 1988; Graham and

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Collins, 1996; Kühn and Müller, 2000), whereas knowledge of the sandy littoral zone in lenitic ecosystems is scarce and only a little information is available about turnover and retention of particulate organic matter (POM) and dissolved organic matter (DOM; Beulker and Gunkel, 1996; Hakenkamp et al., 2002).

Carbon flux within the interstices during the infiltration process is not only determined by the influx of DOM (among others cyanotoxins), but also by the deposition of POM (detritus, living algae cells), the primary production of epispammic and interstitial algae, the transport of fine POM (FPOM) to deeper sediment layers and the mineralisation of POM and DOM. Mechanical wave effects and topography-related pressure gradients enhance advective forces that favour interstitial transport (Huettel and Rusch, 2000). The infiltration process is also strongly influenced by colonization of sediment surface and interstitial spaces by epispammic and interstitial algae and bacteria. They participate in metabolic processes and have a strong effect to the extent of biological clogging by production of extra-cellular polymeric substances (EPS; Gunkel and Hoffmann, 2006).

The role of bioturbation processes in the upper sediment layer has frequently been studied using different natural and artificial tracer materials, e.g. radionuclides, colour- or fluorochrome-dyed microspheres, laboratory cultivated algae, sediment particles or metal-doped sediment (Gerino et al., 1998; Solan et al., 2003). Studies on fine particle transport in the interstices are mainly reported from rivers using fluorescent-labelled bacteria (Hall et al., 1996), yeast (Paul and Hall, 2002), pollen (Wanner and Pusch, 2000) or radio-labelled seston particles (Georgian et al., 2003). But still the choice of added POM in experiments is insufficient; bacteria, yeast and seston are minor representatives of POM in limnic waters and cannot be used to detect penetration and shredding of POM by interstitial organisms. The use of cultured algae is a better approach (Huettel and Rusch, 2000), but it is not possible to distinguish them from in situ grown algae.

A novel fluorescein-5-isothiocyanate (FITC) fluorescent labelling method allows the study of vertical particle transfer in sediments by the application of FITC-labelled natural organic substrates (e.g. algae, leaves) originating from the sampling site as well as analysis of the biological decay of particulate organic material. With a particle size ranging from 10 to 1000 μm being used, this covers a large and varying size spectrum. The ingestion of FITC-labelled organic matter by the fauna was positively tested in advance by experiments with both cultured organisms and meiofauna inhabiting the studied sediment.

Transport studies were conducted in in situ cores as whole core technique, which were exposed in the shallow (<0.5 m depth) littoral zone of the Lake Tegel, Berlin, a mesotrophic lake. The area studied is characterized by lake shore erosion and reed die-back; about 100 m from the lake shore a well gallery (down to 60 m depth) is used for water abstraction as bank filtrate for drinking water supply.

Focus of the investigations is the analysis of the lake/low land river infiltration zone, the interstitial, as a small boundary layer of about 30 cm depth with high biological activity (Beulker and Gunkel, 1996) and to evaluate the significance of the biotope for the self-purification processes in natural and induced groundwater recharge (Hoffmann and Gunkel, 2006). Clogging phenomena occur, but up to now the significance of the processes such as mechanical (e.g. POM input, gas bubbles), chemical (e.g. precipitation of calcium carbonates) and biological effects (e.g. the formation of extra-cellular polymeric substances, EPS) are not sufficiently known. The potential for DOC reduction of the infiltration water (in the range 20–40%) and the source of the remaining DOC of about 5 mg L^{-1} DOC in the ground water (Grünheid et al., 2005) makes it necessary to analyse not just the DOC input with the lake's water but also DOC formation and mineralisation within the interstices.

Material and methods

Study area

Lake Tegel is a lowland lake situated in Berlin, a glacial enlargement of the River Havel, with an area of 396 ha and a mean depth of 6.6 m (Table 1). Water balance and water quality is determined by the inflow of two rivulets (Tegeler Fließ, Nordgraben) and by water exchange with the River Havel (Fig. 1). After a severe eutrophication period, a phosphate elimination plant was built and nowadays the lake water quality is mesotrophic, but organic rich anoxic sediments are still typical and periodically cyanobacteria blooms occur (Heinzmann and Chorus, 1994; Schauser et al., 2006a, b).

Lake Tegel has a sedgy littoral zone with forest stands, sporadically interrupted by beach sections caused by erosion, with sparse macrophyte growth (reed *Phragmites australis,* water lily, *Nuphar lutea*). Near the shore of Lake Tegel, bank filtration for Berlin's water supply is done through several galleries with 116 wells, 30–60 m deep, distance to the lake is about 100 m. The pumping rate for each well amounts from 50 to 150 $m^3 h^{-1}$.

Experiments were conducted at a water depth of 30–50 cm, about 3 m away from the splash water zone, and different micro-habitats were studied (sandy erosion shore, *Phragmites* stand, *Nuphar* stand) at the eastern shore of Lake Tegel (N52°34′13.81″ E 13°15′25.52″ to N52°34′10.65″ E13°15′24.42″).