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THE IMPACT OF GRAVEL EXTRACTION ON HYPORHEIC ECOLOGY: A CASE STUDY OF THE BAČA RIVER (W SLOVENIA)

Dissertation

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1 INTRODUCTION

1.1 General introduction

Rivers and streams are an integral and important part of the landscape. They provide a range of habitats supporting a wealth of wildlife, from the river water itself, to the banks and the surrounding floodplain or valley. They participate in landscape modification by erosion of land and transport of sediments (Allan, 1995), play key roles in the regulation and maintenance of biodiversity in the landscape and are important natural corridors through landscape for aquatic fauna (Dynesius and Nilsson, 1994). At present, rivers and streams are viewed in three spatial dimensions. Connections and interactions occur between the channel and its floodplains and terraces (riparian zone), between the channel and groundwater below the channel and between upstream and downstream units of the river continuum (Schwoerbel, 1961b; Stanford and Ward, 1988; White, 1993; Gibert et al., 1994a; Stanford, 1998). Alluvial sediments, extending vertically and laterally from the river channel are the area of active exchange of water and dissolved material between river and groundwater. This transitional zone in porous aquifer was defined as hyporheic zone (Orghidan, 1959). It forms a dynamic, energetically rich source-sink zone, without clearly defined boundaries which fluctuate in time and space (Boulton et al., 1992a).

The hyporheic zone is very important as a transitional zone between rivers and groundwater (Gibert et al., 1990). It can extend laterally up to two kilometers (Stanford and Ward, 1988), vertically for some meters (Marmonier et al., 1992), and have volume that is several times greater than that of surface stream (Valett et al., 1990). The porous sediments in banks adjacent to rivers can act as buffers to rising water levels and reduce, delay, or even prevent the occurrence of flooding (Brunke and Gonser, 1997). Further on, the hyporheic zone plays a central role in maintenance of water quality. It acts as physical, biological and chemical filter (Gibert et al., 1990), where the sediment particles impede the flow of silt and particulate matter, microbial biofilms coating the sediments take up or transform organic compounds, and dissolved minerals and metals are precipitated and trapped by physical filter. And lastly, the hyporheic zone is a habitat for many surface and groundwater dwelling invertebrates (Gibert et al., 1994a) and a site of spawning and egg incubation for some salmonid species (Geist and Dauble, 1998). It has been recognized that biota living in the riparian and hyporheic zone of the rivers contribute the majority of energy flow in lotic ecosystems (Ward et al., 1998). The structural and functional characteristics of hyporheic invertebrate communities reflect the transitional nature of this habitat. Communities consist of species with different degree of affinities to surface and groundwater, ranging from surface species to exclusively groundwater species (stygobionts) (Gibert et al., 1994a).

On the other hand, fresh waters are one of the most exploited resources of the World. Rivers and streams serve as a supply of potable water. They are a source for irrigation and hydroelectric power. In addition, running waters transport large quantities of sediments due to erosion processes in headwater areas, which are later deposited downstream. Those sediments have been, and still are, extensively exploited. They are used for preparation of construction aggregate for roads and highways (base material and asphalt), pipelines (bedding), septic systems (drain rock in leach fields), and concrete (aggregate mix) for highways and buildings (Kondolf, 1997). Exploitation of alluvial sand and gravel has several advantages for aggregate users: the material is granulated, well-sorted, and generally clean (*sensu* organic deposits). The source of material is generally close to the destination, reducing transportation costs; alluvial sediments require little processing, and are periodically replaced from upstream during high flow events. And lastly, the environmental costs of sediment extraction are generally not considered in cost-benefit analysis, making this source much more profitable than other alternatives (Kondolf, 1997). Commonly, the extraction of river sediments causes the users disagreement in the local community because it is in cross purpose with other activities, such as fisheries, recreational or esthetic functions, or with the need for stable river channels. The negative consequences of gravel exploitation are the alteration of physical environment (geomorphology and hydrology of the river channel), and ecological conditions (organisms and their environment) (Jensen and Mogensen, 2000).

The impacts of in-stream sand and gravel extraction on river ecology have been rarely studied. Mostly, the physical impacts have been anlysed (Kondolf, 1997; Gaillot and Piégay, 1999; Jensen and Mogensen, 2000; Rinaldi et al., 2005), while less is known about responses of organisms to those changes. Depletion of suitable spawning habitats for fish and decrease in benthic invertebrate

abundance and taxonomic richness have been observed (Pearson and Jones, 1975; Rivier and Seguier, 1985; Brown et al., 1998; Kelly et al., 2005). The response of hyporheic invertebrate community to in-stream sediments extraction has not been studied until present at all. The scarce studies related to this topic were the studies of the effects of management works on the interstitial fauna and biofilm in the channels of the Rhone River (France) (Claret et al., 1998; Claret et al., 1999a) where modifying the hydrological exchange between surface and groundwater resulted in changes in biofilm activity and biodiversity and invertebrate community composition. Brunke and Gonser (1997) stressed out that human impacts on hyporheic zone may lead to reductions in exchange processes, which connect running waters to their surroundings, and thus diminish the ecological integrity of groundwater and surface water ecosystems.

The purpose of this doctoral thesis was to analyze the short-term effects of in-stream gravel extraction on the hyporheic invertebrates in the pre-alpine gravel-bed Bača River (W Slovenia), and in accordance with this topic, to synthesize current scientific information regarding the environmental effects of in-stream sand and gravel exploitation from rivers and streams. The structural and functional characteristics of the hyporheic invertebrate community from the Bača River were studied together with its respond to natural variation in environmental factors and to gravel extraction activities carried out in this river channel. The study was carried out in order to examine to what extent the invertebrate fauna can cope with disturbances due to gravel extraction.

The Bača River was selected as a study river, to obtain first data on structural and functional characteristics of hyporheic communities of the Soča River basin, which is, at one hand, one of the most preserved rivers in the whole Alpine space, with low pollution level and low level of hydrological modifications (Natek, 1998), especially in the upper basin. On the other hand, downstream from Tolmin the river channel is intensively modified to enable functioning of the chain of hydropower plants placed along the river Soča, which includes the formation of impoundments and countinous sediment withdrawal at several sites. Consequently, a great care is needed for a future management of the whole basin, to improve or at least to maintain the good ecological status of this river and its tributaries, which could be as well a potential water supply for citizens. Due to this, along with analyzing the ecological effects of gravel extraction, an attempt was made to describe the “state of the art” of the driving forces and regulatory processes in the Soča River catchment regarding the sediment management.

1.2 Environmental impacts of gravel extraction

Alluvial sediments are exploited either from pits in river floodplains and terraces, or by in-channel (in-stream) mining, removing sand and gravel directly from river beds with heavy equipment (Kondolf, 1997). Commercial gravel mining is removing or obtaining a supply of gravel for industrial uses, such as road construction material or concrete aggregate. Gravel can also be removed for flood control (Jensen and Mogensen, 2000). The excavation of sediments directly from the rivers is generally conducted due to commercial reasons (mining), maintenance activities (removal of material from channels in order to maintain the design depth) and remediation (removal of contaminated sediments) (Jensen and Mogensen, 2000). Gravel extraction from the rivers often occurs at multiple times and at multiple sites along a given stream, resulting in impacts that are likely to be both chronic and cumulative. The impacts are usually referred to under the general term of “mechanical pollution” (Rivier and Seguier, 1985).

The nature and severity of potential environmental impacts from in-stream mining are dependent on the geologic setting and characteristics of the stream, the type of extraction techniques employed, the location of extraction, and the amount of material extracted (Langer, 2003). One of the principal causes of negative environmental impacts from in-stream mining is the removal of more sediment that the system can replenish (Langer, 2003). Extraction can have a direct impact on the stream's physical habitat parameters such as channel morphology, bed elevation (i.e. lowering), substrate composition and stability, in-stream roughness elements (large woody debris, boulders, etc.), depth, turbidity, sediment transport, flow velocity and temperature (Jensen and Mogensen, 2000). In-stream sediment mining can disrupt the preexisting balance between sediment supply and transporting capacity, and can result in channel incision and bed degradation (Kondolf, 1997). Channel incision can reach values of up to 12-14 m (Rinaldi et al., 2005). This is partly because gravel “armors” the bed, stabilizing banks and bars, whereas removing this gravel accelerates erosion. Degradation and erosion can extend

upstream and downstream of an individual extraction operation (Rivier and Seguier, 1985). Erosion, increased velocities, concentrated flows, and bank undermining with subsequent loss of riparian habitat can occur upstream of the extraction site due to a steepened river gradient resulting in the release of additional sediment to downstream reaches, where the channel may aggrade and become unstable (Kondolf, 1997). Degradation can deplete the entire depth of gravel on a channel bed, exposing other substrates that may underlie the gravel (Rinaldi et al., 2005). Due to gravel removal, downstream gravel bars receive less bed material from upstream than is being carried away by fluvial transport. Further on, in-stream gravel extraction can increase suspended sediment, sediment transport, water turbidity, and gravel siltation (Kondolf, 1997). The most significant change in the sediment size distribution resulting from gravel removal is a temporal decrease in sediment size caused by fine material deposition into the mining site. The fine material can travel long distances downstream as a plume of turbidity while the gravel is being removed, and during floods, turbidity is likely to be higher than normal for even longer distances downstream due to the higher flow rate and increased entrainment of sediments as a result of channel deformation or armor layer removal (Brown et al., 1998). Bed degradation can change the morphology of the channel and decreases channel stability. The impacts of gravel extraction extend also to marine shoreline areas, where deficit in sediments cause the eroding of coastal area (Gaillot and Piégay, 1999).

Operation of heavy equipment in the channel bed can directly destroy aquatic habitats and has the potential to cause toxic chemical spills. Stockpiles of overburden and gravel left or abandoned in the channel or floodplain can alter channel hydraulics during high flows. During high water, the presence of stockpiles can cause fish entrapment, and fine material and organic debris may be introduced into the water, resulting in downstream sedimentation. The stockpiles may also concentrate flows on the stream bed or floodplain resulting in increased localized erosion. Removal or disturbance of in-stream roughness elements (gravel itself and large woody debris) during gravel extraction lowers the structural complexity of the stream or river ecosystem. These elements are important in controlling channel morphology and stream hydraulics; in regulating the storage of sediments, gravel and particulate organic matter; and in creating and maintaining habitat diversity and complexity. Dry pit and wet pit mining in floodplains may lower the level of groundwater table, reduce stream flows, increase water temperature, and create potential sites for fish entrapment (Langer, 2003). Lowering of groundwater table may occur when floodplain pits are pumped by operators to increase production, and by evaporation of surface water in large pits. Reductions in groundwater table can consequently result in a decrease in stream flow. Subsurface connectivity between pits and streams also presents a possibility of increased stream temperatures when pit surface water is heated by the sun and eventually drains to the stream during low water levels.

The type and magnitude of channel response to sediment mining depend mainly on the ratio between extraction and sediment replenishment rates (Rinaldi et al., 2005). The effects of mining will be especially severe and difficult to reverse where material is extracted at a rate greatly exceeding the replenishment rate, such as in rivers with relatively low rates of catchment sediment supply, in channelized reaches, in rivers with thin cover of alluvium over bedrock, and in rivers where mining coincides with other human activities that reduce upstream sediment delivery (Rinaldi et al., 2005).

Incision can be expected to influence the pattern of upwelling and downwelling of the water along the channel. Where gravel deposits are thick, incision can lead to greater upwelling of cooler groundwater into surface water. Where the thickness of gravel over bedrock is limited, however, incision decreases (or in some case eliminates) the volume of gravel deposits over bedrock, reduces the volume of the hyporheic zone and thereby reduces the available invertebrate habitat (Kondolf et al., 2002). Further on, groundwater flow paths and the groundwater-surface water exchanges of water, nutrients, organisms, and chemical constituents are modified. These changes may have effects on the food web ecology of the river system (Kondolf et al., 2002).

Destruction of the riparian zone during gravel extraction operations is additional consequence of sediment exploitations and can have multiple deleterious effects. The riparian zone includes stream banks, riparian vegetation, and vegetative cover. Damaging any one of these elements can cause stream bank destabilization resulting in increased erosion, sediment and nutrient inputs, and reduced shading and bank cover leading to increased stream temperatures (Rinaldi et al., 2005).

The effect to biota can be divided into direct effects caused by extraction activities and indirect effects caused by changes in the flow patterns and by an excess of suspended sediment (Rivier and Seguier,

1985; Jensen and Mogensen, 2000). Direct effects are removal or reducing of existing habitat, which is neutralized by the establishment of new habitats, the change of water depth at the extraction site, which can cause the shifting of existing system into the new one, and the increase in turbidity, which has negative effects only when the turbidity significantly exceeds the natural variation in turbidity levels in the area (Jensen and Mogensen, 2000). River bed incision might induce weak biofilm development and activities in the sediment, changes in vertical distribution of bacteria and biofilm activities, decrease in sediment efficiency in oxygen consumption and dissolved organic carbon mobilization (Bärlocher and Murdoch, 1989), and nitrate production (Claret et al., 1998). Suspended sediments can cause clogging up the natural interstices in substratum, which are vital to certain species of invertebrates and fish (Rivier and Seguier, 1985). Indirect effect can include, along with alteration of hydrological patterns, and clogging, the release of chemical compounds if the sediments are contaminated with toxic compounds (Jensen and Mogensen, 2000). Decreases in habitat diversity, expressed through changes in river bed substrates and hydraulics can reduce fish and benthic community diversity (Rivier and Seguier, 1985; Brown et al., 1998; Kelly et al., 2005). The summary and complex interactions of the impacts of sediment exploitation are shown in the Figure 1.

1.3 Hyporheic zone

Surface water flows not only in the open stream channel but also through sediments below stream water. The flow of water occurs in three dimensions: longitudinally down the channel; vertically between the open channel and underlaying sediments; and laterally to or from the riparian zone (Jones and Holmes, 1996). The saturated porous area beneath the stream bed and within the stream banks have been named hyporheic zone (Orghidan, 1959). The hyporheic zone has been defined conceptually as the saturated porous areas beneath the stream bed and into the stream banks that contain some proportion of channel water or that have been altered by channel water infiltration (advection) (Schwoerbel, 1961a; Triska et al., 1989; White, 1993). Modern definitions emphasize the dynamic ecotone model where the hyporheic zone can be defined as spatially fluctuating ecotone between the surface stream and the deep groundwater (Gibert et al., 1990). Below and laterally of the hyporheic zone is phreatic zone (the saturated zone of an unconfined aquifer) with specific physical, chemical and biological characteristics (Daubree, 1887; Danielopol, 1982).

In the hyporheic zone, the river water passes back and forth between the active channel and subsurface flow paths. The interaction is rapid enough that, within several kilometers, stream water in the relatively small channels is often completely exchanged with the porous water of the hyporheic zone (Harvey and Wagner, 2000). At the reach scale, the pattern of convection follows upwelling-downwelling model. A decreasing stream depth at the end of a pool, forces surface water down into the sediments (downwelling), which displace the interstitial water that may travel for some distance before upwelling into the surface stream (Boulton et al., 1998). Both, small and large hyporheic flow paths are usually present along streams; however the greatest interactions with the stream usually occurs in relatively short hyporheic flow paths that return to the stream within centimeters to tens of meters (Harvey and Wagner, 2000) (Figure 2).

The hyporheic corridor concept (Stanford and Ward, 1993) predicts gradients in relative size of the hyporheic zone, hydrologic retention and sediment size. Thus, a hyporheic development is predicted to be the least in headwater streams, peak in the intermediate reaches, and then decline in lowland rivers. The size of the hyporheic zone depends on the extent and strength of the surface-groundwater interactions, which are a function of sediment porosity, channel morphology, stenght of groundwater upwelling and stream discharge (Dahm et al., 1998).

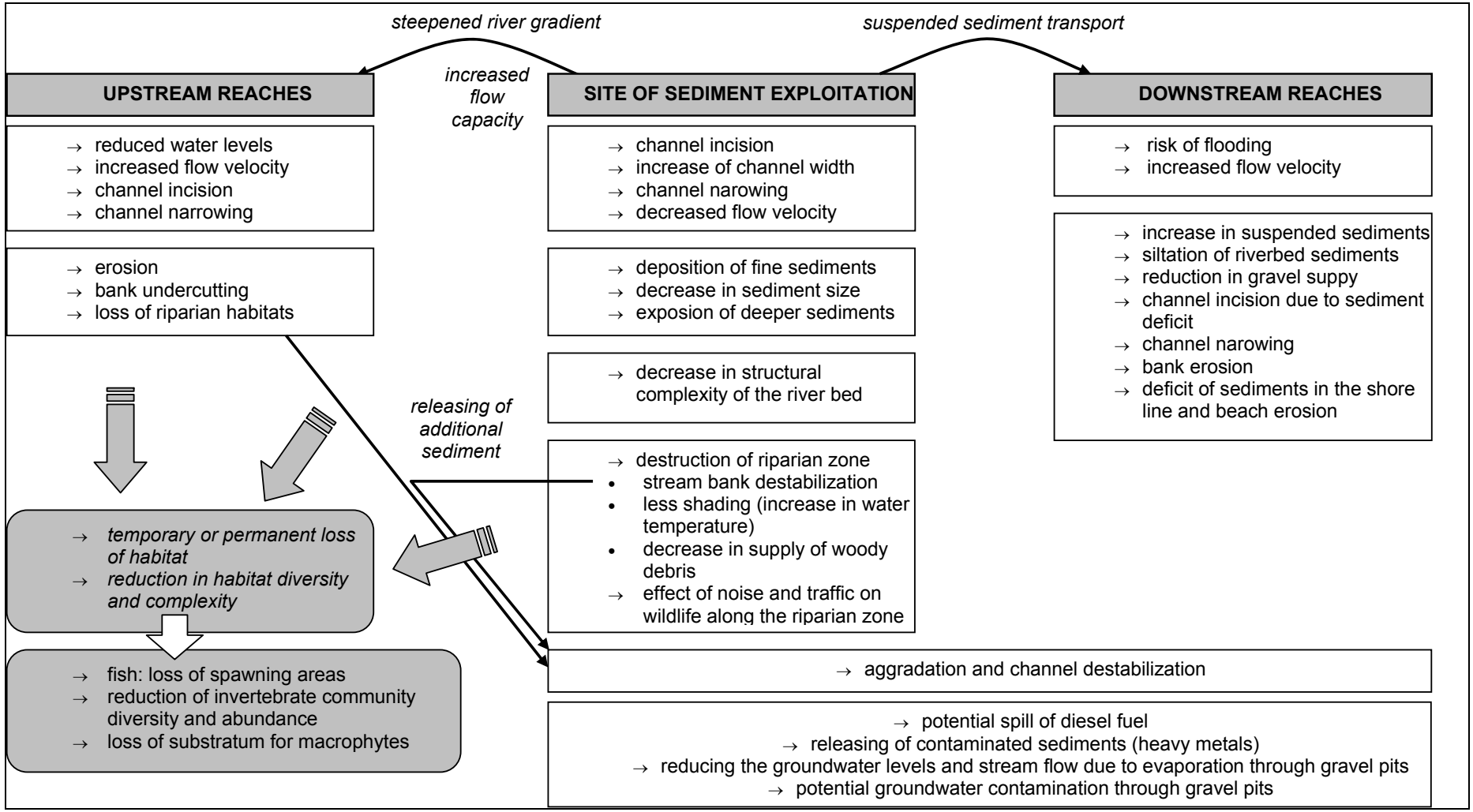

Figure 1. *A review of environmental impacts of sediment exploitation from alluvial rivers (summarized from the literature cited in References).*

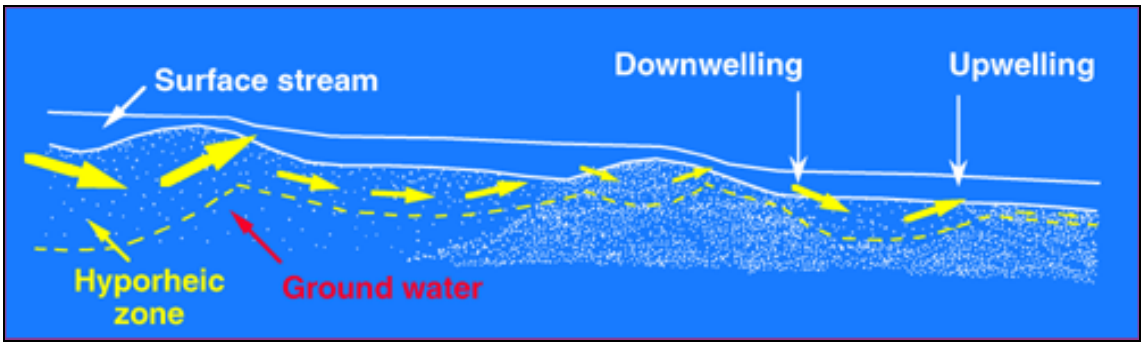

Figure 2. *Surface–subsurface exchange patches induced by spatial variation in streambed topography and sediment permeability. Arrows indicate direction of flow and their width corresponds to flux rate of advected channel water within the sediments (after Malard et al. (2002)).*

The hyporheic zone is of functional and structural significance not only for the hydrology but also for ecology of the alluvial floodplain (Stanford and Ward, 1993). Exchange of the surface water and groundwater in the hyporheic zone is important in maintaining, and regulating for overall stream processes through storage and release of carbon, nutrients, and other dissolved substances. Exchanges of the water have direct consequences for the physical, chemical and biological patchiness in the hyporheic zone (Dole-Olivier, 1998). The importance of hydrologic exchange between streams and hyporheic zones is that keeps surface water in close contact with chemically reactive mineral coatings and microbial colonies in the subsurface, which has the effect of enhancing biogeochemical reactions that influence downstream water quality (Gibert et al., 1990; Harvey and Bencala, 1993; Mulholland et al., 1997; Harvey and Wagner, 2000). Therefore, the hyporheic zone contributes significantly to the metabolism of stream ecosystems (Grimm and Fisher, 1984), and biological self-purification capacity of the stream is increased by the contribution of an intact and active hyporheic zone (Pusch, 1996).

The interstitial spaces among sediment particles in the hyporheic zone, filled by porous water, are occupied by a diverse array of aquatic invertebrates, termed the “hyporheos” (Orghidan, 1959). Hyporheos is composed of stygoxenes, stygophiles and stygobionts (Thienemann, 1925). Stygoxenes are organisms that have no affinities with groundwater systems, but occur accidentally there (Brancelj and Dumont, 2007). They passively penetrate into alluvial sediments and can influence processes in groundwater ecosystems, functioning as either predator or prey (Gibert et al., 1994b). Stygophiles are intermediate between stygobionts and stygoxenes: they spend part of their life belowground, and may even be more common in groundwater than in surface waters (Brancelj and Dumont, 2007). Stygobionts are specialized groundwater forms, living exclusively in ground waters. Some are widely distributed in all types of groundwater systems (karstic/fissured and alluvial/porous) and some are restricted to the deep groundwater substrata of porous aquifer. They display morphological and biological adaptations to the interstitial life where pore size and absence of light are limiting factors. They are distinguishable from surface organisms through traits such as reduction of eyes, loss of body pigment, small size, elongated shape and reduction of setae (Camacho et al., 1992). They are adapted to the oligotrophic conditions and low oxygen concentrations, have low metabolic rates (Simcic et al., 2005) and a high tolerance of low oxygen levels (Danielopol et al., 1994).

The hyporheic sediment pores can act as an aquatic refuge for invertebrates during droughts (Williams, 1977), can be used by early instars of benthic insects as refuge against strong currents (shear stress), extreme temperatures and offering stable substrates during bed load movement (Schwoerbel, 1964; Ward, 1992). The loss of fauna from the stream bed during floods is expected to be low if the depth of scour into the bed is less than the total depth of the hyporheic zone and the fauna is predicted to be distributed more deeply in the stream bed at higher flow (hyporheic refuge hypothesis) (Palmer et al., 1992). Hyporheic zone can be used as well, as a nursery by some insect taxa (e.g. Leuctridae, Heptagenidae) (Malard et al., 2003). The hyporheic fauna also contribute significantly to the overall biodiversity of the river ecosystem (Malard et al., 2003).

During the last four decades, numerous studies have investigated the relationships between biodiversity and distribution of hyporheic invertebrates and environmental factors (Williams and Hynes,

1974; Godbout and Hynes, 1982; Dole-Olivier and Marmonier, 1992b; Franken et al., 2001; Hunt and Stanley, 2003; Malard et al., 2003; Storey and Williams, 2004). It was shown that spatial and temporal variability of hydrological and geomorphological processes plays an important role in determining habitat heterogeneity, habitat stability, and connectivity between habitat patches, and thereby structuring biodiversity patterns (Dole-Olivier et al., 1993; Ward et al., 1998). Malard et al. (2003) have found positive correlations between taxonomic richness and temperature, the influence of groundwater and the amount of organic matter. Storey and Williams (2004) have demonstrated the influence of depth on invertebrate richness, density and taxonomic composition. Several consistent patterns have been recognized showing the differences in invertebrate community between downwelling and upwelling zones (Dole-Olivier and Marmonier, 1992b; Brunke and Fischer, 1999; Mermillod-Blondin et al., 2000), between river bed and river banks (Williams, 1989; Boulton et al., 1992a), and gradual changes with depth (Williams and Hynes, 1974).

Fluvial dynamics and bed sediment characteristics determine the hydraulic conductivity of hyporheic flow paths, the heterogeneity of pore space and particle size, oxygen levels, organic and inorganic contents and other habitat conditions (Ward et al., 1998) (Figure 3). Those habitat conditions are dynamic in time and space and largely determine the characteristically patchy distribution and abundance of biota in surface water as well as in groundwater (Stanford, 1998). Size of sediments shape the environment of the stream and constitute the precise habitat of the hyporheic community in porous systems. Every stream and groundwater organism interacts in complex ways with the sediment during its lifetime (Ward et al., 1998). Thermal regime of running waters is controlled by climate, insolation and hydrology (Ward, 1985). The sediments of upwelling zones have stable temperatures, while the temperature of sediments in downwelling zones varies with that of stream (Shepherd et al., 1986). Seasonal shifts in temperature influence the biogeochemical processes in the hyporheic zone (Sheibley et al., 2003) and have primary control on phenologies, life histories, physiology, behaviour, local distribution patterns of aquatic organisms, and set the limits of their distributional range (Ward and Stanford, 1982). Dissolved oxygen is an important environmental parameter in porous habitats (Ward et al., 1998). A strong relationship between dissolved oxygen (DO) concentrations and density, diversity and composition of invertebrate communities in the hyporheic zone were found (Williams and Hynes, 1974; Rouch, 1988; Danielopol, 1991). Organic matter (i.e. organic carbon) is present within the sediments as particulate (i.e. dead) organic particles (POC) and dissolved organic matter (DOC), as living organisms and as biofilm (Leichtfried, 1988). DOC is the mayor energy source in the heterotrophic groundwater systems while particulate organic matter gains importance in upper sediment layers. Thus the sediment biota is dependent on inputs from autotrophic, surface habitats (Brunke and Gonser, 1997). DOC entering the stream bed from stream water sources is assumed to differ in quality from the DOC entering the streambed from “old” hyporheic and groundwater sources (Hendricks, 1996).

Hyporheic invertebrates are assumed to be mostly detritivores (Boulton et al., 1992a), but also grazers or predators. The potential food source for this fauna is biofilm coating inorganic particles (Bärlocher and Murdoch, 1989). The hyporheic biofilms consist of bacteria, fungi, heterotrophic algae, protozoans and micrometazoans (Hendricks, 1993). The variables that affect the extent, composition, and food quality of the biofilms probably influence the distribution of grazing invertebrates (Gibert et al., 1994a). Several studies have investigated the relationship between food resources and invertebrate communities. The role of food supply is important because it determines the potential strength of biotic interactions, particularly competition (Storey and Williams, 2004). The correlations between invertebrate density and the amount and quality of POC have been demonstrated (Bretschko and Leichtfried, 1988; Strayer et al., 1997). Brunke and Fischer (1999) have shown the positive correlations between invertebrate richness and density and bacterial abundance and production. Franken et al. (2001) have found that invertebrate density and richness were correlated with sediment protein content, which is a measure of biofilm development. Along with hydrology, substrate type, and more variable resources (e.g. food), life histories of species, compensatory upstream migrations and behaviour (daily vertical migration) could be important factors in creating certain distribution patterns of hyporheos (Bretschko and Klemens, 1986).

Many studies of hyporheic invertebrate communities have been conducted on headwater, mountainous, gravel-bed streams with turbulent hydrology. Storey and Williams (2004) investigated spatial responses of hyporheic invertebrates to seasonal changes in a gravel bed stream (Ontario, Canada), while longitudinal patterns of hyporheic invertebrates were examined in a glacial river of Switzerland (Malard et al., 2003). The relative contributions of the magnitude and direction of vertical

hydrological exchange, subsurface sediment composition and physical and chemical properties of porous water in determining the distribution of hyporheic invertebrates was studied in a gravel-bed stream from New Zealand (Olsen and Townsend, 2003). A contribution of the hyporheic zone to ecosystem metabolism was analyzed in a pre-alpine, gravel-bed river from Switzerland (Naegeli and Uehlinger, 1997).

The impacts of natural disturbances, such as spates on the hyporheic communities have been investigated by many authors (Marmonier and Creuzé Des Châtelliers, 1991; Dole-Olivier and Marmonier, 1992c; Palmer et al., 1992; Boulton and Stanley, 1995; Dole-Olivier et al., 1997; Matthaei et al., 1999; Olsen and Townsend, 2005) while studies of anthropogenic impacts are less frequent. It has been shown that composition of hyporheic assemblages vary among streams with differing land-use types (Boulton et al., 1997). In Slovenia, the hyporheic invertebrate communities of karstic, low-land, gravel-bed rivers in relation to different land use and anthropogenic disturbance were studied (Mori and Brancelj, 2005).

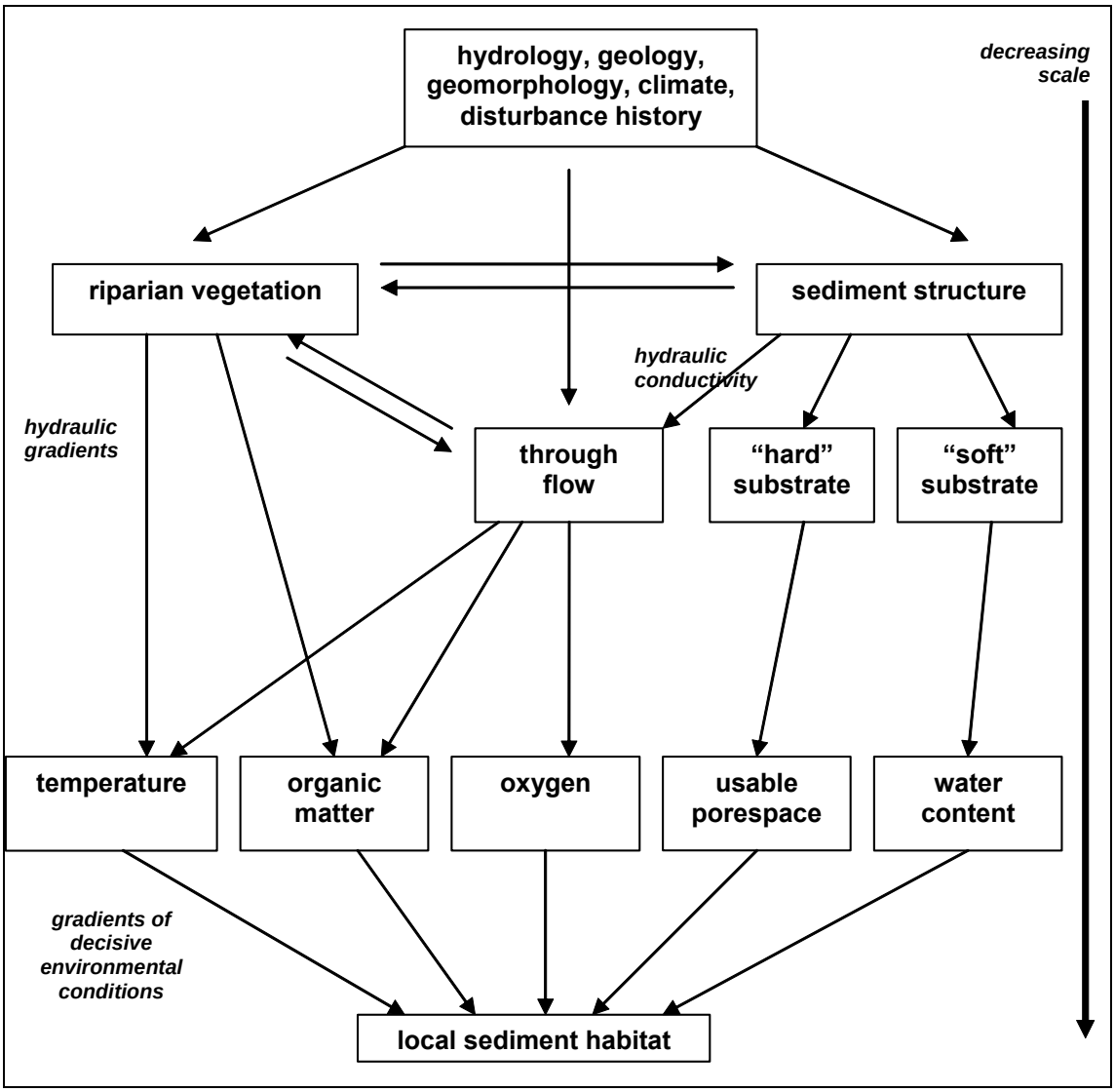

Figure 3. *Hierarchial conceptualisation of factors controlling local sediment habitat conditions of major importance to hyporheic biota (after Ward et al., 1998).*

1.4 Drift

Drift is a downstream transport of aquatic invertebrates and is a common phenomenom in running waters. Drift has two main sources: plankton organisms from standing waters (lakes, accumulations) that drift into the rivers (allochthonous drift) and organisms from the river benthos that enter drift (autochthonous drift) (Hynes, 1972). Here only autochthonous drift from the rivers will be discussed.

Drift phenomena has been widely studied since the 50's of 20th century (Waters, 1961; Waters, 1965; Elliot, 1967; Larkin and Mckone, 1985; Flecker, 1992; Saltveit et al., 2001) Several categories of drift have been used in the literature: catastrophic drift, behavioural drift (active drift and distributional drift) and constant drift (random and accidental drift) (Brittain and Eikeland, 1988).

Catastrophic drift usually refers to the flood conditions during which the substrate is physically disturbed by high discharge, or to other major, adverse events, such as drought and high temperatures. *Behavioral drift* includes drift due to two different behavioural aspects. Firstly, animals drift indirectly as a result of their activity. For example, while foraging, animals may lose their foothold and enter the drift. Secondly, animals may actively enter the water column, for example to escape from a predator (*active drift*). *Distributional drift* is envisaged as a method of dispersal, especially in the very young stages soon after egg hatching (Waters, 1965; Müller, 1973). Waters (1965) suggested that because absolute growth is greatest in later instars, energy demands may lead to greater intraspecific competition, foraging activity and drift. Waters further proposed that final instar individuals may disperse prior to emergence or pupations, in preparation for reproductive activity or, that larger organisms may protrude farther into the current, increasing the risk of dislodgement. *Constant drift,* also called background drift, is defined as drift in low numbers due to accidental dislodgement from the substrate irrespective of any diurnal periodicity (Waters, 1965).

Drift is usually measured as drift density (numbers per volume of water filtered) or as drift rate (numbers passing a point during a time period, usually the number for the entire stream per 24 hours) (Allan, 1995). Animals in drift traverse a substantial length of stream. How far animals travel varies with species, water velocity and perhaps also with turbulence. When animals are moving downstream they spend much more time on the stream bottom than in the water column (Larkin and Mckone, 1985). Animals drift a short distance, regain the bottom, re-enter the drift once again, and so on.

The insect taxa, Ephemeroptera, Plecoptera, Trichoptera and Simuliidae are the most numerous representatives of drift (Allan, 1995). The downstream transport of invertebrates varies with season, from day to day and during the course of the day (Brittain and Eikeland, 1988). Drift has been influenced by abiotic parameters, such as current/discharge, photoperiod, and water chemistry, and by biotic parameters such as benthic densities, predators, competition, life cycle stages and endogeneous rhythms (Brittain and Eikeland, 1988).

An increase in discharge or vater velocity leads to increased drift (Crisp and Robson, 1979). The increase in drift recorded can be explained by increasing the scouring effect of increasing water velocities on the substrate. Such shear stress can increase the chance of dislodgement when animals are active, as well as removing them from their shelters or displacing their habitat (Mackay and Kalff, 1973). Other factors, such as low discharge (drough) and man made regulations can also increase drift rates (Brittain and Eikeland, 1988). Furthermore, drift is dependent on photoperiod. The number of drifting animals is usually greater by night than by day, often as much as an order of magnitude greater (Waters, 1965). Although most taxa show a nocturnal peak in numbers, the Chironomidae usually are reported to be aperiodic, while water mites and some trichopterans are day-active (Allan, 1995). Concentrations of oxygen, pH and temperature are other environmental factors affecting drifting of organisms (Brittain and Eikeland, 1988). Several other factors, most of which fit within the category catastrophic drift, have been shown to increase drift rates. These include sedimentation (Rosenberg and Wiens, 1978), insecticides (Lauridsen and Friberg, 2005), and dredging (Pearson and Jones, 1975).

Due to heterogeneous composition of drift (different taxa with different behavioural patterns) and fluctuation of abiotic factors, the relationships between benthic densities and drift rates are not clear (Brittain and Eikeland, 1988). Some species drift density dependent, while some don't, and some behave differently in different environmental conditions. Drift can be influenced also by food availability and quality. It seems likely that food shortage stimulates increased activity which in turn leads to

increased drift (Brittain and Eikeland, 1988). Further on, it was proposed that predation could partially explain the diel periodicity and relative abundance of invertebrates in stream drift (Peckarsky, 1979).

Drift is an important component in colonization and recolonization of denuded stream substrates (Williams and Hynes, 1976a). The importance of drift as a means of locomotion between suitable microhabitats provides a reasonale model for the patchy distribution of stream invertebrates (Minshall and Petersen, 1985). Drift has been shown to be the most important pathway of recolonization after spates and after experimental disturbance (Matthaei et al., 1997). The other role of invertebrate drift could be that it enables aquatic organisms to escape unfavourable physical, chemical, or biological situations (Brittain and Eikeland, 1988). However, mortality poses a real threat to drifting organisms. Moreover, for certain quatic organisms (fish, net-spinning caddis larvae) drift provides an important food source.

1.5 Disturbance and recolonisation

Disturbances have traditionally been viewed as uncommon, irregular events that cause abrupt structural changes in natural communities, moving them away from homeostatic, near-equilibrium conditions (Sousa, 1984). Disturbance is both a major source of temporal and spatial heterogeneity in the structure and dynamics of natural communities and an agent of natural selection in the evolution of life histories. Disturbances can be described by their frequency (e.g. the 100-year flood), duration (length of time), magnitude (areal extent), intensity (force exerted), and severity (the biological response) (Sousa, 1984).

In stream ecosystems, disturbance is defined as any relatively discrete event in time that is characterized by a frequency, intensity, and severity outside a normal oscillation range, and that disrupt normal function of ecosystem, community, or population structure and change resources or the physical environment (Pickett and White, 1985; Resh et al., 1988). Of the three mayor hypotheses relating disturbance to lotic community structure: a) the equilibrium model, b) the intermediate disturbance hypothesis and c) the dynamic equilibrium hypothesis, the latter is the most widely accepted, although specific studies support the former two (Resh et al., 1988). The equilibrium model assumes the constant environment and biotic interactions as determinants of community structure. The intermediate disturbance hypothesis (Connell, 1978) proposes that biodiversity is highest when disturbance is neither too rare nor too frequent. With low disturbance, competitive exclusion by the dominant species rises. With high disturbance, only species tolerant of the stress can persist. In this hypothesis disturbance have the function to mitigate the effects of competition in the stream community, and permits poorer competitors (i.e. species with narrow tolerance) to remain in the system. The dynamic equilibrium hypothesis (Huston, 1979) regards community structure as a tradeoff between growth rates, rates of competitive exclusion, and frequency of population reductions. If the recurrence interval of disturbance is shorter than the time necessary for competitive exclusion, then species that are poorer competitors persist in the system. This serves to increase species richness, unless disturbance is severe or frequent enough to eliminate those with long life cycles. By this hypothesis, the diversity is determined not as much as by the relative competitive abilities of the competing species as by the influence of the environment on the net outcome of species interactions. Normally, in the stream ecosystems, the recurrence intervals of disturbance events (spates, droughts, anthropogenic inputs) are shorter than the time necessary for competitive or predator-prey interactions to lead to the elimination of species (Resh et al., 1988).

Disturbances caused by drastic variations in flow have been considered as one of the most important factors regulating the structure of lotic invertebrate communities (Reice, 1985; Resh et al., 1988; Reice et al., 1990). Mostly, the response of benthic community composition to variations in flow was studied. The effects of disturbance and re-colonization processes of stream invertebrates have been studied by phenomenological accounts of particular events (Boulton et al., 1992b; Palmer et al., 1992; Palmer et al., 1995; Matthaei et al., 1997; Matthaei et al., 1999) by comparative studies in streams with contrasting disturbance regimes (Scarsbrook and Townsend, 1993), and by experimental manipulations. When studying the effects of experimental disturbance, the extent of disturbance differed greatly. Some researchers studied small-scale disturbance by using implanted substrate or disturbing small patches of stream bottom (Williams and Hynes, 1976a; Shaw and Minshall, 1980; Williams, 1980; Reice, 1985; Boulton et al., 1988; Englund, 1991; Bo et al., 2006), while others

disturbed larger patches (Matthaei et al., 1996; Olsen et al., 2007) or used artificial stream channels (Bond and Downes, 2003).

Smaller number of studies has been investigating the effects of disturbance and colonization patterns in the hyporheic zone. It was recognized, that physical disturbance to the hyporheic zone occurs via large scale bed movement during high discharge events (Matthaei et al., 1999), and chemically via temporal fluctuations in the water table (Williams, 1993). Colonization paterns and vertical movements of the invertebrates were studied in the hyporheic zone of a stream reach in Austria (Schmid-Araya, 2000), and Italy (Bo et al., 2006), while the effects of floods on hyporheic invertebrates were investigated in a regulated (Marmonier and Creuzé Des Châtelliers, 1991), and by-passed (Dole-Olivier et al., 1997) channel of the Rhone River (France), in a New Zealand gravel-bed stream (Olsen and Townsend, 2005), and in the Hunter River (Australia) (Hancock, 2006). A faunal dynamics was studied in the hyporheic zone during flooding and drying in a Sonoran Desert stream (USA) (Boulton and Stanley, 1995). The effect of stability of river bed sediments on hyporheic community structure was investigated in several streams from New Zealand (Fowler and Death, 2001).

The rate of invertebrate recovery is dependent on the severity of the disturbance and its areal extent, availability and characteristics of potential colonists, heterogeneity of the disturbed area and timing of the disturbance (Sousa, 1984). The recovery of benthic organisms to pre-disturbance levels is usually fast (Reice, 1985; Boulton et al., 1988; Palmer et al., 1992). The experimental studies of the effects of small-scale disturbances on benthic invertebrates have shown community recovery within a few weeks (Reice, 1985) or recovery after 2 to 3 months (Shaw and Minshall, 1980). The study of response of hyporheic community to a large flood have shown recovery after four and a half months (Hancock, 2006). High resistance and resilience is characteristic for the benthic communities. They response little (e.g. change in species composition) to disturbance (resistance) and the community return to the pre-disturbance composition following displacement by disturbance (resilience) (Harrison, 1979). Groundwater taxa, those that are more abundant deep within sediments, are expected to be more resistant to the disturbance caused by flooding than surface taxa, unless the entire hyporheic zone is disturbed (Olsen and Townsend, 2005). Conversely, the resilience of populations of groundwater taxa may be lower than populations of surface taxa because groundwater taxa are expected to be less fecund and slower growing than related surface taxa (Malard and Hervant, 1999).

The benthic organisms re-colonizing an area of denuded stream substrate are thought to come from four main sources: a) drift, b) upstream migration within the water, c) migration within the substrate and d) aerial sources (e.g. oviposition) (Williams and Hynes, 1976a). After “smaller” spates drift and re-immigration from intacted patches are more important re-colonization mechanisms than recruitment from eggs, while large flood events have a longer lasting impact on the benthic invertebrate and recovery occur mainly through recruitment from eggs (Matthaei et al., 1997). Williams and Hynes (1976b) emphasized the importance of re-colonization up from within the substrate, as the hyporheos consist of the larvae of many stream insects, and also the adults and immature stages of non-insects (meiofauna). On the contrary, Palmer et al. (1992) showed that during large floods, the hyporheic zone in the fine sand sediments can not serve as refuge and that recovery of fauna after disturbance is only partly from the hyporheic sediments and partly through reproduction. Dole-Olivier et al. (1997) and Olsen and Townsend (2005) showed that hyporheic zone may provide patchy refugia, with the significance of the refugia being affected by factors such as the direction of vertical hydrological exchange.

1.6 Legislation and management of alluvial sediment resources

In Slovenia, the awareness of the authorities for the protection of environment is consistent and at present in accordance with European Union Environmental Legislation. The main environmental objectives, such as the preservation, protection and improvement of the quality of the environment, protection of public health, and prudent and rational use of natural resources are covered by Constitution and the Environmental Protection Act (Official Gazette of RS, No. 41/04). The state organs which are involved in environmental legislation are parliament and the Ministry of the Environment and Spatial Planning (MESP). The responsibilities and activities of the MESP relate to the protection of the environment and nature, spatial planning and ensuring that various acts passed by local communities are in line with national legislation.

As summarized in the previous chapter (1.2), the use of alluvial sediments may have several deteriorating effects on river ecosystem. Moreover, different interests can meet in the area of river valley exploited. Due to this, national regulations on resource use are established. The use of alluvial sediments for commercial reasons is regulated by the Water Act (Official Gazette of RS, No. 67/02, 2/04), and the Nature Conservation Act (Official Gazette of RS, No. 56/99, 31/00, 110/02, 119/02, 41/04). The Water Act determines exploration permits, water rights, monitoring and revitalization of waters. Extraction of alluvial deposits is subject to a water right in the form of a water permit issued by the Environmental Agency or a concession granted by the Government. Funds from water rights and water use fees are collected in the Water Fund and are used for water management. The Nature Conservation Act prescribes biodiversity conservation measures and a system for the protection of valuable natural features. Subjected to those Acts are different decrees, such as Decree on water fees (Official Gazette of RS, No. 103/02) and decree on concessions for the commercial exploitation of alluvial deposits at local level.

1.7 Outline

Hyporheic zone of the Bača River was studied in order to define the invertebrate community living in the gravel-bed of the pre-Alpine river system and to investigate how gravel extraction from the river channel influence the structural and functional biodiversity of the hyporheic communities. This research should contribute to answer the question how hyporheic invertebrate community responds to variation in discharge, temperature and food resources through the year, as well as, how the human-induced physical disturbance due to gravel extraction effects the taxonomic richness, density, size spectra of invertebrates, microbial activity and organic matter contents of hyporheic zone and invertebrate drift. The research should stress out the importance of biological processes in the hyporheic zone for the quality of adjacent groundwater and reveal the potential effects of gravel extraction on the stream metabolism and groundwater quality. Unfortunately, a large flood, which coincidently felt together with the period of gravel extraction, blurred the consequences of gravel extraction activities on hyporheic fauna. On the other hand, we had an opportunity to study the response and recovery of hyporheic fauna to natural disturbance and to compare it to the anthropogenic one.

Further on, the in-stream gravel extraction, a common commercial activity in the Soča River catchment, has been observed during the research period, and an attempt was made to describe the most important socio-economic forces driving those activities, followed by analysis of type of environmental pressures, current state and impacts on the environment. According to this, the society response to the gravel extraction activities was identified.

1.7.1 Hypotheses

In this research the following hypotheses has been put forward:

a) discharge is the major factor shaping the hyporheic community living in the sediments of the Bača River;
b) the community responses to anthropogenic disturbance at impacted site will be different than responses to natural variations through the year at reference site;
c) the structure of catastrophic drift will be significantly different than natural one;
d) the vagile taxa such as aquatic insect larvae will be the first taxa in the recolonization of disturbed sediments, followed by meiofauna.

2 THE STUDY AREA

The Bača River, a fourth order stream in western Slovenia, is a tributary of the Idrijca River, which is along with the Tolminka and the Vipava Rivers, one of the main tributaries of the Soča River. The Soča River flows into the Adriatic Sea (Figure 4). The Bača River drainage area covers 145 km^2. It flows for 25 km through the narrow valley of Baška Grapa and joins the Idrijca River at the village Bača pri Modreju. Few kilometers onwards the Idrijca River merges with the Soča River at the village Most na Soči. The characteristics of the Baška Grapa valley are extremely narrow bottom and steep slopes (V shaped valley – Vintgar type). The valley is placed in the area of the Julian Alps (incl. Bohinj mountains), and is surrounded with the peaks between 1000 and 2000 m a.s.l. The valley widens at the end of Baška Grapa. The catchment area is composed of limestone and dolomite rock, and the slopes are overgrown by the fir-beech forests (*Homogyno sylvestris-Fagetum*) (Dakskobler, 2002).

The annual rainfall of the catchment area is between 2000 and 3000 mm per year and the mean annual air temperatures are between 6 ºC and 12 ºC (Fridl et al., 1998). The downstream part of the Bača Valley has characteristics of subterranean climate due to influence of the Adriatic Sea. The mean annual water temperatures, measured at hydrographic station of Bača pri Modreju, in 1998, 1999 and 2004 were 8.8, 9.4 and 9.8 ºC, respectively. In 2004, the lowest water temperature was 0.9 ºC (November) and the highest 18.4 ºC (August) (source: Environmental Agency, Ministry of the Environment, Spatial Planning and Energy).

The Bača River is a run-off fed stream, where discharge is primarily a function of rainfall. Consequently, the predictability of discharge rates is relatively low, especially in October and November. The mean annual discharges were 7.1 m^3s^{-1} for a period between 1961 and 1990, and 6.6 m^3s^{-1} for a period between 1991 and 2004 (source: Environmental Agency, Ministry of the Environment, Spatial Planning and Energy). The mean maximum and minimum daily discharges for 13 years were 38.7 and 2.6 m^3s^{-1} respectively. The lowest daily discharge usually occurred in August and the highest in October/November (Figure 5). The analysis of hydrological data for the period of 45 years for the Bača River as well for the Soča River showed a general decrease in the average minimum low discharges and, on the other hand, the increase in the annual extremes of high discharges (Ulaga, 2002). The global climate change and changes in land use are probably the main reasons for such trends.

Gravel supply in rivers is dependent upon the catchment area, topography, lithology, and rainfall (Kelly et al., 2005). Due to specific conditions (high precipitation rates, steep relief, erosion-prone rock), the Bača River is aggrading and sediment production in the drainage basin is high, resulting in the frequent delivery to the river. Consequently, the Bača River has good developed gravel bars, especially in downstream reaches. The upstream reaches are, due to railway and road running along the narrow valley, technically regulated at some parts. The Bača River is important from the fisheries point of view. In the river are the important spawning sites for marble trout (*Salmo marmoratus* Cuvier, 1817) and grayling proper (*Thymallus thymallus* Linnaeus, 1758).

“Bedload traps” were constructed in the Bača River channel in 2000 to prevent the sediment overloading of the hydropower reservoirs, which are located downstream on the Soča River (Figure 6). Gravel traps were constructed upstream from the village Bača pri Modreju, extending in the last 1 km before the confluence of the Bača River with the Idrijca River, and were for the first time emptied in 2004. One advantage of gravel traps as a method for harvesting gravel is the concentration of mining impacts at one site, where heavy equipment can remove gravel without impacting riparian vegetation or natural channel features. If gravel is removed from the downstream end of the deposit, and a grade control structure at the upstream ends of the gravel trap, the headcutting upstream from the extraction is prevented and there is little or no hydraulic impact upstream due to the extraction (Kondolf et al., 2002).

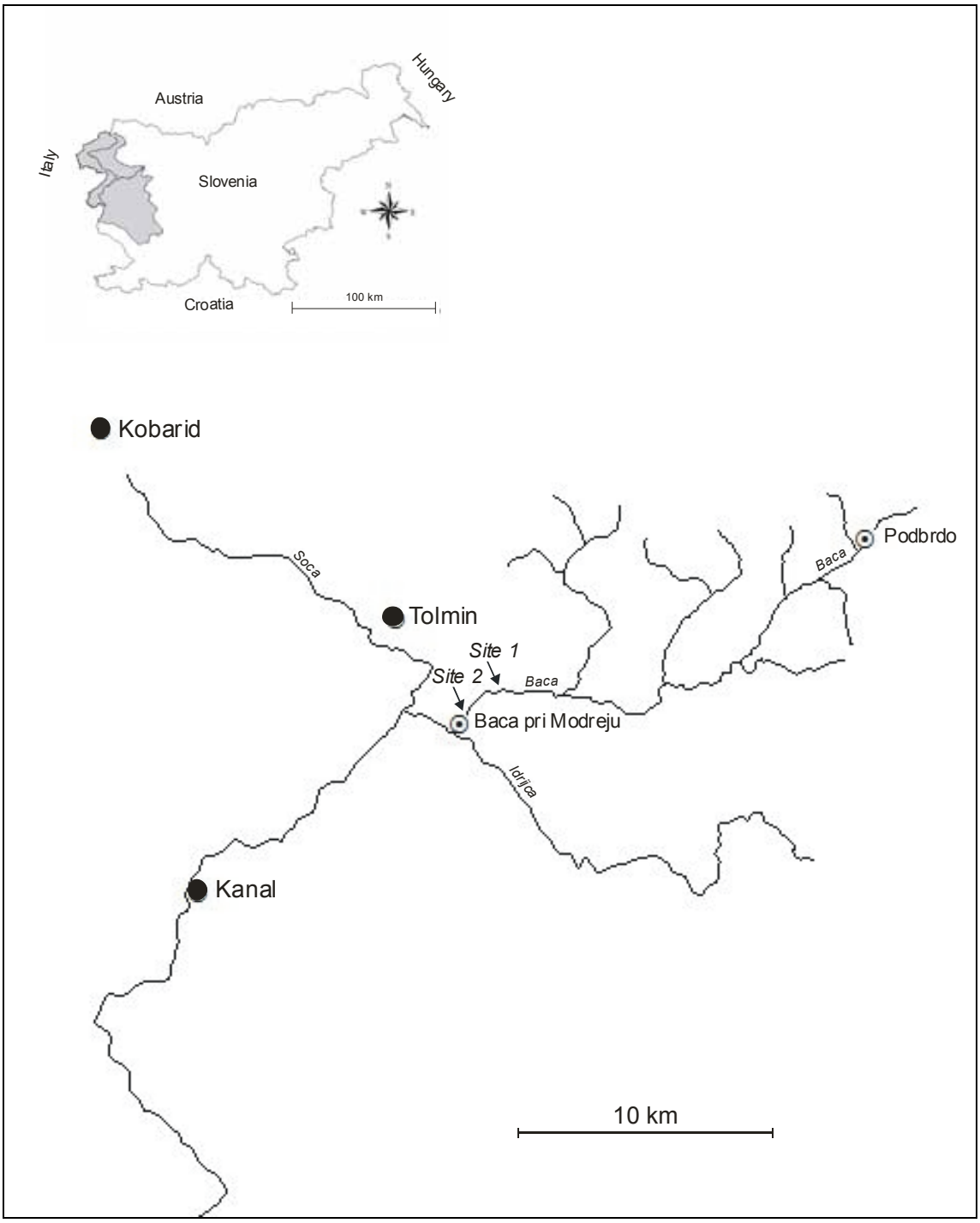

Figure 4. *Map of the Soča River with its tributary the Bača River and the study sites (site 1 – reference site; site 2 – impacted site)*

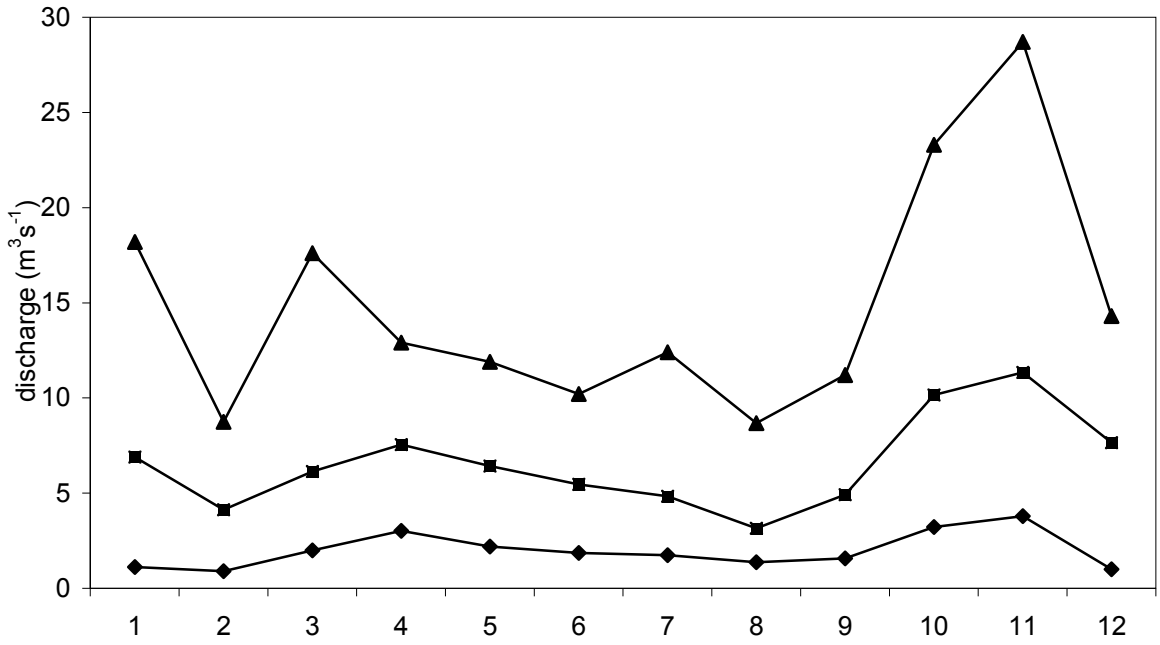

Figure 5. *Maximum (triangles), mean (squares) and minimum (diamond) monthly discharges (m^3s^{-1}) of the River Bača (W Slovenia) for the period 1991-2004 (source: Environmental Agency of Republic Slovenia).*

Figure 6. *The photo of bedload traps (impacted site) in the Bača River near the village Bača pri Modreju based on real satellite images taken in July 2007 (source: http://earth.google.com). The circle indicates the area of sampling.*

3 MATERIAL AND METHODS

3.1 Sampling sites and hydrographic events

Sampling was carried out from June 2004 to May 2005. Two sampling sites were selected, named reference (Gauss Krueger coordinates: x=5113650; y=5406900) and impacted site (Gauss Krueger coordinates: x=5112200; y=5405325). The first site (reference site) was located 3 km upstream from the outflow of the Bača River into the Idrijca River and the second (impacted site) 0.5 km upstream from the Idrijca River at the altitude between 190 and 180 m.a.s.l. (Figure 4). At reference site the hyporheic invertebrate community was observed in relation to natural variation of environmental factors. At impacted site the gravel extraction was carried out (on the location of gravel traps). At reference and impacted site, the first sampling was conducted on June 11 2004 (pre-disturbance data). A large flood with a maximum discharge of 176 m^3s^{-1} occurred on October 10 2004 (mean daily discharge of 108 m^3s^{-1}), followed by two smaller discharge peaks on October 16 and 31 (mean daily discharge of 38 and 44 m^3s^{-1}, respectively) (Figure 7). The flood caused intensive substratum movement and replacement along the whole stream channel (reference and impacted site). The sampling was carried out on days 5, 12 and 20 after high flow events (post-disturbance data). The next sampling was carried out in January (day 74), March (day 137) and May 2005 (day 206). At impacted site, two samplings where carried out before the high flow events and gravel extraction (on June 11 and September 16 2004) and one between two high flow peaks (on October 22 2004), a day before gravel extraction. The samplings after gravel extraction were conducted at the same time intervals as at reference site. The period of gravel extraction activities (October 23 – 28 2004) coincidently felt together with the period of high flow.

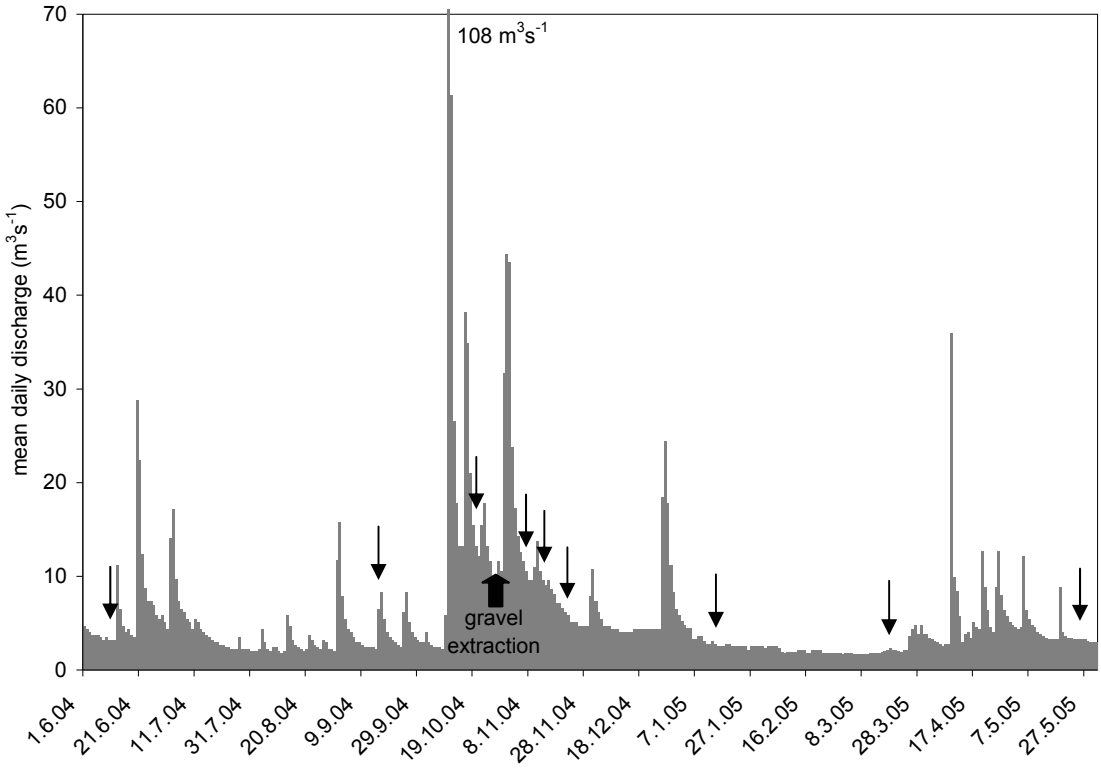

Figure 7. *Mean daily discharge (m^3s^{-1}) of the Bača River (W Slovenia) during the study period. Arrows indicate the sampling dates and the period of gravel extraction.*

3.2 Gravel extraction activities

The gravel extraction activities started on October 23 2004 at 10.45, when one dredger started to excavate gravel from the right bank of the channel upstream of the barrage and continued with excavating downstream of it (Figure 8). During the first day, extraction was carried out for four hours, from 10.45 untill 14.45. The right side of the channel was deepened up to 3 m in the length of 100 m. The belts of increased turbidity were observed downstream of extraction, continuing to the confluence with the Idrijca River and even further downstream (few kilometers downstream). The excavation continued on October 25, when the whole channel in the length of 100 m downstream of the barrage was deepened up to 3 m during 10 hours period. The next day (October 26), the bedload trap was partly depleted, and the whole river channel was deepened up to 3 m in the length of 100 m. Gravel extraction activities ended on October 28. During all four days (October 25-28) the extraction was carried out from 7.00 in the morning until 22.00 in the evening.

The extraction was followed by high discharge from October 30 to November 2, when large amounts of gravel were transported along the Bača River. The part of gravel transported downstream was captured by bedload trap. The river bottom was filled with newly deposited sediment and water depth decreased at this site, while downstream of barrage the water depth remained around 3 m.

Figure 8. *Instream gravel extraction from the Bača River at Bača pri Modreju village on October 23 2004 (photo M. Osanič).*

3.3 Sampling in the hyporheic zone

Within both sampling sites, two habitat types were studied: river bed sediments and gravel bars. At both sites, six samples, located 4-6 m apart, were taken along the length of a 100 m-long riffle, three in the river bed sediments (sampling points - RB1, RB2, RB3) and three in gravel bars (sampling points - GB1, GB2, GB3) (Figure 9, 10). During each sampling date, the sampling points were selected approximately at the same point than at previous sampling. However, due to changes in river channel

geomorphology by spates and gravel extraction, the samples could not be taken from exactly the same points during all samplings.

Hydraulic head measurements (measurement of the direction of flow in the sediments - vertical hydrological gradient – upwelling or down-welling) were conducted at all sampling occasions in the river bed. Hydraulic heads were measured with T-bar, a short metal bar with a sharpened tip at the end. T-bar was inserted into a metal tube and both of them were hammered into the sediment. The inner T-bar was then removed and a transparent measuring plastic tube was introduced into the outside metal tube. Next, the metal tube was removed, so that only the transparent measuring plastic tube remained in the sediment. The head difference between surface water and hyporheic water was directly read from the transparent tube (Figure 11).

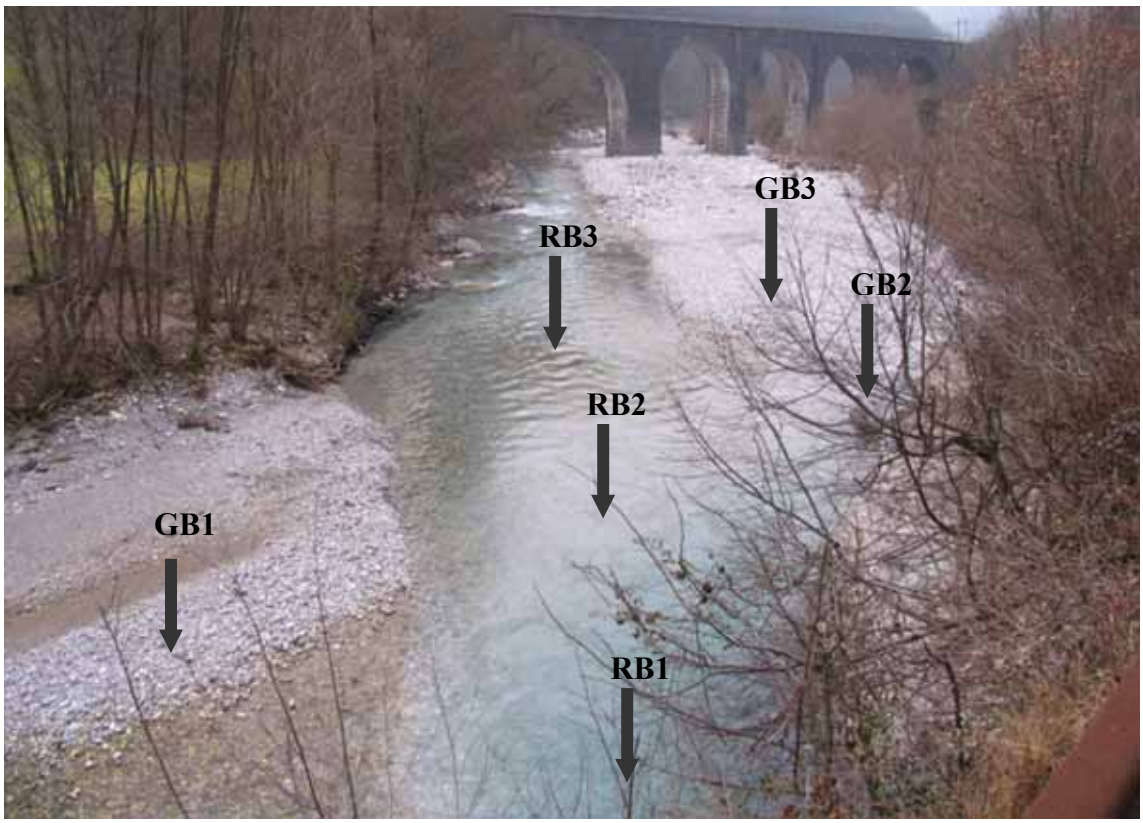

Figure 9. *Sampling points on the Bača River (W Slovenia) at reference site - site 1 (photo taken in January 2005).*

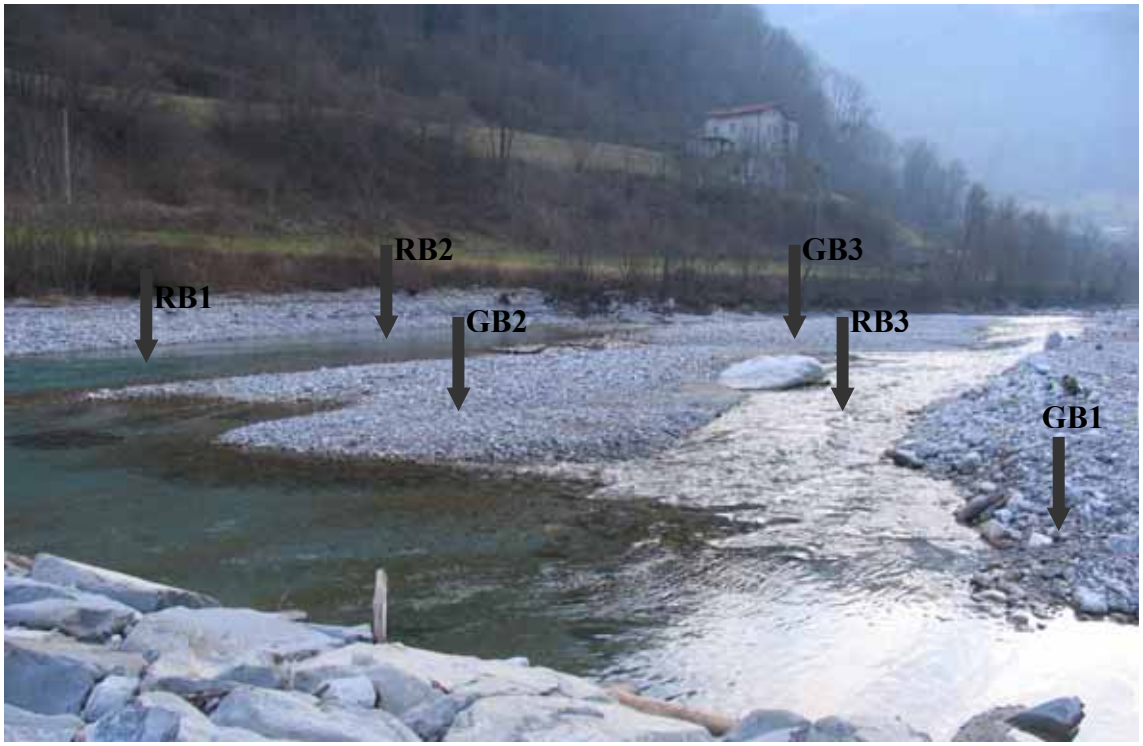

Figure 10. *Sampling points on the Bača River (W Slovenia) at impacted site - site 2 (photo taken in January 2005).*

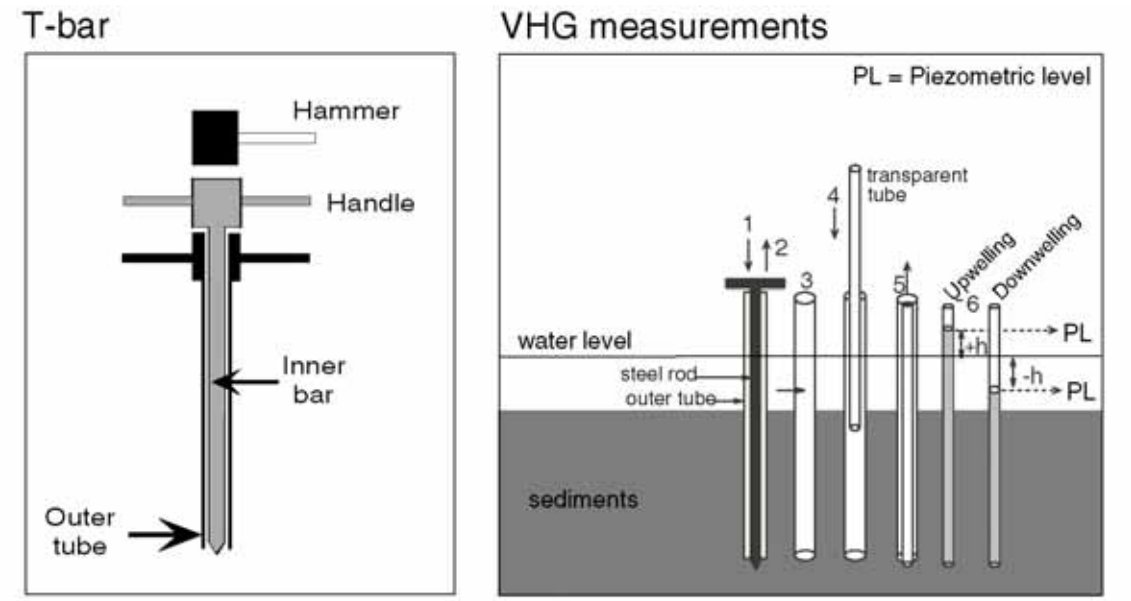

Figure 11. *Schematic presentation of the T-bar (left) and principle of the measurement of pressure differential between surface water and hyporheic water – the vertical hydrological gradient (VHG) (right) (Malard et al., 2002).*

Hyporheic invertebrates were collected from a depth between 30 and 60 cm in the river bed and from a depth between 60 and 90 cm in gravel bars. Steel pipe was hammered (internal diameter of 42 mm) into the sediments and first ten litres of hyporheic water were extracted using a Bou-Rouch piston pump (Bou, 1974). The mixture of sediment, organic matter, organisms and water was poured into a 10-L bucket and filtered through a 100 µm mesh net. Sediment left in the bucket was elutriated 5 times to separate all the animals and organic matter from the sediment. During the elutriation process, water was filtered through the same net as before. Invertebrates and organic matter were transferred into

plastic sample jars and preserved with 4% formaldehyde. The remaining sediment was collected in the plastic bottle and carried to the laboratory for further measurements. A one-liter sample of fine sediment (very fine sand and silt particles of size less than 100 µm) which remained in suspension and a sample of remaining coarser sand particles (particles greater than 100 µm) were stored separately for the analysis of microbial oxygen consumption and respiratory electron transport system (ETS) activity of biofilm. An oxygen probe (WTW Multiline P4, Oxi 320) was inserted into the Bou-Rouch pipe. Oxygen and temperature were measured after extracting the biological sample. Additionally, specific conductivity was determined, using Tetracon 325 probe. At the end of pumping, a 250 mL sample of water was withdrawn for chemical analyses. Water samples were filtered through 0.45 µm membrane filter and filtrates were stored for 1-3 days at 4ºC prior to analysis.

3.4 Drift sampling

Invertebrate drift was sampled using net drift samplers (diameter of 20 cm, mesh size 100 µm). Drift was sampled on October 23 (the first day of gravel extraction) and on October 26 2006. The drift was collected at reference site, at impacted site and 200 m downstream from the impacted site. At impacted site (site 2) three nets were positioned 10 m below the site where gravel extraction was carried out (Figure 12). The nets collected animals from the beginning of the disturbance. During the day nets were emptied every two hours and during the night (after the dark) every 6 hours. Invertebrates and organic matter were transferred from nets into plastic sample jars and preserved with 4% formaldehyde solution.

Figure 12. *Drift sampling carried out during gravel extraction in the Bača River (W Slovenia) at impacted site on the first day of excavation (23rd October 2004). Drift nets are pointed out by yellow arrows (photo M. Osanič).*

3.5 Laboratory work

a) chemical analyses
Water samples were analyzed with APHA standard methods (Clesceri et al., 1998). pH was measured using a WTW pH 540 GLP pH meter with a TetraCon 325 probe, and alkalinity (µeq l^{-1}) using titration after Gran (Clesceri et al., 1998). Nitrate, ortho-phosphate, sulphate, chloride, sodium, potassium, calcium and magnesium were measured by ion exchange chromatography (Metrohm, 761 Compact IC). Chemical oxygen demand (COD) was determined by oxidation with $KMnO_4$ and titration with oxalic acid (Clesceri et al., 1998).

b) sediment analyses
Sediment extracted during sampling was dried and separated with meshes of different size into four fractions (> 2 mm, 2 - 1 mm, 1 - 0.5 mm, 0.5 - 0.1 mm). The largest fraction (> 2 mm) was of size from 2 to 5 mm due to sampling method - use of piston pipe, which could not pump up larger particles. The amount of each fraction was measured and expressed as volume (mL) in 10 liters. The amount of fine sediment fraction (very fine sand and silt particles of size smaller than 100 µm) was determined by leaving 1 liter of hyporheic water settling down for 24 hours and measuring the amount of settled particles (mLL^{-1}).

The amount of organic matter (particles > than 100 µm) in the samples was estimated by loss- on-ignition (LOI) method (Pusch and Schwoerbel, 1994). After retrieval of invertebrates, the remaining organic matter was extracted from the sample and put into a ceramic vessel and oven-dried (24 h, 105ºC). Dried organic matter was weighed, burned at 520 ºC for 2 h and weighed again. The difference in mass before and after the ignition was used to calculate the LOI. The loss of mass on ignition was taken to be the organic matter present in the sample. The amount was expressed as mg per 10-L of hyporheic sample.

c) metabolic activity analyses
The intensity of potential and actual mineralization through microbial communities was estimated by measuring oxygen consumption and respiratory electron transport system (ETS) activity in the surface and hyporheic water, and in the fine (particles < 100 µm) and coarse (particles > 100 µm) sediment fraction.

Oxygen consumption rate was estimated under laboratory conditions using the closed bottle method (Lampert, 1984). Ground glass stoppered bottles (160 ml) were filled with water aerated in advance for 24 h. Air was passed through a water-filter to eliminate particles and bacteria. Three bottles received about 1 g wet mass of sediment (measured to the nearest 0.001 g) each for oxygen consumption measurement, while three bottles without sediment served as controls. All bottles were closed and kept in dark at a standard temperature of 20ºC. After 48 h, the concentration of dissolved oxygen in the experimental and control bottles was measured using a polarographic oxygen electrode (OXI 96, WTW). The difference between the oxygen concentrations in the experimental bottles and that in the controls was taken as the amount of oxygen consumed by micrometazoans and microbial communities. Respiratory data are expressed as $\mu LO_2 gWW^{-1} h^{-1}$.

ETS activity was measured using the method originally proposed by Packard (Packard, 1971), and modified by G.-Tóth (G.-Toth, 1999). Samples were homogenized in 4 ml volume of ice-cold homogenization buffer using an ultrasonic homogenizer (Cole-Parmer) for 3 min at 40 W, and centrifuged for 4 min at 0ºC at 8500 x g (2K15, Sigma). Within 10 min 0.5 ml of homogenate (in triplicate) was incubated with 1.5 ml substrate solution and 0.5 ml reagent solution for 40 min at standard (20ºC) temperature. The reaction was stopped by adding 0.5 ml stopping-solution. Blanks (1.5 ml substrate solution and 0.5 ml reagent solution) were incubated and stopped as for the test samples, and 0.5 ml of homogenate was then added. Formazan production was determined spectrophotometrically (Lambda 12, Perkin-Elmer) from the absorbance of the sample at 490 nm against the blank within 10 min of stopping the reaction. ETS activity was measured as the rate of tetrazolium dye reduction which was converted to equivalent oxygen utilised per wet mass in a given time interval ($\mu L\ O_2\ gWW^{-1}\ h^{-1}$) (Kenner and Ahmed, 1975).

d) faunistic analyses
Invertebrates were sorted, counted under stereomicroscope and identified to the lowest possible taxonomic level depending on their development stage. Most insect larvae were early instars (body size approximately 5 mm), making identification feasible to the genus or family level. Rotatoria, Hydridae, Turbellaria, Nematoda, Oligochaeta, Hydracarina, Gastropoda, Amphipoda, Isopoda and Tardigrada were not identified to the lower taxonomic levels, while Copepoda, Cladocera and Ostracoda were determined to the species level. Insect larvae were sorted into body length size classes using an ocular micrometer to separate different development stages.

Organisms were assigned to three ecological categories, so called ecotypes. They were divided into stygophiles, which were further on divided into holo-hyporheos and mero-hyporheos, and stygobionts. The classification was based on their affinity to the hyporheic habitat. As holo-hyporheos were classified species of Turbellaria, Hydridae, Nematoda, Oligochaeta, Rotatoria, Hydracarina, Gastropoda, Copepoda, Ostracoda, Cladocera, Tardigrada, and Gammarus that may be present during all life stages either in hyporheic or in benthic habitats, but they predominate in hyporheic zone. As mero-hyporheos were considered larvae of aquatic insects that spend part of their aquatic-stage in the surface and a part in hyporheic zone (early stages for protection from predators or later for more favorable conditions). As stygobionts were considered true groundwater taxa that complete their entire life cycle exclusively in subsurface water.

3.6 Data analysis

a) Size classes of macroinvertebrates
The analyses are focused on density and diversity (structural approach), as well as on the contribution of the different ecotypes (functional approach) within the community. Further on, the occurrence/frequency of different size classes of macroinvertebrates was measured in the samples (< 1mm; 1-4.9 mm; 5-10 mm; > 10 mm).

b) Diversity and evenness indices
Diversity and evenness was measured using:

- taxonomic richness (S)
- Shannon's diversity index (H) (Shannon, 1948)
- Shannon's equitability (E_H) (Magurran, 1988)

Taxonomic richness is the number of all species in a sample.

Shannon's diversity index is based on information theory, where is a measure of the average degree of “uncertainty” in predicting to what species an individual chosen at random from a collection of S species and N individuals will belong. The equation is:

$$H = -\sum_{i=1}^{n} p_i \ln p_i \qquad (1)$$

where p_i is the fraction of individuals belonging to the i-th species and ln is its natural logarithm.

Shannon's equitability (E_H) assumes a value between 0 and 1 with 1 being complete evenness. The equation is:

$$E_H = \frac{H}{H_{\max}} = \frac{H}{\ln S} \qquad (2)$$

where H is Shannon’s diversity index, H_{max} is maximum Shannon's diversity index and S is the taxonomic richness (the number of all species in a sample).

c) analyses of variance (ANOVA)
A two–way analysis of variance (ANOVA) with replication on density and diversity indices with habitat type (river bed, gravel bars) and date of analysis as main factors was performed to test differences in invertebrate community between hyporheic samples from river bed and gravel bars and between sampling dates. *Post hoc* Tukey's honest significant difference tests (Fowler et al., 1998) were performed to determine pairwise differences when significant differences among habitat types were observed. Invertebrate densities and taxonomic richness were $\log_{10}$ (x+1) transformed in order to minimize differences among variances.

d) species accumulation curves
The sample-based rarefaction curves (Mao Tau curves or expected species accumulation curves) (Gotelli and Colwell, 2001) were calculated with 95 % confidence intervals, using the analytical formulas to perform quantitative comparison among communities (Colwell et al., 2004; Mao et al., 2005). Rescaling of the expected species accumulation curves (and their 95 % confidence intervals) by individuals was carried out to compare datasets in terms of species richness instead of species density (number of species per unit of area) (Gotelli and Colwell, 2001). Rarefaction curves estimate species richness for a sub-sample of the pooled total species richness, based on all species actually discovered. An equivalent formula for expected richness, but not for the variance was independently developed by Ugland (Ugland et al., 2003). In addition, the total expected number of taxa based on Chao's function $\hat{S}_{Chao1}$ was calculated (Equation 3). The calculations were computed using software application EstimateS (Version 8.0, http://purl.oclc.org/estimates) (Colwell, 2005).

The Chao's function $\hat{S}_{Chao1}$ is defined as:

$$\hat{S}_{Chao1} = S_{obs} + \frac{F_1^2}{2F_2} \tag{3}$$

where S_{obs} is total number of species in all samples pooled and F1 *and* F2 are the frequencies of singletons and doubletons (species with only one or two individuals) in the pooled samples.

e) relationship between environmental variables and fauna
Physical, chemical and biological data were compared among nine sampling occasions using Student t-test, one-way or two-way ANOVA (date, site, date-site interaction). If non-normal, the data were $\log_{10}(x+1)$ (for density) or $\sqrt{(x+ 3/8)}$ (for taxonomic richness) transformed. Tukey-Kramer's test was used to conduct multiple comparisons (Fowler et al., 1998).

Comparison of taxonomic composition among samples was conducted using hierarchical cluster analysis based on the Bray-Curtis index of dissimilarity (Bray and Curtis, 1957). Distance trees were constructed using clustering with the linkage method or Unweighted Pair Group Method with Arithmetic Mean (UPGMA). In this method, the distance between two clusters is calculated as the average distance between all pairs of objects in the two different clusters.

Detrended correspondence analysis (DCA) was used to examine the variation in community composition between both sampling sites and each sampling occasion. DCA is unimodal method of indirect ordination and was developed to correct the major two problems of correspondence analysis, the arch effect and compression of the ends of the gradient (Ter Braak and Prentice, 1988). These problems are corrected by detrending and rescaling. The arch effect is removed by dividing the first axis into segments, and re-centering samples (detrending). Rescaling is the process of shifting the positions of samples along ordination axes to make the beta diversity constant.

Spearman's rank correlation coefficient was used to search for relationship between environmental parameters, such as metabolic activity of microbes, amount of organic matter, sediment composition, nutrients, temperature, and invertebrate diversity and density (Fowler et al., 1998).

The relationships between environmental variables and the abundances of invertebrate taxa were explored using canonical correspondence analysis (CCA) (Ter Braak and Prentice, 1988). CCA is a direct gradient analysis and assumes that species have unimodal distributions along environmental gradients. The analyses were done using computer program CANOCO version 4.5 (Ter Braak and Šmilauer, 2002). An unrestricted random Monte Carlo permutation test was performed to determine

the statistical significance of individual environmental variables and canonical axes. Results were represented as ordination diagrams.

3.7 Social aspects

For the analytical presentation of the current status regarding gravel extraction in the Soča River basin, a DPSIR framework (Drivers, Pressure, State, Impact, Response) have been used, which is a general framework for organising information about the state of the environment (Oecd, 1993). The Drivers-Pressures-State-Impact-Response (DPSIR) approach was developed by the Organisation for Economic Cooperation and Development (OECD) and is extensively used by the European Environment Agency (EEA) to provide an insight into environmental processes and the links between human activities and their impact on the environment. The DPSIR framework assumes cause-effect relationships between interacting components of the social, economic and environmental systems, which include:

- DRIVER - Driving forces of environmental change (e.g. anthropic activity)
- PRESSURE - Pressures on the environment (e.g. modification of river)
- STATE - State of the environment (e.g. river health)
- IMPACT - Impacts on population, economy and ecosystems
- RESPONSE - Response of the society (e.g. concessions, permits)

Hence, 'Driving Forces' are considered normally to be the economic and social policies of governments, and economic and social goals of those involved in industry. 'Pressures' are the ways that these drivers are actually expressed, and the specific ways that ecosystems and their components are perturbed, i.e. for the ecosystem effects of fishing, the central pressure would be fishing effort. These pressures degrade the 'State' of the environment, which then 'Impacts' upon human health and ecosystems, causing society to 'Respond' with various policy measures, such as regulations, information and taxes (Borja, 2006).

The gravel activity in the catchment was observed and described, but it was not under the control of the author. The identification of the most important stakeholders involved in gravel extraction activities in the Soča catchment was carried out in order to make the schematic presentation of interactions and connectivity among them.

4 RESULTS

4.1 Characteristics of the hyporheic zone of the Bača River

4.1.1 Hydrology and geomorphology

The Bača River had highly fluctuating discharge during sampling period (from June 2004 to May 2005), reflecting its torrential nature (Figure 7). Mean daily discharge ranged from 1.6 m^3s^{-1} (March 2005) to 108 m^3s^{-1} (October 2004). Comparative analysis of peak discharges for 2004 showed, that even in October and November, when peak discharge was approximately 100-folds higher than minimal discharge, discharge do not exceed the ± 2 standard deviation of 13-years average of monthly maximum discharges (Figure 13). This arbitrary chosen measurement gave us a general idea about, whether the spate is within the normal seasonal variation for the stream or it is an unusual event

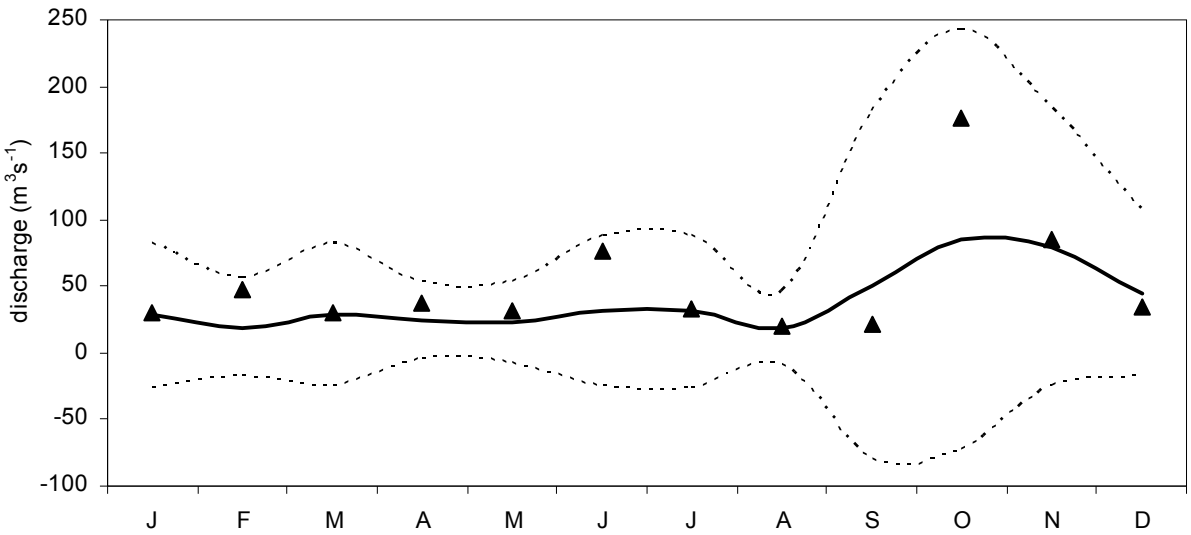

Figure 13. *Average monthly maximum discharges (solid line) for a period from 1991 to 2004 with ± 2 SD (dashed lines) for the Bača River (W Slovenia). Absolute maximum monthly discharges in 2004 are represented by triangles.*

Stream-bed sediments at both sites were composed of heterogeneous mixture of boulders, cobbles, pebbles, gravel, sand and silt. The nature of habitat examined, which was not easily accessed hinder the attempts to describe the more detailed sediment composition of hyporheic zone. The amount of sediments extracted by piston pump was used as an indicator of permeability and rate of consolidation of river bed sediments (Malard et al., 2002).The amounts of sediments extracted varied between both sampling sites and habitat types (Figure 14), but amounts were not statistically significantly different. The highest mean values and the greatest variation in sediment amounts were observed in the river bed at impacted site. This is partly a consequence of recent sediment perturbation by gravel extraction activities and the construction of the bed load trap, where the new sediments coming from upstream are accumulating. The sediment extracted was primarily of size up to 5 mm and particles smaller than 1 mm prevailed in all samples (Figure 15). The size of sediment extracted is determined and limited by sampling methodology (piston pump).

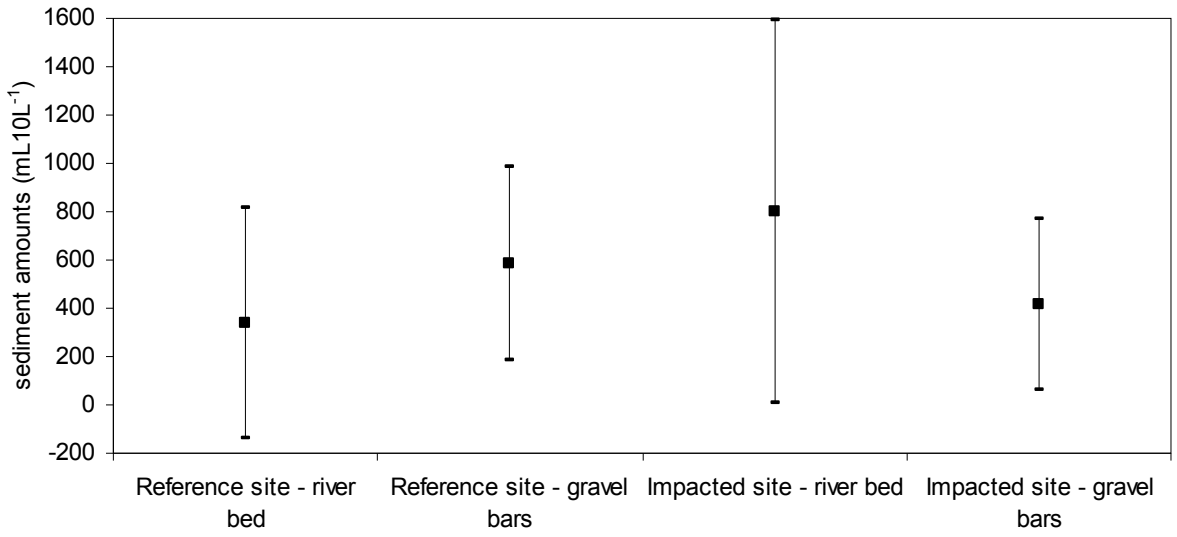

Figure 14. *The mean amounts ± SD of total sediments (mL 10L^{-1}) extracted from the hyporheic zone of the Bača River (W Slovenia) (average values for seven sampling dates).*

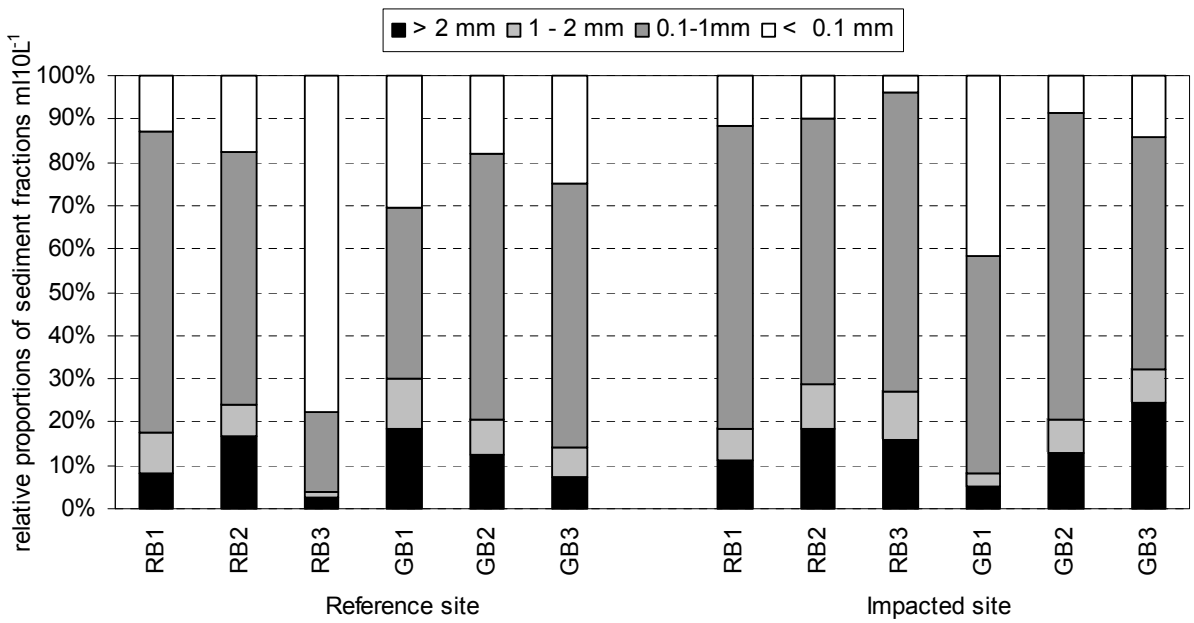

Figure 15. *The composition of sediments extracted from the hyporheic zone of the Bača River (W Slovenia) (average values for seven sampling dates).*

4.1.2 Physical and chemical characteristics

The mean values of physical and chemical parameters measured at each site are given in Table 1. Greater seasonal variation of surface and hyporheic temperatures was observed at the impacted site. Comparison of water temperatures between surface, river bed, and gravel bars sediments in the Bača River revealed great fluctuations in time and space due to variation in air temperatures, discharge levels and hydrological exchanges between surface and subsurface (Figure 16). Greater fluctuations and deviations from surface water temperatures were observed at gravel bars than in river bed sediments. Dissolved oxygen was close to 100 % saturation in surface water, while saturation in hyporheic water from river bed was around 90 % and from gravel bars around 80 %. Specific conductivity gradually decreased from gravel bars to gravel bed sediments and surface water.

However, differences in values were rather small, indicating prevalence of surface water in the sediments and short retention times. Little differences between surface water and sediments, and small temporal variations were observed in pH values, concentrations of calcium and nitrate concentrations (Table 1). Concentrations of phosphates were below limit of detection. The mean amounts of organic matter, expressed as LOI, were from 0.3 to 0.5 g10L^{-1}. The differences in mean amounts of organic matter between river bed sediments and gravel bars were observed at reference site, but not at impacted site. However, Student t-test revealed no statistically significant differences in organic matter (LOI) neither among sites, and neither among habitat types.

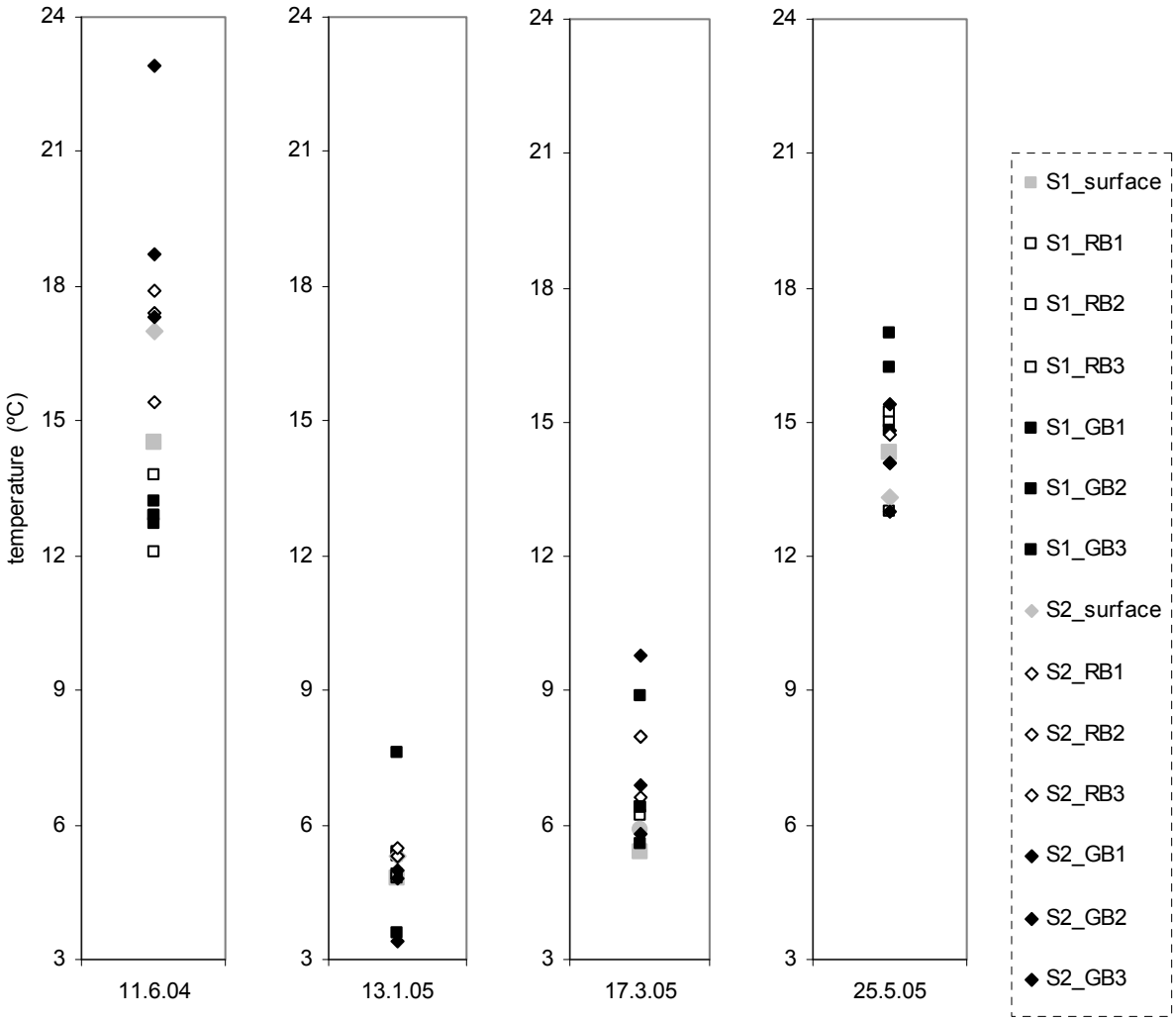

Figure 16. *Temperatures of surface and hyporheic water at four dates and two sampling sites in the Bača River (W Slovenia). S1 – reference site; S2 – impacted site, RB – river bed; GB – gravel bars.*

Table 1. *Average values (± SD) for physical and chemical parameters of surface water and hyporheic water from the river bed (depth 30-60 cm) and gravel bars (depth 60-90 cm) of the Bača River (W Slovenia).*

	Reference site			Impacted site		
	surface water	river bed	gravel bars	surface water	river bed	gravel bars
T (ºC)	9.2 ± 4.1	9.7 ± 4.3	10.4 ± 4.6	10.5 ± 5.0	10.8 ± 4.9	11.0 ± 5.8
dissolved oxygen (%)	106 ± 6	90 ± 13	82 ± 12	100 ± 4	94 ± 7	82 ± 15
specific conductivity (μScm^{-1})	273 ± 7	275 ± 12	281 ± 13	273 ± 8	271 ± 9	280 ± 16
pH	8.3 ± 0.1	8.1 ± 0.1	8.1 ± 0.1	8.3 ± 0.1	8.2 ± 0.1	8.1 ± 0.1
Ca^{2+} (mgL^{-1})	45.9 ± 2.6	45.4 ± 2.9	46.7 ± 4.8	44.7 ± 2.5	45.7 ± 3.4	43.3 ± 13.7
NO_3^- (mgL^{-1})	4.3 ± 0.6	4.1 ± 0.2	4.1 ± 0.5	3.9 ± 0.2	4.0 ± 0.6	4.2 ± 0.4
organic matter ($g10L^{-1}$)		0. 3 ± 0.3	0.5 ± 0.4		0.4 ± 0.6	0.4 ± 0.3

4.1.3 Biofilm activity

Mean oxygen consumption rates of the river bed sediments at the reference site were 1.44 ± 0.94 $\mu LO_2gWW^{-1}h^{-1}$ for fine sediment fraction and 0.24 ± 0.15 $\mu LO_2gWW^{-1}h^{-1}$ for coarse sediment fraction (Figure 17). At the impacted site, mean oxygen consumption rates for all sampling dates were 2.41 ± 1.53 $\mu LO_2gWW^{-1}h^{-1}$ for fine sediment fraction and 0.19 ± 0.14 $\mu LO_2gWW^{-1}h^{-1}$ for coarse sediment fraction sampled from the river bed, while in the gravel bars, rates were 2.39 ± 1.37 $\mu LO_2gWW^{-1}h^{-1}$ for fine sediment fraction and 0.14 ± 0.05 $\mu LO_2gWW^{-1}h^{-1}$ for coarse sediment fraction (Figure 17). No significant differences in oxygen consumption rates were observed between reference and impacted site and between habitat types ($p>0.05$). Since oxygen consumption rates for fine sediment fraction were the same, whether taken from reference or impacted site, or from the river bed and gravel bars, and the same for the coarse sediment fraction, pooled data were compared between the two fractions. Values were significantly lower in coarse sediment fraction (0.19 ± 0.13 $\mu LO_2gWW^{-1}h^{-1}$) than in the fine one (2.2 ± 1.4 $\mu LO_2gWW^{-1}h^{-1}$; $t = 14.72$, d. f. = 96, $p<0.001$).

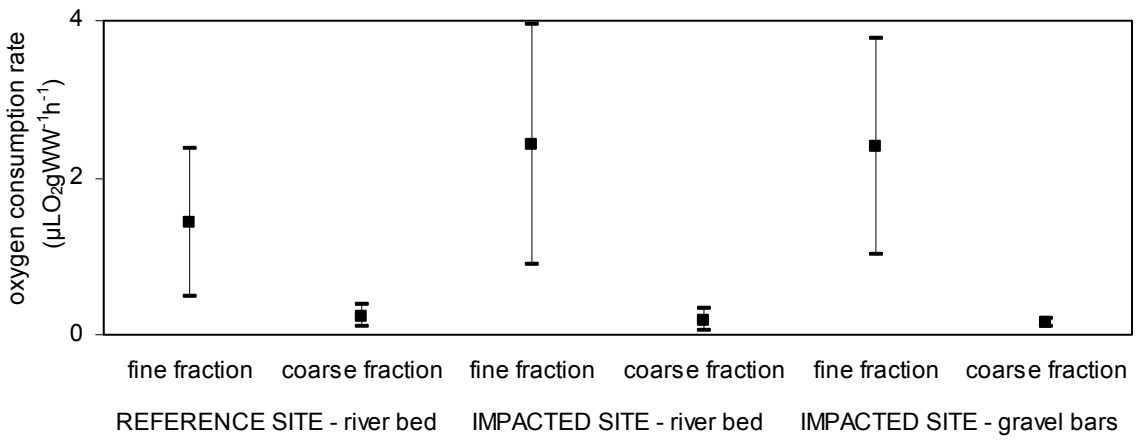

Figure 17. *Mean (± SD) oxygen consumption rates for fine and coarse sediment fractions from the river bed at reference site ($n_{fine,\ coarse}$= 9, 16) and from the river bed ($n_{fine,\ coarse}$ =20, 24) and gravel bars at impacted site ($n_{fine,\ coarse}$ =13, 16) of the Bača River (W Slovenia), measured at standard temperature of 20 ºC.*

Mean ETS activity was 3.2 ± 2.03 $\mu LO_2L^{-1}h^{-1}$ for the hyporheic water from the river bed at reference site, 2.8 ± 2.99 $\mu LO_2gWW^{-1}h^{-1}$ for fine sediment fraction, and 0.26 ± 0.20 $\mu LO_2gWW^{-1}h^{-1}$ for coarse sediment fraction taken from the same site (Figure 18a, b, c). At impacted site, mean ETS activity was 3.84 ± 2.94 $\mu LO_2L^{-1}h^{-1}$ for the hyporheic water from the river bed and 6.5 ± 3.94 $\mu LO_2L^{-1}h^{-1}$ for the hyporheic water from the gravel bars (Figure 18a). Mean (± SD) ETS activity in fine sediments sampled from the river bed was 3.56 ± 3.43 $\mu LO_2gWW^{-1}h^{-1}$ and 2.88 ± 1.34 $\mu LO_2gWW^{-1}h^{-1}$ in

sediments sampled from the gravel bars (Figure 18b), while mean (± SD) ETS activity (± SD) of coarse sediment fraction sampled from the river bed was 0.25 ± 0.15 $\mu LO_2 gWW^{-1}h^{-1}$ and 0.19 ± 0.02 $\mu LO_2 gWW^{-1}h^{-1}$ in the sediments sampled from the gravel bars (Figure 18c).

Results showed that ETS activity of hyporheic water from gravel bars at impacted site was significantly higher (ANOVA; $p<0.001$; data log transformed) than ETS activity of the hyporheic water from the river bed at reference and of the hyporheic water from river bed at impacted site. No significant differences in ETS activity of fine or coarse sediment fraction respectively were observed between reference and impacted site and between habitat types ($p>0.05$). The lack of significant differences among samples allowed us to pool the data and compare ETS activity of fine and coarse sediment fraction. Fine sediment fraction (mean ± SD; 3.16 ± 2.85 $\mu LO_2 gWW^{-1}h^{-1}$) had statistically highly significant higher metabolic potential than coarse fraction (0.23 ± 0.15 $\mu LO_2 gWW^{-1}h^{-1}$) ($t = 15.60$, d. f. = 107, $p<0.001$; data log transformed).

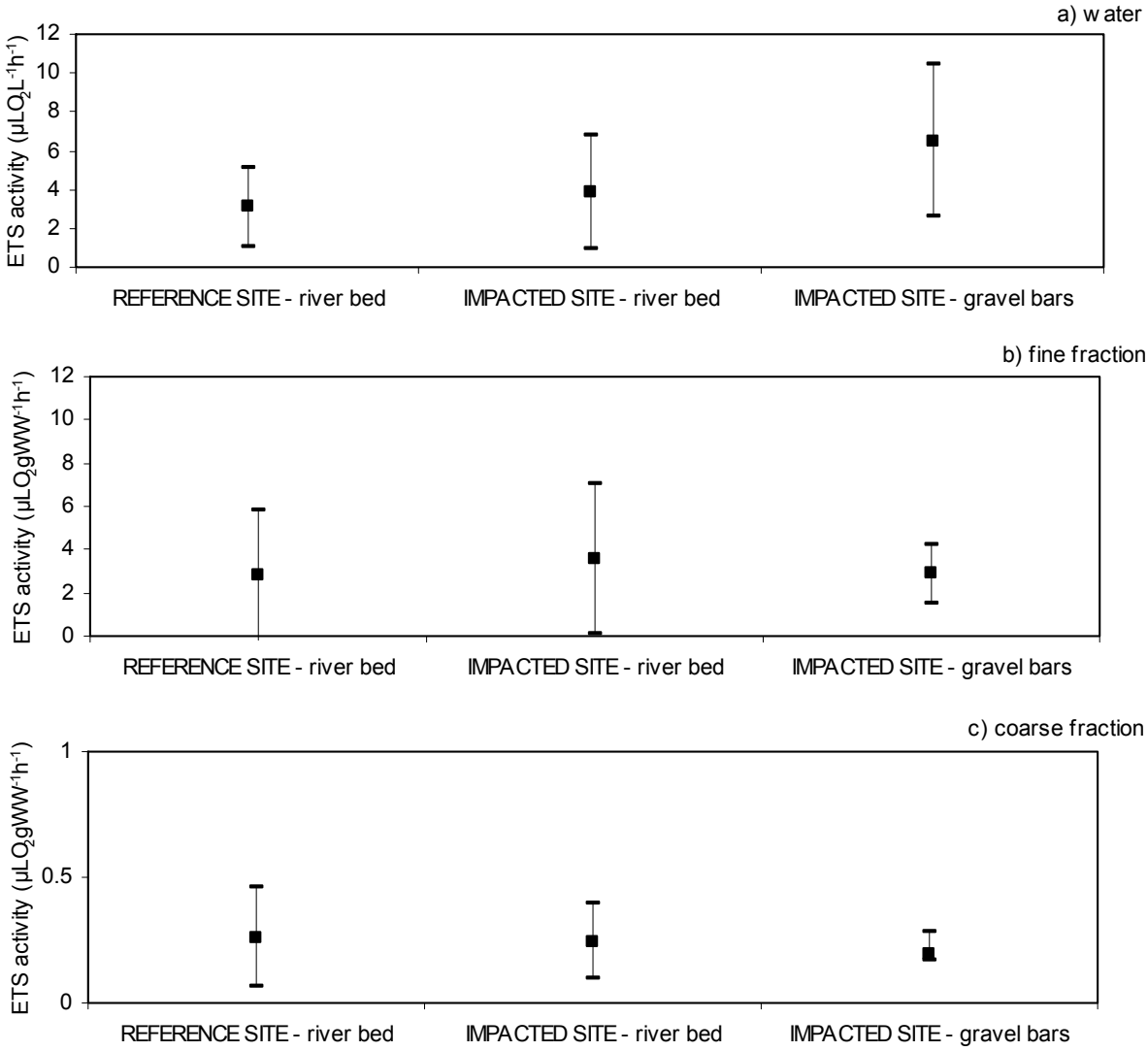

Figure 18. *Mean values (± SD) of ETS activity of the hyporheic water (a), fine fraction (b) and coarse fraction (c) of sediments from the river bed at reference site ($n_{water, fine, coarse}$=18, 15, 16) and from the river bed ($n_{water, fine, coarse}$=24, 23, 24) and the gravel bars ($n_{water, fine, coarse}$=18, 14, 17) at impacted site of the Bača River (W Slovenia), measured at standard temperature of 20°C.*

ETS activity of fine and coarse sediment fraction statistically significantly correlated with oxygen consumption rates (Figure 19a, b). Correlation coefficient was 0.5 for fine ($p<0.001$) and 0.3 for coarse sediment fraction ($p<0.05$). Furthermore, a negative correlation between amounts of fine sediment and

ETS activity of fine sediment fraction was calculated (Figure 20), with correlation coefficient of -0.60 ($p<0.001$). Therefore higher fine sediment amounts resulted in lower ETS activity.

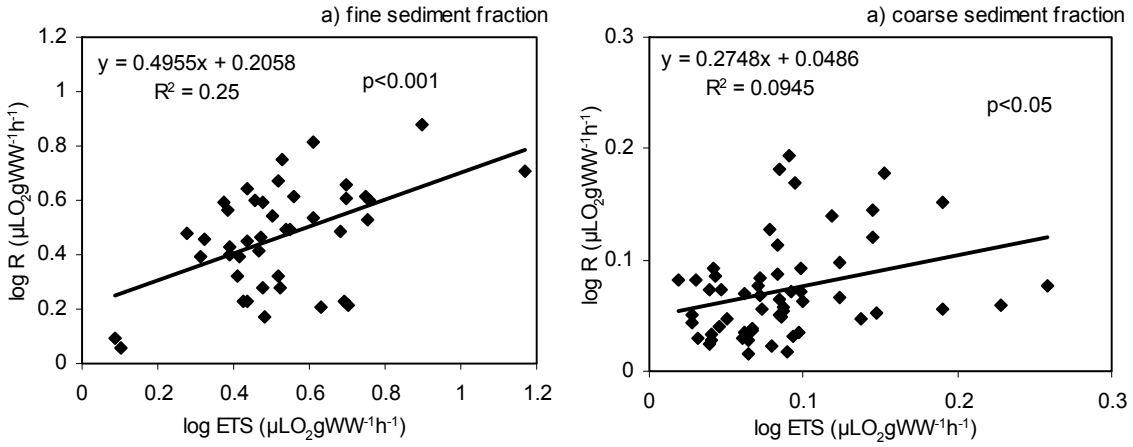

Figure 19. *Relationship between ETS activity (log ETS) and oxygen consumption rate (log R) in the fine (a) and coarse sediment fraction (b) of the hyporheic zone from the Bača River (W Slovenia). Pooled data from reference and impacted site and from river bed and gravel bars sediments are presented.*

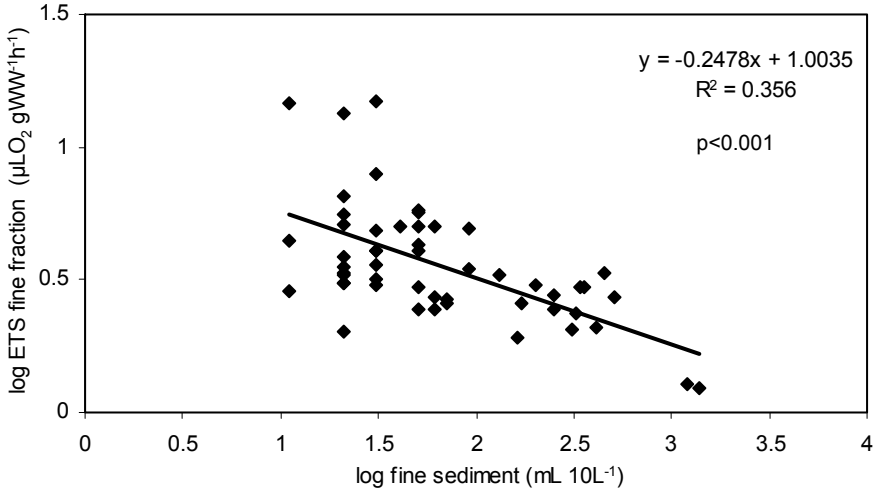

Figure 20. *Relationship between fine sediment amounts (particles < 100 µm) and ETS activity of fine sediment fraction in the samples from the hyporheic zone of the Bača River (W Slovenia). Pooled data from reference and impacted site and from river bed and gravel bars sediments are presented.*

4.1.4 Hyporheic invertebrate community of the Bača River

A total of 88 taxa and 42 449 individuals were collected during nine sampling dates (48 samples from the river bed, and 36 from gravel bars) in the hyporheic zone of the Bača River (stygoxenes not included). Out of 88 taxa (γ-diversity), 60 taxa were collected from both habitat types, while 20 taxa were collected only from river bed sediments (mostly insect larvae) and 8 from gravel bars (mostly microcrustacea). Altogether, 39 taxa belonged to the mero-hyporheos, 37 to the holo-hyporheos and 12 were stygobionts (Table 2). The most frequent taxa occurring in the majority of samples were Chironomidae, *Leuctra* sp. (mero-hyporheos); Nematoda, Oligochaeta, juveniles of Cyclopoida (holo-hyporheos); and *Diacyclops languidoides* (Lilljeborg, 1901) (stygobionts).

The mean number of taxa per sample was 13.6 ± 6.2 for samples from the river bed sediments and 12.4 ± 6.0 for samples from gravel bars (in 10 L of sample; pooled data from both sites). Mean number of individuals per sample was 480 ± 552 for samples from the river bed sediments and 539 ± 597 for samples from gravel bars (in 10 L of sample; pooled data from both sites). Since not only species, but higher taxonomic levels as well, were included in the analysis the taxonomic richness on a species level is higher. Student t-test revealed no significant differences in taxonomic richness and densities among habitat types (t test, $p>0.05$) (Figure 21a, b).

Relative densities of invertebrate taxa in samples from the river bed sediments and from gravel bars are shown in Figure 22 (pooled samples from both sampling sites). At both habitat types, fauna was dominated by juveniles of Cyclopoida, and early stages of *Leuctra* sp. (Plecoptera), Chironomidae (Diptera) and Baetoidea (Ephemeroptera) larvae. In the river bed sediments, cyclopoid juveniles, chironomids and *Leuctra* sp. contributed 60 % of the overall density, while in the samples from gravel bars Chironomidae contributed less (4 %) to the total density.

The mean Shannon's diversity index (H) for the community from the river bed sediments was 1.61 ± 0.6 and from gravel bars 1.51 ± 0.4 (pooled samples from both sampling sites). The comparison of Shannon's diversity index showed no significant differences among river bed sediments and gravel bars (t-test, $p>0.05$). The mean Shannon's equitability (E_H) was 0.66 ± 0.2 for the communities from river bed sediments and 0.67 ± 0.22 for the communities from gravel bars.

Comparison of occurrence of different ecotypes in the river sediments (mero- and holo-hyporheos, stygobionts) revealed no significant differentces in taxonomic richness or density of ecotypes between habitat types (Figure 23, 24). At both habitat types, the proportions of number of mero- and holo-hyporheos taxa were similar (41-45%) and followed by low proportion of stygobiotic taxa (14%). Relative abundances of mero-hyporheos (53%) were higher than holo-hyporheos (45%) and stygobiotic abundances (2%) in the river bed sediments, while in gravel bars abundances of holo-hyporheos prevailed (57%), followed by mero-hyporheos (41%) and stygobionts (2%).

The species accumulation curves (Mao-Tau curves) for samples from the river bed sediments and gravel bars showed similar sampling efficiency (Figure 25). The 90 % of total taxa sum was collected after 32 samples (out of 48 or 67% of all samples) in the river bed sediments and after 25 samples (out of 36 or 69 % of all samples) from gravel bars.

Table 2. *List of fauna collected in the hyporheic zone of the Bača River (W Slovenia) from June 2004 to May 2005. Taxa are grouped by their ecological classification (Mh – mero-hyporheos; Hh – holo-hyporheos; St – stygobionts), and arranged in the order from the most to the least frequent. Numbers represent frequency of occurrence (number of samples where taxa or ecotypes were present). Stygoxenes not included. * indicates euryecous taxa, which are here considered as holo-hyporheos).*

MERO-HYPORHEOS	
Chironomidae	78
Leuctra sp.	62
Tipulomorpha	56
Baetoidea (Baetidae+Siphlonuridae)	51
Ceratopogonidae	29
Dryopoidea	28
Polycentropodidae	20
Habroleptoides sp.	16
Simuliidae	16
Heptageniidae	11
Athericidae	11
Rhithrogena sp.	8
Sericostomatidae	7
Brachyptera sp.	7
Scirtidae	7
Goeridae	6
Siphlonurus sp.	6
Chloroperlidae	6
Beraidae	5
Ephemerella sp.	5
Hydropsychidae	4
Baetis sp.	4
Thaumaleidae	4
Amphinemura sp.	3
Dytiscidae	3
Glossosomatidae	2
Leptoceridae	2
Limnephilidae	2
Rhyacophilidae	2
Ephemerellidae	2
Ephemera sp.	2
Leptophlebiidae	2
Perlidae	2
Brachycentridae	1
Centroptilum sp.	1
Nemouridae	1
Nemoura sp.	1
Taeniopterygidae	1
Empididae	1
total frequency of mero-hyporheos	**83**

HOLO-HYPORHEOS	
Nematoda	78
Oligochaeta	72
Cyclopoida copepodites	71
Harpacticoida copepodites	55
Acarina	48
Copepoda nauplia	45
Acanthocyclops vernalis (Fischer, 1853)*	39
Acanthocyclops gmeineri Pospisil 1989	36
Gastropoda	29
Bryocamptus zschokkei Schmeil 1893	29
Diacyclops languidus (G. O. Sars, 1863)	22
Bryocamptus dacicus (Chappuis, 1923)	22
Echinocamptus pilosus (Van Douwe, 1911)	19
Epactophanes richardi Mrázek, 1893	17
Bryocamptus minutus (Claus, 1863)	11
Alona costata Sars, 1862	11
Candoninae juveniles	9
Attheyella crassa (G.O. Sars, 1862)*	7
Moraria varica (Graeter, 1911)	7
Tardigrada	6
Ostracoda juveniles	5
Candona candida (Müller, 1776)	5
Turbellaria	4
Gammarus sp.	4
Hydridae	3
Paracyclops fimbriatus (Fischer, 1853)	3
Alona guttata Sars, 1862	3
Chydorus sphaericus (O.F. Müller, 1785)*	3
Pseudocandona albicans (Brady, 1864)	3
Rotatoria	2
Eucyclops serrulatus (Fischer, 1851)*	2
Attheyella wierzejskii (Mrázek, 1893)	2
Cyclops vicinus Ulianine,1875*	1
Megacyclops viridis (Jurine, 1820)*	1
Moraria poppei (Mrazek, 1893)*	1
Paracamptus schmeili (Mrázek, 1893)	1
Alona quadrangularis (Müller, 1776)*	1
total frequency of holo-hyporheos	**82**

STYGOBIONTS	
Diacyclops languidoides (Lilljeborg, 1901)	39
Bryocamptus pygmaeus (Sars, 1863)	21
Bryocamptus typhlops (Mrázek, 1893)	14
Parastenocaris gertrudae Kiefer 1968	12
Isopoda (cf. *Proasellus* sp.)	11
Niphargus sp.	10
Parastenocaris nolli alpina Kiefer, 1960	8
Speocyclops infernus (Kiefer, 1930)	4
Graeteriella unisetigera (Graeter, 1908)	1
Nitocrella slovenica Petkovski, 1954	1
Fabaeformiscandona breuli n.sp.	1
Bathynella sp.	1
total frequency of stygobionts	**59**

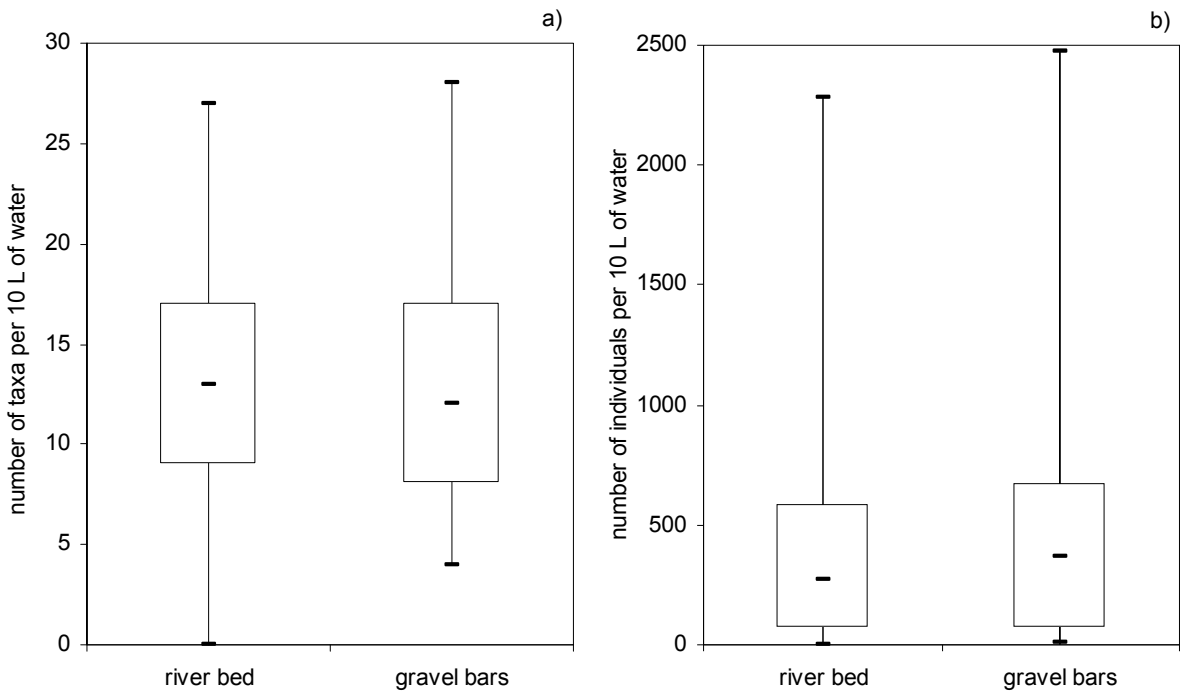

Figure 21. *Box plots for invertebrate taxonomic richness (a) and densities (b) in the hyporheic zone of the Bača River (W Slovenia). Data from both sampling sites and from seven sampling dates were pooled (n_{RB}=48, n_{GB}=36). Lower line – the smallest observation; lower box line - lower quartile (Q1); middle line – median; upper box line - upper quartile (Q3); upper line – the largest observation.*

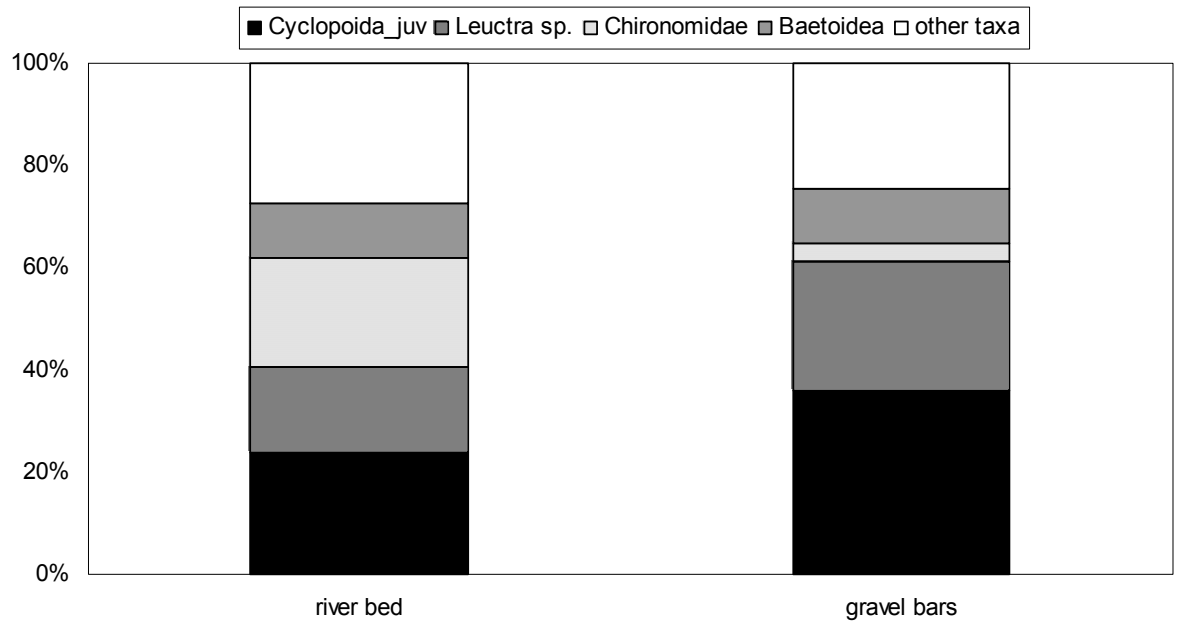

Figure 22. *Relative densities of invertebrates in the samples from the river bed sediments and gravel bars (pooled samples from both sampling sites) of the Bača River (W Slovenia).*

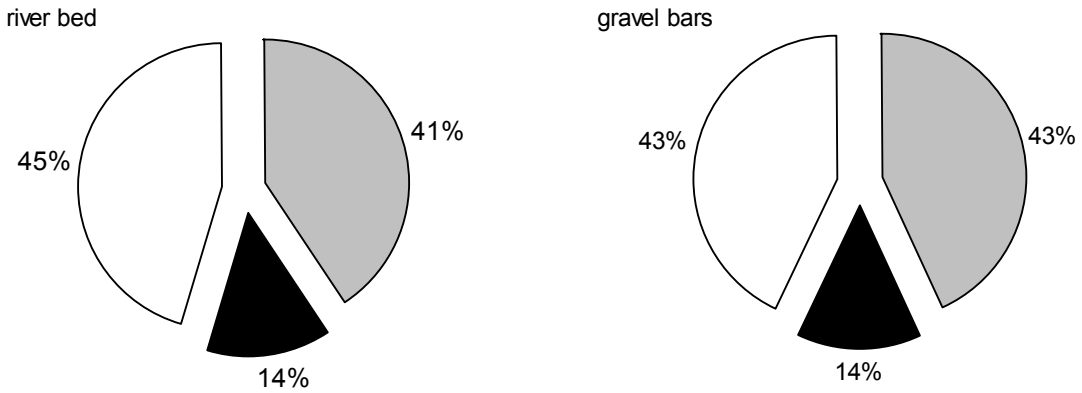

Figure 23. *Relative proportions of different ecotypes taxa (mero-hyporheos – white color; holo-hyporheos – grey color; stygobionts – black color) collected in the Bača River (W Slovenia) hyporheic zone. Pooled data from river bed sediments (n=48) and gravel bars (n=36) are presented.*

Figure 24. *Relative abundances of different ecotypes (mero-hyporheos – white color; holo-hyporheos – grey color; stygobionts – black color) living in the Bača River (W Slovenia) hyporheic zone. Pooled data from river bed sediments (n=48) and gravel bars (n=36) are presented.*

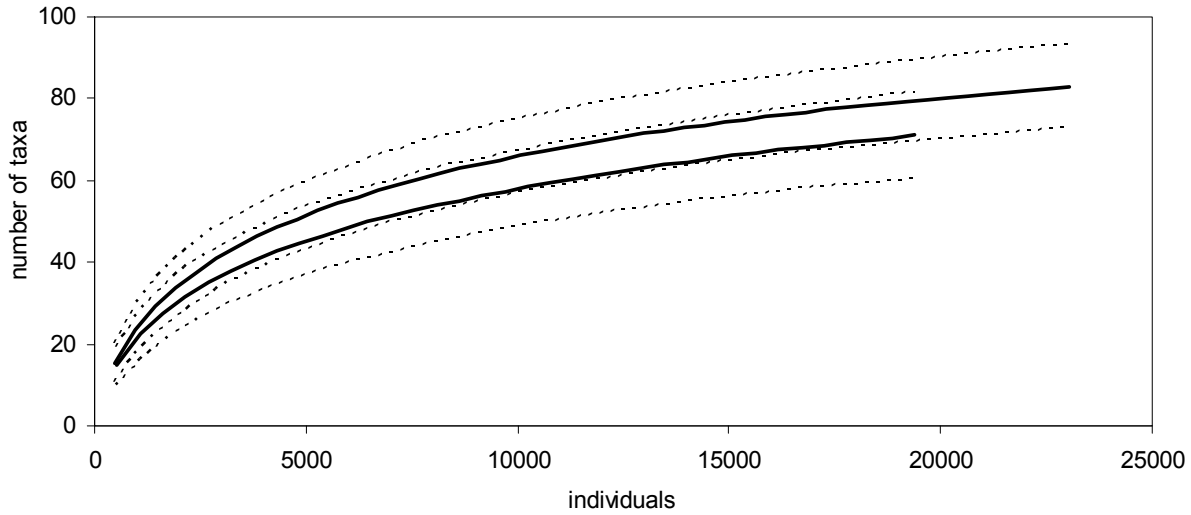

Figure 25. *The accumulation curves of samples from the Bača River (W Slovenia) sediments and gravel bars (nine dates, all sampling stations n=84) based on Mao-Tau analyses (Colwell et al., 2004) rescaled to the number of individuals. The solid line is the accumulation curve and the two dotted lines are the 95% confidence intervals.*

4.2 The impacts of gravel extraction on the hyporheic zone processes

4.2.1 Hydrology

Fluctuations in discharge lead to the changes in subsurface flow patterns over the time at both sampling sites. Moderate fluctuations in upwelling and down-welling (± 1 cm) occurred at all sampling points in the river bed (Figure 26). After spates in October and November 2004 and gravel extraction at impacted site, stronger down-welling occurred at impacted site at all sampling points. The greatest increase in down-welling was observed at sampling point at the downstream end of the sampling area (RB3; - 30 cm).

4.2.2 Sediment composition, organic matter and biofilm activity

In the samples taken from the hyporheic zone of the Bača River from June 2004 to May 2005, particles smaller than 1 mm prevailed (Figures 27, 28). In total, they were represented by 81 % of total volume of sediments extracted at reference site and by 77 % at impacted site. At reference site, the volume of sediment of all particle sizes remarkably decreased in November samples as a result of the spate at the end of October 2004, which caused the great sediment replacement in the river bed and washed out finer sediment. On the contrary, at impacted site, the sediment volume increased in post-disturbance samples. Even after three, five and seven months after gravel extraction the sediment amounts extracted with the pump were higher than those from pre-disturbance samples. A two–way analysis of variance (ANOVA) with replication on samples from gravel bed (three replicates, log transformed data) showed no significant difference between dates, but significant differences between sites (ANOVA, $p<0.05$, $F = 10.6$). Comparison of total sediment amounts from samples taken at reference site revealed significant differences of November samples from samples taken in June 2004, and March and May 2005 (t-test; $p<0.05$), while at impacted site, samples taken in June 2004 differed from samples taken in October and November 2004 (t-test; $p<0.05$).

The amounts of particulate organic matter (POC), expressed as LOI, were variable among samples from the same sampling date and as well during time at both sampling sites (Figure 29). In June samples, POC amounts were similar in samples from gravel bars when comparing reference and impacted site and lower in samples from river bed sediments at impacted site comparing to reference site. They increased greatly in October at impacted site (samples from river bed), while at reference site were not measured in this period of time. At reference site, a decrease in POC amounts was observed in November samples, while at impacted site POC remain similar until May. In May, the amounts of POC were lower comparing to other dates at both sites. At reference site, samples from May 2005 were significantly different from samples taken in June 2004, January and March 2005 (one way ANOVA, $p<0.01$, $F = 2.47$). At impacted site, samples taken in May 2005 were significantly different from all other samples (one way ANOVA, $p<0.001$, $F = 2.11$). A two–way ANOVA with replication (three replicates, log transformed data) showed significant difference between dates, but not sites (ANOVA, $p<0.05$, $F = 2.79$).

The respiration was the lowest in January at reference site, while at impacted site the respiration was low in October, November and January. There was observed peak in respiration in March 2005 at both sites (Figure 30a, b). Oxygen consumption rates of fine and coarse sediment fraction did not differ significantly between sites and dates (ANOVA, $p<0.05$).

At reference site, ETS activity of sediments was the lowest in January and the highest in March, while at impacted site the maximum values were measured in March and September as well (Figure 31b, c). ETS activity of hyporheic water, and of fine and coarse sediment fraction from reference site did not differ significantly from that from impacted site and did not changed significantly among dates (ANOVA, $p>0.05$). Despite insignificant differences in ETS activity among sites, the greater range of measured values was observed in the samples of the hyporheic water at impacted than at reference site (max-min: 11.67 (RB) and 14.62 (GB) versus 8.04 µL O_2 L^{-1} h^{-1} (RB)).

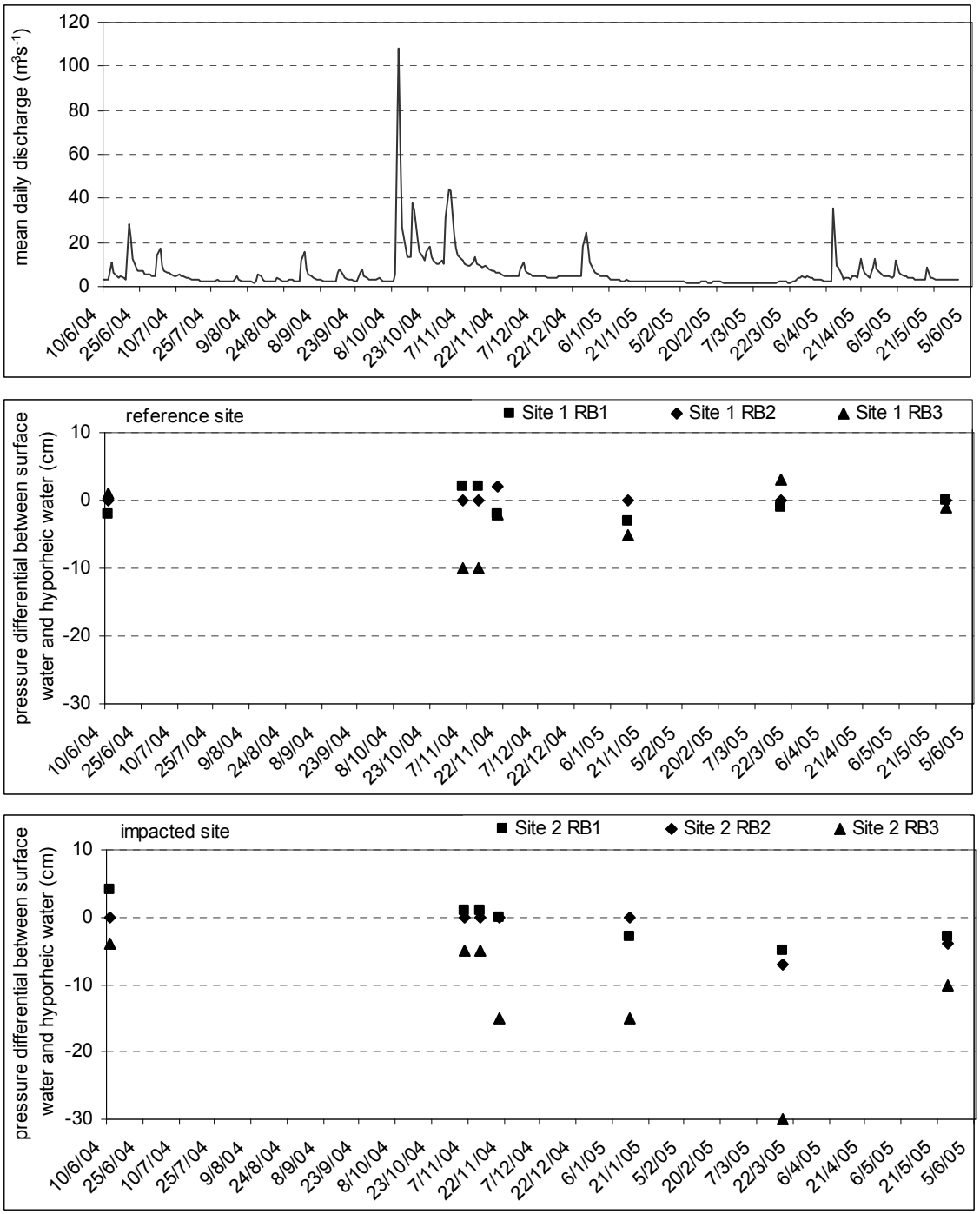

Figure 26. *Mean daily discharge of the Bača River (W Slovenia) from June 11 2004 to May 31 2005 (upper diagram) and results of hydraulic head measurements at reference (middle diagram) and impacted site (lower diagram) during seven sampling dates, and at three sampling points.*

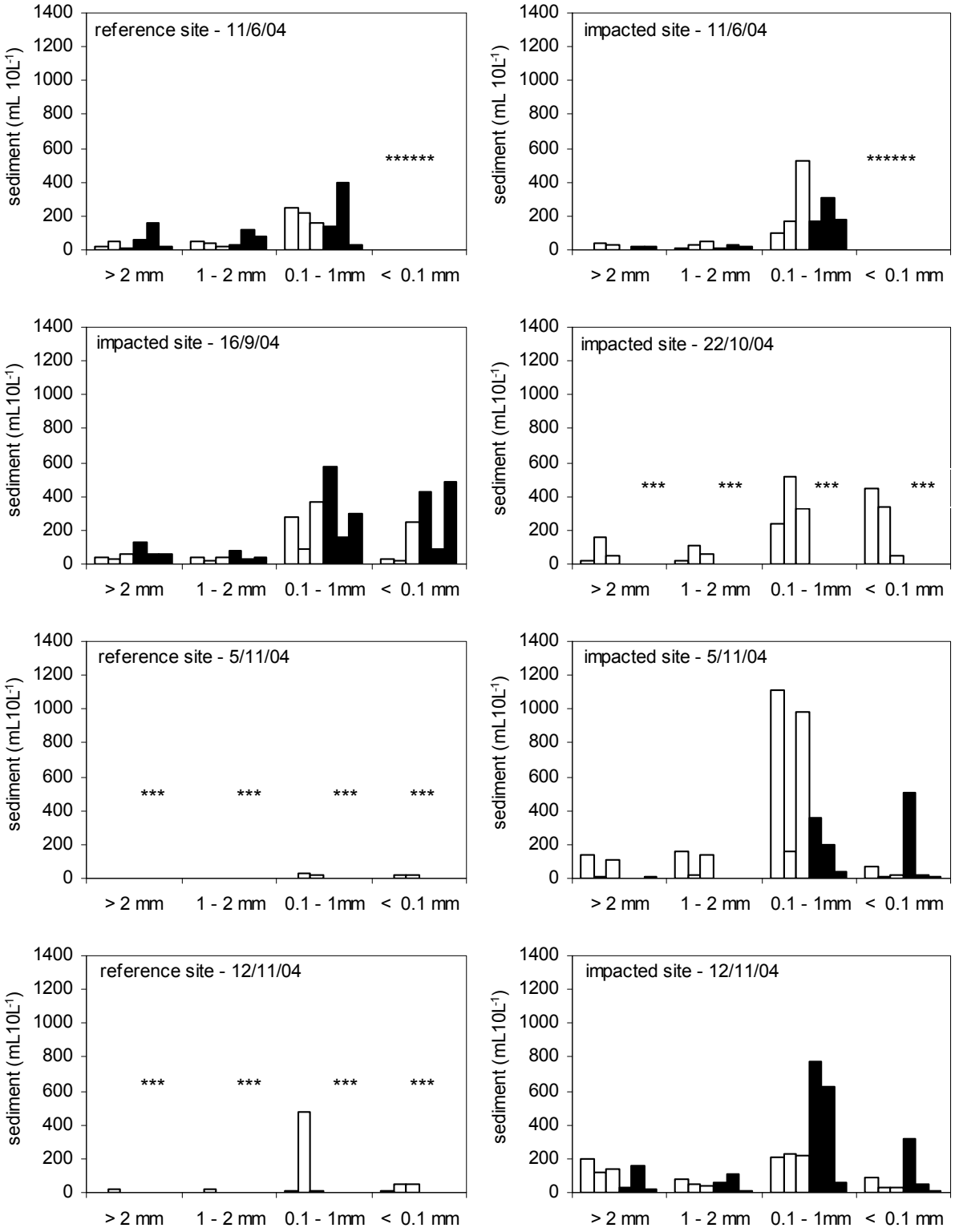

Figure 27. *Spatial and temporal variation in volume composition of sediments from the samples taken at reference and impacted site in the Bača River (W Slovenia) from June to November 2004. White columns: samples from river bed; black columns: samples from gravel bars. * - not sampled.*

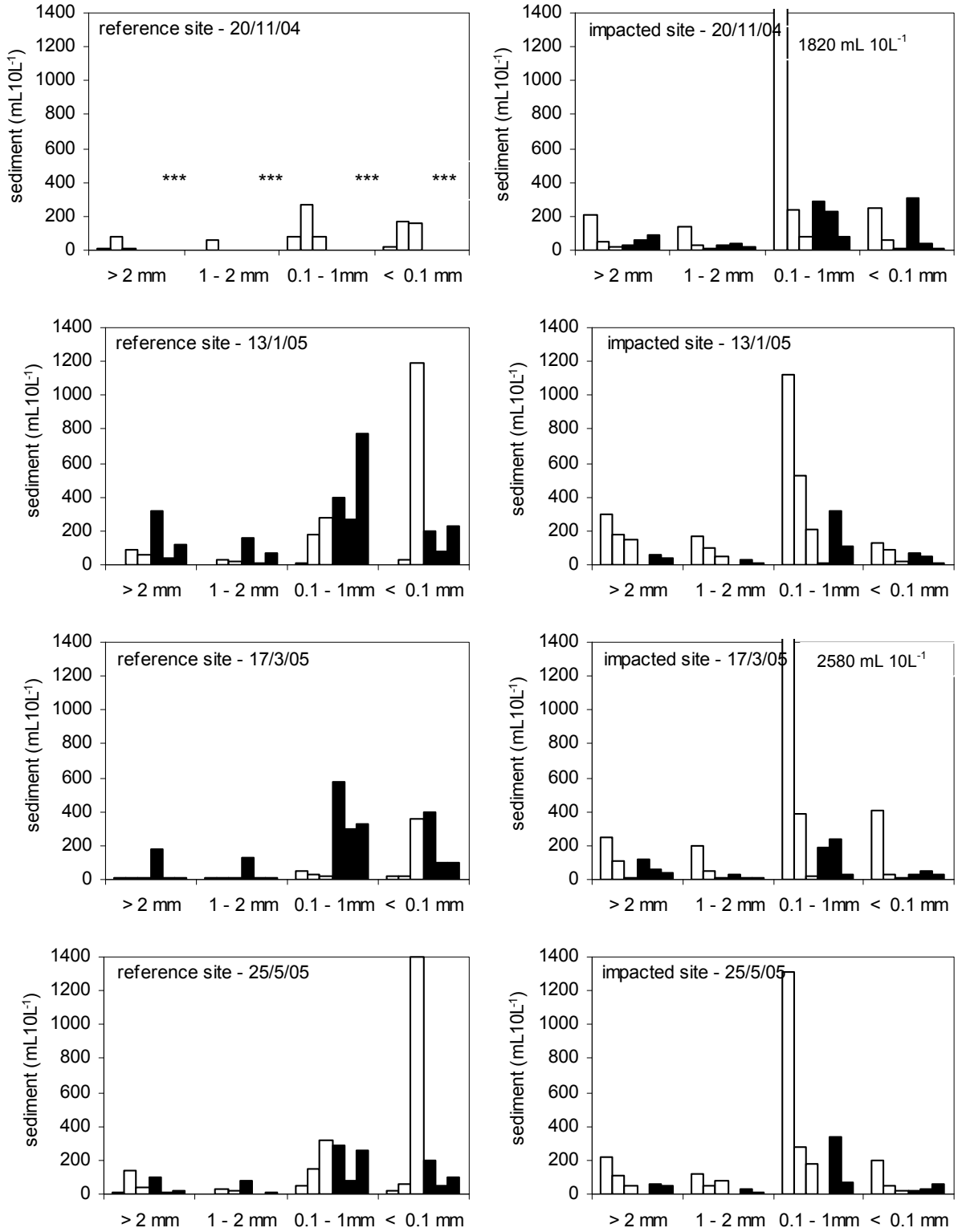

Figure 28. *Spatial and temporal variation in volume composition of sediments from the samples taken at reference and impacted site in the Bača River (W Slovenia) from November 2004 to May 2005. White columns: samples from river bed; black columns: samples from gravel bars. * - not sampled.*

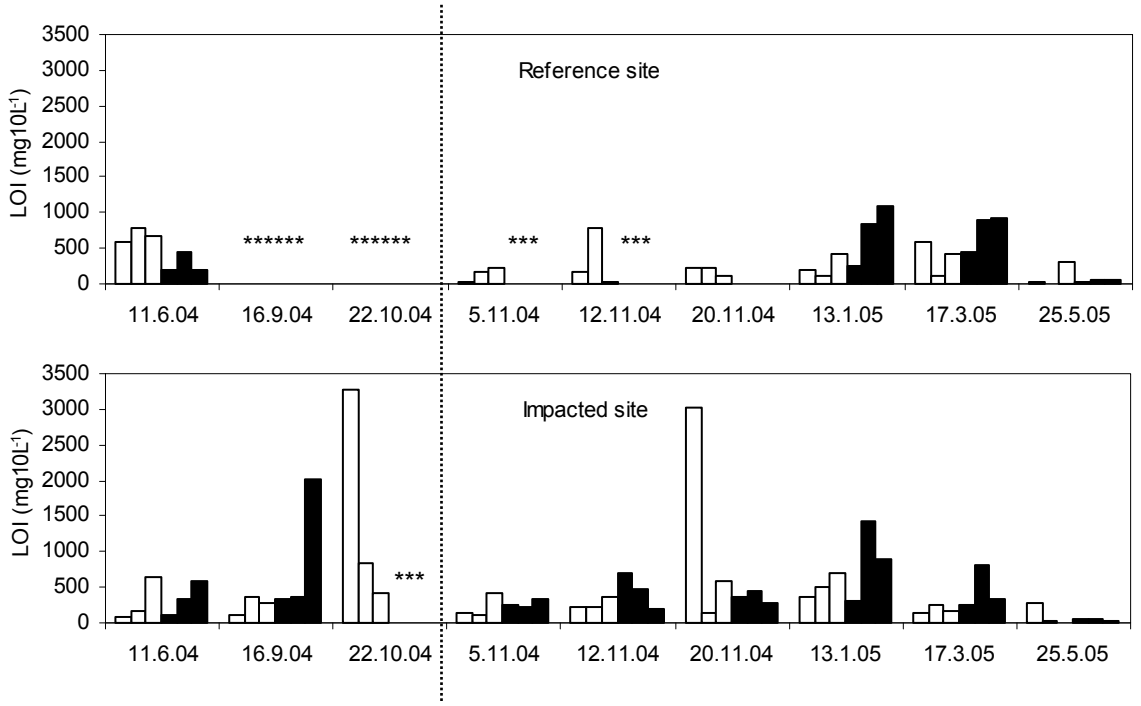

Figure 29. *Spatial and temporal variation of particulate organic matter (POC), expressed as loss-on-ignition (LOI), in the samples taken from the hyporheic zone at reference site (above) and impacted site (below) of the Bača River (W Slovenia). White columns: samples from the river bed; black columns: samples from gravel bars. * - not sampled. Vertical dashed line separate pre-disturbance and post-disturbance samples.*

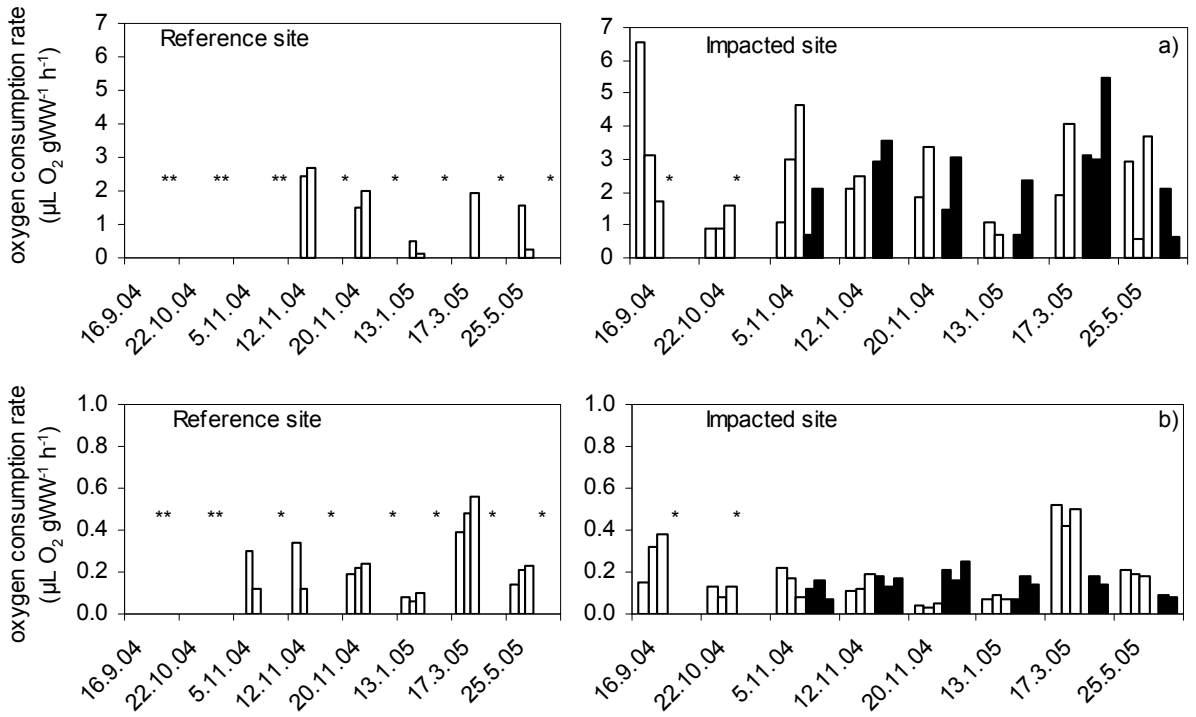

Figure 30. *Oxygen consumption rates of (a) fine sediment fraction and (b) coarse sediment fraction from samples taken at reference and impacted site from the hyporheic zone of the Bača River (W Slovenia), measured at 20°C. White columns: samples from the river bed; black columns: samples from gravel bars. * - not sampled.*

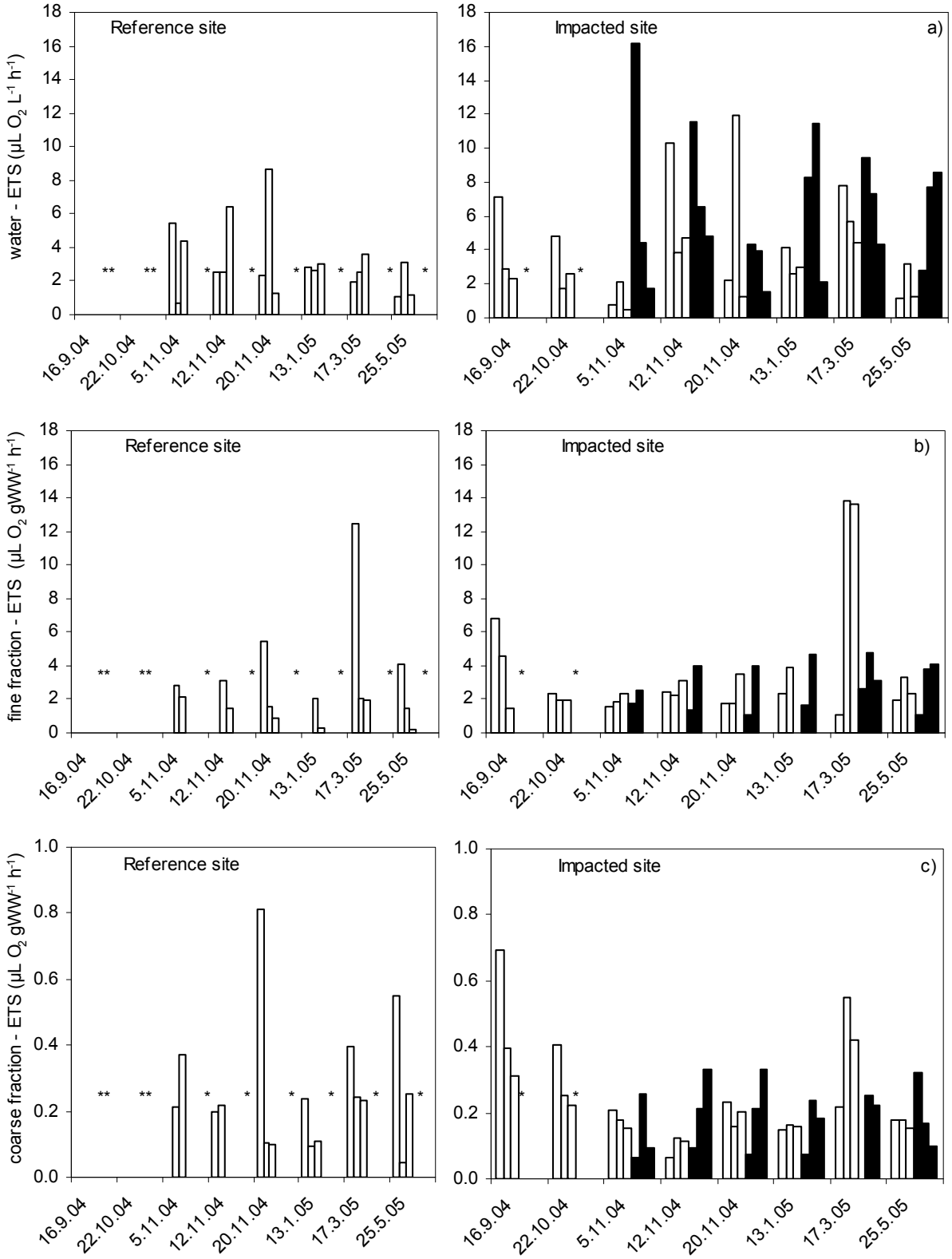

Figure 31. *ETS activity of (a) hyporheic water (RB – white columns; GB – black columns), (b) fine sediment fraction, and (c) coarse sediment fraction at reference and impacted site from the river bed sediments (RB – white columns) and gravel bars (GB – black columns) of the river Bača (W Slovenia). * - not sampled. Measurements were made at 20°C.*

4.2.3 Hyporheic invertebrate density and diversity

Results of Student t-test confirmed that hyporheic community in June 2004 (pre-disturbance date) on both sites did not differ significantly in total density, densities of selected taxa and taxonomic richness (Table 3). Only Cylopoida densities were significantly higher at reference site. Representatives of *Acanthocyclops gmeineri* Pospisil 1989 and *Acanthocyclops vernalis* (Fischer, 1853) predominated in those samples.

At reference site, invertebrate densities ranged from 0 to 1462 individuals in the river bed sediments and from 91 to 1917 in the samples from gravel bars. At impacted site, densities ranged from 9 to 2283 individuals in the river bed sediment and from 6 to 2477 in the gravel bar samples. At reference site, a significant decrease in hyporheic invertebrate densities was observed in November (Figure 32, Table 3). In January and March 2005, mean invertebrate densities exceeded densities from June 2004 samples, and were similar again in May 2005. In March, the samples from the gravel bars at reference site had much higher mean invertebrate densities comparing to other samples. Cyclopoida and *Leuctra* sp. contributed high invertebrate density in those samples. At impacted site, mean invertebrate densities were low in November (after gravel extraction) and increased in January, mostly due to abundant early developmental stages of *Leuctra* sp. and Baetoidea (*Baetis* sp. and *Siphlonurus* sp.) larvae. At both sites, variation in densities between sampling points was low in June, November and May, while in September, October, January and March differences in densities between samples were high (Figure 32, below).

A two-way ANOVA, with dates and sites as factors, showed a significant effect of time, but not significant differences between sites (only samples from river bed sediments were considered in the analysis) (ANOVA, df = 28, MS_{within}= 0.33). However, a one-way ANOVA revealed statistically more significant differences in invertebrate densities among dates at impacted ($p<0.001$) comparing to reference site ($p<0.5$) (Table 3). At reference site, statistically significant difference was calculated between first November samples and March samples (Tukey-Kramer test for unequal sample sizes). At impacted site, significant differences were between June samples and first November samples, between September samples and all three November samples, between October samples and first two November samples, between first November samples and second November samples, and between second and third November samples and January, March and May samples (Tukey-Kramer test for unequal sample sizes).

Table 3. *A summary of Student t-test for comparing pre-disturbance samples (samples form June 2004) from the reference and impacted site of the Bača River (W Slovenia), of one-way ANOVA for comparing dates (June and six post-disturbance dates), and of two-way ANOVA (site and date as factors). Only significance levels are presented (*p<0.05, **p<0.01, ***p<0.001).*

	Student t-test	one-way ANOVA	one-way ANOVA	two-way ANOVA		
		reference site	impacted site	date	site	interaction
density	NS	*	***	*	NS	NS
taxonomic richness	NS	NS	***	*	NS	NS
Nematoda	NS	NS	NS	NS	NS	NS
Oligochaeta	NS	***	***	***	NS	NS
Acarina	NS	NS	*	**	***	NS
Cyclopoida juveniles	NS	***	***	***	NS	NS
Cyclopoida	*	**	***	***	NS	NS
Harpacticoida juveniles	NS	NS	**	*	NS	NS
Harpacticoida	NS	NS	NS	NS	NS	NS
Baetoidea	NS	NS	**	*	*	NS
Leuctra sp.	NS	*	***	***	*	*
Chironomidae	NS	NS	NS	NS	NS	NS

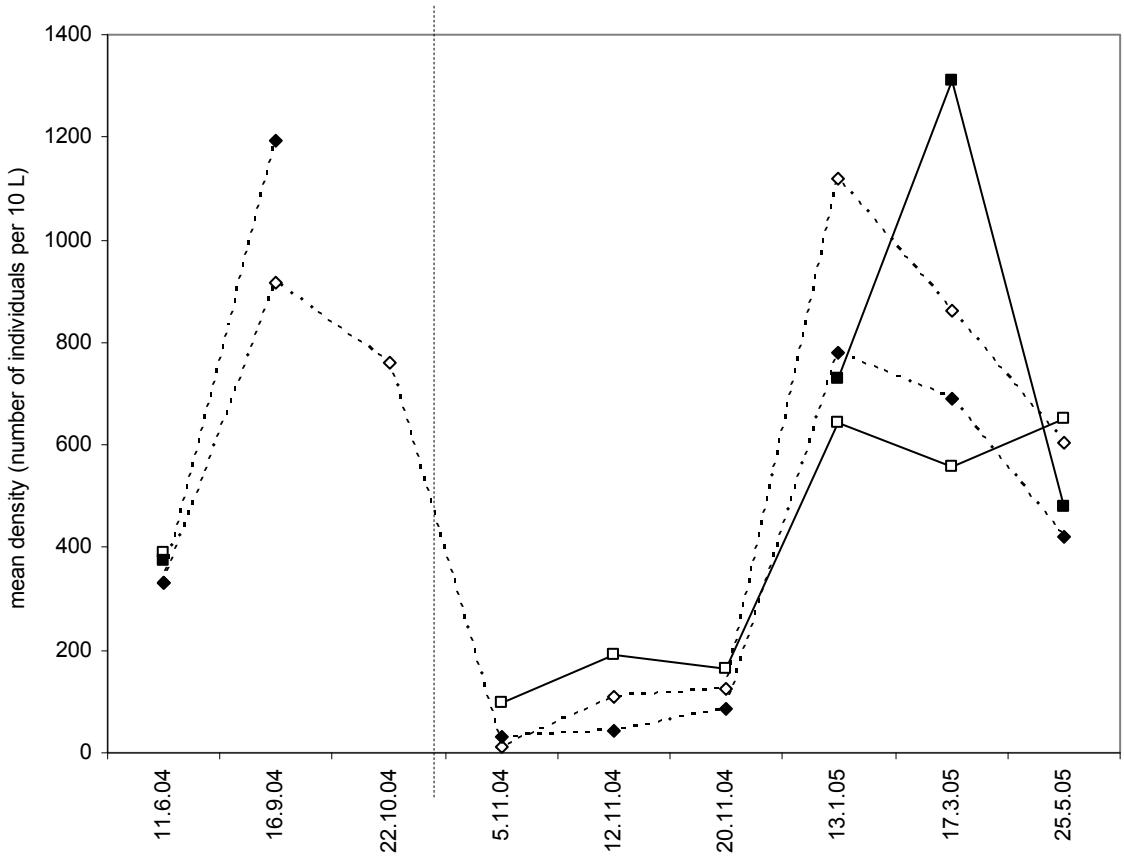

Figure 32. *Mean densities of hyporheic invertebrates at reference (■, □, full black line) and at impacted site (♦, ◊, dashed line) of the Bača River (W Slovenia) for all sampling dates (above). Hyporheic invertebrate densities in gravel bed (□) and gravel bars (■) at reference site and in gravel bed (◊) and gravel bars (♦) at impacted site (below). In September and October 2004 only impacted site was sampled. Vertical dashed line indicates a period of disturbance.*

Mean taxonomic richness in June 2004 was higher in the river bed sediments comparing to gravel bars at both sites and higher values were observed at reference site comparing to impacted site (Figure 33, upper graph). However, Student t-test showed no statistically significant differences in taxonomic richness among sites and habitat types ($p>0.5$) (Table 3). At reference site, taxonomic richness did not varied significantly through the time (Figure 33, upper and middle graph; Table 3), while at impacted site, a significant decrease in invertebrate richness was observed in November, in a month after gravel extraction (Figure 33, middle and lower graph). A one-way ANOVA on data from impacted site showed significant differences in taxonomic richness between samples taken a week after disturbance and samples taken before the gravel extraction (June) and from those taken in January, March and May. Further on, taxonomic richness was two weeks after gravel extraction different from that in January 2005 (Tukey-Kramer test for unequal size). The fastest increase in taxonomic richness after gravel extraction was observed at the most up-stream sampling points (RB1 and GB2) (Figure 33, lower graph). A two-way ANOVA, with dates and sites as factors, showed a significant effect of time, but not sampling site on taxonomic richness (Table 3).

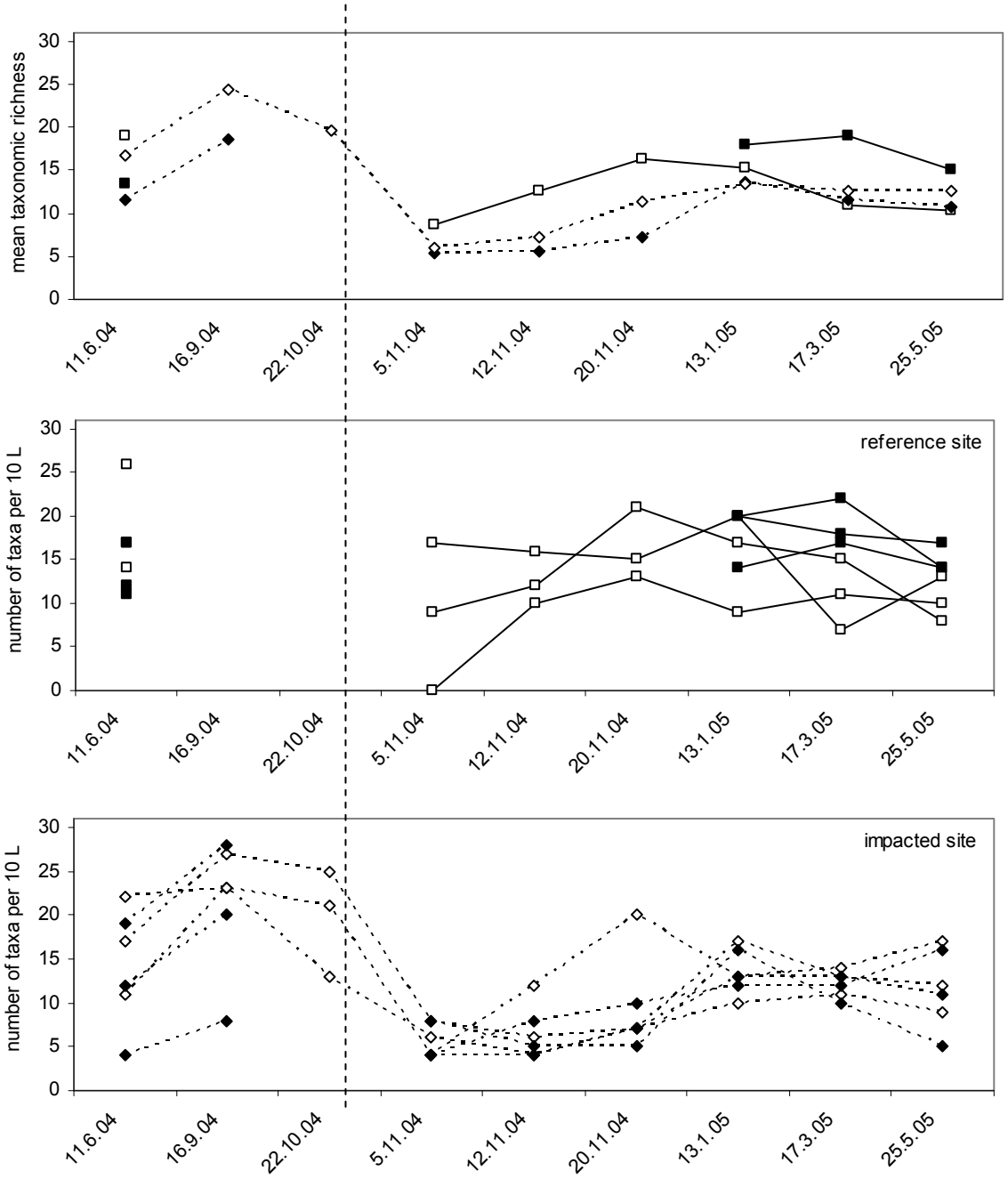

Figure 33. *Mean taxonomic richness of hyporheic invertebrate communities from the Bača River (W Slovenia) at reference (river bed □, gravel bars ■, full black line) and impacted site (river bed ◊, gravel bars ♦, dashed line) (upper graph). Number of taxa in the samples from reference (middle graph) and impacted site (lower graph). In September and October 2004 only impacted site was sampled. Vertical dashed line indicates a period of disturbance.*

The mean Shannon's diversity index was the same for the community from the reference and impacted site sampled in June 2004 (Table 4), with the lower values for the communities from gravel bars. At reference site, mean diversity decreased in the first two weeks of November 2004 (after spates), but in the third week reached similar values than in June. Again, diversity decreased in January, March and May samples at reference site. At impacted site, mean diversity decreased after gravel extraction, and was lower than at reference site until March 2005. Mean Shannon's equitability was in June 2004 similar in the communities from both sites (0.7). At reference site, the equitability was similar during all sampling dates, with the exception of January and March samples, where the values were lower comparing to other dates (0.5 and 0.6). At impacted site, the community equitability

increased in the first two weeks after gravel extraction (0.8). In a third week after gravel extraction and in the samples from January and March, the community equitability decreased (0.5, 0.4 and 0.6), while in May it was high again (0.9).

Table 4. *Mean Shannon's diversity index and mean Shannon's equitability (± SD) calculated for the samples from the hyporheic zone of the Bača River (W Slovenia) (n=3). In September and October 2004 only impacted site was sampled. The juveniles (Copepoda, Ostracoda) are included in the calculations.*

	11.6.2004	16.9.2004	22.10.2004	5.11.2004	12.11.2004	20.11.2004	13.1.2005	17.3.2005	25.5.2005
mean Shannon's diversiy index									
reference site									
river bed	2.1 ± 0.1			1.1 ± 1.0	1.8 ± 0.7	2.0 ± 0.4	1.5 ± 0.7	1.2 ± 0.3	1.6 ± 0.2
gravel bars	1.8 ± 0.4						1.5 ± 0.4	1.6 ± 0.4	1.5 ± 0.4
impacted site									
river bed	2.1 ± 0.4	2.1 ± 0.4	1.7 ± 0.3	1.6 ± 0.3	1.6 ± 0.6	1.1 ± 0.6	1.0 ± 0.8	1.6 ± 0.5	1.5 ± 0.1
gravel bars	1.5 ± 0.3	2.0 ± 0.1		1.3 ± 0.1	1.3 ± 0.5	1.5 ± 0.7	1.5 ± 0.4	1.3 ± 0.2	1.3 ± 0.0
mean Shannon's equitability									
reference site									
river bed	0.7 ± 0.1			0.7 ± 0.3	0.7 ± 0.3	0.7 ± 0.2	0.6 ± 0.3	0.5 ± 0.1	0.7 ± 0.1
gravel bars	0.7 ± 0.2						0.5 ± 0.2	0.6 ± 0.1	0.6 ± 0.1
impacted site									
river bed	0.7 ± 0.1	0.7 ± 0.1	0.7 ± 0.2	0.8 ± 0.2	0.8 ± 0.0	0.5 ± 0.3	0.4 ± 0.3	0.6 ± 0.2	0.9 ± 0.3
gravel bars	0.6 ± 0.2	0.7 ± 0.2		0.9 ± 0.0	0.8 ± 0.4	0.6 ± 0.3	0.6 ± 0.2	0.6 ± 0.3	0.5 ± 0.1

4.2.4 Community composition

In June, Cyclopoida juveniles, together with *Leuctra* sp. contributed more than 40% of specimens to total invertebrates in the samples from river bed sediments at reference and impacted site, and between 50 and 70 % of all community from gravel bars at both sites (Figure 34a, b). In November samples, Chironomidae greatly dominated by numbers at reference site, while the community at impacted site was composed mostly of representatives of Chironomidae, Baetoidea, Oligochaeta, and Nematoda. In January, chironomids prevailed in the river bed sediments at reference site, while larvae of *Leuctra* sp. dominated in the gravel bars at reference site and in both habitat types at impacted site. In the samples collected in March and May 2005, the community composition was similar to that from June 2004 at both sites.

Individual taxa responded differently to October spates and gravel extraction at impacted site. Nematoda, Harpacticoida, and Chironomidae densities did not significantly changed through the time at reference, neither at impacted site (Table 3). Densities of Oligochaeta, Cyclopoida (juveniles and adults) and *Leuctra* sp. significantly changed at both sites, while densities of Acarina, Harpacticoida juveniles and Baeitoidea were significantly different among dates at impacted, but not at reference site. A two-way ANOVA revealed impact of date on Oligochaeta, Cyclopoida (adults and juveniles), and Harpacticoida juveniles, date and site on Acarina, Baetoidea and *Leuctra* sp. and statistical significant interaction for *Leuctra* sp.

Individuals of Nematoda, Oligochaeta and Acarina occurred in low densities in the hyporheic zone of the Bača River (up to 150 individuals in a water sample of 10 L) comparing to other taxa (up to 600 or 1000 individuals in a water sample of 10 L) (Figure 35a, b, c). Densities of those taxa decreased after spates and gravel extraction. Nematods reached the pre-disturbance densities, while oligochaetes and water mites did not. Similarly, mean Copepoda densities decreased in November samples and in

spring reached pre-disturbance densities (Figure 35d). However, the recovery was moderate at impacted site, especially in gravel bars. Mean densities of individuals of Baetoidea and *Leuctra* sp. were low in pre-disturbance samples at both sites but increased greatly at impacted site in January (Figure 36a, b). Additionally, in January, mean density of *Leuctra* sp. increased considerably in the sediments of gravel bars at reference site, probably in accordance with their annual life cycle. Mean densities of chironomids remained low at impacted site after gravel extraction while at reference site were higher (Figure 36c).

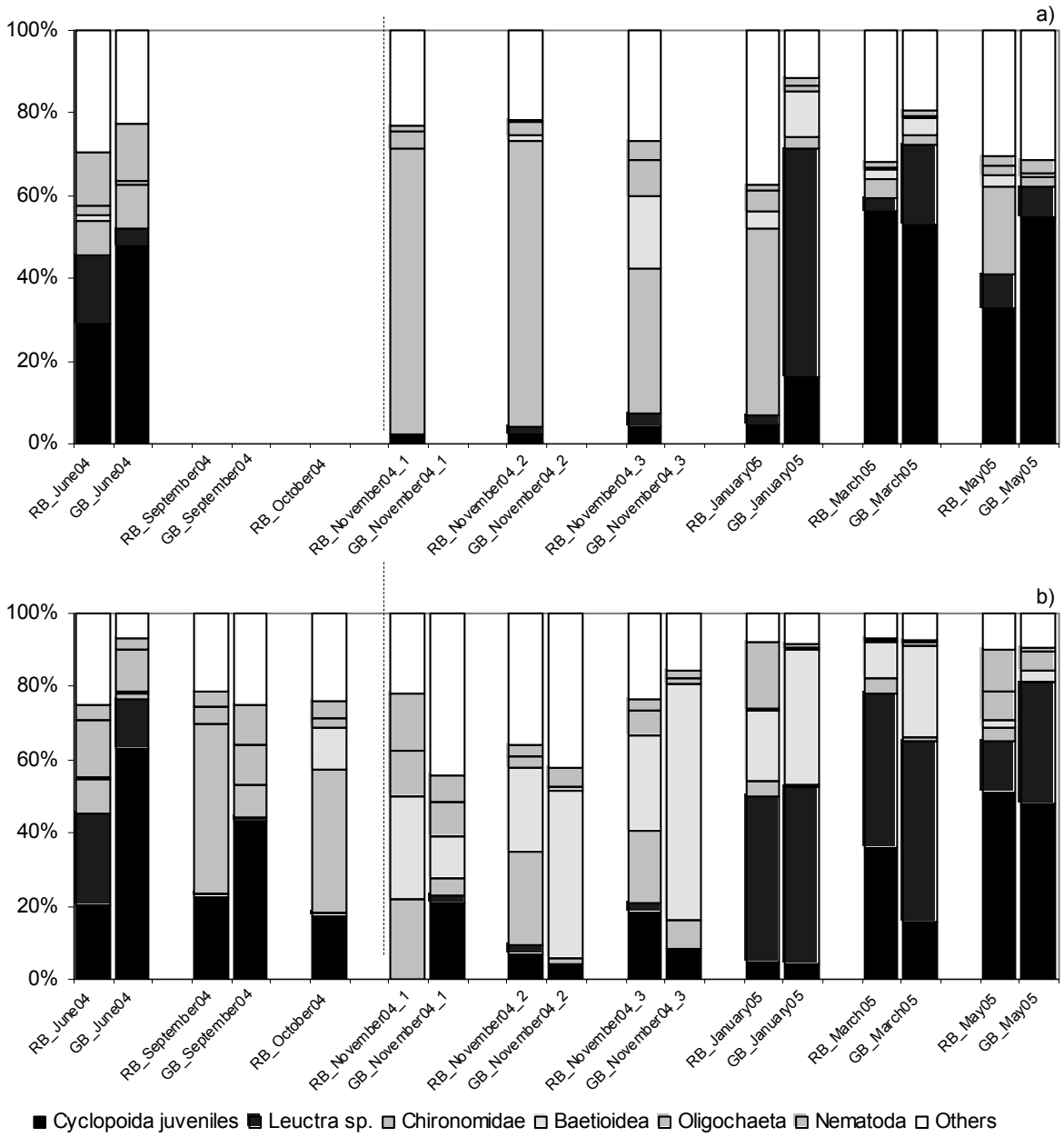

Figure 34. *Taxonomic composition of the hyporheic communities from the Bača River (W Slovenia) at (a) reference and (b) impacted site through the time. Vertical dashed line indicates a period of disturbance.*

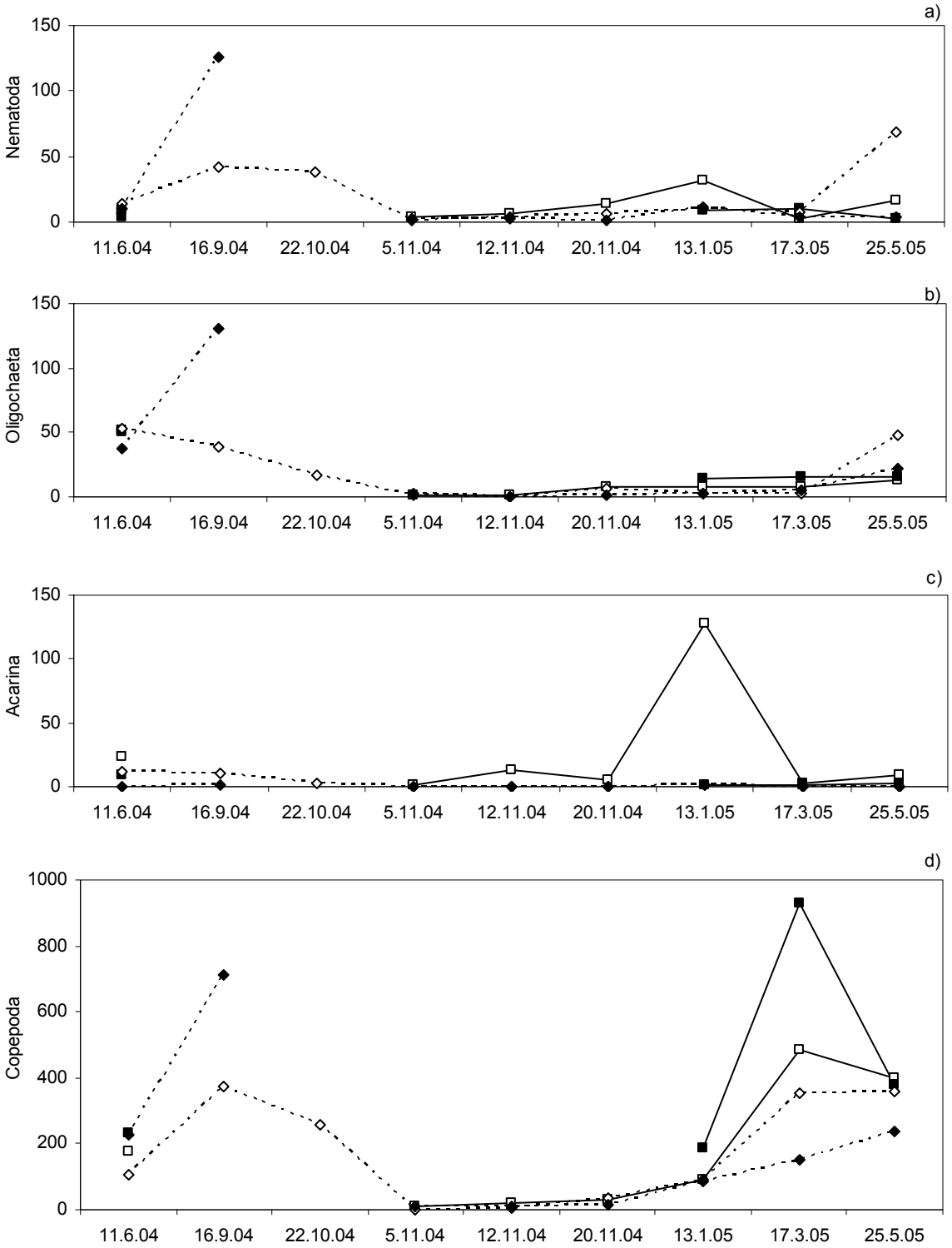

Figure 35. *Mean densities of (a) Nematoda, (b) Oligochaeta, (c) Acarina and (d) Copepoda in the hyporheic samples from the Bača River (W Slovenia) collected from June 2004 to May 2005 (□ river bed and ■ gravel bars sediments at reference site – full black line; ◊ river bed and ♦ gravel bars sediments at impacted site – dashed line).*

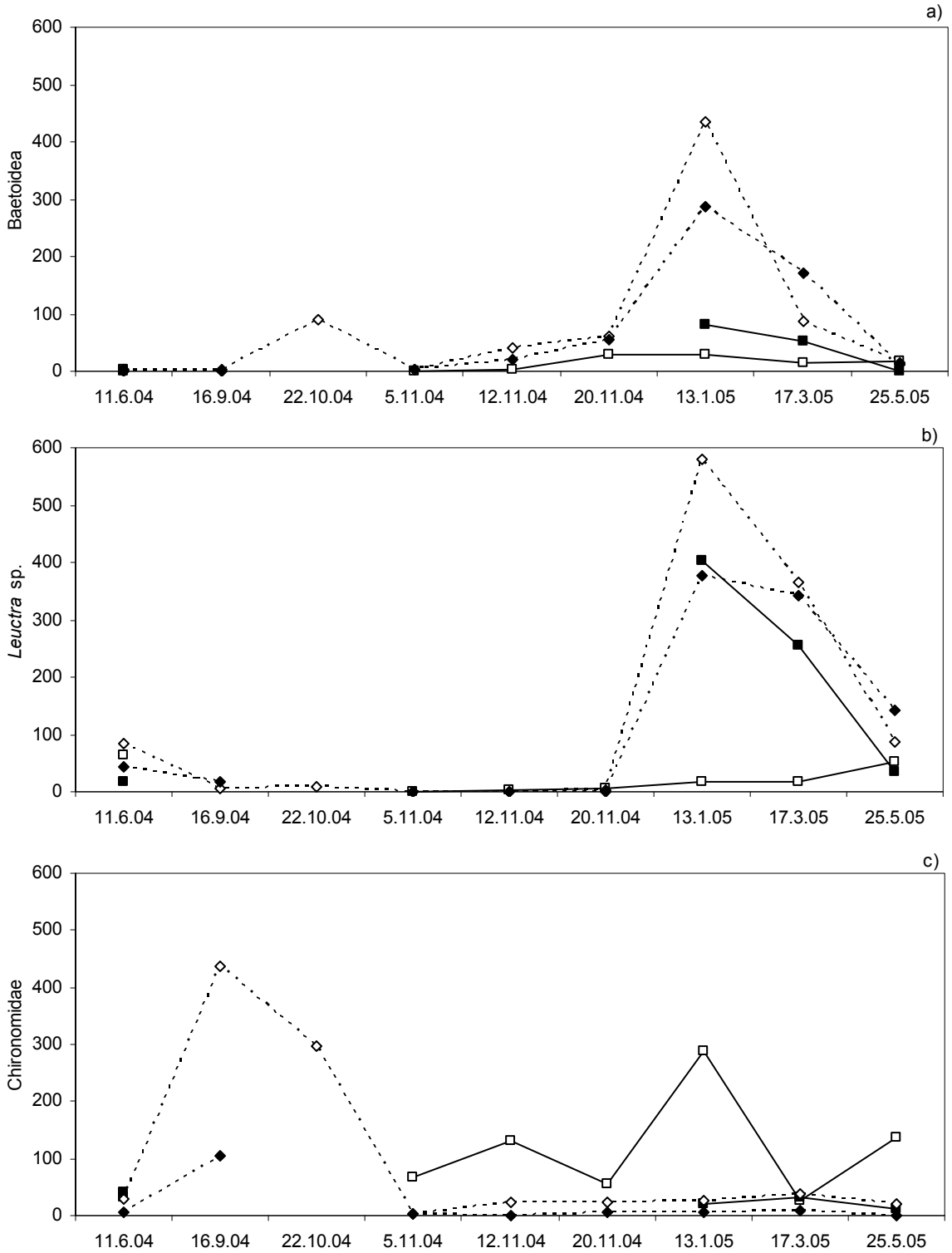

Figure 36. *Mean densities of (a) Baetoidea, (b) Leuctra sp. and (c) Chironomidae in the hyporheic samples from the Bača River (W Slovenia) collected from June 2004 to May 2005 (□ river bed and ■ gravel bars sediments at reference site – full black line; ◊ river bed and ♦ gravel bars sediments at impacted site – dashed line).*

The cluster analysis of the hyporheic samples collected from the river bed sediments and gravel bars at reference site, on the basis of Bray-Curtis index of dissimilarity, resulted in grouping of samples from March 2005 and May 2004 into the same group (Figure 37). However, dissimilarity among samples was still relatively high (0.26 – 0.64). The most distant from other samples were samples

collected in November 2004. Relatively homogenous group was formed by third replicates from river bed (RB3) from different sampling dates. Little variation in taxonomic richness was observed at this sampling point through the time. Variation in densities existed mainly due to increase in Chironomida and Acarina densities in January. Despite little differences in total densities and taxonomic richness between habitat types, the cluster analysis revealed greater similarity of the samples from river bed and gravel bars comparing to the similarity between both habitat types.

At impacted site, the cluster analysis of samples from the river bed and gravel bars revealed clustering of samples collected in June 2004 and May 2005, in September and October 2004, and of samples collected in January and March 2005 (Figure 38). The most distant samples were those collected in November 2004 (after disturbance). The lowest dissimilarity was observed between communities from the river bed and that from the gravel bars two and three weeks after disturbance and in January 2005. Low dissimilarity was calculated as well among samples taken a week after disturbance and among samples taken through the time at the gravel bar sampling point 1 (GB1).

Results of DCA analysis are graphed separately for each sampling site (reference and impacted) and for June and November sampling occasions (Figure 39, 40). During DCA ordination greater variation between samples taken at impacted site was observed comparing to reference site (Figure 39) - a greater spread of samples from impacted site occurred along both axes comparing to reference site. However, similarity of samples from the reference and impacted site taken in June was detected (Figure 40, left). On the contrary, samples taken in November at impacted site showed greater spread along Axis 1 (to the right), while samples taken in November at reference site had lower scores on the Axis 1 (Figure 40, right). Samples from the impacted site with high scores on Axis 1 were associated with greater numbers of Tardigrada, Baetoidea and Chloroperlidae. In contrast, Bathynellacea, *Cyclops vicinus* and *Diacyclops* sp. were more abundant to the left of Axis 1. Rotatoria, Hydridae, juveniles of Ostracoda, *Ecdyonurus* sp. and *Acanthocyclops vernalis* were highly positively correlated with Axis 2. Axis 1 accounted for 14.9 % of the variance in the data, while Axis 2 accounted for 8.3 % of the total variance in the data for the DCA (Table 5). Cumulative percentage variance of species data for first two axes was 23.2 %.

Table 5. *Summary of DCA analysis.*

Axes	1	2	3	4	Total inertia
Eigenvalues	0.538	0.299	0.166	0.106	3.613
Lengths of gradient	2.897	2.837	2.622	2.250	
Cumulative percentage variance of species data	14.9	23.2	27.8	30.7	
Sum of all eigenvalues					3.613

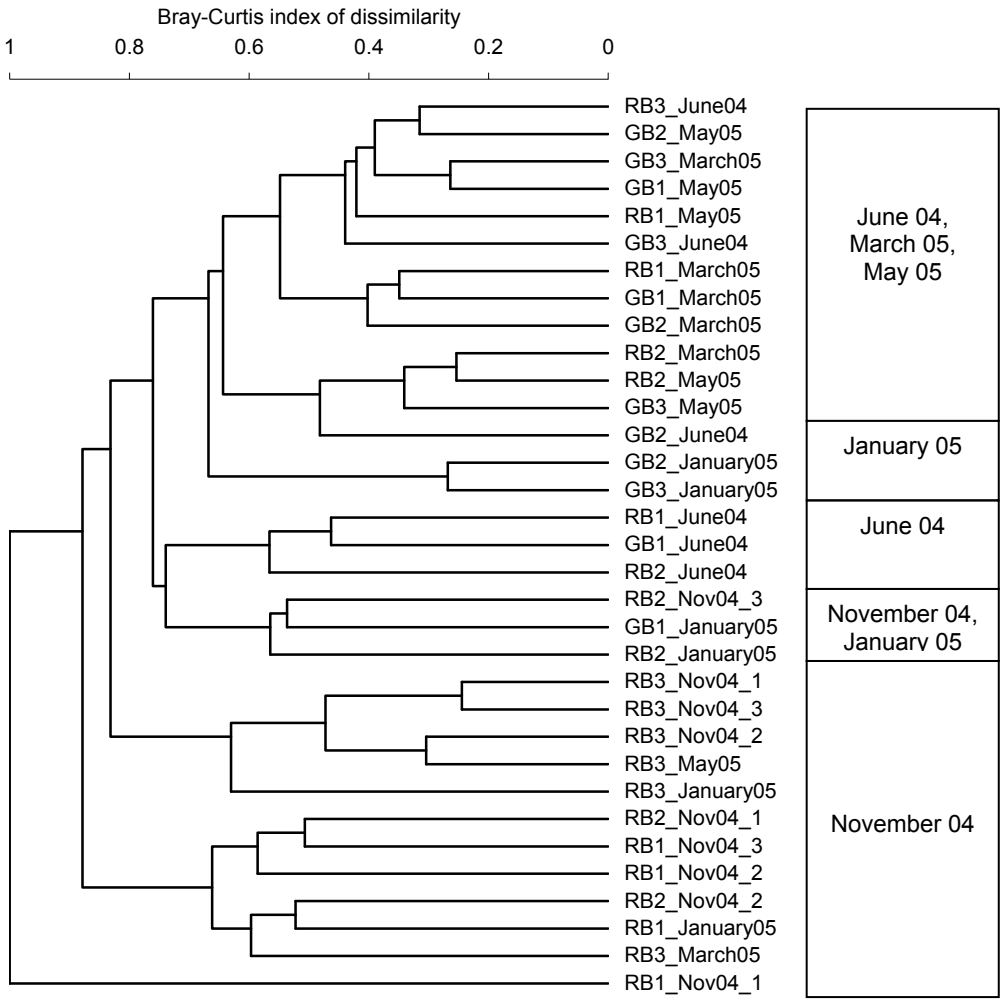

Figure 37. *Cluster diagram based on absolute taxa abundances, using Bray-Curtis index of dissimilarity. Samples from the hyporheic zone of the Bača River (W Slovenia) collected from the river bed sediments and gravel bars at the reference site from June 2004 to May 2005 are analysed. RB1, RB2, RB3 – samples from the river bed sediments; GB1, GB2, GB3 – samples from gravel bars.*

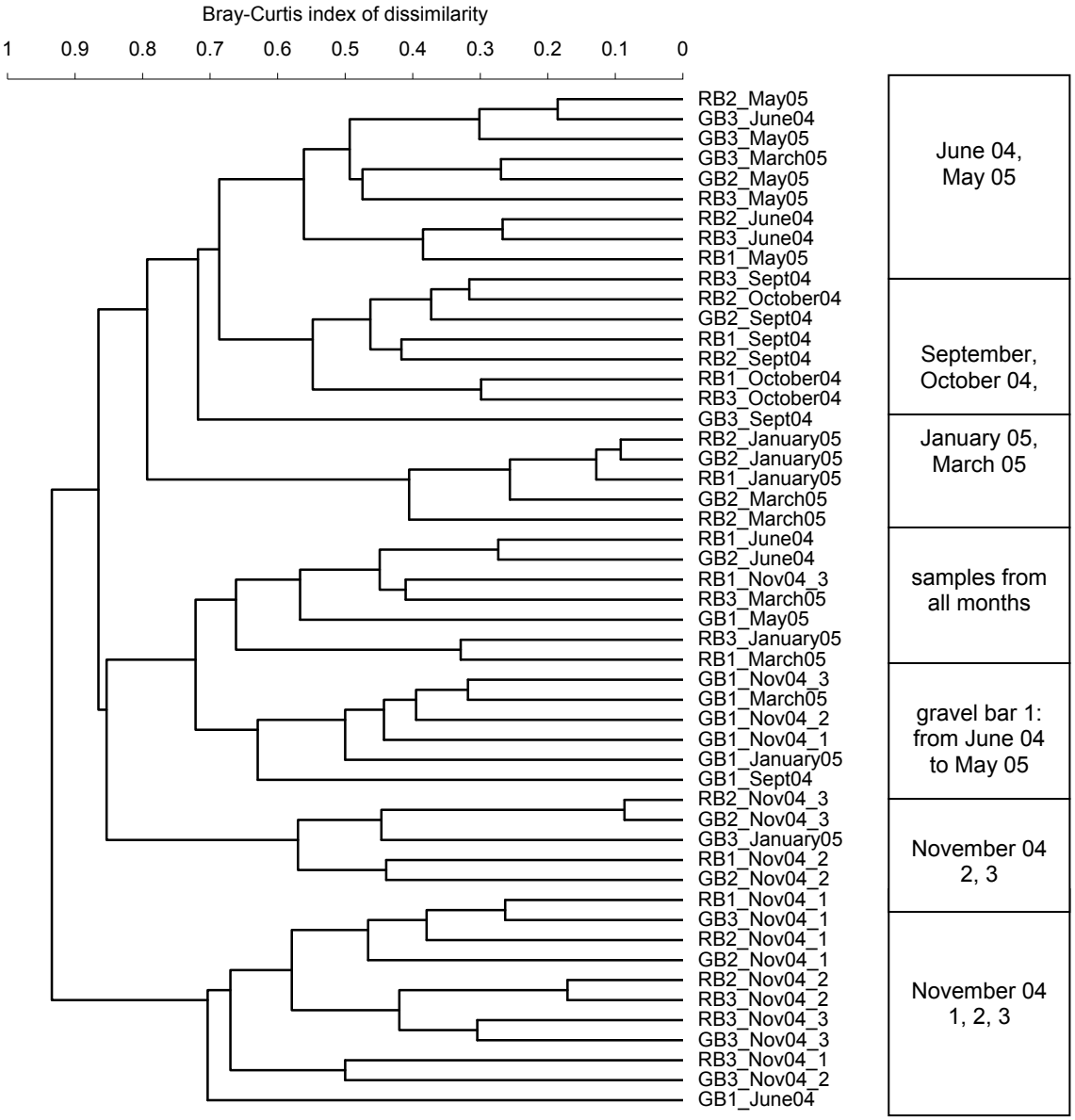

Figure 38. *Cluster diagram based on absolute taxa abundances, using Bray-Curtis index of dissimilarity. Samples from the hyporheic zone of the Bača River (W Slovenia) collected from the river bed sediments and gravel bars at the impacted site from June 2004 to May 2005 are analysed. RB1, RB2, RB3 – samples from the river bed sediments; GB1, GB2, GB3 – samples from gravel bars.*

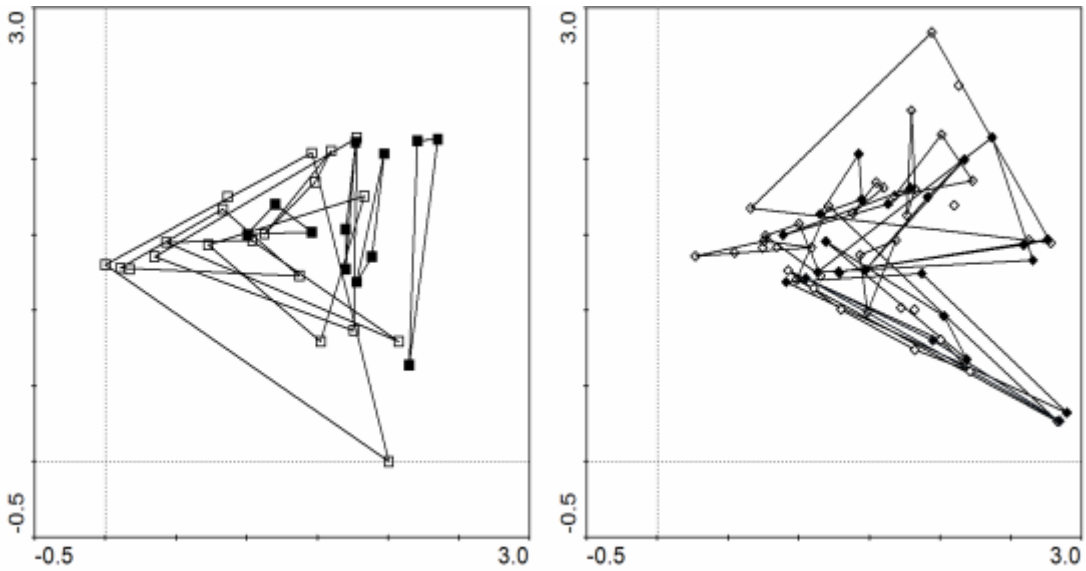

Figure 39. *DCA ordination diagrams for the hyporheic samples collected in the Bača River (W Slovenia) at reference (left) and impacted site (right) from June 2004 to May 2005. □ - river bed at reference site; ■ - gravel bars at reference site; ◊ - river bed at impacted site; ♦ - gravel bars at impacted site.*

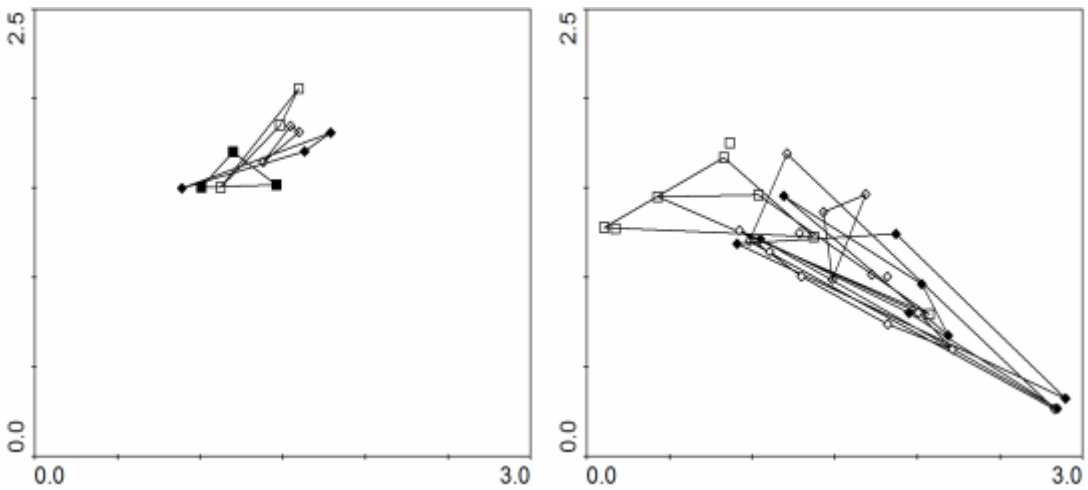

Figure 40. *DCA ordination diagrams for the hyporheic samples collected in the Bača River (W Slovenia) in June 2004 (left) and November 2004 (right). □ - river bed at reference site; ■ - gravel bars at reference site; ◊ - river bed at impacted site; ♦ - gravel bars at impacted site.*

4.2.5 Ecotype distribution

In June 2004, in the Bača River hyporheic zone, holo-hyporheos dominated by abundance in the samples taken from both sampling sites and stygobionts occurred in low numbers (Figure 41a, b). At reference site, an increase in proportion of mero-hyporheos abundances was observed in the samples collected after spates (November 2004), while in March and May 2005, proportions were again similar to those in June 2004. Similarly, at impacted site, mero-hyporheos abundances increased in samples collected after gravel extraction, but not to such extent as at reference site. On the contrary, when considering taxonomic richness, the proportions among mero- and holo-hyporheos and stygobionts were more or less similar all the year round at both sites (Figure 42a, b). Those results showed that spates caused the changes in relative proportion of ecotypes abundances, but not of their taxonomic

richness. At reference site, the mero-hyporheos, mostly chironomid larve were the first recolonizers, while at impacted site the mechanism of recolonization was different. Holo-hyporheos, such as Nematoda and Oligochaeta were represented by higher relative abundances comparing to reference site. Stygobionts represented only a small proportion of total abundance and taxonomic richness during the whole sampling period and were more abundant in the samples from the reference site than from the impacted one.

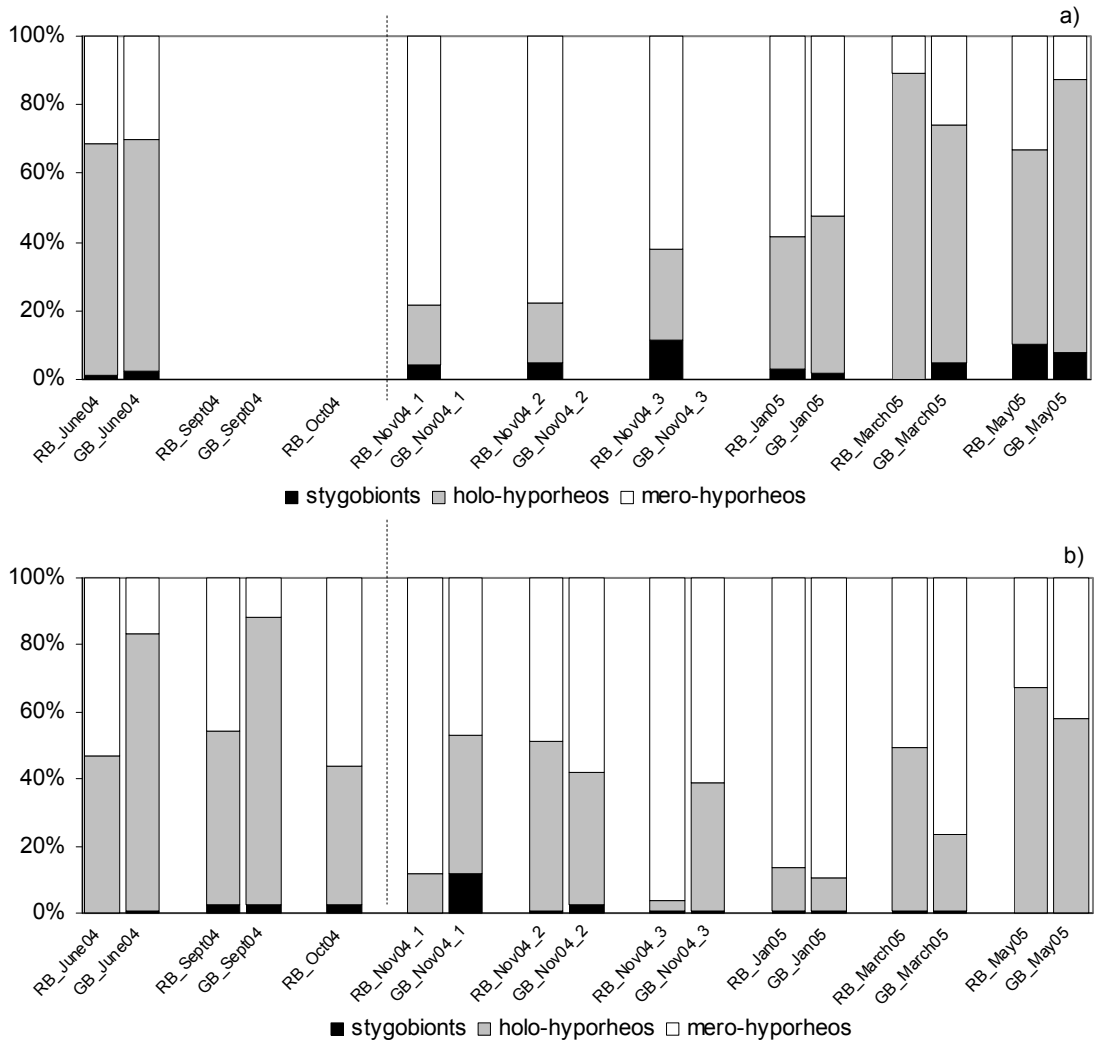

Figure 41. *Relative abundances of different ecotypes in the hyporheic zone of the Bača River (W Slovenia) at reference (a) and impacted (b) site over the time. Vertical dashed line indicates a period of disturbance. RB – river bed; GB – gravel bars.*

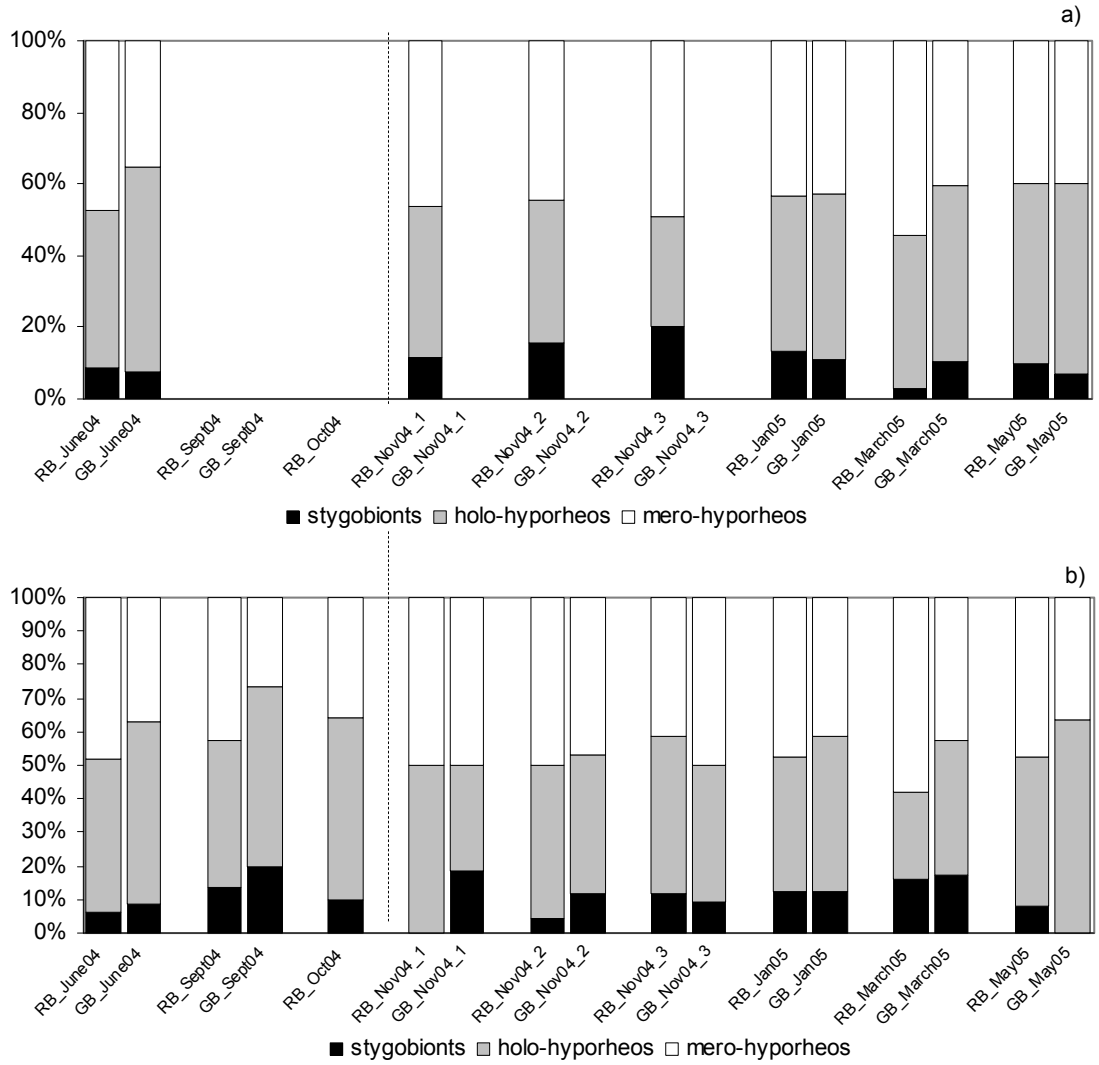

Figure 42. *Relative numbers of taxa of different ecotypes in the hyporheic zone of the Bača River (W Slovenia) at reference (a) and impacted (b) site over the time. Vertical dashed line indicates a period of disturbance. RB – river bed; GB – gravel bars.*

4.2.6 Size classes

Size classes of Ephemeroptera and Plecoptera larger than 5 mm and of Diptera larger than 4 mm occurred in low proportions in all samples (from both sampling sites and all dates) (Figure 43). At reference site, the individuals of Ephemeroptera of a size between 1 and 4.9 mm prevailed during all sampling period in the samples collected in the river bed sediments, while the individuals smaller than 1 mm occurred abundantly in June 2004, March and May 2005 samples from gravel bars. At impacted site, in June and September 2004, and March and May 2005 samples prevailed size class of 1 – 4.9 mm, while during October and November 2004, and January 2005 samples the larvae smaller then 1mm dominated.

Plecoptera were present at both sampling sites in low numbers, and the smallest size classes (1 - 4.9 mm, < 1 mm) prevailed. At reference site, the Plecoptera larvae of a size between 1 - 4.9 mm predominated in June 2004, and March and May 2005 samples, while in November 2004 and January 2005 samples, the smaller larvae prevailed. Similarly, at impacted site, larvae of a size between 1 - 4.9 mm prevailed in June, September and October 2004 and May 2005 samples, while smaller individuals dominated in November 2004, and January and March 2005 samples.

At reference site, a decrease in proportion of the smallest class of Diptera was observed in spring samples (March and May 2005), and the proportion of the smallest size class was higher in the samples from the river bed than from gravel bars. At impacted site, the relative proportion of the smallest size class (< 1.9 mm) gradually decreased in post-disturbance samples from both habitat types.

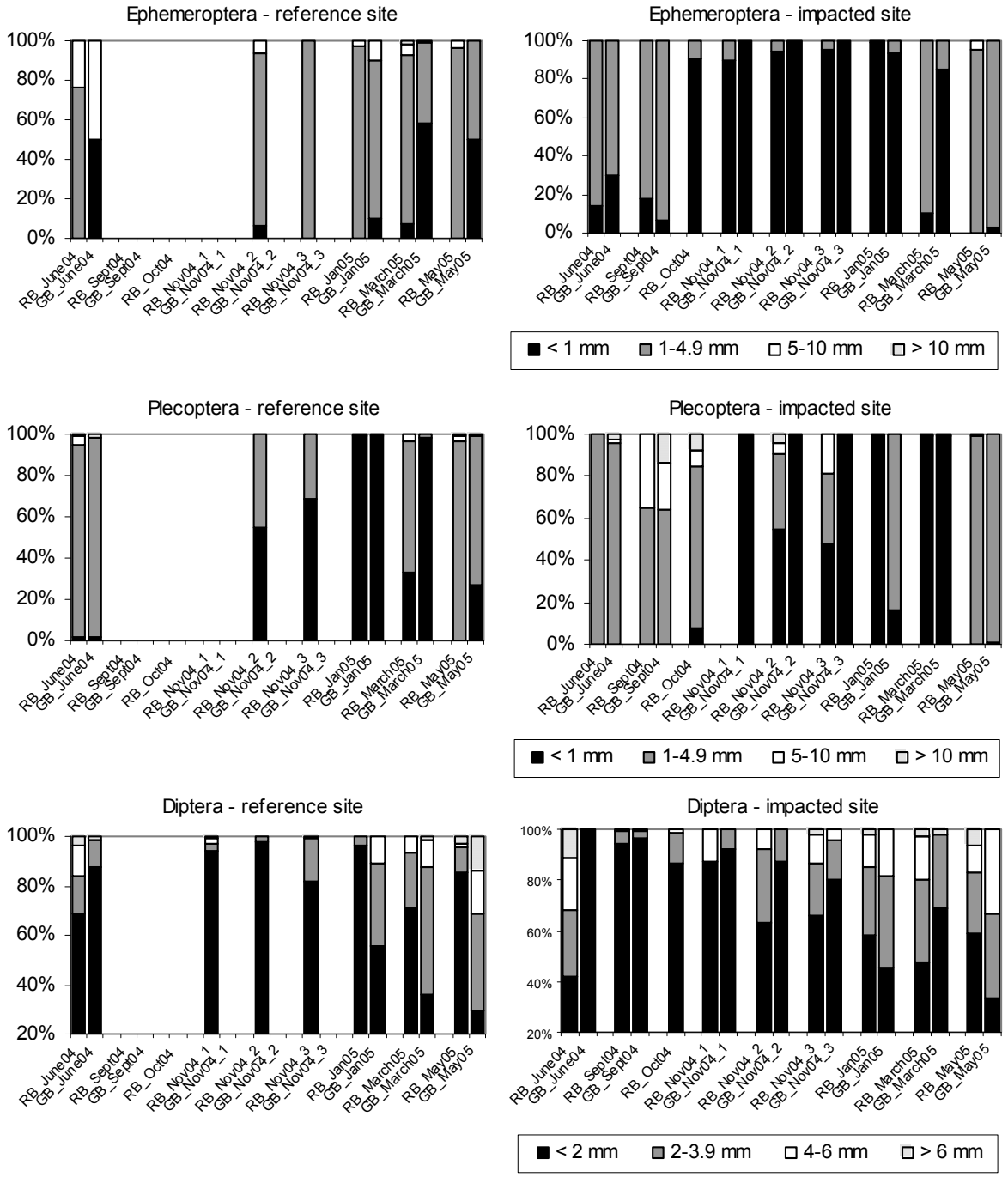

Figure 43. *Relative proportions of size-classes of Ephemeroptera, Plecoptera and Diptera at reference (a) and impacted (b) site over the time in the hyporheic zone of the Bača River (W Slovenia).*

4.2.7 Catastrophic drift

Drift samples taken at reference site, impacted site and 200 m downstream from the gravel extraction site on the Bača River on October 23 and 26 2004 (during gravel extraction) contained the mayority of invertebrate taxa that were collected from the hyporheic zone, with the exception of Bivalvia, which were not found in the hyporheic samples (Table 6). During all drift measurements, the most abundant taxa were Harpacticoida, Chironomidae, Trichoptera and other Diptera. On the first day of gravel extraction, when drift samples from the reference site were compared to the samples from the impacted site and the site 200 m downstream of impacted site, taxonomic richness in the drift was lower at reference site (natural drift: behavioural and constant), comparing to the drift from the other two sampling sites (catastrophic drift). During this sampling, representatives of Gastropoda, Oligochaeta, Tardigrada, Isopoda and *Gammarus* sp. were found in catastrophic drift samples (impacted site and 200 m downstream from impacted site), but not in natural drift samples (reference site). On the fourth day of gravel extraction (October 26 2004), when extraction was intensively carried out from 7.00 in the morning to 22.00 in the evening, the number of taxa was higher in the drift measured few meters from the impacted site comparing to that 200 m downstream from the impacted site. The representatives of Hydrozoa, Nematoda, Bivalvia, Tardigrada, Copepoda (nauplia), Ostracoda, *Niphargus* sp., Isopoda, Copepoda nauplia, Ostracoda, and Bathynellacea were present in drift samples measured few meters from impacted site, but not in drift 200 m downstream.

Drift rates (the number of individuals per 1 hour) were more than 10 times higher at both sites below the extraction site comparing to the reference site (Table 7). After dredger stopped to work, drift rates decreased at impacted and downstream site as well. On October 26, the drift rates from the impacted site were higher comparing to that from downstream site. Harpacticoida, Chironomidae, Trichoptera and Diptera composed from 50 to 90 % of total invertebrate drift (Figure 44a, b). On the October 23, Trichoptera were the most abundant at reference site, while at impacted and downstream site Chironomidae prevailed by numbers. At impacted site, the relative proportions of Diptera and Trihoptera increased in drift after the dredger stopped to excavate. Further on, the proportions of Nematoda, Acarina, Cyclopoida and Ephemeroptera in drift were higher during gravel extraction and considerably decreased when dredger stopped to work. At downstream site, differences in drift taxonomic composition during daytime were not so prominent. On October 26, at impacted site, Plecoptera, Ephemeroptera and Coleptera dominated in the drift during the night, while during the day, when the dredger was active, along with Harpacticoida, relative abundances of Cyclopoida increased. At downstream site, harpacticoids and chironomids prevailed in the drift during all 24 hours. However, during the night the proportions of Trichoptera, Gastropoda, Acarina, and Cyclopoida were higher and proportions of Plecoptera were lower comparing to the day drift.

Results of the drift sampling indicated that gravel extraction caused the drifting of invertebrates that normally are not present in drift, such as stygobionts (*Niphargus* sp., Bathynellacea) or enter drift in low abundances, such as some holo-hyporheos (Cyclopoida). The catastrophic drift differed from natural one in taxonomic composition and the drift composition varied between day and night time. In our study, the proportions of EPT random drift were higher during the night. The exception was drift at the site downstream from the impacted site, where Plecoptera had higher relative abundances during the day than night.

Table 6. *List of invertebrate taxa found in drift samples from the reference site, impacted site and 200 m downstream from the impacted site on the Bača River (W Slovenia) taken on October 23 and 26 2004 (during gravel extraction). Taxa are listed from the most abundant ones to the least abundant.*

October 23 2004			October 26 2004	
reference site	impacted site	200 m downstream	impacted site	200 m downstream
Harpacticoida	Harpacticoida	Harpacticoida	Harpacticoida	Harpacticoida
Chironomidae	Chironomidae	Chironomidae	Chironomidae	Chironomidae
Trichoptera	Trichoptera	Trichoptera	Trichoptera	Trichoptera
Diptera	Diptera	Diptera	Diptera	Diptera
Plecoptera	Acarina	Acarina	Cyclopoida	Ephemeroptera
Ephemeroptera	Coleoptera	Coleoptera	Plecoptera	Oligochaeta
Acarina	Ephemeroptera	Cyclopoida	Ephemeroptera	Cyclopoida
Nematoda	Cyclopoida	Ephemeroptera	Oligochaeta	Plecoptera
Coleoptera	Nematoda	Oligochaeta	Acarina	*Gammarus*
Cladocera	Oligochaeta	Plecoptera	Coleoptera	Gastropoda
Cyclopoida	Plecoptera	Nematoda	Nematoda	Acarina
	Cladocera	Cladocera	Cladocera	Coleoptera
	Isopoda		Bivalvia	
	Gastropoda		*Niphargus* sp.	
	Tardigrada		Copepoda nauplia	
	Gammarus sp.		Isopoda	
			Ostracoda	
			Bathynellacea	
			Tardigrada	
			Gastropoda	
			Hydra	
			Gammarus sp.	

Table 7. *Drift rates (numbers of individuals per hour) during sampling on October 23 and 26 2004 in the Bača River. Numbers represent number of individuals collected in individual sampling net in a sampling period and calculated as a number of individuals per one hour. On October 23, gravel extraction was carried out from from 10.45 untill 14.45, and on October 26, from 7.00 untill 22.00.*

	23rd October 2004			26th October 2004	
	reference site	impacted site	200 m downstream	impacted site	200 m downstream
	10.00-16.00	**10.45-16.45**	**11.00-17.00**	**22.30-7.00**	**23.00-8.00**
net 1	31	355	349	108	9
net 2	11	531	187	46	45
				22	
		16.45-00.45	**17.00-1.00**	**7.30-18.30**	**8.00-16.30**
net 1		57	45	499	56
net 2		113	84	362	105
				207	
				19.00-21.30	**16.30-22.00**
net 1				496	43
net 2				490	59
net 3				374	

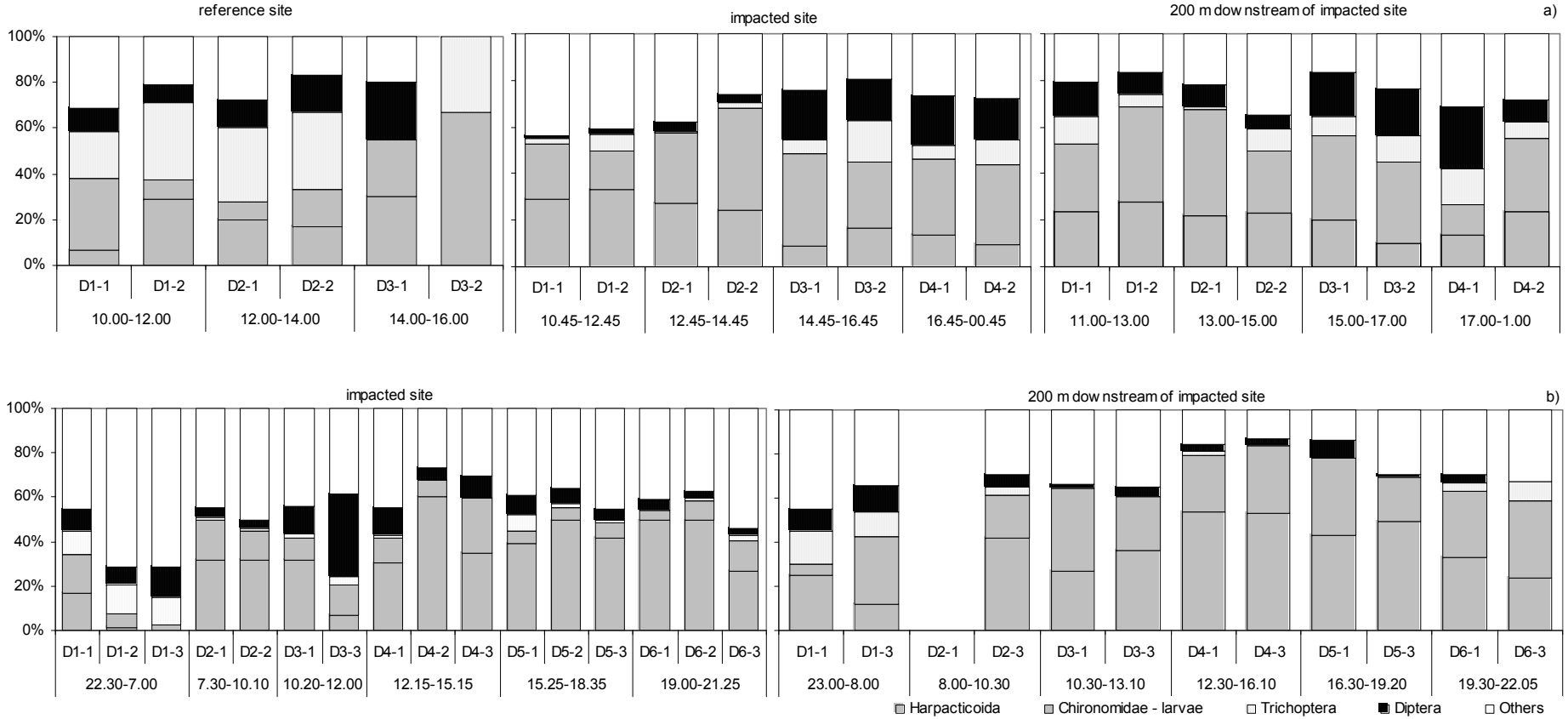

Figure 44. *Relative proportions of major invertebrate taxa occurring in the natural drift at reference and in the catastrophic drift at impacted site and 200 m downstream from the site of gravel extraction in the Bača River (W Slovenia), sampled on October 23 2004 (a) and October 26 2004 (b). D1, D2, D3, D4, D5, D6 – the names for samples obtained from drift nets from different time periods. During each time period, two or three replicates (drift nets) were collected.*

4.2.8 Relationships between environmental factors and hyporheic invertebrate community

The canonical correspondence analysis (CCA) on data from reference site accounted for 76.3 % of the total variance in the species data, with the first axis representing 27.4 % of the species-environment relationship (Table 8). The first axis was positively correlated with fine sediments amounts, oxygen consumption rate on fine sediments and ETS activity of hyporheic water and in negative correlation with conductivity and habitat type (Figure 45). The second axis accounted for a further 15.2 % of the species-environment relationship. The Monte Carlo permutation test indicated the statistical significance of fine sediments, particulate organic matter and conductivity ($p<0.01$) on species occurence. Distribution of samples relative to the first two axes revealed distinct differences in communities sampled in November 2004 from other dates (Figure 45).

The canonical correspondence analysis (CCA) on data from impacted site accounted for 61.5 % of the total variance in the species data, with the first axis representing 38.6 % of the species-environment relationship (Table 9). The first axis was in positive correlation with ETS activity of hyporheic water and ETS activity of fine sediment fraction and in negative correlation with fine sediment amounts, the major ions (sulphates, nitrates, Ca, Na, Mg) and temperature (Figure 46). The second axis accounted for a further 18.5 % of the species-environment relationship and was in positive correlation with habitat type and in negative correlation with ETS activity on coarse sediment fraction. The Monte Carlo permutation test indicated the statistical significance of fine sediments, ETS activity on fine and coarse sediment fraction, temperature and nitrates. In the ordination diagram, the samples taken in a month after gravel extraction were clearly separated from others (Figure 46).

Spearman rank correlation coefficients between total density, taxonomic richness, density of the six the most common taxa and major environmental parameters are given in Table 10. The analyses support the trends indicated by CCA. The temperature was positively correlated with oligochetes densities, while densities of nematods and baetids were in negative correlation with temperatures. For the total density and taxonomic richness and for the most of taxa, with the exception of nematods, baetids and *Leuctra* larvae, there was positive correlation with oxygen saturation. Similarly, total sediment, fine sediment and organic matter amounts correlated positively with the majority of taxa at least at one site. Almost no correlation between nitrate and sulphate concentrations, oxygen consumption rates of biofilm, and ETS activity in the hyporheic water, and invertebrate densities was observed. However, a positive correlation between total density and densities of baetids and *Leuctra* sp. at impacted site, and strong negative correlation ($rs=60$) between nematods and ETS activity of fine sediment fraction at reference site was calculated.

Table 8. *A summary of canonical correspondence analysis (CCA) of relationship between hyporheic invertebrates and environmental parameters in the hyporheic zone of the Bača River (W Slovenia) at reference site.*

Axes	1	2	3	4	Total inertia
Eigenvalues	0.57	0.315	0.241	0.185	2.722
Species-environment correlations	0.971	0.908	0.913	0.962	
Cumulative percentage variance					
of species data	20.9	32.5	41.4	48.2	
of species-environment relation	27.4	42.6	54.2	63.1	
Sum of all eigenvalues					2.722
Sum of all canonical eigenvalue					2.078

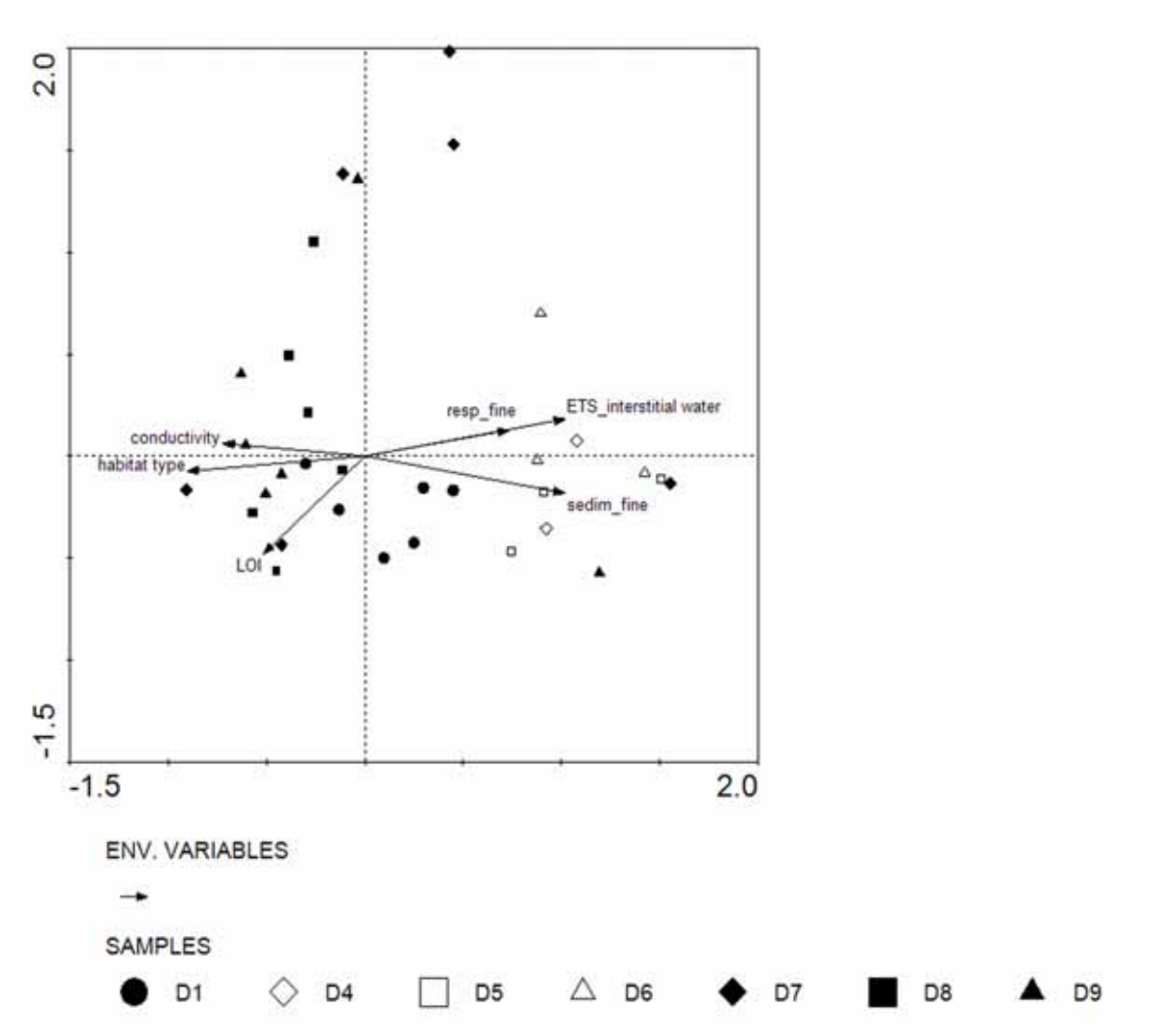

Figure 45. *Canonical correspondence analysis (CCA) biplot of the hyporheic invertebrate samples from the Bača River (W Slovenia) collected at reference site relative to 20 environmental parameters. Six the most important are displayed as arrows on diagram. D1-D9 are abbreviations for nine sampling dates; D1 - 11.6.04, D2 - 16.9.04, D3 - 22.10.04, D4 - 5.11.04, D5 - 12.11.04, D6 - 20.11.04, D7 - 13.1.05, D8 - 17.3.05, D9 - 25.5.05.*

Table 9. *A summary of canonical correspondence analysis (CCA) of relationship between hyporheic invertebrates and environmental parameters in the hyporheic zone of the Bača River (W Slovenia) at impacted site.*

Axes	1	2	3	4	Total inertia
Eigenvalues	0.539	0.259	0.123	0.105	2.272
Species-environment correlations	0.969	0.955	0.673	0.868	
Cumulative percentage variance					
of species data	23.7	35.1	40.5	45.1	
of species-environment relation	38.6	57.1	65.9	73.4	
Sum of all eigenvalues					2.272
Sum of all canonical eigenvalues					1.397

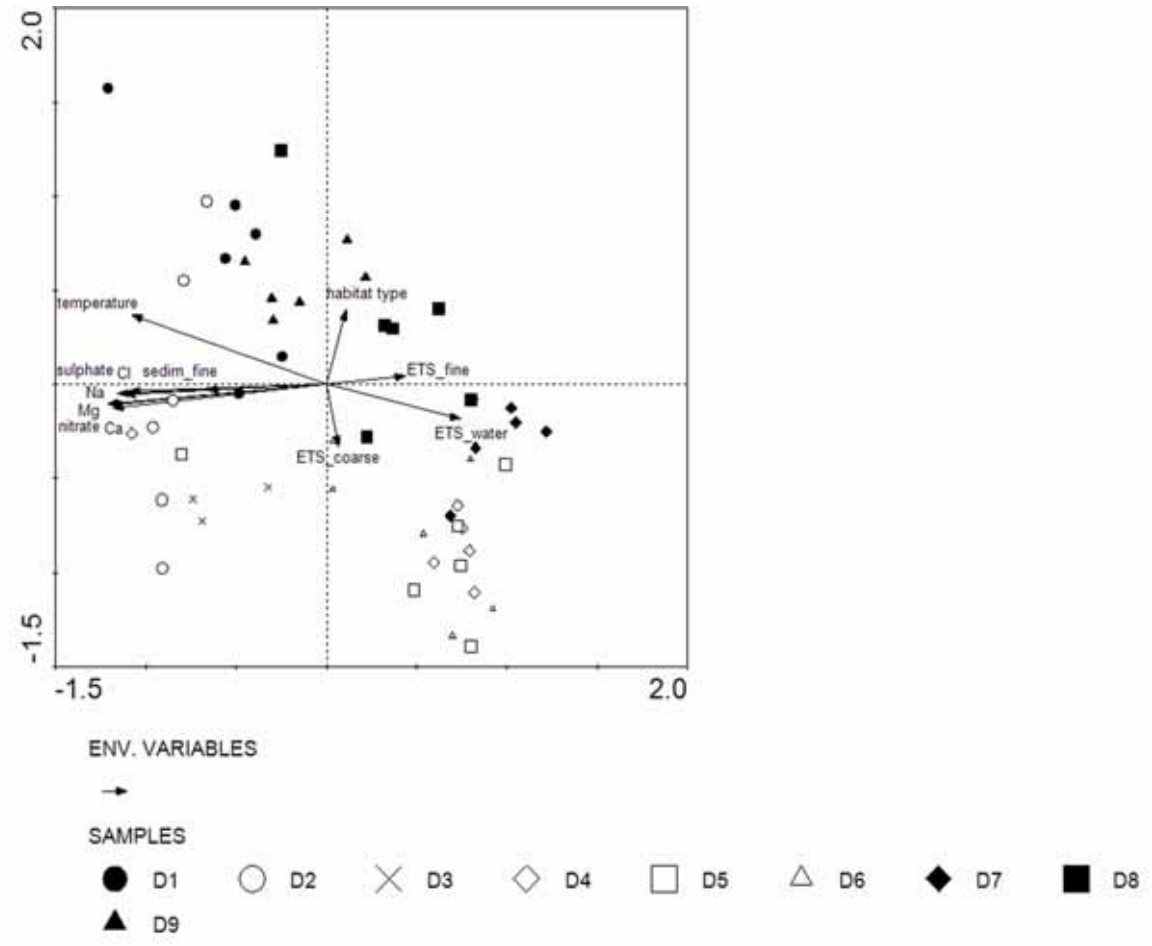

Figure 46. *Canonical correspondence analysis (CCA) biplot of the hyporheic invertebrate samples from the Bača River (W Slovenia) collected at impacted site relative to 20 environmental parameters. Six the most important are displayed as arrows on diagram. D1-D9 are abbreviations for nine sampling dates; D1 - 11.6.04, D2 - 16.9.04, D3 - 22.10.04, D4 - 5.11.04, D5 - 12.11.04, D6 - 20.11.04, D7 - 13.1.05, D8 - 17.3.05, D9 - 25.5.05.*

Table 10. *Spearman rank correlation coefficients between total density, taxonomic richness, density of the six the most common taxa and major environmental parameters. ETS – respiratory electron transport system activity of biofilm. * p<0.05, ** p<0.01, *** p<0.001.*

		density	taxa richness	Nematoda	Oligochaeta	Cyclopoida	Baetoidea	*Leuctra* sp.	Chironomidae
temperature (°C)	*Ref S*	-0.13	-0.18	-0.42*	0.26	0.25	-0.46*	-0.08	-0.13
	Imp S	-0.19	-0.07	0.06	0.63***	0.19	-0.46**	-0.24	-0.03
oxygen saturation	*Ref S*	0.23	-0.26	-0.15	-0.37	0.47*	0.29	-0.06	0.06
	Imp S	0.58**	0.59**	0.23	0.50**	0.62***	0.22	0.35	0.49**
NO_3	*Ref S*	-0.02	0.05	-0.11	-0.59	-0.20	0.14	0.36	-0.28
	Imp S	0.30	0.30	0.27	0.17	0.24	0.06	-0.15	0.31
SO_4	*Ref S*	0.40	0.09	0.02	-0.25	0.32	0.66*	0.48	0.28
	Imp S	-0.06	-0.17	-0.16	0.16	0.03	0.00	0.34	-0.28
total sediment amounts	*Ref S*	0.47**	0.40*	0.27	0.39*	0.37*	0.38*	0.40*	0.29
	Imp S	0.22	0.21	0.33**	0.10	-0.05	-0.07	0.04	0.31*
fine sediment amounts (particles < 100 µm)	*Ref S*	0.51**	0.47*	0.34	0.40*	0.57**	0.20	0.40*	0.39*
	Imp S	0.38*	0.39**	0.65***	0.45**	0.55***	-0.15	0.14	0.33*
particulate organic matter	*Ref S*	0.33	0.42*	0.33	0.34	0.15	0.40*	0.55**	0.28
	Imp S	0.27	0.32*	0.36**	0.04	0.06	0.10	0.17	0.28*
oxygen consumption fine fraction	*Ref S*	-0.53	-0.37	-0.40	-0.62	-0.62	-0.18	-0.38	0.13
	Imp S	-0.11	-0.17	-0.42*	-0.22	-0.18	0.00	-0.11	-0.05
oxygen consumption coarse fraction	*Ref S*	-0.18	-0.32	-0.37	-0.04	0.03	-0.26	0.03	-0.14
	Imp S	0.06	0.02	-0.07	-0.02	0.18	-0.21	0.09	0.15
ETS hyporheic water	*Ref S*	-0.12	0.14	-0.18	-0.31	-0.26	-0.01	-0.34	-0.08
	Imp S	0.14	0.03	0.08	-0.04	0.07	0.09	0.16	-0.17
ETS fine fraction	*Ref S*	-0.24	-0.36	-0.60*	-0.20	0.06	0.42	0.13	-0.43
	Imp S	0.40*	0.22	-0.16	0.02	0.26	0.55***	0.48**	0.12
ETS coarse fraction	*Ref S*	0.06	-0.10	-0.23	-0.19	0.14	0.14	0.47	-0.16
	Imp S	0.25	0.33*	0.06	0.14	0.21	0.01	0.20	0.40*

4.3 The current status of management of alluvial sediments in the Soča river catchment

Sediment extraction in the Soča catchment is carried out due to following ***Drivers***:

a) maintanance of the hydroelectric power plants accumulation basins on the Soča River (the company "*hydroelectric power plants SENG" - Soške elektrarne Nova Gorica)*
b) emptying the bed-load traps on the Soča, Bača and Tolminka Rivers to reduce down-stream transport of sediments (the company "*hydroelectric power plants SENG" - Soške elektrarne Nova Gorica)*
c) economical extraction at four sites along the Soča River (private companies)
d) regular maintenance of river channels and water infrastructure in order to minimize the risk of flooding (government, performer - the company VGP Hidrotehnik).

The results of sediment extraction are visible as ***Pressure*** on overall flow characteristics and water balances and on morphological alterations of rivers in the Soča catchment.

Current ***State*** in the Soča catchment can be described by proportion of modificated channels, and by numbers of sites along the river where gravel extraction is carried out on regular basis (Figure 47, 48).

The ***Impacts*** are shown as loss of habitats for freshwater organisms (aquatic invertebrates and fish) and impacts on flora and fauna (mostly birds) of gravel bars.

The ***Response*** are regulatory measures set up by government in form of concessions. Regarding the four drivers, four concessions have been passed by government:

a) Decree on the concession for the commercial exploitation of the waters of the Soča, Idrijca and Bača for the generation of electricity (Official Gazette RS 63/96; 88/04; 83/06);
b) Decree on the concession for the removal of alluvial deposits in sediment traps on the Soča, Tolminka and Bača Rivers (Official Gazette of RS, 67/03 – Appendix A)
c) Decree on concessions for commercial exploitation of alluvial deposits of the river Soča (Official Gazette of RS, No. 99/01- Appenix B);
d) Decree on concessions for performing public services in the area of water management (Official Gazette of RS, No. 42/03, 121/04, 67/05).

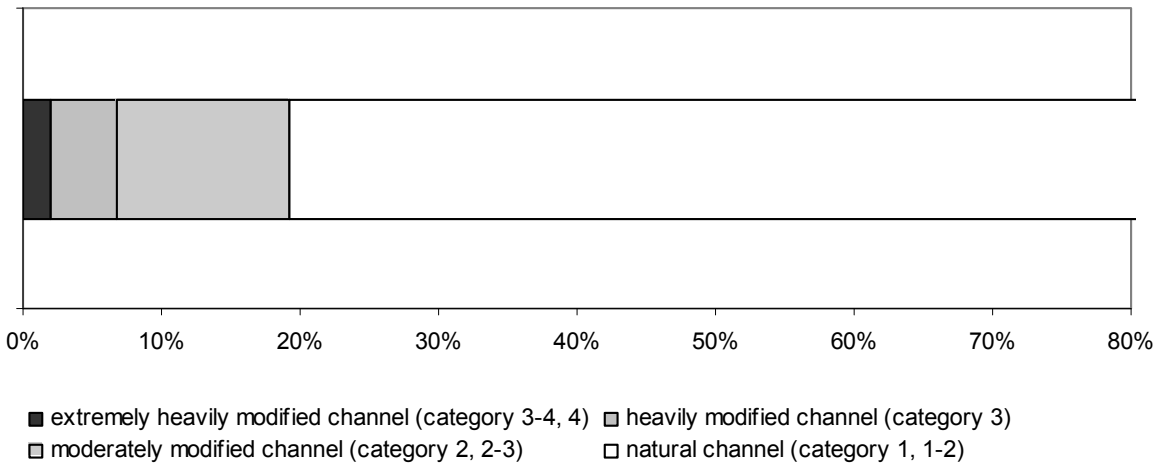

Figure 47. *The proportions of the lengths of river channels that are in natural state (white), moderately modified (incline lines), heavily modified (gray) and extremely heavily modified (black). The upper and middle flow of the Soča River with tributaries (W Slovenia) before passing the Slovenian-Italian border is considered in the analysis (See Figure 48). Source: Environmental Agency, http://gis.arso.gov.si/, August 13 2007.*

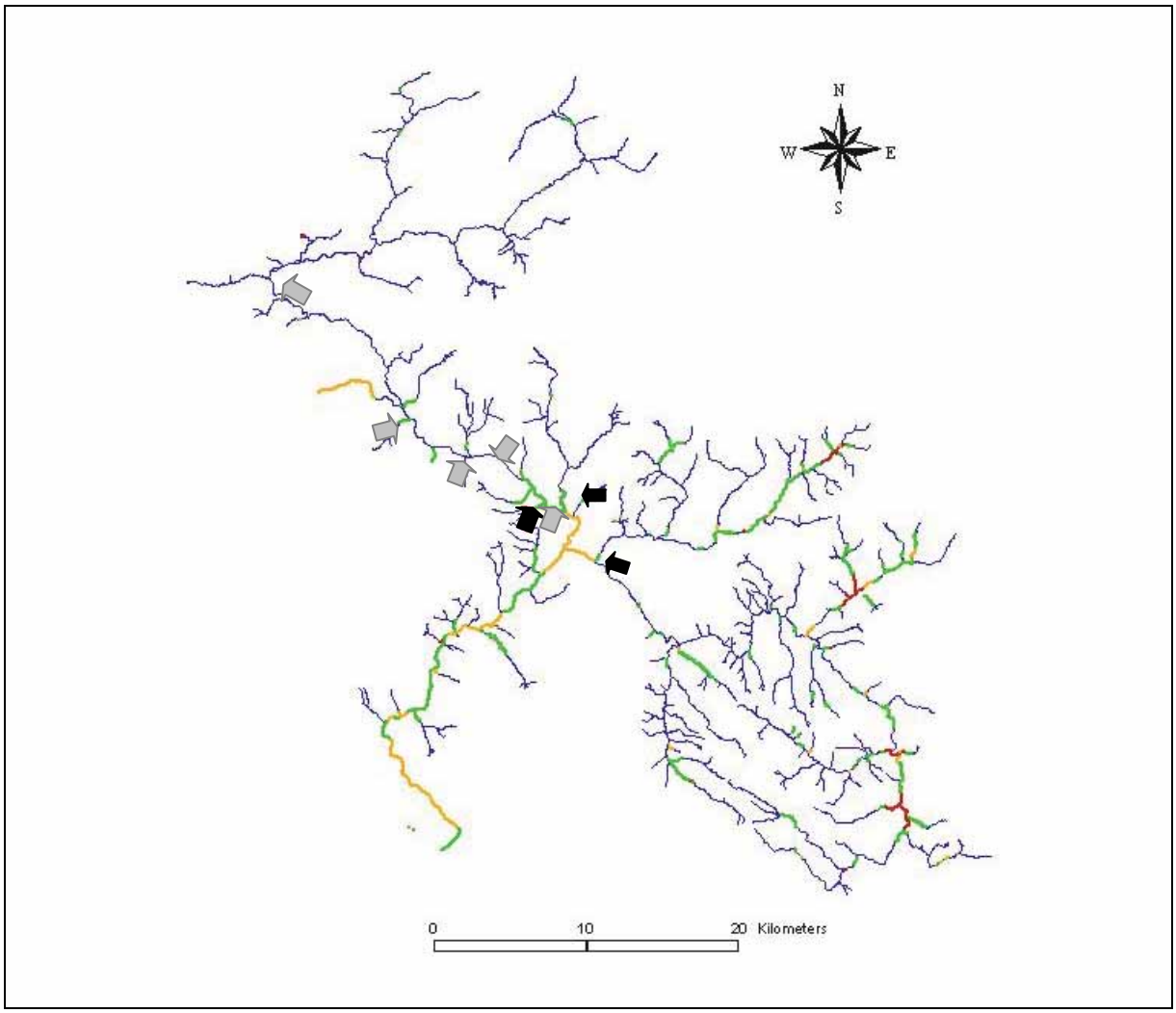

Figure 48. *Classification of the Soča River and its tributaries on the basis of the intensity of channel modification. Blue - natural channel = category 1 & 1-2; green - moderately modified channel = category 2 & 2-3; yellow - heavily modified channel = category 3; red - extremely heavily modified channel = category 3-4 & 4. Black arrows represent locations of bed-load traps and gray arrows locations of economic gravel extraction. Source: Environmental Agency, http://gis.arso.gov.si/, August 13 2007.*

Figure 49 represents the most important stakeholders regarding the management of river bed sediments in the Soča catchment. The umbrella governmental institution is *Ministry of the Environment and Spatial Planning* (*MESP*), which is responsible for the environment at state level. For the river sediment management sector is responsible *Environment Directorate* with its *Department for Waters*. *Environment Directorate* performs professional tasks in the field of systemic legal environmental issues, provides expert groundwork for the drawing-up of regulations, and coordinates tasks falling within the competence of the Ministry. Under the Ministry administration are *Environmental Agency* (*EA*) and *Inspectorate of the Republic of Slovenia for the Environment and Spatial Planning. EA* performs expert, regulatory and administrative tasks related to the environment at the national level. *Inspectorate* controls proper performance of national regulations, regarding environmental protection and management of waters. Both, *EA* and *Inspectorate* have regional offices in Nova Gorica.

Professional public institutions established by government to execute different task in order to efficiently carry out national program on the environmental protection and sustainable development are *Institute for Water of the Republic of Slovenia* (*IzVRS*), *Institute of the Republic of Slovenia for Nature Conservation* (*IRSNC*), and *Fisheries Research Institute of the Republic of Slovenia* (*FRIRS*). *IRSNC, IzVRS and FRIRS* collaborate together in the preparation of expert opinions requested by

MESP. IRSNC operateS in the field of natural protection, *IzVRS* in the field of water management and *FRI* in the field of fish management.

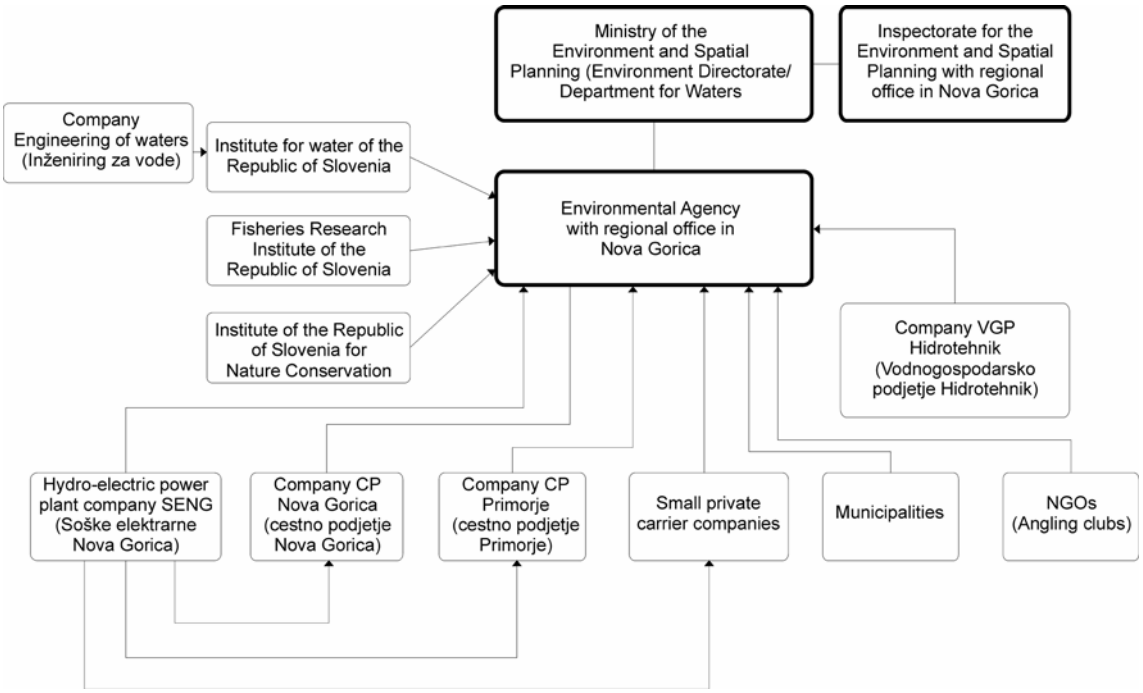

Figure 49. *Stakeholder analysis regarding sediment management in the Soča catchment.*

The company *"VGP Hidrotehnik"* (*Vodnogospodarsko podjetje Hidrotehnik*) gained concession from the *MESP* to carry out water management services, which include maintenance works in the river channels and restoration after storms and floods. The company *"Engineering of waters"* (*Inženiring za vode*) is performing measurements needed for the preparation of annual programs regarding gravel extraction at all locations in the Soča catchment. Several private carrier companies gained concessions for the economical exploitation of alluvial sediments from the Soča River. For the maintainance and emptying of sediment traps on the Bača, Tolminka and Soča Rivers, is obliged the company "*hydroelectric power plants SENG"* (*Soške elektrarne Nova Gorica*). *SENG* have agreements with several companies to extract sediments from bed load traps and accumulation basins (*CP Nova Gorica, CP Primorje, private carrier companies*).

The interests of local inhabitants are represented by *Municipalities* of Bovec, Idrija, Kanal ob Soči, Kobarid, Nova Gorica and Tolmin, which cooperate with *EA* in the preparation of annual gravel extraction plans. The most influential civil society organisations (non-governmental organizations - *NGO*s) are angling clubs (RD Tolmin, RD Idrija, RD Soča). They actively participate in preparation of annual extraction plan with EA in Nova Gorica.

The concessions for the removal of alluvial deposits in sediment traps and for commercial exploitation of alluvial deposits contain the general guidelines for the exploitation of sediments. Before the extraction, detailed programme of the activities is prepared by the regional office of *EA* in Nova Gorica on annual basis for each site. The meetings are set up with the representative of the company *Engineering of waters* (performer of the *Institute for water of the republic of Slovenia - IzVRS*), representatives of municipalities, concessionars, the *Institute of the Republic of Slovenia for Nature Conservation - IRSNC*, *Fisheries research institute of the Republic of Slovenia - FRIRS,* and NGOs - *angling clubs*. A detailed extraction program includes the period of extraction, the expected amounts of sediments extracted and the mode of extraction. The site of exploitation is inspected before the gravel extraction activities by the company *Engineering of waters*, *IRSNC*, *EA* and fisheries representative. The *EA* had determined two periods during the year when the in-stream gravel

extraction is permitted. It is agreed that extraction can be performed in a period from January 15 to March 15 and from September 15 to October 31.

5 DISCUSSION

5.1 The characteristics of the hyporheic zone of the Bača River

5.1.1 Environmental features

The Bača River is a fourth-order prealpine stream with highly variable discharge (pluvio-nival regime) and rich in gravel supply. Due to steep flow gradient and high discharge rates, the permeability of its sediments is good and surface water flows through sediments with short retention time. The surface water has low mean annual temperatures (9.8 °C in 2004), comparable to other prealpine rivers (Naegeli and Uehlinger, 1997) and it is poor in nutrient concentrations (nitrates, phosphates). Acccording to those characteristics (low nutrient concentrations), the river could be classified as oligotrophic system.

Seasonal changes in surface and hyporheic water temperatures were observed at both sites, with greater variation at impacted site. The temperature of running waters depends on climate, elevation, extent of riparian vegetation, relative importance of groundwater inputs (Allan, 1995) and water depth and flow velocity. Loss of riparian vegetation can have great impact on the increase of summer temperatures. Reference site is situated in narrowed part of the valley, partly shaded by riparian vegetation, while the impacted site is at the point where the valley is opening, and the riparian vegetation was removed due to works connected with river channel regulation and building a bedload trap. Comparison of water temperatures between surface, river bed, and gravel bar sediments in the Bača River revealed greater fluctuations and deviations from surface water temperatures at gravel bars than in the river bed sediments. The main reasons for such differences are probably direct exposure to high or low air temperatures (conductivity through sediments) and more intensive fluctuation of exchange rates between surface and groundwater in gravel bar sediments. Several researchers showed that within the sediments of alluvial rivers, due to heterogeneity in permeability and hydraulic head, the water may show a wide array of temperature regimes, depending on localized rates of down-welling from the surface, mixing ratios with the groundwater, residence times and upwelling from the groundwater (Stanford and Ward, 1993; Brunke and Gonser, 1997).

The oxygen saturation was high in river bed sediments as well as in gravel bars, indicating good sediment permeability. In well sorted and coarse river bed sediments oxygen concentrations are normally high (Bretschko, 1991; Stanford et al., 1994) and hypoxia (< 3 $mgO_2\ L^{-1}$) is not a problem for organisms inhabiting this type of hyporheic zone. The interpretation of heterogeneous spatial distribution of dissolved oxygen in hyporheic zone is rather complex, due to many factors influencing the mode and quantity of dissolved oxygen entering and circulating within sediment. Dissolved oxygen in subsurface sediments depends on the permeability and porosity of the sediments, and the intensity of sediment respiration, which is further on controlled by dissolved organic carbon (Ward et al., 1998). Additionally, dissolved oxygen in river bed sediments is strongly influenced by the flow rate of surface water, dial fluctuations in surface concentrations, depends on a degree of mixture between surface and groundwater and retention time of water in sediments (contact time), and can be enriched by atmospheric oxygen or water recharges through the unsaturated zone (Malard and Hervant, 1999).

Along with temperature and oxygen contents, measuring specific conductivity of the surface and hyporheic water is a relative good method for tracing the influence of the surface water in the sediments (White et al., 1987; Pospisil, 1994). The specific conductivity is an approximate predictor of total dissolved ions, which are, due to longer association with rocks, in higher concentrations in ground waters than in surface waters. In the hyporheic zone of the Bača River, specific conductivity gradually decreased from gravel bars to river bed sediments and surface water. However, differences in values were rather small, indicating prevalence of surface water in the sediments and its short retention times.

Small differences between surface water and water flowing through the sediments and small temporal variations were observed in pH values, concentrations of calcium and nitrate concentrations. Hydrologic exchange between surface and subsurface water has a strong effect on nutrient dynamics and nutrient spiraling in stream ecosystems, due to high ratios of surface area of sediments to volume of water in sediments, and relatively slow advective flow of water within sediments compared to the surface (Mulholland and Deangelis, 2000). The hydraulic gradient and hydraulic conductivity are

shown to be the main parameters influencing the rates of hydrologic exchange, and hence the rates of biochemical processes (Vervier et al., 1992; Findlay, 1995; Jones and Holmes, 1996). Hydraulic gradient is a difference in water pressure between two bodies of water, whereas hydraulic conductivity is a measure of resistance to flow imposed by a porous substrate (e.g. stream sediments) (Jones and Holmes, 1996). Those two parameters depend on substrate permeability and heterogeneity. Permeability controls the flux of water and hence the distance over which nutrient transformations occur, as well the spatial distribution of redox conditions in the sediments. In highly permeable sediments, hydrological exchanges are large, but nutrient transformations might occur over longer distances (Vervier et al., 1992). Water flux through highly permeable sediments of the Bača River is relatively fast, and consequently no significant differences in nitrate concentrations were observed between surface water, and water in river bed sediments and gravel bars.

Particulate organic matter (POC) was patchy in distribution in the sediments. The patchiness is determined by hyporheic currents, which are frequently deflected and divided by boulders within the sediment and therefore generate a spatial mosaic of habitat patches, which differ in terms of flow velocity, flow direction, temperature and of source of organic matter (in quality and quantity) (Pusch and Schwoerbel, 1994). The organic matter can enter the river bed sediments from the stream surface by hydraulic down-welling (small particles) or burial during floods (mixed small and big particles) (Jones and Holmes, 1996).

Higher oxygen consumption rates and ETS activity were measured in the fine (particles < 100 µm) than in the coarse sediment fraction, as a consequence of higher surface area to volume ratio on fine particles, which supports higher metabolic activity on fine particles (Baker et al., 2000). Relatively low oxygen consumption rates and ETS activitiy of hyporheic sediments in the Bača River could be explained by the low values of POC, DOC and low water temperatures, which determine low intensity of metabolic processes in the system.

Ecological processes in the hyporheic zone are influenced by water movement, permeability (hydraulic conductivity), substrate particle size, resident biota, and the physical and chemical features of the overlying stream and adjacent aquifers (Boulton et al., 1998). The exchange of water has direct consequences for the physical, chemical and biological “patchiness” in the hyporheic zone (Dole-Olivier, 1998). The measurements of physical and chemical parameters in the hyporheic zone of the Bača River showed high uniformity of environmental conditions across sampling stations. Probably the coarse-grained bed sediments are the reason for relatively high hydraulic conductivity of the hyporheic zone and little differences in metabolic activity between habitat types.

5.1.2 Hyporheic invertebrate community

A large number of invertebrate taxa were collected during nine sampling dates at both sites, but the hyporheic community was dominated by a few taxa, namely Cyclopoida (copepodites) and *Leuctra* larvae. Cyclopoida have often been reported as a major component of hyporheos by other investigators (Boulton et al., 1992a; Hunt and Stanley, 2003), and *Leuctra* sp. is known to spend the larval developmental stages deep in the hyporheic zone (Sivec, 2003). Juvenile Copepoda stages dominated in the hyporheic zone of the glacial Roseg River, Switzerland (72% of all individuals), where harsh environmental conditions, such as low temperatures (below 4ºC), shape the community composition (Malard et al., 2003). On the contrary, in a prealpine Swiss river, where the majority of invertebrates occurred in the depth of 10 cm, Chironomidae and Simuliidae (Diptera) prevailed by abundances, followed by *Rhithrogena* sp., *Leuctra* sp. (Plecoptera), *Brachyptera risi* (Morton, 1896) and *Baetis* sp. (Ephemeroptera) (Matthaei et al., 1996). Dominance of Cyclopoida and juveniles of *Leuctra* in samples is partly a result of selective sampling method. It was demonstrated that in the samples obtained by pumping, the relative abundances of Copepoda and Ostracoda are over-estimated, while EPT (Ephemeroptera-Plecoptera-Trichopter) taxa are under-represented relative to colonization pots and freeze-core samples (Fraser and Williams, 1996; Scarsbrook and Halliday, 2002). The reason is probably the filtering effect of the interstices. Larger animals and animals with a body morphology that make it possible for them to grasp on to substrate particles are likely to resist the suction of the pump and are therefore likely to be underrepresented during sampling. Scarsbrook and Halliday (2002) suggested that pump sampling should be used only when the sampling sites are relatively similar in hydraulic conductivity.

In the hyporheic zone of the Bača River mero-hyporheos (mostly insect larvae) prevailed by density and taxonomic richness, followed by holo-hyporheos (mostly microcrustacea). Stygobionts (groundwater dwelling species) were represented by low density and low taxa numbers. Similar observations were obtained during study of hyporheic invertebrates from gravel bed rivers from central Slovenia (Sava River catchment), where stygobionts occurred frequently, but in low numbers (Mori, 2004; Mori and Brancelj, 2005). It was previously shown that stygobionts are indicators of a weak influence of surface water (Stanford and Ward, 1988). If groundwater prevails in the hyporheic zone, the numbers of stygobionts increase (Dole-Olivier and Marmonier, 1992b). Furthermore, in deeper, phreatic zone, stygobionts prevail by species richness and abundances (Danielopol et al., 2000).

In rivers that experience frequent fluctuations in discharge, frequent modification of river bed and high loads of suspended sediment, the biota is adapted to cope with such conditions and therefore express greater persistence, resistance and rate of recovery than less variable systems (Poff and Ward, 1990). Such conditions are characteristic for the Bača River, where discharge rates are irregular, unpredictable, and highly dependent on precipitation. In the streams experiencing frequent disturbance, highly mobile species prevail (Scarsbrook and Townsend, 1993). The mobility is needed to move into refugia before and during floods and to recolonize vacated areas after a disturbance (Townsend and Hildrew, 1994). Resilient lotic communities include substantial proportions of baetid, leptophlebiid, and sometimes heptageniid mayflies, multivoltine black flies (Simuliidae), browser and gatherer chironomids and Hydropsychine caddisflies (Mackay, 1992). The proportion of stgyobionts in the hyporheic zone is low in such streams (Fowler and Death, 2001). Those statements are in accordance with our results, where insect larvae, such as Leuctridae and Baetidae, prevailed in the samples, and stygobionts were present in low numbers. Successful colonizers have life cycles that allow them to take advantage of temporary benign periods in disturbed streams, and at the same time to benefit from such features in these streams as are unsilted substrates and early succesional stages in periphyton development (Mackay, 1992). Streams with a flashy flow regime are dominated by weedy (r-selected) species (Townsend, 1989), which have ability to reproduce quickly and have short generation times.

5.2 The impacts of gravel extraction on the hyporheic zone processes

5.2.1 The gravel extraction and natural disturbance

Due to the fact that it is very important for sustainable management to have knowledge about how the fauna can cope with disturbance, the effects of natural and anthropogenic influences on hyporheic invertebrates and their environment are discussed here. High flow events are naturally occurring events, while gravel extraction is a result of human activities, but both are a source of disturbance for river fauna.

The hyporheic zone of the Bača River suffered physical disturbance by a flood that peaked at 176 m^3s^{-1} in October 2004. The flood caused replacement and rearrangement of sediments in the river channel. This event coincidently occurred at the same time as the period of gravel extraction, that was carried out at impacted site at the end of October 2004. Therefore, the natural disturbance event (replacement of river bed sediments by spate) overlapped with the anthropogenic disturbance event (gravel extraction) at impacted site.

5.2.2 Hydrology, geomorphology and physico-chemical characteristics

The results of measuring vertical hydrological gradient (VHG) in the Bača River sediments indicated a moderate increase in the surface flow into the sediments in the month after spates at reference site. However, in spring, direction and intensity of the surface flow was again similar to that from the first sampling in June 2004. At impacted site, an intensive increase of the surface flow into the sediments was observed after gravel extraction, which stayed similar during all sampling dates after gravel extraction. The variations in vertical exchange of water influence the spatial and temporal extent of the hyporheic zone and its fauna (Olsen and Townsend, 2003). The vertical hydrological gradient was shown to be the major determinant of hyporheic community composition (Dole-Olivier and Marmonier, 1992b; Mermillod-Blondin et al., 2000). The size of hyporheic flow paths fluctuates in response to

seasonal fluctuations in surrounding groundwater levels, increases in stream discharge and stream velocity that accompany storms (Angradi and Hood, 1998), and diel fluctuations in groundwater levels caused by evapotranspiration (Harvey et al., 1991). During wet season, water fluxes into hyporheic zone decrease due to the opposing force of higher groundwater levels, as a result of rain on the lower hill slope (Harvey and Wagner, 2000). Furthermore, direction of the water flux is affected by streambed topography and meandering of the channel (Harvey and Wagner, 2000). In the case of the Bača River, the increase in the intensity of surface flow into the sediments at reference site could be explained by changes in discharge rates and sediment replacement due to spates, and at impacted site by changing the river bed topography (deepening the river bed) and sediment composition due to sediment extraction from the river channel. The latter caused more persistent changes in the hyporheic flow paths than the former. Therefore, the in-stream gravel extraction directly affected hyporheic invertebrate by removal of sediments (removal of habitat) and indirectly by changing the VHG, which changed hydrological, physical and chemical conditions in the hyporheic zone. The proportion of surface water in the hyporheic zone increased (down-welling), which could have deterious effects on stygobiotic fauna, adapted to more stable environmental conditions (up-wellling). Stygobionts have been shown to be extremely sensitive to hydrological patterns and sediment grain size (Dole-Olivier and Marmonier, 1992a). Increased down-welling could cause the increased input of POC and DOC in the sediments and consenquently in the groundwater (Brunke and Gonser, 1997).

The sediment composition at reference site was dependent on discharge rates, as the high discharge washed out smaller particles (< 5 mm) and permeability increased after spates in October 2004. The observed flushing out of fine sediments (< 5 mm) was in accordance with expectation of Boulton (2000) that flood waters will increase exchange between surface and interstitial waters by flushing interstitial silt (Boulton, 2000) and in contrast with the observations of Olsen and Townsend (2005), where the flood resulted in a significant increase in the proportion of fine sediments (< 1 mm). The sediment amounts in the samples from impacted site increased after gravel extraction. The greatest increase was observed in regard to particles of size 0.1 - 1 mm. This is most probably a consequence of recent sediment perturbation by gravel extraction activities and of bed load trap, where new sediments transported from upstream are accumulating. The bed load trap aggravates downstream movement of transporting sediment. The fraction of particles smaller than 1 mm are ecologically the most important (Ward et al., 1998). Large amounts of small particles clog larger interstices, increase the resistance to water flow and reduce the habitat space for the sediment community. Increased amounts of fine sediments at impacted site caused decreased permeability of sediments. The exchange between surface water and sediments was reduced due to gravel extraction.

Sediment features may indirectly affect the hyporheic community by altering hyporheic physical and chemical conditions, such as temperature, concentrations of oxygen and nutrients, through changes in water residence time (Jones and Holmes, 1996). Substrate characteristics affect also the accumulation and size of detritus particles (Mackay, 1992). Despite the changes in sediment composition at both sites and an increase in fine sediment particles at impacted site after gravel extraction, the oxygen saturation remained high during all samplings (above 70 % in river bed sediments and above 60 % in gravel bars). Similarly, conductivity did not vary significantly between the dates at both sampling sites. From those data we can conclude that an increase of particles of the size between 0.1 – 5 mm in the hyporheic zone of the Bača River did not affect the sediment permeability to such extent that significant changes in water residence time would appear. Good oxygenation of hyporheic zone in this river could be explained by fast surface flow and good sediment permeability, low water temperatures (mean annual temperature of 9.8 °C in 2004), and a lack of input of large amounts of fine sediments (particles < 100 µm) from the surface and low concentrations of nutrients (nitrates, phosphates) in the water.

Particulate organic matter (POC) amounts decreased in the samples taken after spate at reference site, while at impacted site POC remained more or less similar until May. In May, the amounts of POC were low at both sites due to decomposition and consumption by organisms. The temporal distribution of organic matter in the sediments is a consequence of its type, the hydrological regime, season, and the mechanism of transport (Leichtfried, 1988). Similar trend of accumulating large quantities of particulate organic matter during spring runoff, and declining in midsummer and increasing in the autumn, was observed in the sediments of a Canadian stream (Williams, 1980). The spates washed out the organic matter at reference site, while at impacted site the sediments were mixed up during gravel extraction and POC from deeper layers was placed in the shallow hyporheic zone that we sampled. On the contrary, in the study of a New Zealand gravel bed stream, the burial of fresh POC in

the hyporheic zone (40 cm of depth) was observed after floods (Olsen and Townsend, 2005). Other authors also stated that maximum storage of POC occurs during high discharge and surface runoff, which imports allochtonous material from the land and also in autumn after defoliation (Brunke and Gonser, 1997). One of the reasons for low POC amounts in the Bača River at reference site after spates could be the type of selected sampling site. The deposition of POC along the river channel is heterogeneous. At some reaches the POC is accumulating and at some it is outwashing.

5.2.3 Biofilm activity

Little variations in oxygen consumption rates and electron activity transport (ETS) of biofilm were observed in the sediments of the Bača River over time. A study of an oligotrophic gravelbed river in the USA revealed similar relative uniformity of respiration measurements, indicating relatively equivalent aerobic microbial activity on a macro-scale (metres to kilometres) (Craft et al., 2002). On the other hand, several other studies showed a high spatial and temporal variation in respiration (Hendricks, 1996) and in activity and production of hyporheic biofilm (Blenkinsopp et al., 1991; Hendricks, 1996). Variations in respiration could be due to different levels of dissolved oxygen, dissolved organic and anorganic carbon, and dissolved inorganic nitrogen (Triska et al., 1993). Those studies were conducted in sandy-bed streams, which have in comparison with gravel-bed streams lower permeability of hyporheic sediments and consenquently a greater variation in environmental factors, important for biofilm activity. Blenkinsopp et al. (1991) found increased electron transport activity during spring, while winter activity was low relative to other seasons. An increased level of ETS activity in the spring could be related to increased primary production in surface water, while the smaller autumnal peak could be attributed to both, degradation of photosynthetic community and DOC inputs from leaf fall (Blenkinsopp et al., 1991). Because the measurements of microbial activity in the Bača hyporheic zone were conducted at standard temperature (20°C), our results don't demonstrate direct influence of temperature fluctuation on metabolic activity. However, the seasonal variation in temperatures can have impact on microbial abundance and through this indirectly influence metabolic activity in the hyporheic zone.

The ETS activity and respiration of biofilm did not change significantly after spates and gravel extraction. Colonization studies of biofilm revealed relative short colonization times, up to 5 days of rapid occupation, and an increase in ETS activity, followed by a slower increase in cell densities and smaller fluctuations (Sabater and Romani, 1996). According to those results, the sampling frequency in the Bača River sediments was too low to detect a possible change in ETS activity and respiration after spates and gravel extraction in this river. However, examination of contribution of different sediment fractions in the hyporheic zone at impacted site to the total ETS activity revealed differences between river bed sediments and gravel bars (Simčič and Mori, 2007). The differences could be due to different intensity of exchange of surface water within hyporheic zone and the rate of consolidation of sediments. Furthermore, a negative correlation was calculated between fine sediment amounts (particles < 100 μm) and ETS activity of fine sediment fraction. The increase in fine sediment particles leads to a decrease in microbial activity. Therefore, any changes in sediment composition, especially changes in fine sediment amounts, have impact on biofilm productivity and consequently influence the overall river metabolism.

5.2.4 Hyporheic invertebrate community

Hyporheic invertebrate densities decreased at reference site due to spates at the end of October 2004, while at impacted site spates, along with gravel extraction, caused a similar trend of low densities in November and an increase in January 2005. It was previously shown that floods can cause considerable disturbance to the hyporheos (Olsen and Townsend, 2005). The experimental study of small scale disturbance impact on benthic community showed major reductions in densities immediately following the disturbance (Reice, 1985). The recovery to nearly normal population levels was achieved in about four weeks. In the study of colonization of the newly created channel, benthic densities, comparable with the river upstream, were reached sooner than species richness (Gore, 1982). Community reached similar densities as upstream river section after 70-125 days, and similar species richness after one year. Reice (1985) studied recolonization after tumbling the patches of cobbles in the stream, while Gore (1982) studied recolonization of a 0.6 km long newly formed

channel. A study of the consequences of stream channel rehabilitation on benthic invertebrates, conducted in the summer months, revealed recovery to pre-disturbance densities within eight days (Tikkanen et al., 1994). Probably the intensity of disturbance was not as strong as in our case, where large amounts of sediments were removed. Additionally, rehabilitation was conducted in the summer months, when recolonization rates are higher. This was shown by Williams (1980), who found strong correlation between temperature and colonization rates in a study of temporal patterns in recolonization of stream invertebrates in a Canadian gravel bed stream. Lower colonization rates were observed in the winter months (December – March) compared with the summer months (June-September). Therefore, along with spatial extent of disturbance, the time of year during which disturbance occurs may influence the magnitute of its effects.

The response of a stream community to disturbance and its ability to recover are expected to be related to the diversity of its constituents, both structurally and functionally (Resh et al., 1988). A stream with a diverse pre-disturbance biota should have more species available as potential recolonists for community recovery. Also, streams with greater preponderance of "fugitive" species or greater predominance of organisms with short life cycles (like chironomids) should recover faster from a disturbance (Resh et al., 1988). In the case of the Bača River, hyporheic community is composed mostly of taxa with *r*-selection, which have high fecundity, small body size, short generation time, and the ability to disperse offspring widely. Consenquently, the community is highly resilient, having high recolonization rates.

In autumn, January and March samples, invertebrate densities were high at both sites. This is partly due to massive occurrence of early instars of Ephemeroptera and Plecoptera larvae, which occurred abundantly in those samples. The stream invertebrate densities are highest in the autumn months, due to the input of organic material and due to the fact that animals are just about to metamorphose to adults (Williams and Hynes, 1976b). However, in the hyporheic zone of the Bača River, mean densities in January samples from the river bed exceeded densities from the autumn samples, mostly due to abundant early development stages of *Leuctra* sp. and Baetoidea (*Baetis* sp. and *Siphlonurus* sp.) larvae. Densities of *Leuctra* increased in January at both sites, while densities of Baetoidea increased only at impacted site. Because densities of *Leuctra* increased at both sites, this increase could be due to normal life cycle of this genus. However, densities of Baetoidea increased only at impacted site. This could be due to removal and mixing up of sediments during gravel extraction, which could somehow induce hatching of their eggs.

Diversity and eveness of the hyporheic community studied was expressed as taxonomic richness, Shannon's diversity index and Shannon's equitability. Little depletion of taxa was observed after the period of high discharge (one month of elevated mean daily discharge rates with three peaks of 108, 38 and 44 m^3s^{-1}) at reference site. The spate affected the community only to such degree that the majority of taxa remained in the sediments and regeneration to the pre-spate conditions at reference site was fast. Investigation of flood effects on hyporheic invertebrates in a New Zealand river revealed small decrease in taxonomic richness after spates and recovery to predisturbance levels in one month (Olsen and Townsend, 2005). Experimental studies of disturbance (100-m river reach included) showed recovery of number of benthic taxa to the level at control site in 3 days and recovery of invertebrate density in 30 days (Matthaei et al., 1996). The gravel extraction at impacted site caused significant reduction in invertebrate taxonomic richness, with recovery occurring after two and a half months. Those results were in accordance with the conclusions of Matthaei et al. (1997), where the effects of experimental disturbance were compared with the effects of natural disturbance (flood) on benthic invertebrates. Their findings suggested that experimental disturbance has a more severe impact on taxon richness than natural disturbance. The reason for this more severe impact could be that experimental disturbances are very sudden, whereas discharge increases more gradually during a spate (Matthaei et al., 1997).

The Shannon's diversity index was lower in the samples taken after spate and gravel extraction at both sites, while equitability did not change after spates at reference site and it increased at impacted site. This was partly in accordance with the study of Olsen and Townsend (2005), where hyporheic invertebrate diversity decreased after spates, but equitability increased. Furthermore, the samples from river bed sediments and gravel bars had similar diversity and equitability. But on the contrary, when comparing harpacticoid (Copepoda) assemblages in the four gravel-bed rivers from central Slovenia (Mori, 2004), equatibility among species was higher in the assemblages from the river banks compared to the river bed sediments. The environment at the river banks was relatively inhospitable,

resulting in equal distribution of individuals among species. Similarly, the higher equitability in the distribution of individuals among taxa was observed in a New Zealand gravelbed river in the upwelling areas, where groundwater prevails, compared to down-welling zones (Olsen and Townsend, 2003). In the Bača River sediments, the environmental conditions in the river bed sediments and gravel bars are similar, resulting in similar invertebrate community characteristics.

Differences in annual variation of taxa densities between sites were due to different disturbance types (spate *vs*. gravel extraction) occurring at sites, and differences in variation of densities between taxa were due to different sources of colonization, different colonization rates and different phenology of invertebrate taxa. Our results indicate sensitivity of oligochaetes, cyclopoids and *Leuctra* sp. to the changes in discharge, and sensitivity of Acarina, Harpacticoida and Baetoidea taxa to in-stream modifications of the Bača River. That was partly in accordance with the results of Olsen and Townsend (2005), which showed that nematodes and ostracods densities did not significantly change after floods, while copepods densities did. Oligochaeta and Acarina have previously been shown to be among the most sensitive taxa to spates (Boulton et al., 1992b). Statistically significant decrease in oligochaetes densities was observed after dredging in a chalk stream from the US, but not in other benthic invertebrate densities (Pearson and Jones, 1975). The experiment conducted in a Canadian stream during summer showed different colonization sources for different invertebrate taxa, colonizing artificial substrates (Williams and Hynes, 1976a). Nematodes and oligochaetes invaded by moving downstream and upstream, while cladocerans and ostracods more frequently moved upstream than downstream. Cyclopoids colonized by moving upstream and from deeper sediment layers. Mayfly, caddis and chironomid larvae colonized mainly from the drift, although for chironomids aerial invasion and movement from the substrate and upstream were also important (Williams and Hynes, 1976a). Similarly, another study showed that Copepoda colonized denuded areas from sediments and from water (drift), while Chironomids colonized mostly by drift (Palmer et al., 1992). In general, in the permanent streams downstream movement, both within substrate and by drift, is the dominant movement pattern of invertebrates (Delucchi, 1989). Shaw and Minshall (1980) noted differences in colonization rates of benthic invertebrates due to differences in substrate type and amount of food (fine particulate organic matter and periphyton). Genus *Baetis* has been recognized as a rapid colonizer, actively searching for shelter and food resources (Boulton et al., 1988). On the contrary, Delucchi (1989) demonstrated that baetids and representatives of the genus *Leuctra* have low rates of movements within stream sediments, while chironomids and *Paraleptophlebia* sp. move with higher rates.

Functional classification of the invertebrates (ecotypes) was carried out on the basis of the degree of affinity for different subsurface habitats. Changes in conditions in subsurface habitats (e.g. through groundwater extraction, sedimentation) can alter the proportions of these categories, providing a useful biological indicator of subsurface dynamics (Claret et al., 1999b). Stygobionts are expected to be more resistant to the disturbances caused by flooding than epigean taxa, unless the entire hyporheic zone is disturbed (Olsen and Townsend, 2005). Conversely, the resilience of stygobiotic populations may be lower than populations of epigean taxa, because stygobionts are expected to be less fecund and slower growing than related epigean taxa (Malard and Hervant, 1999). In previous studies it was proposed that sedimentation of fine particles would lead to an overall decline of epigean abundances, as hyporheic spaces fill, and that erosion due to channel adjustments would also lead to falls in numbers of epigean and increases in numbers of stygobionts (Claret et al., 1999b). In the case of the Bača River, little differences in the proportions of stygobionts, as well as holo- and mero-hyporheos, were observed between reference and impacted site after gravel extraction. Relatively small area of gravel exploitation (length of 100 m) that enables quick recolonization and dynamic discharge, which continuously despose and outwash the sediments, are probably the reasons for little variation in ecotype distribution through the time.

5.2.5 Catastrophic drift

Harpacticoida, Chironomidae, Trichoptera and some Diptera were the most abundant taxa occurring in the natural (behavioural and constant) and catastrophic drift measured in the Bača River. Chironomida were recorded in high densities in the drift of a Norvegian snowmelt river (Saltveit et al., 2001), Simuliidae prevailed in the drift of a Swiss prealpine river sampled in February (Matthaei et al., 1996) and Chironomidae, Simuliidae and Hydracarina prevailed in the drift samples from the same river, but sampled in the summer after a large flood (Matthaei et al., 1997). In most streams, the insect taxa

(Ephemeroptera, Plecoptera, Trichoptera and Simuliidae) are usually of most quantitative importance in drift, as these groups often dominate benthos in such habitats (Brittain and Eikeland, 1988). The presence of meifauna (Copepoda, etc.) in our samples and prevailance of Harpacticoida was due to the use of smaller mesh size (100 µm) of drifting nets, comparing to other studies (mesh size of 500 µm). In accordance with this, the study conducted in the Alpine streams (Trentino, Italy), where the same mesh size net was used (100 µm), revealed the dominance of harpacticoida in drift (Maiolini et al., 2005).

Results of the drift sampling indicated that gravel extraction caused the drifting of invertebrates that are normally not present in drift, such as stygobionts (*Niphargus* sp., Bathynellacea and some Isopoda, Copepoda and Ostracoda), or enter drift in low abundances, such as some holo-hyporheos (Cyclopoida). The catastrophic drift differed from natural one in taxonomic composition and higher drift rates were measured during gravel extraction. Similarly, a study of dredging effects on invertebrates from a chalk stream (USA) revealed an increase in drift rates and occurrence of flatworms, molluscs, leeches and caddis larvae in drift (Pearson and Jones, 1975). Those taxa were normally not present in drift from this stream at all.

Dial variation in drift composition was demonstrated in many studies (Saltveit et al., 2001). Many Ephemeroptera, Plecoptera and Trichoptera taxa (EPT) had their drift maximum during the night, while Chironomidae did not show any consistent pattern. In our study, the proportions of EPT were higher during the night drift at impacted site, while at the site 200 m downstream from the impacted site Plecoptera occurred in higher relative abundances during the day than at night. The proportions of Nematoda, Acarina, Cyclopoida and Ephemeroptera in catastrophic drift were higher during gravel extraction and considerably decreased soon after dredger stopped to work.

Drift sampled 200 m downstream from the impacted site had lower taxonomic richness and drift rates than drift taken at impacted site. Drift distance is a function of species, life cycle stage, light intensity, current velocity, substrate (including the degree of vegetational cover) and other stream characteristics, such as depth and the presence of pools (Elliott, 1971). In benthic invertebrates, drift distances are relatively short, from few centimeters to several meters, although in some cases distances of several hundred meters have been reported (Brittain and Eikeland, 1988). The gravel extraction in the Bača River caused an increase in drifting invertebrates only in short distance (100-m scale).

5.2.6 The importance of environmental factors for the hyporheic invertebrate community from the Bača River

The analyses of the importance of environmental factors for hyporheic invertebrate community from the Bača River revealed the great importance of the presence of fine sediment fraction (particles < 100 µm) in the hyporheic sediments. Similarly, Olsen and Townsend (2003, 2005) found correlations between fine sediment and hyporheic invertebrate distribution. Analysis of hyporheic communities from Oklahoma (USA) streams revealed the importance of substrate composition in determining the composition and abundance of invertebrates (Hunt and Stanley, 2003). Fine sediment may have direct effect on invertebrates by altering habitat characteristics (such as pore size) or by restricting their ability to feed, respire or move (Olsen and Townsend, 2003). Indirect effects of increasing fine sediment amounts are reflected in changing permeability and hyporheic residence time of water, which indirectly affect physical and chemical conditions (Jones and Holmes, 1996), and consenquently biofilm activity in the hyporheic zone. Biofilm is a potential food resource for many invertebrates inhabiting hyporheic zone. The indirect impact of fine sediment amounts on invertebrate community was shown through the analysis of correlation between fine sediment amounts and ETS activity of fine sediment fraction, conducted in our study. ETS activity decreased after an increase in fine sediment amounts in the hyporheic sediments. Probably the decreased permeability due to increased fine sediments (clogging of intersices) influences the metabolic activity of biofilm. It was previously shown that ETS activity decreases with increasing consolidation of the sediment (Songster-Alpin and Klotz, 1995). Consenquently, the food resources for invertebrates decrease.

Dissolved oxygen saturation in the hyporheic zone is often strongly related to the hyporheic invertebrate community (Franken et al., 2001). Higher invertebrate densities were found in the coarser sediments, rich in oxygen, compared to the sediments with lower oxygen contents, when studying

streams from eastern USA (Strayer et al., 1997). However, this was not the case in our study. Oxygen saturation in the hyporheic zone of the Bača River was high (> 60%) during all samplings and at all sampling points, so oxygen concentrations were not a limiting factor for the fauna living here.

CCA analyses indicate that the amount of particulate organic matter was important for the hyporheic community at reference, but not at impacted site. Previous studies of relationship between POC in the hyporheic zone and hyporheic densities have also produced mixted results, with some reporting significant relationships (Williams and Hynes, 1974; Strayer et al., 1997) and some reporting no relationships (Godbout and Hynes, 1982). A significant correlation between POC and taxonomic richness was shown for both sites, between POC and Nematoda and Chironomidae for impacted site, and between POC and Baetoidea and *Leuctra* sp. for reference site. The correlation between *Leuctra* sp. and Chironomidae and organic matter contents has been previously shown in the study of invertebrate recolonization in a Swisss prealpine river (Matthaei et al., 1996). This indicated the importance of POC as food source for the two taxa. However, POC was probably not a limiting factor for their recolonization because it returned much faster to undisturbed levels than their population levels (Matthaei et al., 1996).

A positive correlation between ETS activity of fine sediment fraction and total density and densities of baetids and *Leuctra* sp. was calculated at impacted site, and strong negative correlation between ETS activity of fine sediment fraction and nematods was calculated at reference site. The latter could indicate a competition between nematods and microorganisms for the finest organic particles.

Due to the fact that amounts of fine sediments are an indirect indicator of discharge rates and physical disturbances within the river bed, and that invertebrate density greatly decreased after October spate and in-stream gravel extraction, we can conclude that discharge and gravel extraction activities in the river channel were one of the major forces that shaped the hyporheic invertebrate community in the Bača River. However, parameters such as hydrology, geomorphology, and disturbance history of specific sites act together with biological interactions, temperature, seasonal and inter-annual variation to determine structure of hyporheic communities (Strayer et al., 1997). The relative importance of different biotic and abiotic factors vary in both space and time due to the diversity of microhabitats and variation in discharge (Reice, 1985).

5.3 The "state of the art" of regulatory processes regarding gravel extraction in the Soča catchment

The DPSIR framework and stakeholders analysis gave us a general idea about sediment management in the Soča catchment. The DPSIR framework provides an overall mechanism for analyzing environmental problems, with regard to sustainable development (Borja, 2006). Driving forces are normally considered to be the economic and social policies of governments, and economic and social goals of those involved in industry. In the case of sediment management in the Soča catchment, the main driving forces are the economic goals of the hydroelectric power plant company of Soške elektrarne Nova Gorica for optimal functioning of HPP, the governmental policy for maintainance of river channels in order to protect citizens from detrimental effects of rivers and streams, and the economical goals of several constructing companies in order to obtain aggregates of high quality and high economical value.

'Pressures' are the ways in which these drivers are actually expressed, and the specific ways in which ecosystems and their components are perturbed. These pressures degrade the 'State' of the environment, which then 'Impacts' upon human health and ecosystems, causing the society to 'Respond' with various policy measures, such as regulations, information and taxes; these can be directed at any other part of the system (Borja, 2006).

Regarding the responses, government has prepared a good regulatory system, which includes several Decrees on concession, with the aim to control the interventions into the river channels in this catchment. The communication process regarding preparation of annual programs on gravel extraction revealed to be good, with several different stakeholders having opportunities to participate in decisions. The development of environmental policies is a complex process, which mixes legal requirements with issues of technical feasibility, scientific knowledge and socio-economic aspects, requiring intensive multi-stakeholder consultations (Ridder et al., 2005). Socio-cultural constraints to

gravel extraction fall under public concerns for quality of life, property, visual impairment, and environmental quality.

The main weakness was revealed to be the lack of scientific background on gravel extraction effects in this catchment regarding ecological impacts (impacts on aquatic invertebrates, fish, birds and riparian flora). There is also the problem of ecosystem fragmentation (distruption of the countinuity of river ecosystem). Several sites of gravel extraction along the Soča River cause fragmentation of this river ecosystem, leading to structural and functional impoverishment of the ecosystem.

6 CONCLUSIONS AND RECOMMENDATIONS

The Bača River is a prealpine stream with highly fluctuating hydrological regime, with the main peak occurring in the autumn due to high precipitation rates. The surface-groundwater exchange is dynamic through time, and water flux through highly permeable sediments is relatively fast. Due to rapid exchanges of surface-subsurface water, the oxygen saturation in the sediments is high, and conductivity, nutrient concentrations and biofilm activitiy in the hyporheic water are relatively low. The hyporheic community of the Bača River is resilient to the changes in environmental conditions, especially to fluctuations in discharge, and it is dominated by mero-hyporheos (especially insect larvae), followed by holo-hyporheos (mostly meiofauna). Due to unstable environmental conditions and prevailance of surface water in the hyporheic zone, the stygobionts are represented in low numbers.

The in-stream gravel extraction affected the surface-subsurface water exchanges, by increasing down-welling due to sediment removal and deepening the stream bed, and changed the sediment composition at impacted site. Furthermore, gravel exploitation led to higher fluctuations in surface and hyporheic temperatures, compared to the reference site, due to removal of riparian vegetation, which has a function of shadowing the stream channel. The short-term impacts of in-stream gravel extraction on invertebrate community were immediate reductions in taxonomic richness and density. Recovery time to pre-disturbance conditions was relatively short (two months). Interpretation of direct effects of gravel extraction on hyporheic community was confounded by the seasonality of invertebrate species and by fluctuation due to variation in discharge. Environmental fluctuations, individual species life cycles and biotic interactions determined the variation of hyporheic invertebrate community through time. Gravel extraction caused the drifting of invertebrates that are normally not present in drift, such as stygobionts (*Niphargus* sp., Bathynellacea and some taxa of Isopoda, Copepoda and Ostracoda) or enter drift in low abundances, such as some holo-hyporheos (Cyclopoida).

The spatial extent of the gravel extraction activities in the river channel determines the recovery of hyporheic invertebrates. Larger the impacted area, slower is the recolonization process. In addition, the season when disturbance occurs has an important influence on the recovery of invertebrates. During cold season (winter) recolonization is slow, while during summer invertebrates colonize faster. Spring/early summer gravel-extraction might have shorter term effect compared to autumn/winter one, due to breeding of most species in the warmer part of the year. On the other hand, during summer the gravel extraction activity removes the latest stages of insect larvae (before the mature stage), which prevents their reproduction and causes lower abundances of those organisms in the area. The input of fine sediments (particles < 100 µm) in the sediment intersices, due to extraction activities, can have strong effects on biofilm activity (lower activity) and invertebrate community (lower density and diversity). The impact of fine sediment input due to gravel extraction should be minimized in order to sustain the existing hyporheic invertebrate community. The negative effects on hyporheic biofilm activity and invertebrate community result in impoverished self-purification capability of affected river. In the river systems that are connected with alluvial groundwater ecosystems, the gravel extraction can cause “contamination” of groundwater with surface water due to increased down-welling.

Despite the fact that results of this one-year study showed high resilience of hyporheic invertebrates from the Bača River, the impacts of in-stream gravel extraction should be studied on a longer term (decades) scale and in the whole catchment (from the spring to the outflow). Attention should be paid to accumulated impacts of continuous gravel exploitation from multiple sites. Moreover, the hyporheic zone is only one structural part of the complex river ecosystem. The integrated research of impacts is needed in the other areas of riverine ecology, from riparian habitats, including impact on wildlife and vegetation to surface water, its quality and biodiversity.

The practice of regulatory process based on concessions for the sediment extraction passed by the government proved to be efficient in the case of gravel extraction from the Soča River and its tributaries. This practice should be implemented to the other river basins in Slovenia, where such concessions do not exist yet (Drava, Mura). Further on, the number of sites exposed to gravel extraction activities shoud be minimized in the Soča catchment in order to prevent further fragmentation of this river ecosystem and direct extraction from the river channel should be strictly prohibited.

7 SUMMARY

In-stream gravel extraction has many deterious effects on geomorphology and hydrology of the river channel, as well as on riverine and riparian biota. The majority of research analysing the effects of in-stream sediment exploitation focused on the effects of gravel extraction on river geomorphology and hydrology, and some of them studied effects on fish spawning and benthic organisms. Nothing is known about effects of in-stream gravel extraction on the hyporheic biota and its environment. Consenquently, the purpose of this doctoral thesis was to analyze the short-term effects of in-stream gravel extraction on the hyporheic invertebrates in the pre-alpine gravel-bed Bača River (W Slovenia). Moreover, due to the fact that most of the nature-protecting problems are the result of interaction of ecological processes with economic forces, decision-making processes and public opinion, in this doctoral thesis an attempt was made to describe the "state of the art" of the management processes and use of alluvial sediments in the Soča River catchment.

The structural and functional characteristics of the hyporheic invetebrate community from the Bača River (W Slovenia) were studied together with its response to natural variation in environmental factors and to gravel extraction activities carried out in the river channel in October 2004. Sampling was carried out from June 2004 to May 2005 (nine sampling dates) and the gravel extraction was conducted in the week at the end of October 2004. Two sampling sites were selected: the reference site, where hyporheic invertebrate community was observed in relation to natural variation of environmental factors, and the impacted site, where gravel extraction was carried out. Two different habitat types were distinguished at both sites, river bed sediments and gravel bars. Physical and chemical parameters, together with the amount of particulate organic matter (POC) were measured through time at both sites and both habitat types. Respiratory electron transport system (ETS) activity and oxygen consumption in the hyporheic water, and in the fine (particles < 100 µm) and coarse (particles > 100 µm) sediment fraction collected from the hyporheic zone were measured in order to estimate the intensity of mineralization through microbial communities.

The Bača River had highly fluctuating discharge, with mean daily discharge ranging from 1.6 to 108 m^3s^{-1} during one year period (June 2004 - May 2005). The highest peaks of flow occurred in October and November 2004. River bed sediments were composed of mixture of boulders, cobbles, gravel, sand and to lesser extent of silt (particles < 0.0625 mm; Wentworth scale). Temperature of surface water ranged from 5 - 15.4 ºC and of hyporheic water from 3.4 - 22.9 ºC during nine samplings. The mean oxygen saturation in the hyporheic zone was relatively high (above 80 %) and lower in the gravel bars (82 % - both sites) and higher in the river bed sediments (90 % - reference site and 94 % - impacted site). Differences in conductivity of surface and hyporheic water were modest (mean values: 273 - 281 μScm^{-1}), indicating short retention times of surface water in the sediments. Further on, little differences between surface and hyporheic water and small temporal variations were observed in pH values (mean values: 8.1 - 8.3), concentrations of calcium (mean values: 43.3 - 46.7 mgL^{-1}) and nitrate concentrations (mean values: 3.9 - 4.3 mgL^{-1}). Concentrations of phosphates were below detection limit. The mean amounts of particulate organic matter (POC) in the hyporheic sediments were between 0.3 and 0.5 $g10L^{-1}$.

Mean oxygen consumption rates of the river bed sediments from reference site were 1.44 for fine and 0.24 $\mu LO_2gWW^{-1}h^{-1}$ for coarse sediment fraction, and 2.41 for fine and 0.19 $\mu LO_2gWW^{-1}h^{-1}$ for coarse sediment fraction sampled from the river bed sediments at impacted site, and 2.39 for fine and 0.14 $\mu LO_2gWW^{-1}h^{-1}$ for coarse sediment fraction in the samples from gravel bars at impacted site. No significant differences in oxygen consumption rates were observed between reference and impacted site and between habitat types ($p > 0.05$), but significant differences existed between coarse and fine sediment fraction (pooled data, $p < 0.001$). Mean ETS activity was 3.2 $\mu LO_2L^{-1}h^{-1}$ for the hyporheic water from the river bed at reference site, 2.8 for fine and 0.26 $\mu LO_2gWW^{-1}h^{-1}$ for coarse sediment fraction taken from the same site. At impacted site, mean ETS activity was 3.84 $\mu LO_2L^{-1}h^{-1}$ for the hyporheic water from the river bed and 6.5 $\mu LO_2L^{-1}h^{-1}$ for the hyporheic water from the gravel bars. Mean ETS activity in the fine sediments sampled from the river bed was 3.56 $\mu LO_2gWW^{-1}h^{-1}$ and 2.88 $\mu LO_2gWW^{-1}h^{-1}$ in the sediments sampled from the gravel bars, while mean ETS activity of coarse sediment fraction sampled from the river bed was 0.25 and from gravel bars 0.19 $\mu LO_2gWW^{-1}h^{-1}$. Fine sediment fraction had statistically higher significant metabolic potential than coarse fraction ($p<0.001$).

A total of 88 taxa and 42 449 individuals were collected during nine sampling dates. 39 taxa belonged to the mero-hyporheos, 37 to the holo-hyporheos and 12 were stygobionts. Representatives of mero-

hyporheos prevailed at both habitat types, followed by holo-hyporheos and stygobionts. No significant differences in diversity and eveness among habitat types were observed. At both habitat types, hyporheic fauna was numerically dominated by juveniles of Cyclopoida, and early stages of *Leuctra* sp. (Plecoptera), Chironomidae (Diptera) and Baetoidea (Ephemeroptera) larvae.

An increase in down-welling was observed at the site of gravel extraction after deepening the river bed due to sediment removal. The amounts of extracted sediment decreased after the spate at the end of October 2004 at reference site, while at impacted site the sediment amounts increased in post-disturbance (after gravel extraction) samples. POC amounts decreased in November samples at reference site, while at impacted site POC remained more or less similar until May. Oxygen consumption rates of fine and coarse sediment fractions and ETS activity of hyporheic water and of fine and coarse sediment fraction did not differ significantly among sites and dates.

At both sites, a significant decrease in overall hyporheic invertebrate density was observed in post-disturbance samples. Spates at the end of October are probably the main reason for decrease in invertebrate densities at reference site, while at impacted site the spates together with removal of sediments caused depletion of organisms. On the contrary, taxonomic richness at reference site did not decrease to such extent as at impacted site. Cyclopoida juveniles, together with *Leuctra* sp. composed more than 40% of total invertebrates in the samples from river bed sediments at reference and impacted site, and between 50 and 70 % of all community from gravel bars at both sites in predisturbance samples. After disturbance, Chironomidae greatly dominated by numbers at reference site, while the community at impacted site was composed of representatives of Chironomidae, Baetoidea, Oligochaeta, Nematoda and others. Individual taxa responded differently to October spates and gravel extraction at impacted site. Nematoda, Harpacticoida, and Chironomidae densities did not significantly change through time at reference, neither at impacted site, while densities of Oligochaeta, Cyclopoida (juveniles and adults) and *Leuctra* did. Densities of Acarina, Harpacticoida juveniles and Baeitoidea were significantly different among dates at impacted, but not at reference site. Our results indicate possible sensitivity of oligochaetes, cyclopoids and larvae of *Leuctra* to the changes in discharge and possible sensitivity of Acarina, Harpacticoida and Baetoidea taxa to in-stream modifications of the river channel.

In pre-disturbance samples, holo-hyporheos dominated by abundance and taxonomic richness at both sampling sites. Stygobionts represented only a small proportion of total abundance and taxonomic richness during the whole sampling period. At reference site, an increase in proportion of mero-hyporheos densities occurred after spates. At impacted site, mero-hyporheos abundances increased after gravel extraction, but not to such extent as at reference site. When considering taxonomic richness, the proportions among different ecotypes were more or less similar throughout the year at both sites. When considering the size-spectra of Ephemeroptera, Plecoptera and Diptera, smaller individuals prevailed in the samples after the spates and gravel extraction, indicating recolonization from egg hatching after disturbance.

Drift samples taken at reference site and impacted site and 200 m downstream from the impacted site contained the majority of invertebrate taxa that were collected from the hyporheic zone. Harpacticoida, Chironomidae, Trichoptera and Diptera composed from 50 to 90 % of total invertebrate drift. Taxonomic richness of drift samples and drift rates from impacted site were higher compared to reference site and to the site 200 m downstream from impacted site on both sampling dates. The proportions of Nematoda, Acarina, Cyclopoida and Ephemeroptera in catastrophic drift were higher during gravel extraction and considerably decreased when dredger stopped to work. Gravel extraction caused the drifting of invertebrates that are normally not present in drift, such as stygobionts (*Niphargus* sp., Bathynellacea and some Isopoda, Copepoda and Ostracoda), or enter drift in low abundances, such as some holo-hyporheos (Cyclopoida). The catastrophic drift differed from natural one in taxonomic composition in drift rates (number of individuals per hour).

CCA analysis revealed the importance of fine sediments for the invertebrate distribution at both sites. Additionally, an important role for community distribution played, at reference site the amount of particlulate organic matter and conductivity, and at impacted site ETS activity in fine and coarse sediment fraction, temperature and nitrates. Spearman rank correlation coefficients showed significant positive correlation of the temperature with oligochetes densities, while densities of nematods and baetids were in negative correlation with it. Oxygen saturation was positively correlated with total density, taxonomic richness and with the majority of taxa, with the exception of nematods, baetids and

Leuctra larvae. Similarly, sediment composition and POC amounts correlated positively with the majority of taxa. Little correlation between oxygen consumption rates of biofilm, nitrate and sulphate concentrations and invertebrate densities was observed. However, a positive correlation between total density and densities of baetids, and strong negative correlation between nematods and ETS activity of fine sediment fraction was calculated.

The short-term analysis of impacts of in-stream gravel extraction on hyporheic zone processes in the Bača River revealed that discharge plays a mayor role in determining the hyporheic invertebrate densities and taxonomic composition in this river. High discharge rates in autumn caused significant decrease in hyporheic invertebrate densities, but not taxonomic richness, and prevailance of mero-hyporheos in the community. Gravel extraction caused changes in the mode of water exchange between surface and subsurface, and changes of sediment composition at impacted site. The impacts on the invertebrates were immediate reductions in density and taxonomic richness, and changes in taxonomic composition. Recovery of the hyporheic community in this river was relatively fast at both sampling sites, indicating high resilience of aquatic fauna living in the Bača River sediments. The impact of fine sediments (< 100 µm) on the processes in the hyporheic zone and hyporheic invertebrate community was strongly confirmed in this study. Therefore, any increase in fine sediment inputs can have deterious effects on hyporheic community. Long-term studies of gravel extraction effects on hyporheic fauna are needed to search for long-term ecological impacts on the hyporheic zone.

Regarding sediment management in the Soča catchment, the main driving forces are the economic goals of the hydroelectric power plant company of Soške elektrarne Nova Gorica for optimal functioning of HPP, the governmental policy for maintainance of river channels in order to protect citizens from detrimental effects of rivers and streams, and the economical goals of several constructing companies in order to obtain aggregates of high quality and high economical value. Stakeholders involved in the sediment management are Ministry of the Environment and Spatial Planning (Environment Directorate, Department of Waters), Environmental Agency, Inspectorate of the Republic of Slovenia for the Environment and Spatial Planning, Institute of the Republic of Slovenia for Nature Conservation, Institute for Water of the Republic of Slovenia, Fisheries Research Institute of the Republic of Slovenia, the companies VGP Hidrotehnik, Engineering for Waters, SENG hydroelectric power plant company, CP Nova Gorica, CP Primorje, small private carrier companies, municipalities and NGOs (angling clubs). The mayor public concerns regarding gravel extraction are the quality of life, property, visual impairment, and environmental quality. The minimalization of gravel extraction sites in the Soča catchment is needed in order to prevent fragmentation of this river ecosystem.

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APPENDICES

Appendix A. *Decree on the concession for the removal of alluvial deposits in sediment traps on the Soča, Tolminka and Bača Rivers (Official Gazette of RS, 67/03).*

Na podlagi prvega odstavka 198. člena Zakona o vodah (Uradni list RS, št. 67/02 in 110/02 – ZGO - 1) in 23. člena zakona o varstvu okolja (Uradni list RS, št. 32/93, 44/95-odl. US, 1/96, 9/99 – odl. US, 56/99 – ZON, 22/00 – ZJS in 67/02 – ZV-1) izdaja Vlada Republike Slovenije

U R E D B O
o koncesiji za odvzem naplavin iz lovilnih jam na reki Soči, Tolminki in Bači

1. člen
(predmet koncesije)

S to uredbo Vlada Republike Slovenije (v nadaljnjem besedilu: koncedent) določa pogoje za podeljevanje koncesije za odvzem naplavin na delih vodnega telesa rek Soče, Tolminke in Bače.

2. člen
(območje koncesije)

(1) Deli vodnega telesa rek Soče, Tolminke in Bače iz prejšnjega člena so vodna telesa med gorvodno in dolvodno mejo vodnega telesa, določena v naslednji tabeli:

VODOTOK	OBČINA	KOORDINATE GORVODNE MEJE VODNEGA TELESA Y	X	KOORDINATE DOLVODNE MEJE VODNEGA TELESA Y	X
Soča	Tolmin	5399557	5117884	5401286	5116254
Tolminka	Tolmin	5402928	5116098	5403042	5115564
Bača	Tolmin	5405567	5112751	5405165	5111981

(2) Posamezni del vodnega telesa rek iz prejšnjega odstavka je določen s koordinatami gorvodne meje in dolvodne meje dela vodnega telesa, ki so prevzete iz državnega koordinatnega sistema (v Gauss-Krügerjevi projekciji), odčitane v temeljnih topografskih načrtih Republike Slovenije v merilu 1:5000.

3. člen
(vsebina koncesije)

(1) Koncesija po tej uredbi obsega:
1. odvzem in skladiščenje naplavin,
2. pripravo frakcij peska iz naplavin za gradbene namene,
3. urejanje in vzdrževanje objektov za dostop oziroma dovoz do mesta odvzema naplavin ter urejanje in vzdrževanje vodnih objektov na celotnem območju koncesije.

(2) Količina v koledarskem letu odvzetih naplavin na posameznem delu vodnega telesa reke Soče, Tolminke in Bače ne sme presegati količin, ki so določene v načrtu izvajanja koncesije za odvzem naplavin na odseku reke Soče, Tolminke in Bače (v nadaljnjem besedilu: program).

4. člen
(pogoji, ki jih mora izpolnjevati koncesionar)

Imetnik pravnomočnega vodnogospodarskega soglasja iz tretjega odstavka 2. člena te uredbe pridobi koncesijo, če:
- da je poravnal davke, prispevke in druge obvezne dajatve, in da proti njemu ni uveden postopek prisilne poravnave, stečaja ali likvidacijski postopek ali ni prenehal poslovati na podlagi sodne ali druge prisilne odločbe,
- je tehnično usposobljen za odvzem naplavin,
- ima zagotovljeno možnost za pripravo frakcij peska iz naplavin v lastnem obratu ali po pogodbi,
- ima zagotovljeno možnost skladiščenja odvzetih naplavin.

5. člen
(posebni pogoji)

(1) Oseba, ki je pridobila koncesijo (v nadaljnjem besedilu: koncesionar), mora poleg predpisanih pogojev zagotoviti odvzem naplavin izključno v skladu s programom, in sicer takrat, ko:
- je dotok naplavin večji od transportne sposobnosti vodotoka,
- se začne dvigovati gladina vode in dna zaradi odlaganja naplavin,
- je treba zagotoviti konstantno pretočno sposobnost vodotoka in
- odlaganje naplavin ogroža vodne objekte.
(2) Koncesionar sme odvzemati naplavine na odvzemnem mestu v času in na način, kot to določa program, ki ga do 31. oktobra tekočega leta za naslednje leto izdela ministrstvo, pristojno za okolje (v nadaljnjem besedilu: ministrstvo). Ministrstvo lahko program tekom tekočega leta dopolni zaradi izrednih dogodkov, ki imajo vpliv na transport naplavin.
(3) Koncesionar ne sme pripravljati frakcij peska iz odvzetih naplavin na območju struge reke Soče, Tolminke ali Bače. Ustrezna mesta za pripravo frakcij peska se določijo v programu.
(4) Koncesionar mora drugim obstoječim uporabnikom zagotoviti nemoteno izvajanje pravice do rabe reke, kjer odvzema naplavine.

6. člen
(okoljevarstveni pogoji)
(1) Koncesionar mora poleg izpolnjevanja okoljevarstvenih pogojev v skladu s predpisi zagotoviti še:
- ukrepe proti poslabšanju vodnega režima zaradi odvzema naplavin,
- ukrepe, da z odvzemom naplavin ne bodo ogroženi vodni objekti,
- ukrepe, da z odvzemom naplavin ne bo ogrožena stabilnost naravnih odsekov struge vodotoka in s tem povzročena globinska ali bočna erozija,
- ukrepe za preprečevanje poslabšanja kakovosti vode reke, kjer odvzema naplavine,
- migracijo vodnih organizmov,
- ukrepe za zagotovitev najmanjšega možnega vpliva na vodne organizme (drstenje, migracije),
- nemoteno potovanje zadostnega deleža naplavin dolvodno po vodotoku,
- ohranjanje biotske raznovrstnosti in avtohtonosti habitatov,
- odstranjevanje plavin in drugih odpadkov iz območja odvzemanja naplavin v skladu s predpisi ravnanja z odpadki,
- ukrepe v zvezi s sanacijo, vzpostavitvijo novega oziroma nadomestitvijo prejšnjega stanja po prenehanju koncesije, kot je to določeno v koncesijski pogodbi.
(2) Ukrepi in pogoji iz prejšnjega odstavka se podrobneje določijo v upravnih aktih v zvezi s posegi v prostor.

7. člen
(stroški koncesionarja)
Koncesionar nosi vse stroške v zvezi s koncesijo, ki je podeljena na podlagi te uredbe.

8. člen
(obveznosti koncesionarja)
(1) Koncesionar redno vodi posebno ločeno računovodstvo, evidenco odvzetih količin naplavin in količin prodanih frakcij peska ter poslovnik o odvzemu, skladiščenju in pripravi frakcij peska iz odvzetih naplavin.
(2) Podrobnejši pogoji za izvajanje koncesije se lahko določijo tudi v koncesijski pogodbi.
(3) Koncesionar je dolžan brezplačno odstopiti naplavine izvajalcu javne službe na področju urejanja voda za potrebe vzdrževanja vodotokov in vodnih objektov na območju reke, kjer odvzema naplavine.
(4) Količine, potrebne za izvajanje javne službe, se določijo v programu.
(5) Koncesionar je dolžan za dejansko odvzete količine naplavin plačati vodno povračilo v skladu s predpisi.

9. člen
(pravice koncesionarja)
Koncesionar ima pravico, da frakcije peska, ki jih pripravlja iz odvzetih ali skladiščenih naplavin, uporabi sam zaradi izvajanja lastne dejavnosti ali daje v promet.

10. člen
(začetek in čas trajanja koncesije)
(1) Koncesija se začne izvajati z dnem sklenitve koncesijske pogodbe.
(2) Koncesija se podeli za obdobje do 31. decembra 2010.
(3) Koncesija se lahko na podlagi vloge imetnika podaljša v skladu z zakonom o vodah.

11. člen
(način podelitve koncesije)

(1) Koncesija se podeljuje brez javnega razpisa v skladu s 196. členom zakona o vodah (Uradni list RS, št. 67/02 in 110/02 – ZGO – 1).
(2) Koncesija se podeli imetnikom pravnomočnih vodnogospodarskih soglasij, na podlagi katerih imajo njihovi imetniki pravico na odsekih vodnega telesa iz prvega odstavka 2. člena te uredbe izkoriščati mivko, pesek, prod ali kamen.

12. člen
(plačilo za koncesijo)

(1) Koncesionar plačuje za koncesijo enkrat letno znesek, ki je enak zmnožku med količino naplavin, izraženo v m^3, in 10% povprečno tržno vrednostjo 1 m^3 frakcije peska velikosti 0/32 mm. Količina naplavin za vsako odvzemno mesto je določena v programu.
(2) Povprečna tržna vrednost frakcije peska iz prejšnjega odstavka se določa na podlagi prodajnih cen te frakcije peska, doseženih v preteklem letu, na območju porečja reke Soče.
(3) Za količine odvzetih naplavin, ki jih koncesionar brezplačno, po programu, odstopi za potrebe javne službe, koncesionar ne plačuje koncesije in vodnega povračila.
(4) Plačilo za koncesijo se razdeli med državo in lokalno skupnostjo, na območju katere je odvzemno mesto, v razmerju 50%:50%.
(5) Prihodki iz prvega odstavka tega člena so vir občinskega proračuna in proračuna Republike Slovenije.
(6) Način obračunavanja in plačevanja se podrobneje določi v koncesijski pogodbi.

13. člen
(koncesijska pogodba)

(1) Medsebojna razmerja med koncedentom in koncesionarjem se podrobneje uredijo s koncesijsko pogodbo v skladu z zakonom. V koncesijski pogodbi se podrobneje določi tudi način ureditve pravic in obveznosti med koncesionarjem in koncedentom v primeru spremenjenih razmer vodnega režima rek, na območju katerih koncesionar odvzema naplavine.
(2) Koncesijsko pogodbo sklene v imenu koncedenta ministrstvo.
(3) Količina naplavin za odvzem in čas izvajanja koncesije se določijo v aneksu h koncesijski pogodbi, ki se sklene za obdobje koledarskega leta na podlagi programa za vsako leto posebej.
(4) Koncesionar mora do 31. decembra tekočega leta od koncedenta pridobiti potrjen letni program za izvajanje koncesije v naslednjem letu in skleniti aneks h koncesijski pogodbi za naslednje leto.
(5) S sklenitvijo koncesijske pogodbe se koncesionar zaveže, da bo spoštoval obveznosti iz te uredbe.
(6) V primeru neskladja med to uredbo in koncesijsko pogodbo veljajo določbe te uredbe.

14. člen
(nadzor nad izvajanjem koncesije)

(1) Nadzor nad izvajanjem koncesije izvršujejo inšpektorji, pristojni za vode.
(2) Tehnični nadzor nad izvajanjem programa in načina odvzema naplavin izvaja ministrstvo.

15. člen
(prenehanje koncesije)

Razlogi in način prenehanja koncesije se določijo v koncesijski pogodbi skladno z zakonom o vodah.

16. člen
(veljavnost uredbe)

Ta uredba začne veljati petnajsti dan po objavi v Uradnem listu Republike Slovenije.

Št: 355-01-62/2003
EVA: 2003-2511-0106
Ljubljana, 20.6.2003

Vlada Republike Slovenije
mag. Anton Rop l.r.
Predsednik

Appendix B. *Decree on concessions for commercial exploitation of alluvial deposits of the river Soča (Official Gazette of RS, No. 99/01).*

Na podlagi 23. člena zakona o varstvu okolja (Uradni list RS, št. 32/93, 44/95 - Odl. US, 1/96, 9/99 - Odl. US, 56/99 in 22/00) izdaja Vlada Republike Slovenije Uredbo o koncesijah za gospodarsko izkoriščanje naplavin iz struge reke Soče

1. člen
(območje, predmet in obseg koncesije)

S to uredbo Vlada Republike Slovenije (v nadaljnjem besedilu: vlada) določa pogoje za podeljevanje koncesij za gospodarsko izkoriščanje naplavin (mivka, pesek, prod, kamen) in sicer:

VODOTOK	OB^INA	KOORDINATE GORVODNE MEJE ODSEKA		KOORDINATE DOLVODNE MEJE ODSEKA	
		Y	X	Y	X
Soča	Bovec Kobarid Tolmin	5 385 339,00	5 131 502,00	5 398 687,00	5 118 765,00

Odsek reke Soče je določen z koordinatami gorvodne meje in dolvodne meje odseka, ki so prevzete iz državnega koordinatnega sistema (v Gauss-Krügerjevi projekciji), odčitane v temeljnih topografskih načrtih RS v merilu 1 : 5000.

2. člen
(vsebina koncesije)

Koncesija po tej uredbi obsega:
1. odvzem in skladiščenje naplavin,
2. separiranje in pripravo frakcij iz naplavin za gradbene namene,
3. dajanje v promet posameznih frakcij,
4. urejanje in vzdrževanje objektov za dostop oziroma dovoz do mesta odvzema naplavin ter urejanje in vzdrževanje objektov na mestu odvzema naplavin. Skupna količina v koledarskem letu odvzetih naplavin na posameznem odseku reke Soče ne sme presegati količin, ki so določene v Programu vzdrževanja vodnega režima reke Soče in vodnogospodarskih objektov in naprav na reki Soči (v nadaljnjem besedilu: Program).

3. člen
(pogoji, ki jih mora izpolnjevati koncesionar)

Koncesionar mora izpolnjevati sledeče pogoje:
- da je gospodarska družba registrirana v Republiki Sloveniji oz. samostojni podjetnik posameznik priglašen v vpisnik podjetnikov pri izpostavi republiške uprave za javne prihodke, za opravljanje dejavnosti pridobivanja gramoza in peska in dajanja le-teh v promet,
- da je poravnal davke, prispevke in druge obvezne dajatve in da ni proti njemu uveden postopek prisilne poravnave, stečaja ali likvidacijski postopek ali ni prenehal poslovati na podlagi sodne ali druge prisilne odločbe,
- da ima veljavno dovoljenje pristojnega organa za opravljanje dejavnosti, ki je predmet koncesije in je tako dovoljenje zahtevano s posebnim predpisom,
- da ne opravlja javne službe na področju vodnega gospodarstva,
- da je tehnično usposobljen za odvzem naplavin,
- da ima zagotovljeno možnost za separiranje in pripravo frakcij iz naplavin v lastnem obratu ali po pogodbi,
- da ima zagotovljeno možnost skladiščenja odvzetih naplavin.

Koncesija se lahko podeli največ 10 koncesionarjem hkrati.

4. člen
(posebni pogoji)

Naplavine je dovoljeno odvzemati izključno v skladu z ugotovljeno potrebo po urejanju vodnega režima in sicer takrat ko:
- je dotok naplavin večji od transportne sposobnosti vodotoka,
- obstaja možnost potencialnega dvigovanja gladine vode in dna zaradi odlaganja naplavin,
- je treba zagotoviti konstantno pretočno sposobnost vodotoka,
- odlaganja naplavin ogroža vodnogospodarske objekte in naprave,
- je ogrožen ali bistveno zmanjšan dotok vode v podzemne vode.

Koncesionar sme odvzemati naplavine na odvzemnem mestu v času in na način, kot to določa Program, ki ga do 31. oktobra tekočega leta za naslednje leto izdela ministrstvo, pristojno za gospodarjenje z vodami (v nadaljnjem besedilu: ministrstvo). Koncesionar ne sme separirati odvzetih naplavin na območju struge reke Soče. Ustrezna mesta za izvajanje separiranja bodo določena v aneksu h koncesijski pogodbi skladno s Programom. Koncesionar mora drugim obstoječim uporabnikom zagotoviti nemoteno izvajanje pravice do gospodarskega izkoriščanja reke Soče.

5. člen
(okoljevarstveni pogoji)

Koncesionar mora poleg izpolnjevanja okoljevarstvenih pogojev v skladu s predpisi zagotoviti še:
- ukrepe proti poslabšanju vodnega režima zaradi odvzema naplavin,
- ukrepe, da z odvzemom naplavin ne bo povzročen nastanek jam in zajed,
- ukrepe, da z odvzemom naplavin ne bodo ogroženi vodnogospodarski objekti,
- ukrepe, da z odvzemom naplavin ne bo povzročena globinska ali bočna erozija,
- ukrepe za preprečevanje poslabšanja kakovosti vode reke Soče,
- igracijo vodnih organizmov,
- ukrepe, da z odvzemom naplavin ne bodob ogrožena drstišča v času drstitev,
- nemoteno potovanje deleža naplavin dolvodno po vodotoku,
- ohranjanje biotske raznovrstnosti in avtohtonosti habitatov,
- ukrepe v zvezi s sanacijo, vzpostavitvijo novega oziroma nadomestitvijo prejšnjega stanja po prenehanju koncesije, če je to določeno v koncesijski pogodbi.

Ukrepi in pogoji iz prejšnjega odstavka se podrobneje določijo v upravnih postopkih za poseg v prostor.

6. člen
(stroški koncesionarja)

Koncesionar nosi vse stroške v zvezi s koncesijo, ki bo podeljena na podlagi te uredbe.

7. člen
(obveznosti koncesionarja)

Koncesionar redno vodi posebno ločeno računovodstvo, evidenco odvzetih količin naplavin, in količin prodanih frakcij ter Poslovnik o odvzemu, skladiščenju in pripravi frakcij iz odvzetih naplavin. Podrobnejši pogoji za izvajanje koncesije se lahko določijo tudi v koncesijski pogodbi. Koncesionar je dolžan brezplačno odstopiti naplavine izvajalcu javne službe na področju vodnega gospodarstva za potrebe vzdrževanja vodotokov in vodnogospodarskih objektov na vplivnem območju reke Soče. Količine, potrebne za izvajanje javne službe, se določijo v Programu. Koncesionar je dolžan za dejansko odvzete količine naplavin plačati vodno povračilo v skladu s predpisi, ki urejajo vode.

8. člen
(začetek in čas trajanja koncesije)

Koncesija se začne izvajati z dnem sklenitve koncesijske pogodbe. Koncesija se podeli za obdobje do 31. decembra 2010. Koncesija se po poteku časa iz prejšnjega odstavka lahko podaljša na način in pod pogoji, določenimi v 19. členu te uredbe in v koncesijski pogodbi.

9. člen
(plačilo za koncesijo)

Koncesionar plačuje za koncesijo enkrat letno znesek, ki je enak zmnožku količine naplavin, in 10 % povprečne tržne vrednosti 1 mł frakcije 0/32 mm. Količina naplavin za vsako odvzemno mesto je določena v Programu. Povprečna tržna vrednost omenjene frakcije se določa na podlagi prodajnih cen te frakcije, doseženih v preteklem letu, na območju reke Soče. Za količine odvzetih naplavin, ki jih koncesionar brezplačno, po Programu, odstopi za potrebe javne službe, koncesionar ne plačuje koncesije in vodnega povračila. Plačilo za koncesijo se razdeli med državo in lokalno skupnostjo, na območju katere je odvzemno mesto na reki Soči, v razmerju 50% : 50%. Če leži odvzemno mesto v več lokalnih skupnostih, si lete delež plačila za koncesijo, ki jim pripada, razdelijo skladno s pripadajočim deležem odvzemnega mesta. Prihodki iz prvega odstavka tega člena so vir občinskega proračuna in proračuna Republike Slovenije. Način obračunavanja in plačevanja se podrobneje določi v koncesijski pogodbi.

10. člen
(način pridobitve koncesije)

Koncesija se podeli na podlagi javnega razpisa. Javni razpis izvede ministrstvo. O izbiri koncesionarja odloči Vlada z upravno odločbo. Koncesionar mora v roku 6 mesecev od izdaje odločbe o izbiri koncesionarja skleniti koncesijsko pogodbo, sicer koncesija preneha veljati.

11. člen
(vsebina javnega razpisa)

Javni razpis mora vsebovati:
- podatke o koncedentu,
- predmet koncesije,
- pogoje za pridobitev koncesije,
- podatke, ki jih mora vsebovati prijava na razpis,
- začetek in čas trajanja koncesije,
- čas in kraj oddaje prijav,
- rok za izbor koncesionarja,
- prednostna merila za izbor koncesionarja,
- postopek za izbor koncesionarja,
- rok v katerem bodo prijavitelji obveščeni o izboru,
- odgovorno osebo za dajanje informacij med razpisom.

12. člen
(prednostna merila za izbor koncesionarja)

Kot prednostna merila upoštevajo:
- boljša tehnična usposobljenost za odvzem, skladiščenje in pripravo frakcij,
- ustreznejša rešitev zagotavljanja varstva okolja
- ustreznejša idejna zasnova o načinu odvzema, skladiščenja in predelave naplavin.

13. člen
(objava in izvedba javnega razpisa)

Javni razpis se objavi v Uradnem listu Republike Slovenije in traja najmanj 40 dni od dneva objave. Javni razpis je uspešen, če je do poteka razpisnega roka predložena vsaj ena veljavna prijava. Prijava na javni razpis je veljavna, če je pravočasna in v celoti izpolnjuje vse zahteve javnega razpisa. Če javni razpis ni uspel, se lahko ponovi.

14. člen
(koncesijska pogodba)

Medsebojna razmerja med koncedentom in koncesionarjem se podrobneje uredijo s koncesijsko pogodbo v skladu z zakonom. V koncesijski pogodbi se podrobneje določi tudi način ureditve pravic in obveznosti med koncesionarjem in koncedentom v primeru spremenjenih razmer. Koncesijsko pogodbo sklene v imenu koncedenta vlada. Odvzemna mesta na reki Soči, količina naplavin za odvzem in čas izvajanja koncesije se določijo v aneksu h koncesijski pogodbi, ki se sklene za obdobje koledarskega leta na podlagi Programa za vsako leto posebej. Koncesionar mora skleniti do 31. decembra tekočega leta aneks h koncesijski pogodbi, za naslednje koledarsko leto. S sklenitvijo koncesijske pogodbe se koncesionar zaveže, da bo spoštoval obveznosti iz te uredbe. V primeru neskladja med to uredbo in koncesijsko pogodbo veljajo določbe te uredbe.

15. člen
(razlogi in način prenehanja koncesijskega razmerja)

Razmerje med koncedentom in koncesionarjem preneha:
- s prenehanjem koncesijske pogodbe,
- z odvzemom koncesije.

Pogoji in način prenehanja koncesijskega razmerja se podrobneje uredijo s koncesijsko pogodbo.

16. člen
(prenehanje koncesijske pogodbe)

Koncesijska pogodba preneha:
- po preteku časa, za katerega je bila sklenjena,
- z razdrtjem,
- če koncesionar v roku, določenem v tej uredbi ne podpiše aneksa h koncesijski pogodbi,

- če je proti koncesionarju uveden postopek prisilne poravnave, stečaja ali likvidacijski postopek ali je prenehal poslovati na podlagi sodne ali druge prisilne odločbe,
- če ni vodil posebnega ločenega računovodstva in drugih evidenc zaradi izvajanja nadzora, skladno s 7. členom te uredbe ali ni dal predpisanih podatkov državnim organom,
- če ne zagotovi odvzem naplavin na način in pod pogoji kot jih določa Program,
- če mu je bila po pridobitvi koncesije izdana pravnomočna sodna ali upravna odločba zaradi kršitve okoljevarstvenih predpisov, koncesijske pogodbe ali upravnih aktov izdanih za izvajanje koncesije. Razlogi in pogoji za razdrtje in druge medsebojne pravice in obveznosti se določijo v koncesijski pogodbi.

17. člen
(odvzem koncesije)

Koncesija se lahko odvzame:
- če koncesionar ne začne z izvajanjem koncesije v roku, določenem s koncesijsko pogodbo,
- če je v javnem interesu, da se preneha izvajati koncesija.

Pogoji odvzema koncesij se določijo v koncesijski pogodbi.

18. člen
(prenos koncesije)

Prenos koncesije na drugega koncesionarja je možen le z dovoljenjem vlade.

19. člen
(podaljšanje koncesije)

Koncesionar lahko predlaga vladi podaljšanje koncesijske pogodbe in sicer šest mesecev pred prenehanjem veljavnosti koncesijske pogodbe. Koncesija se lahko podaljša, če koncesionar izpolnjujeb vse pogoje in obveznosti iz te uredbe ter če še naprej obstajajo možnosti in potrebe po dstranjevanju aplavin. Koncesija se podaljša s sklenitvijo nove koncesijske pgodbe.

20. člen
(nadzor nad izvajanjem koncesije)

Nadzor nad izvajanjem koncesije izvršujejo pristojni nšpektorji. Tehnični nadzor nad izvajanjem Programa in načina odvzema naplavin izvaja ministrstvo in izvajalec javne službe kot rečna nadzorna služba.

21. člen
(veljavnost uredbe)

Ta uredba začne veljati petnajsti dan po objavi v Uradnem listu Republike Slovenije.

Ljubljana, dne 27. septembra 2001.
Vlada Republike Slovenije
dr. Janez Drnovšek l. r.
Predsednik