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Destructive effect of quarry effluent on life in a mountain stream

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Abstract: Quarrying is a widespread method for acquiring construction material. The studies of quarrying effects to date have been conducted mostly in the fields of geology, (hydro)geochemistry and landscape management while ecological studies on effects of quarrying are surprisingly few. The goal of this study was to assess some ecological effects of quarry mining on mountain stream habitats. The study was performed at Bistra Stream on Medvednica Mountain in NW Croatia. The quarry is located 3 km downstream from the spring. Samples were taken at four sites on four dates during the spring of 2006. Standard physico chemical parameters were measured and triplicate benthos samples were taken using a 30 × 30 cm Surber sampler. Turbidity, pH and temperature increased significantly downstream of the quarry. All biocenotic descriptors decreased significantly downstream of the quarry including total taxa (by 60%), total number of individuals (by 85%), diversity index (by 56%). The most important cause of such changes in the macroinvertebrate assemblage structure was the change in pH and turbidity. The magnitude of changes in the macroinvertebrate assemblage structure was due to the extremely long duration of disturbance. However, we believe that the recovery of aquatic assemblages, upon closure of the quarry, would be fast and successful because of nearby streams that may serve as a recolonizing source.

Key words: quarry; fine sediment; mining; macroinvertebrates; disturbance; stream; Croatia

Introduction

Quarrying is a method for acquiring various geological materials (rocks and minerals), and has been extensively employed worldwide. The effect that quarrying has on the environment is mostly equated with the evident scars on the landscape and is considered severe but nevertheless local. The focus of studies to date has been confined to the field of geology, (hydro)geochemistry and (terrestrial) landscape management (Wheater & Cullen 1997; Gaiero et al. 1997; Jim 2001; Špičková et al. 2008; Kim et al. 2007). Papers related to the biological assessment of the effects of quarrying on aquatic systems are sparse (Nuttall 1972; Nuttall & Bielby 1973). This is surprising, given both the imaginable and the proven effects of various mining effluents (Quinn et al. 1992; Kim et al. 2007; Mishra et al. 2008). Most quarries produce extreme amounts of fine particles (Felekoglu 2007) which might be transported by wind across great distances and affect all types of habitats. Furthermore, some quarries utilize water in the exploitation process and are situated near natural water supplies that could be affected. Diabase (used for asphalt mixture) quarries are a typical example. Important phase in the exploitation of diabase is the rinsing of extracted material. For this purpose stream channel may be widened forming a shallow pond. Such interventions result in different types of disturbance that have been recognized as an important factor in structuring the invertebrate assemblages (e.g., Lake 2000; Death 2002). The first disturbance we expected is an increased amount of suspended solids and turbidity of stream water. With channel widening, slowed flow and increased turbidity we expected an increase in water temperature and decrease of primary production and consequently a decrease in the amount of dissolved oxygen.

A second aspect of quarry disturbance is the settling of suspended fine particles on a natural cobble-gravel substrate. Sedimentation and siltation is an overwhelming stress for the native invertebrate assemblages (Wood & Armitage 1997; Weigelhofer & Waringer 2003). Primary producer's abundance is lowered and stream metabolism is changed, food quality for macroinvertebrates degrades and interstices are filled, rendering these habitats inadequate for macroinvertebrates (Quinn et al. 1992; Parkhill & Gulliver 2002; Bo et al. 2007). We therefore expected a decrease in macroinvertebrate abundance and diversity downstream of the quarry. On the other hand, mountain streams are widespread in the temperate zone and are located near each other. Those unaffected can provide both refugia and a source for recolonization especially for temporary stream fauna (insects that live in streams only during larval development), which represents the majority of species and individuals within these assemblages. Other representatives (here mostly Oligochaeta) are largely burrowing and interstitial species that dwell within the sediment, so we expected that the disturbance would not affect them severely (Weigelhofer & Waringer 2003). All of these facts may alleviate the effect of the disturbance.

A third disturbance that we expected is a change in water chemistry caused by the quarry effluent which is likely to be stressful for most taxa regardless of their life history and environmental preferences (Gaiero et al. 1997; Kim et al. 2007; Mishra et al. 2008). The impacts of a combination of these disturbances on macroinvertebrates have not yet been studied. The goal of this research was to asses: 1) the effect of quarrying on physicochemical properties of water and structure and abundance of macroinvertebrate assemblages, 2) the downstream distance to which the effects of disturbance extend, 3) which of the taxa are the most sensitive/resilient to the disturbance.

Material and methods

Study area

The study was carried out at Bistra Stream on Medvednica Mountain situated in NW Croatia near the capital, Zagreb, with the highest peak at 1035 m a.s.l. The mountain is geologically extremely complex with igneous, sedimentary and metamorphic rocks dating from the Paleozoic to the Cenozoic era. Bistra Stream is located on the NW slope in the mid section of the mountain. The spring is situated on green schist from the Devonian at 820 m a.s.l. The stream runs over schists, dolomite marl and sandstones of younger origin (Cretaceous) before reaching the section with igneous rocks, basalt and diabase (dolerite, gabbro). The quarry is located in this area 3 km downstream from the spring. For the purpose of the rinsing process a terrace was made within the quarry. In this area the stream is widened forming a large pool section (approximately 20 × 30 m), where the flow velocity falls under 10 cm s^{-1}.

Before reaching the quarry Bistra is a typical mountain stream of the temperate region with a cobble and pebble bed (some boulders) and thick riparian vegetation that shades the entire width of the channel (maximum 3.5 m). The stream attains the same characteristics immediately after the quarry.

Four sampling sites were chosen: 0 – upstream of the quarry (control), 1 – immediately after the quarry, 2 – approximately 1500 m downstream and 3 – approximately 3000 m downstream at the edge of the forest before the stream exits and becomes a lowland stream. All of the sampling sites were situated in Cretaceous igneous rocks (diabase and gabbro).

Sampling and data analyses

The sampling was done at four dates during the spring of 2006. This time was chosen because at that time both the quarry and the invertebrates reach their peak activity. Physico-chemical parameters were measured partly *in situ* using respective probes (pH WTW 330i, conductivity Hach Sension 5, temperature and dissolved oxygen content WTW Oxi 96) and partly in the laboratory (COD using $KMnO_4$ equivalency titrimetric method and turbidity using SiO_2 equivalency spectrophotometric method).

Triplicate benthos samples were taken using a 30 × 30 cm Surber sampler with mesh size 300 μm and their mean was used as a single data point for given date (yielding four data points per site). Identification of the collected specimens was done to the lowermost taxonomic level based on Macan & Cooper (1960) for Gastropoda, Waringer & Graf (1997) for Trichoptera, Zwick (2004) for Plecoptera, Bauernfeind & Humpesch (2001) for Ephemeroptera, Nilsson (1997) for Diptera and Nilsson (1996) for Coleoptera.

Macroinvertebrates were isolated, identified to the lowermost taxonomic level and counted (abundance was calculated per square meter). General biocenotic descriptors were used in the analyses: total number of taxa, total number of individuals, Shannon's diversity index, Simpson's evenness index, number of individuals of permanent fauna, number of individuals of temporary fauna, permanent to temporary fauna ratio (P : T), total number of Ephemeroptera, Plecoptera and Trichoptera (EPT), number of juvenile EPT individuals (1^{st} and 2^{nd} instar) and percentage of juvenile individuals of EPT.

Permanent stream fauna consists of all the macroinvertebrates that spend their entire life in stream (e.g., Mollusca, Oligochaeta, Crustacea, some Coleoptera) and temporary fauna consists of the macroinvertebrates that leave the stream during their life (insects). We have separated the fauna in this manner to observe whether the species that leave the stream at some point in life exhibit different disturbance sensitivity because temporary fauna may readily recolonize the affected habitats from other nearby streams while permanent fauna may recolonize habitats almost exclusively from the upstream section of the same stream. In addition, temporary fauna tend to enter the drift as a response to disturbance more than permanent fauna (Brittain & Eikeland 1988). The EPT were looked at separately because they are common in biological water assessment methods (Larsen et al. 2009). Within this group the individual's ages were considered separately because we expected different disturbance sensitivity due to the changing environmental preferences during the larval development (Williams & Feltmate 1992). Additionally, we have observed that the juveniles of the same species may be found in deeper layers of the substrate than the specimens at later developmental stages as well as different endurance levels than the older individuals (Miliša et al. 2006).

In addition, detailed taxon specific analyses were done using all taxa that were found in abundance greater than five individuals per square meter at least at one of the analyzed sites.

The Mann-Whitney *U* test was used to reveal the differences in studied variables between sites. A non parametric two-independent-groups test was chosen because of low number of data points for which normality cannot be established and because control values were several times higher so the changes among the impact sites would not be revealed using a multiple-independent-groups test. Canonical correspondence analysis (CCA) was used to ordinate the changes of biotic variables in respect to abiotic variables. For the CCA only taxa found in 75% of the control samples (3 out of 4) were used. CCA was performed on 16 data points for 14 taxa and 4 environmental variables. Data were log transformed. Spearman's correlation coefficient was used to link the changes of biotic variables to the changes of abiotic parameters (only for those parameters that were proven to change significantly among the four sites). In the results we will particularly report and subsequently interpret the findings with the level of significance $0.05 < P < 0.09$ as borderline significant to avoid type-two errors in results interpretation (Zar 1996).

Results

Physicochemical effects

Turbidity, pH and temperature were higher downstream of the quarry and dissolved oxygen content,

Table 1. Changes in water characteristics along the study reach.

Site	pH	Temperature (℃)	$[O_2]$ (mg dm^{-3})	Turbidity (mg SiO_2 dm^{-3})	COD (mg O_2 dm^{-3})	Conductivity (μS cm^{-1})
0	7.94 ± 0.09	10.85 ± 1.91	10.02 ± 1.02	0.112 ± 0.015	1.90 ± 0.78	229 ± 11.0
1	8.13 ± 0.07*	15.15 ± 2.14*	8.99 ± 0.70	0.236 ± 0.082*	1.62 ± 1.05	226 ± 15.6
2	8.12 ± 0.10*	13.90 ± 2.89*	9.68 ± 0.84	0.170 ± 0.027*	1.62 ± 0.96	226 ± 17.9
3	8.04 ± 0.15	14.45 ± 3.75*	9.03 ± 0.89	0.162 ± 0.044*	1.72 ± 1.07	224 ± 19.1

Explanations: Mean values ± SD are given; * significantly changed variables in comparison to the values at the control site (Mann-Whitney U test, $P < 0.05$).

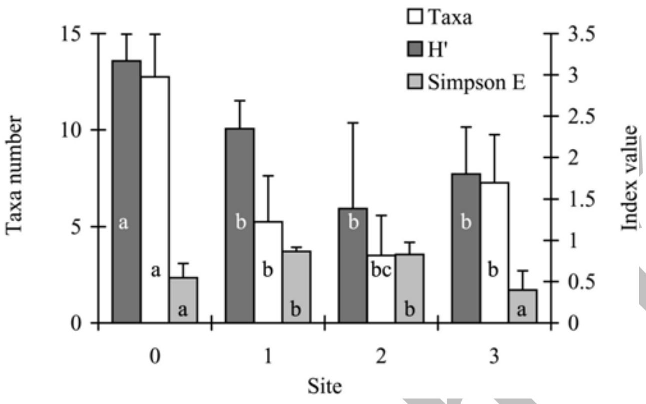

Fig. 1. Changes in richness of macroinvertebrate assemblages along the study reach. Note that the indices values are on the secondary y axis (H' – in bits per individual; Simpson's E – no unit). The letters (a, b, c) suggest which of the parameters are significantly different among sites, e.g., if the same letter is present for a parameter at more sites, these are not different.

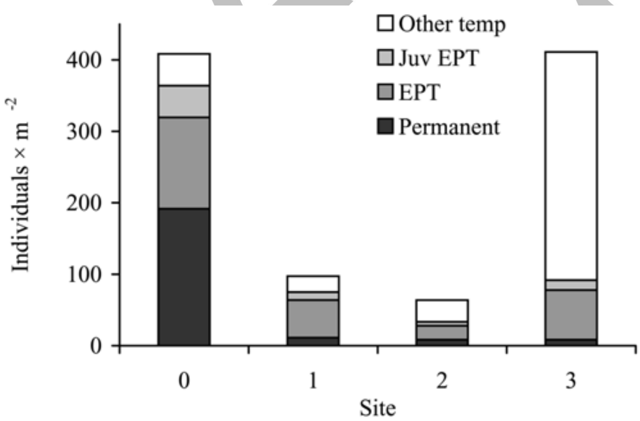

Fig. 2. Changes in the structure of macroinvertebrate assemblages along the study reach. Other temp – Temporary taxa excluding Ephemeroptera, Plecoptera and Trichoptera (EPT); Juv EPT – Juvenile EPT (1st and 2nd instars).

COD and conductivity values were lower (Table 1). Significant differences were found for turbidity among sites 0 and all other (site 0 – site 3, $P = 0.083$), for pH between site 0 and sites 1 and 2 and for temperature only between sites 0 and 1. From a physicochemical point of view sites downstream of the quarry (1, 2 and 3) were not found to be statistically different from each other (Table 1). COD, dissolved oxygen content and conductivity were not found to be significantly different among the studied sites.

Biocenotic effects

Almost all studied biocenotic factors were found to be significantly changed between site 0 and sites 1 and 2. Only the value of Simpson's evenness index increased while all other biocenotical descriptors decreased (Fig. 1). At the farthest downstream site (3) significantly lower values of total taxa, individuals of permanent fauna, P : T ratio and EPT number ($P < 0.09$) still remained (Fig. 2). From the biocenotic point of view sites 1 and 2 were not found to be different. Both site 1 and site 2 were found to be different from site 3. They both had fewer total individuals, less temporary fauna and a higher evenness index. Additionally, site 2 had significantly fewer taxa overall and fewer EPT (Figs 1, 2).

Through taxon specific analyses (Table 2) we found that Gastropoda, Hydrobiidae, Oligochaeta, *Gammarus fossarum*, Ephemeroptera (*Rhithrogena* sp.), juvenile Plecoptera and *Glossosoma* sp. were most sensitive to the disturbance as their abundance decreased significantly at all sites downstream of the quarry. Such decline in abundance of sensitive taxa was responsible for the observed changes in aforementioned biocenotic descriptors.

Additionally, significantly fewer representatives of *Baetis* sp. were found at sites 1 and 2 than at site 0. Coleoptera and *Hydraena* sp. were less sensitive but significantly fewer were found at site 1 than at site 0. Significantly fewer Plecoptera and Trichoptera were found at site 2 than at site 0 (Table 2).

On the other hand, increase in abundance was noted for Tanypodinae. Significantly more were found at site 3 than at other sites. Also, the numbers of Trichoptera and Ephemeroptera increased at site 3 compared to site 2.

No significant change in numbers of any taxa was noted between sites 1 and 2.

A number of taxa were proven to be unaffected by quarry and associated stressors: Simuliidae, Tanypodinae, *Protonemura* sp., *Perla* sp., *Beraea* sp., *Glossosoma* sp., *Cyphon* sp. and *Liponeura* sp.

Most of the biocenotical factors were negatively correlated with turbidity (Spearman's correlation index). At $P < 0.05$, negative correlations with turbidity were observed for total taxa number, total number of individuals, number of individuals of both permanent and temporary fauna and number of individuals of EPT and juvenile EPT as well as percentage of juvenile individuals in total EPT. The Simpson evenness index was posi-

Table 2. Mean abundances in individuals per m^2 with P-levels from Mann-Whitney U tests revealing significance of changes in abundance of each taxon between sites.

	Site 0	Site 1	Site 2	Site 3	*P*-value					
					0–1	0–2	0–3	1–2	1–3	2–3
Gastropoda	44.4	8.3	0.0	2.8	***0.078***	**0.014**	**0.026**	0.131	0.405	N-A
Oligochaeta	113.9	2.8	0.0	0.0	**0.018**	**0.014**	**0.014**	N-A	N-A	N-A
Gammarus fossarum	16.7	0.0	0.0	0.0	**0.013**	**0.013**	**0.013**	N-A	N-A	N-A
Collembola	0.0	0.0	2.8	13.9	N-A	N-A	0.317	N-A	0.317	0.850
Ephemeroptera	94.4	16.7	11.1	41.7	**0.028**	**0.020**	***0.053***	0.877	0.137	**0.017**
Plecoptera	33.3	22.2	11.1	16.7	0.439	***0.076***	0.304	0.278	0.350	0.877
Trichoptera	44.4	25.0	2.8	25.0	0.309	**0.026**	0.375	0.122	0.882	**0.034**
Coleoptera	16.7	0.0	8.3	5.6	**0.047**	0.369	0.225	0.131	0.127	0.752
Diptera	11.1	11.1	2.8	38.9	1.000	0.405	0.457	0.405	0.457	0.122
Simuliidae	5.6	5.6	0.0	5.6	1.000	0.317	1.000	0.317	1.000	0.317
Tanypodiynae	27.8	5.6	25.0	261.1	0.166	0.770	**0.029**	0.122	**0.018**	**0.021**
Hydrobiidae	41.7	8.3	0.0	2.8	***0.078***	**0.014**	**0.026**	0.131	0.405	N-A
Rhithrogena sp.	36.1	2.8	2.8	0.0	**0.025**	**0.025**	**0.013**	N-A	N-A	N-A
Baetis sp.	16.7	2.8	2.8	22.2	**0.032**	**0.032**	0.765	N-A	0.321	0.321
Ephemerella sp.	0.0	0.0	0.0	8.3	N-A	N-A	0.131	N-A	0.131	0.131
Ephemeroptera juvenile	36.1	11.1	5.6	11.1	0.508	0.536	0.766	0.739	0.439	0.343
Protonemura sp.	19.4	19.4	11.1	13.9	0.741	0.294	0.234	0.278	0.225	0.741
Perla sp.	5.6	2.8	0.0	0.0	0.850	0.317	0.317	N-A	N-A	N-A
Plecoptera juvenile	8.3	0.0	0.0	0.0	**0.040**	**0.040**	**0.040**	N-A	N-A	N-A
Beraea sp.	11.1	0.0	0.0	0.0	0.131	0.131	0.131	N-A	N-A	N-A
Glossosoma sp.	27.8	2.8	0.0	8.3	**0.026**	**0.014**	***0.078***	N-A	0.405	0.131
Hydropsyche sp.	0.0	11.1	0.0	0.0	0.131	N-A	N-A	0.131	0.131	N-A
Rhyacophila sp.	2.8	11.1	2.8	11.1	0.405	1.000	0.850	0.405	0.741	0.850
Hydraena sp.	11.1	0.0	2.8	2.8	**0.046**	0.155	0.155	N-A	N-A	N-A
Cyphon sp.	5.6	0.0	2.8	0.0	0.317	0.850	0.317	N-A	N-A	N-A
Liponeura sp.	8.3	5.6	0.0	0.0	0.850	0.317	0.317	0.317	0.317	N-A
Pediciidae	0.0	2.8	0.0	16.7	N-A	N-A	0.317	N-A	0.850	0.317

Explanations: Bold are significant; bold-italicized are borderline significant changes.

tively correlated with turbidity. A negative effect of turbidity was found on total Ephemeroptera, *Rhithrogena* sp., juvenile Plecoptera, *Hydraena* sp., Oligochaeta and *G. fossarum.* The numbers of Gastropoda, Hydrobiidae, Coleoptera ($P < 0.07$), juvenile Ephemeroptera ($P < 0.08$) and *Beraea* sp. ($P < 0.09$) were negatively correlated with turbidity. Only Diptera seem not to be significantly affected by changed turbidity, pH and temperature.

Total taxa number and number of EPT individuals were negatively correlated with temperature ($P < 0.08$). Temperature increase negatively affected Plecoptera (both total and juvenile) and *G. fossarum* the most.

Even though pH change was found significant, pH was found not to have a significant effect on general biocenotical descriptors. Only when a taxon specific approach was employed was a significant negative effect of pH change found. Total Ephemeroptera, *Baetis* sp., *Glossosoma* sp., Oligochaeta and *G. fossarum* were the most sensitive.

Abundance of *Rhithrogena* sp. ($P < 0.07$), juvenile Plecoptera ($P < 0.07$) and *Hydropsyche* sp. ($P < 0.08$) were negatively correlated with both temperature and pH.

The results of the CCA analysis (Fig. 3) reveal the importance and combined negative effects of changed turbidity, pH and temperature on the studied taxa. Axis 1 was highly correlated with the pH ($R = 0.94$) and axis 2 with the turbidity ($R = 0.78$). Comparing the lengths of the environmental vectors we conclude that pH and turbidity are the most important. Most of the studied taxa (except *Protonemura*) are located opposite these two vectors on the left plane. Juvenile EPT display different preferences than the older larvae. While the juveniles are responding negatively to turbidity the older larvae seem affected by the oxygen concentration decrease (too near to the ordination center to firmly claim). Tanypodinae are also near the ordination center which may explain their abundance downstream, as they seem unaffected by these environmental changes.

Discussion

The most important physicochemical effects of the quarry were increase of turbidity, temperature and pH. Increased turbidity resulted both from rinsing the material and from dust settling from air. Temperature increase was undoubtedly caused by increased turbidity with particles absorbing extra solar energy as well as by the broadening of the channel and reducing flow velocity for purposes of rinsing the extracted diabase. This 'pond' is broad, shallow and lacking riparian vegetation so excess accumulation of solar energy is imminent. We consider increase in pH value of pure geochemical origin already noted at a similar site in Korea (Kim et al. 2007). Lowering of pH, temperature and turbidity from site 1 downstream is an indicator of the physicochemical recovery of the system.

Quarrying certainly has a negative influence on

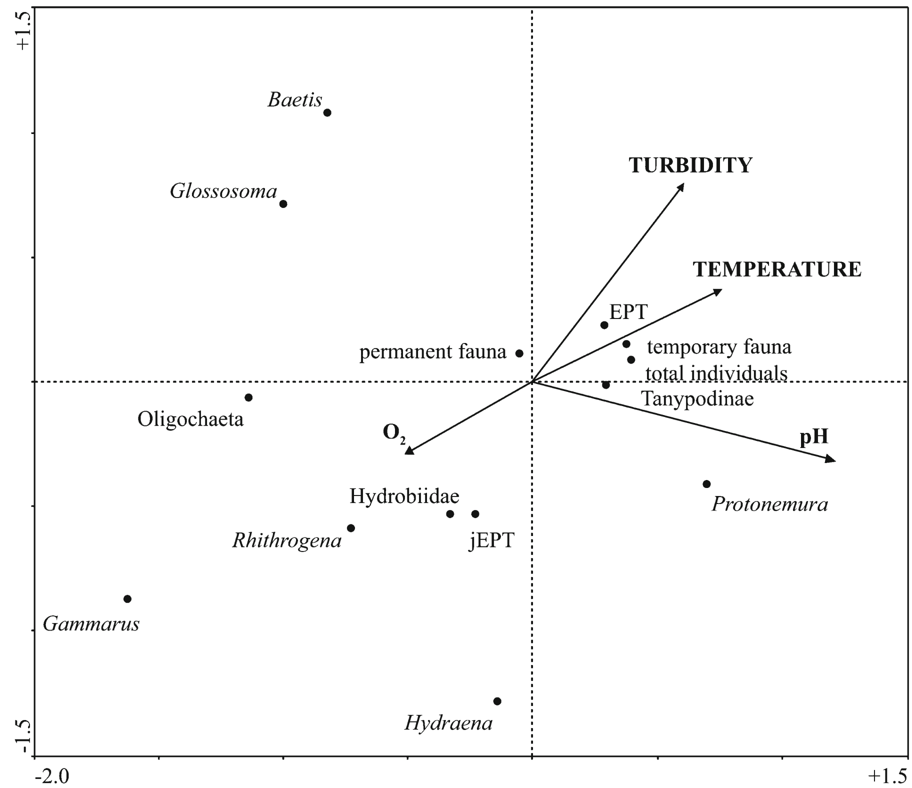

Fig. 3. Canonical correspondence analysis of selected biotic and abiotic variables at Bistra Stream. Eigenvalues and species-environmental factors correlation for the first two axes are Axis 1: Eigenvalue = 0.099; $R = 0.83$, Axis 2: Eigenvalue = 0.040; $R = 0.73$. The two axes explain 88.2% of taxa-environment relation.

the ecology of stream habitats, as proven in this study. However, a number of taxa appeared to be unaffected by this stress. Sediment dwellers and predators were expectedly among those less affected. But also the taxa with low original abundances, e.g., Simuliidae which readily drift and the few specimens may occur along the reach. Because of their low abundances this result should be taken cautiously.

The most evident effect on aquatic macroinvertebrate assemblages is the absence of many taxa downstream of the quarry (Quinn et al. 1992). Several taxa do not recover even 3 km from the quarry, most likely due to the permanence of disturbance from the quarry (Table 2). In short term disturbances, the indigenous taxa are able to recover to initial levels in a matter of weeks (Gray & Ward 1982).

The intensity of disturbance is indicated by almost total (85%) loss of macroinvertebrates immediately downstream of the quarry with virtually complete absence of permanent fauna at all sites downstream of the quarry and also by increase in assemblage evenness. Evenness is normally a measure of assemblage fitness. In our study the disturbance is so great that the evenness index loses its function because of extreme changes in the number of taxa resulting in uniformly low abundances of a decreased number of taxa. The most obvious cause of such changes in macroinvertebrate assemblage structure is change in turbidity and pH (Quinn et al. 1992; Kim et al. 2007). Changes in temperature played a significant role in the community changes as well.

Results of previous work (Nuttall 1972; Larsen et al. 2009) associated poor incidence of plants and macroinvertebrates with the unstable shifting nature of the sand deposits, rather than turbidity. In our study we have linked most of the changes with increased turbidity, i.e., increase in amount of suspended particles. The difference was probably yielded because in the mentioned studies the particles were larger (sand) and deposited more rapidly so turbidity is not even reported as a measure of stress. Also, fine sediments cause a more efficient siltation of interstices, especially in riffles which are abundant at our study site, rendering them unsuitable for most indigenous taxa (Bo et al. 2007; Weigelhofer & Waringer 2003).

The other difference was faunal: *Baetis rhodani*, *Rhithrogena semicolorata* and Oligochaetes were abundant where sand deposition had occurred in previous studies (Nuttall 1972; Gray & Ward 1982; Larsen et al. 2009). In our study these taxa seemed more sensitive which concurs with data of Weigelhofer & Waringer (2003) and Bo et al. (2007). Additional difference may be in the assemblages themselves, e.g., Tubificidae (Nuttall 1972) are an indicator species of organically polluted water or generally of poor quality so the taxa might have developed a higher tolerance in such an environment.

In some previous studies the abundances of Ephemeroptera and Oligochaeta increased with higher fine sediment loads (Gray & Ward 1982; Weigelhofer & Waringer 2003; Larsen et al. 2009). The discrepancies with our findings could be due to the duration of disturbance, which is several years in our study while in their study it was short-term. Also, in our study a change in pH and temperature was noted and Ephemeroptera and Oligochaeta (as well as other taxa) were proven sensitive to such changes. We found that the main reason for changes in the general structure of benthic are increases in suspended solids as found by Gray & Ward (1982).

In natural sediment erosion-settlement survey, total, Ephemeroptera, Plecoptera and Trichoptera richness decreased significantly at the most impacted sites (Larsen et al. 2009).

Baetis genus was reported as one of the most sensitive to sediment disturbance (Bond & Downes 2003). These results are in agreement with our findings but in our study the decrease in abundance was more pronounced. Our findings are most similar to those of Doeg & Koehn (1994) where a reduction of 63.9% in the total abundance and 39.7% in the number of taxa was found. Again, the losses in our study were more pronounced (approximately 85% fewer total individuals and 60% less taxa 1.5 km downstream of the disturbance source).

In our study most effects were still noted after 3 km. Unfortunately, we were not able to test the claims that very fine silt may affect habitats 4.5 km downstream (Doeg & Koehn 1994) because our study reach was only 3 km before the stream exits the forest and enters open grassland. The stream characteristics change extremely, rendering any further biological comparison impossible.

The significant decrease in numbers of *Baetis* sp., Coleoptera (*Hydraena* sp.), Plecoptera and Trichoptera found at sites 1 and/or 2 compared to site 0 was not found between sites 3 and 0. This leads to the conclusion that recovery takes place even while the disturbance is present but only 3 km downstream. Comparing with the findings of the previous experiments and taking into account the significant increase in the numbers of Plecoptera and Trichoptera at site 3, we believe the recovery of aquatic assemblages upon closure of the quarry would be successful (Gray & Ward 1982; Doeg & Koehn 1994). The aspect of recovery (especially of temporary fauna) is promoted by the vicinity of other mountain streams from which absent species are able to recolonize the affected stream (sensu Müller 1982; Winterbourn & Crowe 2001).

We conclude that the effects of quarrying are similar to those in experimental work using natural stream sediments, but more severe. This is a result of difference in the characteristics of stress: 1) quarrying produces extremely long term disturbance and 2) the sediments produced in quarries alter the chemistry of water (e.g., change of pH), which does not occur in experiments where natural stream sediments were used (Kim et al. 2007; Mishra et al. 2008).

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