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Limnologica 37 (2007) 186–192

LIMNOLOGICA

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Effects of clogging on stream macroinvertebrates: An experimental approach

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Received 23 October 2006; received in revised form 4 January 2007; accepted 9 January 2007

Abstract

The influence of streambed sediment clogging on macroinvertebrate communities was investigated in the Lemme creek (NW Italy). To assess how fine sediment accumulation can influence the colonisation process and community composition of macroinvertebrates, we placed 48 traps in the riverbed. The traps consisted of boxes built with metal net (mesh 1 cm, height 15 cm, sides 5 cm) covered with nylon net except for the apex, allowing access exclusively from the top. We created four trap types filled with 100% gravel, 30% sand and 70% gravel, 70% sand and 30% gravel and 100% sand. After 20 and 40 days, we removed 6 traps/type. Macroinvertebrates rapidly colonised the traps, as we found no significant community differences between the two removal dates. Among the four trap types, we found significant differences in taxa number and abundance, which both decreased with increasing clogging. Thus, our study supports the hypothesis that clogging and the accumulation of fine substratum elements strongly affects benthic stream communities.

Keywords: Sedimentation; Interstitial zone; Macroinvertebrates; Functional groups; NW Italy; Piemonte

Introduction

The interstitial zone plays an important role in the ecological processes of lotic ecosystem. Thus studying the interstitial areas in bed sediments (sensu Bretschko, 1992) is of major importance for lotic ecologists to better understand the physical, chemical and biological processes that take place in the streambed (Vervier, Gibert, Marmonier, & Dole-Olivier, 1992). For example, within the streambed interstices, organic matter and nutrients can be retained, transformed and stored (Gibert, Dole-Olivier, Marmonier, & Vervier, 1990). Many ecological processes are based on complex exchanges between the streambed surface and subsurface. In this context, hydraulic gradients at the streambed surface, depth of the hyporheic zone and sediment characteristics, such as bed porosity and hydraulic conductivity, play a major role (Harvey & Bencala, 1993; White, 1993).

Pioneer studies underlined the importance of bed sediments for the distribution of stream insects (Wene, 1940). In fact, macroinvertebrates use substrata for deposition and incubation of eggs, for feeding (Minshall, 1984), as a shelter from predation (Brusven & Rose, 1981), refuge from physical disturbances (Dole-Olivier, Marmonier, & Beffy, 1997; Gayraud, Philippe, & Maridet, 2000; Palmer, Bely, & Berg, 1992) and

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doi:10.1016/j.limno.2007.01.002

during extreme drought events (Fenoglio, Bo, & Bosi, 2006).

Sediment size and depth affect the size of available interstitial space (Maridet & Philippe, 1995); thus they are important parameters in studying macroinvertebrate colonisation and distribution (Rae, 1987). It is likely that fine sediment accumulations may clog the interstices, reducing interstitial water exchange, lowering the concentration of dissolved oxygen among the sediments and finally constraining the movement of some invertebrates in the substrata.

In the last decades, human-induced alterations of the natural morpho-hydrological characteristics have altered the transport–deposition cycle in many rivers, so that clogging has become an important ecological problem (Weigelhofer & Waringer, 2003).

Therefore the aims of this experimental study were: (a) to assess how different amounts of fine sediments (sand) in a coarse substratum (gravel) could influence the colonisation process of macroinvertebrates and (b) to investigate the effect of clogging on macroinvertebrate taxonomic richness, abundance and community composition.

Table 1. Environmental characteristics (mean ± SD) in the stream reach during the study period

Parameter	Values
Conductivity (mS)	354.0 ± 31.3
Dissolved oxygen (mg/L)	8.70 ± 0.27
PH	8.59 ± 0.18
Flow velocity (m/s)	0.65 ± 0.14
Water temperature (°C)	20.4 ± 0.1

Methods

We experimented in the Lemme creek, a small tributary (2nd-order stream with moderate slope) of the Orba River, NW Italy (44° 35′ 45″, 8° 51′ 41″; altitude 430 m a.s.l.). Some abiotic parameters were measured using portable instruments (Eijkelkamp 13.14 and 18.28) (Table 1).

The studied stream has a good environmental quality, reaching the first class in the Extended Biotic Index system (Ghetti, 1997), which corresponds to an environment without traces of human-inducted alteration. To assess how different amount of fine sediments in the substratum can influence colonisation processes and community composition of macroinvertebrates, we placed 48 traps in a large and uniform riffle of the Lemme creek riverbed, using a random distribution (Fig. 1). Each trap consisted of a box built with metal net (5 cm long, 5 cm wide and 15 cm high, mesh width 1 cm, total volume = 0.37 dm^3) that was covered with nylon net (mesh width 250 µm) except for the apex, allowing access for macroinvertebrates exclusively from the top of the trap. Traps were individually numbered: traps from 1 to 12 contained only gravel, traps from 13 to 24 contained 30% sand and 70% gravel, traps from 25 to 36 contained 30% gravel and 70% sand and traps from 37 to 48 contained only sand. The average dimension of the gravel was

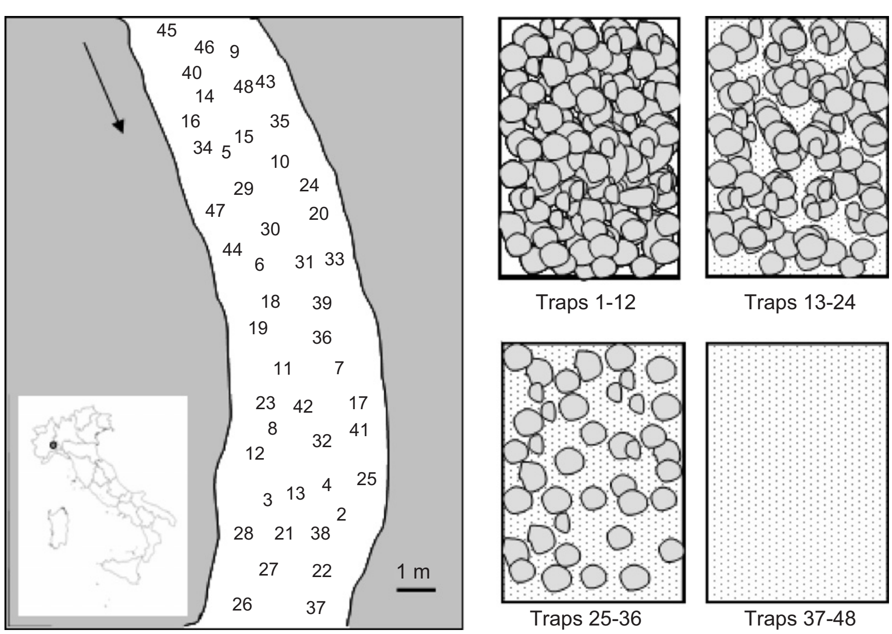

Fig. 1. Lemme creek, traps displacement and scheme of the four trap types (NW Italy 44° 35′ 45″, 8° 51′ 41″; altitude 430 m a.s.l.).

45.0 mm × 23.0 mm × 21.0 mm, while the sand measured meanly 0.25–0.50 mm (sensu Ghetti, 1997).

Traps were positioned in the stream on 28 June 2005 in a uniform, 100 m-long riffle, with the apex orientated upward at the same level of the natural stream substratum, so the depth reached by the traps in the substratum was the same as their height (15 cm). Traps were placed randomly in the stream; thus the composition of traps substratum was not related with the one of the surrounding natural streambed. After 20 and 40 days, we removed 6 traps of each type. In order to analyse abundance and composition of the natural bottom communities, we collected 30 Surber samples, once a week during the study period, in the same riffle area where we had placed the traps, using a 0.06 m^2 Surber sampler (250 μm mesh).

In the laboratory, all organisms were counted and identified to the species or genus level, except for Annelida, early instars of some Trichoptera and Diptera, and others that were identified to the family level. Each taxon was also assigned to a Functional Feeding Group (FFG: scrapers – Sc, shredders – Sh, collectors–gatherers – Cg, filterers – F and predators – P) according to Merritt and Cummins (1996). Moreover, a classification of taxa into seven biological and seven ecological groups was conducted according to the Usseglio-Polatera, Bournaud, Richoux, and Tachet (2000) species traits approach.

Results

In total we collected 14,793 organisms: 7916 macroinvertebrates belonging to 66 taxa in the riverbed and 6877 macroinvertebrates belonging to 55 taxa in the traps (Table 2). Mean abundance in the substratum was 4221.8 organisms/m^2 (±624.8). Highest values of invertebrate densities were found in coarse substrata, while sandy and rocky substrata showed lowest densities. In the functional composition of the invertebrate assemblages, collectors–gatherers were the most represented FFG (33.4% of all organisms), followed by shredders (30.1%), predators (19.2%), filterers (14.4%) and scrapers (2.74%). According to the Usseglio-Polatera et al. (2000) classification, the most represented biological groups in the substratum were the 'e group' (small or medium sized, short-lived, crawlers with aquatic respiration and cemented eggs: 54.8%) and the 'f group' (medium sized, crawlers, shredders with aquatic respiration: 39.4%). Considering ecological groups, the two most abundant groups were 'B' (organisms living in rhithronic rheophilous environments: 37.1%) and 'C' (oligotrophic organisms living in banks and channels of rhitronic and epipotamic, at slow and medium current velocities: 31.4%).

Table 2. Per cent relative abundances of macroinvertebrates collected in the natural streambed and from traps

Taxa	FFG	Natural streambed (%)	Traps (%)
Plecoptera			
Dinocras cephalotes	P	0.21	0.00
Perla marginata	P	0.24	0.04
Leuctra spp.	Sh	29.8	11.4
Protonemura spp.	Sh	0.09	0.04
Ephemeroptera			
Centroptilum luteolum	Cg	0.00	0.01
Ephemera danica	Cg	0.15	0.42
Ecdyonurus spp.	Sc	0.96	0.45
Electrogena spp.	Sc	0.03	0.13
Paraleptophlebia sp.	Cg	0.06	0.00
Habrophlebia sp.	Cg	0.71	5.16
Habroleptoides sp.	Cg	0.03	0.00
Caenis spp.	Cg	0.16	0.54
Baetis spp.	Cg	9.70	4.16
Serratella ignita	Cg	0.90	0.47
Trichoptera			
Sericostoma pedemontanum	Sh	0.01	0.00
Odontocerum albicorne	Sh	0.00	0.01
Hydroptilidae	Sc	0.01	0.20
Psychomyidae	Cg	0.01	0.12
Polycentropodidae	F	0.21	0.90
Goeridae	Cg	0.42	0.13
Beraeidae	Cg	0.69	0.13
Leptoceridae	Cg	2.63	5.86
Hyporhyacophila spp.	P	0.01	0.00
Rhyacophila spp.	P	0.58	0.07
Cheumatopsyche lepida	F	3.92	4.04
Diplectrona felix	F	0.13	0.00
Hydropsyche spp.	F	7.96	14.2
Wormaldia mediana	F	0.56	0.33
Chimarra spp.	F	0.81	0.19
Philopotamus spp.	F	0.06	0.03
Diptera			
Atherix sp.	P	0.01	0.03
Tipula sp.	Sh	0.16	0.09
Empididae	P	0.15	0.03
Chironomidae	Cg	5.53	26.8
Ceratopogonidae	P	0.86	4.86
Tabanidae	P	0.10	0.09
Limoniidae	P	0.80	0.36
Simuliidae	F	0.78	0.12
Psychodidae	P	0.05	0.01
Rhagionidae	P	0.01	0.00
Sciomyzidae	P	0.01	0.00
Anthomydae	P	0.00	0.04
Coleoptera			
Helichus substriatum	Sh	0.01	0.01
Ochthnebius halbherri	Sc	0.03	0.01
Hydraena andrinii	Sc	0.01	0.03
Hydraena minutissima	Sc	0.03	0.00

Table 2. (*continued*)

Taxa	FFG	Natural streambed (%)	Traps (%)
Hydraena spinipes	Sc	0.05	0.01
Haenydra truncata	Sc	0.16	0.01
Haenydra heterogyna	Sc	0.03	0.00
Haenydra devillei	Sc	0.04	0.00
Helodidae (larvae)	Sh	0.05	0.00
Elminthidae (adults)	Cg	11.2	1.13
Elminthidae (larvae)	Cg	0.40	0.54
Stenelmis canaliculata	Cg	0.00	0.07
Gyrinidae (larvae)	P	0.00	0.10
Dytiscidae (adults)	P	0.01	0.00
Heteroptera			
Velia sp.	P	0.06	0.03
Micronecta sp.	P	0.06	0.00
Odonata			
Calopteryx virgo	P	0.00	0.03
Onychogomphus forcipatus	P	0.09	0.17
Boyeria irene	P	0.01	0.03
Megaloptera			
Sialis fuliginosa	P	0.03	0.00
Planipennia			
Osmylus fulvicephalus	P	0.01	0.00
Tricladida			
Dugesia sp.	P	0.21	0.03
Gastropoda			
Ancylus fluviatilis	Sc	1.41	0.06
Hirudinea			
Dina lineata	P	0.01	0.00
Annelida			
Eiseniella tetraedra	Cg	0.09	0.03
Lumbricidae	Cg	0.11	0.01
Lumbriculidae	Cg	0.28	0.15
Naididae	Cg	0.37	0.11
Tubificidae	Cg	0.03	0.00
Arachnida			
Hydracarina	P	15.7	14.8

FFG: Functional Feeding Groups (Cg = collectors–gatherers; F = filterers; P = predators; Sc = scrapers; Sh = shredders).

After exposure, interstitial traps were rapidly colonised, regarding both taxa richness and organism abundance, as we detected no significant differences between the two sampling dates (taxa richness: Mann–Whitney U-test = 263.5, $P = 0.61$; invertebrate abundance: $U = 243.5$, $P = 0.36$).

However, comparing the invertebrate assemblages among the four trap types, we detected evident differences in both taxa and invertebrate numbers.

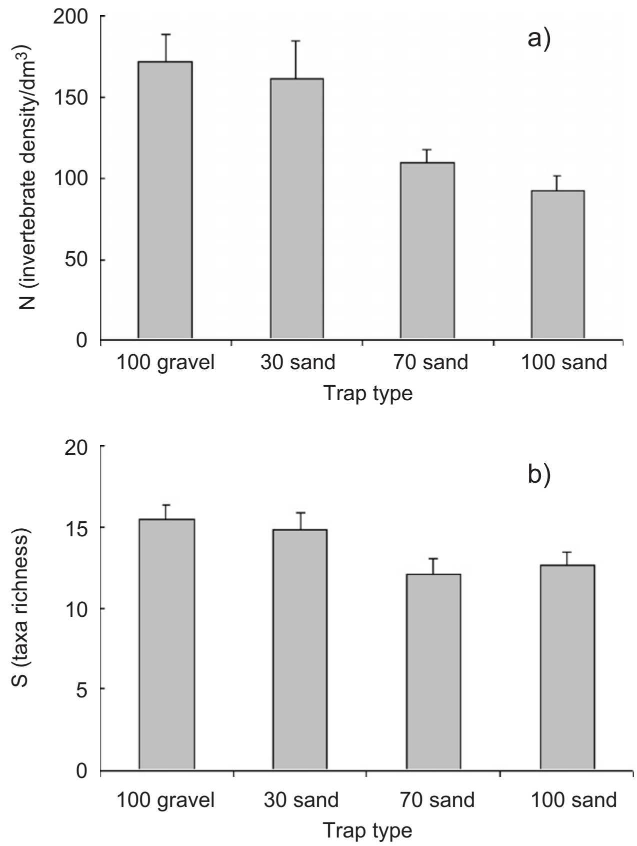

Fig. 2. (a) Abundance of invertebrates in the traps with different granulometry (mean ± SE); (b) taxa richness in the traps with different granulometry (mean ± SE).

Interestingly, the abundance of organisms (Fig. 2a) and the number of taxa (Fig. 2b) were inversely related to the total amount of sand. Differences among traps were significant considering both organism abundance (Kruskal–Wallis test = 14.67, $P = 0.002$) and taxa richness (Kruskal–Wallis test = 7.61, $P = 0.05$).

Collectors–gatherers were the most represented FFG in the traps (50.4% of total), followed by predators (21.8%) and filterers (14.3%), while shredders (12.4%) and scrapers (0.98%) were less represented.

Comparing 100% gravel-filled and 100% sand-filled traps, densities of filterers and scrapers feeding groups were reduced by 44.0% and 12.6%, respectively. In particular the importance of filterers was inversely related with the total amount of sand (Kruskal–Wallis Test = 12.3, $P = 0.006$). The most represented biological group in the traps was the 'e group' (66.8%), followed by 'f group' (23.3%), 'c group' (7.50%), 'h group' (1.64%), 'g group' (0.39%) and 'd group' (0.33%). In the different trap types, the importance of some biological groups, such as 'e' and 'f',' decreased with the increase of sand, while on the contrary sandy substrata were positively related with the abundance of 'h' organisms (multivoltine, burrowers or interstitial

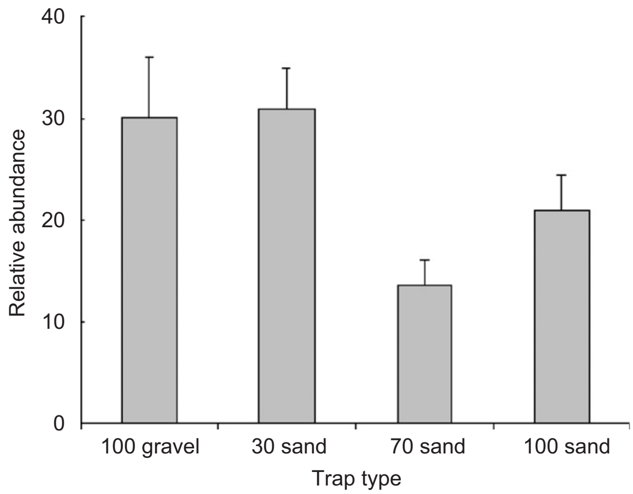

Fig. 3. Total abundance of oligotrophic, rhitronic and epipotamic (sensu Usseglio-Polatera et al., 2000) organisms with the increase of clogging in the artificial substrata (mean ± SE).

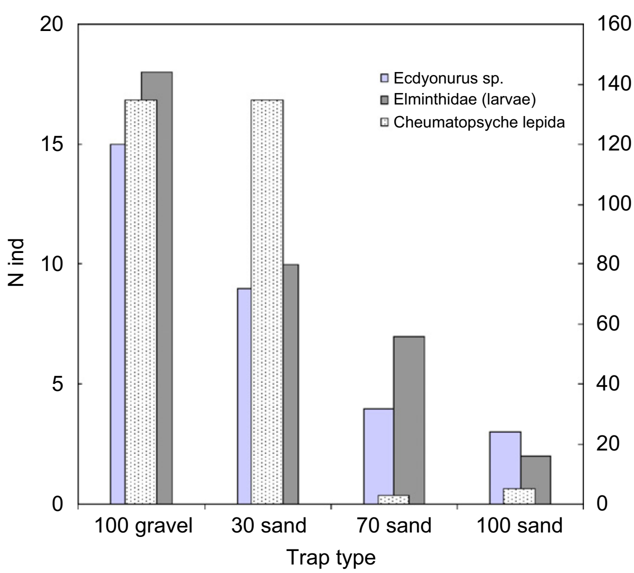

Fig. 4. Abundance of some selected taxa (mean ± SE) in the four clogged trap types: *Cheumatopsyche lepida* (filterer Trichoptera – right *Y*-axis), *Ecdyonurus* sp. (rheophilous, scraper Ephemeroptera), Elmidae larvae (collector–gatherer Coleoptera).

microphagous). Considering the ecological group composition of the traps, we detected no significant differences, with the exception of 'C' organisms (Fig. 3), that were significantly more abundant in substrata with more than 70% of gravel (Kruskal–Wallis test = 9.84, $P = 0.02$).

Analysing the taxonomic composition of the traps, we evidenced some interesting differences among trap types: for example large predators, such as *Perla marginata*, were found only in traps filled with 70% or 100% gravel, avoiding more clogged substrata. Furthermore, rheostenic and litophilous elements, such as Ephemeroptera Heptageniidae, were almost exclusively found in gravel-filled traps (75% of specimens found in traps with more than 70% of gravel), or occurred there in highest abundances (Fig. 4). On the contrary, the number of Oligochaeta tends to increase in the traps filled with conspicuous amounts of fine elements.

Discussion

The Lemme is a typical Apenninic creek, with almost no human-derived impacts and with high levels of invertebrate biodiversity. Taxonomic richness and invertebrate abundances in the substratum were in the range of other Apenninic environments (Fenoglio, Agosta, Bo, & Cucco, 2002), such as functional, biological and ecological composition of the assemblages (Bo, Cucco, Fenoglio, & Malacarne, 2006).

The composition of the bed sediment plays a key role in the colonisation mechanism, composition and abundance of benthic community. Some studies found that in streams with high sediment porosity, the number of invertebrates beneath the top sediment layer may exceed that in the sediment surface by far (Bretschko, 1981; Maridet & Philippe, 1995). Others (Strommer & Smock, 1989; Wagner, Schmidt, & Marxsen, 1993) found extreme low organism densities in interstitial habitats if those had high quantities of sand and low porosity. Walling and Amos (1999) evidenced that the increase of turbidity and sedimentation can represent a serious damage for salmonids in chalk streams of southern England, by reducing the supply of oxygen to the hatching eggs, as well as degrading other characteristics of the channel habitat.

Correspondingly, our traps filled with 100% of sand, i.e. the most clogged ones, provided always the poorest interstitial habitat quality, probably because tight packing of sand grains reduced the trapping of organic detritus, limited the availability of oxygen and lowered the accessible pore space for most of the macroinvertebrates.

In our study, the effect of clogging is very evident and affected organisms belonging to several functional, ecological and biological groups. In particular, the abundance of filterers is strongly reduced by the accumulation of fine elements, probably because of the reduction of water circulation but also because large, semi-voltine, crawlers organisms were not able to colonise clogging environments. The taxonomical, ecological and functional composition of the interstitial assemblages was significantly changed by the accumulation of sand in the substratum of the studied stream: only few groups, such as Oligochaeta, benefited from the clogging process.

Some recent studies have pointed out that the macroinvertebrate fauna of lotic systems can be affected by unnatural, human-induced sedimentation by different indirect and direct effects. Direct effects are, for example, the loss of microhabitat (Rae, 1987), loss of access to trophic resources (Lenat, Penrose, & Eagleson, 1981) and the damage to respiratory systems of organisms (Lemly, 1982). Indirect effects include, for example, the change of the ecological processes that are on the basis of autochthonous and allochthonous sources of energy of the system (Quinn, Davies-Colley, Hickey, Vickers, & Ryan, 1992).

Alteration of stream morphology and human activities in streambeds can increase the clogging and sedimentation process, altering the granulometry of large parts of streambeds and reducing the biological diversity of stream communities. In Apenninic streams of Northwestern Italy, there was a dramatic increase in the regulation and alteration of many lotic systems. After the floods of 1994 and 2000 (Fenoglio, Battegazzore, & Morisi, 2003), a lot of rivers and creeks in this area were morphologically modified, with unnatural increases of sedimentation also in low-order streams.

This study supports the hypothesis that clogging and the increase of sedimentation of fine substratum elements strongly affects the benthic stream invertebrate community, and that this process can diminish the biological diversity of Apenninic lotic environments. Future research should investigate the importance of the organic components in the clogging of the interstitial spaces of streambed substrata.

Acknowledgements

We thank R. Castellaro for his help during field work and G. Ferro for the determination of Coleoptera Hydraenidae.

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