Increased sediment loads in alpine streams: an integrated field study.

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CLOGGING IN ALPINE STREAMS: AN INTEGRATED FIELD STUDY

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CLOGGING IN ALPINE STREAMS: AN INTEGRATED FIELD STUDY

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ABSTRACT

Fine sediment has recently been recognized as one of the major causes of ecological degradation affecting lotic systems. Interestingly, many studies have investigated the impact of clogging on specific compartments of the lotic system, but little or no information is available about the global impact of sedimentation. Aim of this paper is to analyse the influence of fine sedimentation on allochthonous and autochthonous energy inputs and on the structural and functional characteristics of diatom and macroinvertebrate communities. Data were collected in two alpine streams in NW Italy, one interested by the presence of a intense mining area and the other pristine, used as a control. The two rivers greatly differed in terms of suspended solids and bed load characteristics. From ten stations we analysed main physic-chemical characteristics, clogging indicators (using 60 sediment traps), CPOM and photosynthetic pigments amounts, taxonomic and functional characteristics of macroinvertebrate communities. We tested several causal models via path analysis. This approach allowed to identify the weight of different environmental variables on a set of response metrics. Functional traits seem to better reflect the integrate impact originating from quarries in the river basin than traditional community metrics like total abundance and specific richness. This outcome was enforced through the CoInertia Analysis which took in consideration also metrics based on diatom communities. Our study yielded quantitative relations between clogging induced by quarrying activities and the degree of biological impairment and suggests which metrics are more suitable to assess this specific impact.

Key words: allochthonous inputs, autochthonous inputs, diatoms, fine sediments, macroinvertebrates, path analysis, rock quarries

INTRODUCTION

In the last decades, anthropogenic pressures have altered morphological and hydrological features of most lotic systems, so that the transport and deposition of unnatural amounts of fine sediments has become a key ecological problem (Bilotta and Brazier, 2008). Increased sediment transport and deposition are common consequences of landscape or channel alterations: agricultural (Wagenhoff *et al.,* 2011) and logging (Studinski *et al.,* 2012) practices, dams (Baker *et al.*, 2011) and roads (Angermeier *et al.*, 2004) diffusion, catchment urbanization (Naden, 2010), and mining (Griffith *et al.* 2012) are among the main causes of this phenomenon. The increase of exposed bank soils and the removal of riparian vegetation contribute to the massive transport of eroded materials into lotic systems, where they become suspended or deposited sediments (Hornung and Reynolds, 1995).

Increased inputs of fine sediments can result in marked physical modifications of lotic environments (Owens *et al.*, 2005). Fine sediments adsorb or scatter light within the water column modifying optical features of water, increasing turbidity and reducing transparency (Davies-Colley and Smith, 2001). The transport of fine sediments also causes an augmentation of abrasion of benthic environment (Hedrick *et al.*, 2013). On the other hand, sedimentation alters surface and hyporheic characteristics of lotic substrates, filling interstitial pore spaces and even smothering the entire riverbed (Descloux *et al.*, 2010). Increased amounts of fine sediments within the substrate reduce its permeability to gases, water, nutrients and metabolites (Allan and Castillo 2007). Moreover, sedimentation diminishes mesohabitat heterogeneity, increasing similarities among pool, run, and riffle environments (Kemp *et al.,* 2011).

These alterations can result in significant changes in many aspects of stream ecosystems communities. In-stream primary producers seem to be extremely sensitive to sediment increase (Biggs *et al.,* 1999). With the increase of fine inorganic sediments, chlorophyll-*a* amounts usually decline and non-living component of periphyton assemblages increases (Yamada and Nakamura, 2002), resulting in a general lowering of photosynthetic efficiency and algal biomass (Quinn *et al.*, 1992; Izagirre *et al.*, 2009). Moreover, sedimentation increase usually produces evident taxonomic changes in periphytic communities, for example decreasing the proportion of some taxa (Peterson, 1996; Wagenhoff *et al.*, 2011) and enhancing the amount of others (Schofield *et al.*, 2004).

Likewise, transport and accumulation of fine sediment can have dramatic impacts on the abundance and composition of benthic invertebrate assemblages (Buendia *et al.*, 2013). High amounts of fine sediments directly affect some taxa trough the abrasion and damaging of the most delicate body parts, such as gills and filter-feeding apparatus (Lemly, 1982) or through the burial of less motile organisms (Wood *et al.*, 2005). Moreover, clogging of interstitial spaces reduces habitat availability for many taxa, such as most Plecoptera, Ephemeroptera and Trichoptera (Jones *et al.*, 2012). Changes in the functional feeding group structure have been evidenced in clogged streams, probably caused by conspicuous alterations in energy input characteristics (Rabení *et al.*, 2005; Bo *et al.*, 2007).

As evidenced above, ecological and biological impacts of fine sediment deposition have received increasing attention, but unfortunately most studies have so far investigated the response of specific elements or compartments of the lotic biota, while few or no studies were realised with a more integrated and overall approach. Aim of this study is to analyse the influence of unnatural fine sediments deposition on the macroinvertebrate community of a mountain stream at a broad ecological scale, taking also in consideration its influence on autochthonous and allochthonous energy inputs. In particular, we tested: 1) several causal models via path analysis to identify which are the most suitable response metrics to measure the effect of clogging. In this way, we aimed at estimating the direct and indirect weights of each environmental variable on considered metrics; 2) according to an integrated approach, if there are alterations in community composition and functional traits of macroinvertebrates and diatoms in presence of clogging.

METHODS

Study area

This study was realized in two third order streams in the Cottian Alps (Piemonte - NW Italy), the Luserna and the Comba Liussa streams. Both are right-bank tributaries of the Pellice river, located about 7 kilometers away from each other, flowing in parallel and sharing the same climatic conditions. The most noticeable difference between the two streams is the evident contrast in fine sediment amounts. Luserna stream drains one of the most important mining areas of Western Alps: approximately 90 quarries lie in this area, dedicated to the extraction of the Luserna Stone, a leucogranitic orthogneiss (Sandrone *et al.*, 2004). The altered land use, and in particular the logging of trees in a large part of the catchment, together with the intense truck and heavy vehicle traffic on unpaved roads, causes an increase of the fine sediment amount in the Luserna. On the contrary, the Comba Liussa stream, selected as control lotic system, is almost unaffected by human activities, with woodland occupying the entire of the catchment. In order to account for the spatial variability in both fine sediment and biological data, seven transects were selected across the Luserna and three across the Comba Liussa stream (Figure 1).

#figure 1 approximately here #

Data collection

In each sampling transect the following metrics were evaluated: 1) physical- chemical parameters (water dissolved oxygen DO, pH, temperature, conductivity, turbidity) were measured with a multiparametric probe (Hydrolab mod. Quanta), and suspended sediments were determined by gravimetry following the Italian standard methods (APAT-IRSA. CNR, 2003); 2) soluble reactive phosphorous (SRP) nitrate and BOD_5 were determined with a LASA 100 spectrophotometer according to APAT-IRSA CNR standard methods (2003); 3) benthic diatom community, were sampled and treated following the standard procedure (UNI, 2005). Diatoms were identified mainly according to reference floras Krammer and Lange-Bertalot (1986-1991) as well as on recent bibliography including series of Diatoms of Europe Iconographia Diatomologica and relevant scientific papers. Diatom community was evaluated in terms of taxonomic composition, ecological guilds and life forms according to Rimet and Bouchez (2012).

Within each transect, we selected 6 sampling points where the following metrics were measured: deposited sediments, water velocity, autho- and allochtonous energy inputs and those related to macroinvertebrate assemblage. Deposited sediments were determined by means of sediment traps, using the method proposed by Bond (2002), that is considered particularly advantageous in addressing ecological issues. Each trap consisted in a plastic storage box (165 x 95 x 70 mm), with a piece of wire mesh (20×20 mm openings, 1.5 mm gauge wire), cut to fit just inside the box and placed 30 mm from the top of the trap. In field, the boxes were buried in the streambed such that their tops was flush with the bottom. Once the boxes were in place, the wire mesh was covered by a layer of coarse bed material one clast thick. In this way, fine sediments could enter into the traps, over which local hydraulic conditions were comparable to the whole streambed. All 60 traps were displaced on 28 June 2013 and removed after 17 days. The sediment collected in the traps was returned to the laboratory, where it was dried, sieved into 6 size fractions (thresholds: 0.105, 0.25, 0.5, 1, 2 mm) and then weighted. For the statistical analysis only the fraction <0.105 mm was considered (hereinafter fine sediment). Water velocity (0.05 m from the bottom) was measured in each sampling point with a current meter (Mod RHCM Idromar).Inputs coming from photosynthetic activity were measured in triplicate by means of a fluorimetric portable probe (BBE BenthoTorch®) expressly designed for benthic algae. The BenthoTorch® is a Pulse-Amplitude

Modulated (PAM) fluorometer. Light pulses of 5 different wavelengths (470, 525, 570, 590 and 610 nm) are emitted, and the fluorescence response of the microalgal assemblage is recorded at 690 nm. The fluorescence signal is proportional to the pigment density of the Cyanobacteria, Chlorophyta and Bacillariophyta. As confirmed by fluorimetric measures of Chl a, diatoms were the prevailing primary producers. One benthic sample was collected in each sampling point, using a Surber sampler (250 µm mesh size; 0.062 m^2 area) to evaluate the coarse particulate organic matter (CPOM) and macroinvertebrates. Surber were positioned in the patches of stream bed immediately adjacent (laterally) to sediment traps. Collected substrate was conserved into plastic jars with 75 % ethanol. In the laboratory, CPOM was washed through a 250 µm mesh sieve and subsequently hand-sorted. Then, the material was air dried for 24 h, oven dried (105 °C) for 24 h, and then weighed with an electronic balance (accuracy 0.001 g). Macroinvertebrates were collected in the benthic samples used for the quantification of CPOM. In the laboratory, organisms were sorted from the substrate, counted and identified to genus level, except for Chironomidae, Simuliidae and early instars of some Trichoptera and Diptera that were identified to the family level. Each taxon was also assigned to a Functional Feeding Group (FFG: scrapers, shredders, collector-gatherers, filterers and predators) according to Merritt *et al.* (2008). Moreover, all taxa were entered into seven biological and five ecological groups, according to the species traits approach of Usseglio-Polatera *et al.* (2000).

Statistical analysis

In order to implement the path analysis of our data, we referred to Shipley (2004; 2009). Guidelines provided by this author and used for our paper can be summarized as follows: (a) express the hypothesized causal relationships between the variables in the form of a directed acyclic graph; (b) list each of the *k* pairs of variables (X_i, X_j) in the graph that do not have an arrow between them; for each pair, list the set of other variables, **Z**, in the graph that are direct causes of either X_i or X_j. The pair of variables (X_i, X_j) along with its conditioning set **Z** define an independence claim, (X_i, X_j)| **Z**, and the full set of the *k* independence claims defines the basis set B_U; (c) for each element in this basis set, obtain the probability, p_k, that the pair (X_i, X_j) is statistically independent conditional on the variables **Z;** (d) combine the *k* probabilities via the *C* statistic (Shipley 2009; eqn1 further below) and compare it to a chi-squared distribution with 2*k* degrees of freedom. Reject the causal model if the *C* value is unlikely to have occurred by chance (i.e., below the chosen significance level).

Four macroinvertebrate-related metrics were selected (total abundance, specific richness, abundance of Shredders and abundance of Ephemeroptera, Plecoptera and Trichoptera ,EPT) and for each of them a causal model was tested based on the same structure (step (a), Figure 2). These graphs expressed the causal hypothesis that the macroinvertebrate functional metrics are due to three categories of environmental variables: 1) *quarry pressure*, evaluated through the categorical variable presence of quarries (QP) in the river basin and the quantitative variable bed load (BL); 2) *hydraulic conditions* measured through water velocity (V); 3) *energetic inputs*, both allogenic (CPOM) and autocthonous (Chl a). Causal relationships between environmental variables were also considered in the hypothetical model.

#figure 2 approximately here#

The causal structures expressed by the graph were translated into a set of direct separation (d-separation) statements (step (b), Table I) which predict the conditional probabilistic independences that must be true if the causal model is correct, as proposed by Shipley (1999, 2000) and applied in Bona *et al.* (2011). To test each predicted conditional independence (step (c)), we then adopted generalized mixed modeling approach (as in Shipley 2009), which allowed us to deal with the different statistical distributions of the variables involved in the models, and to account for the non-independence of the data collected within each sampling transect. For each element in this basis set, the probability that the pair (X_i, X_j) is statistically independent conditional on the variables **Z** is given by the exact *p*-value for the regression coefficient of the variable whose partial slope should be zero (as reported in Table I).

#table I approximately here#

Starting with this model, to identify a causal graph including only significant path coefficients we tested all sub-models by gradually reducing the number of paths and variables (Thomas *et al.*, 2007). The overall fit of the final model was tested via the C statistic (step (d)), which follows a chi-square distribution with degrees of freedom equal to 2k (Shipley, 1999; 2009):

$$C = -2 \sum_{i=1}^{k} \ln (p_i) \qquad \text{(eqn1)}$$

where k is the number of d-separation statements in the basis set and p_i is the null probability of the independence test associated with the i-th independence claim. Mixed models were fitted via the glmmADMB package (Skaug *et al.,* 2013; Fournier *et al.,* 2012) in R 3.0.1 (R Core Team, 2013).

To check the consistency of the macroinvertebrate response with that of the diatom community, we related the two community data (diatoms and macroinvertebrates) in a symmetric way i.e. neither set takes the response or predictor role by means of the co-inertia analysis (CoIA). CoIA is a general and flexible way to couple two or more data sets, which are ordered along the axes of co-inertia analysis to maximize covariance (Doledec and Chessel, 1994; Dray *et al.*, 2003). The correlation between the two communities was evaluated with the RV coefficient, which is a multivariate generalization of the Pearson correlation coefficient. This coefficient varies between 0 and 1: the closer the coefficient to 1, the stronger the correlation between the datasets. The method finds a common space into which the objects and variables of the data sets can be projected and compared (the distance between sites measures their similarity). For each community we selected the most abundant taxa in the entire dataset (>2% for diatoms and >0.5% for macroinvertebrates). We performed a Monte-Carlo permutation test (9999 permutations in our analysis) to assess the significance of the co-structure of the data tables.

RESULTS

Water quality, bed load and energy inputs

Data for the water quality, bed load and energy inputs of the two streams are summarised in Table II.

#Table II approximately here#

Both streams can be classified as oligotrophic and oligosaprobious according to common water quality classifications (e.g. Hofmann, 1994; Van Dam *et al.*, 1994). Nutrient concentrations are similar in the two rivers with the exception of the SRP, which is higher in the Luserna. However, this difference can be attributed to the higher concentration of total suspended sediments (TSS) in the Luserna river which may alter the phosphorous concentration. Indeed, differences in TSS and bed load between the two rivers are highly significant (Mann- Whitney U-test: $p<0.001$ for both parameters).

The allochthonous input, mainly represented by terrestrial CPOM, resulted significantly higher in the Comba Liussa than in the Luserna stream (Mann-Whitney U-test: $p<0.0001$) Also the comparison in terms of primary production highlights significant differences (Mann-Whitney U-test: $p<0.0001$ for diatoms and for total chlorophyll *a*).

Path Analysis

The path analysis procedure allowed us to define four final models explaining the relationships between environmental variables and macroinvertebrate metrics (Figure 3). In all cases, their fits were satisfactory (according to the values of the C statistic, whose p value was > 0.05 for all models) and all the path coefficients reported in Figure 3 were significant. In all models there is a common structure describing the mutual relationships among environmental variables. In particular the QP showed an effect on BL, Chl a and CPOM. Any direct effect of the BL on the energetic input was proved, while it negatively influenced the total abundance, the abundance of shredders and the EPT. Also the QP showed a negative effect on richness, abundance of shredders and abundance of EPT. Considering the energetic inputs, the CPOM resulted positively significant for richness and total abundance, while Chl a was not included in any final model.

Water velocity resulted a positive factor for Specific Richness, abundance of shredders and EPT abundance.

#figure 3 approximately here #

Co-Inertia

Results obtained from CoIA are shown in Figure 4. The RV coefficient is 0.71, confirming a high correlation in the responses of the two biotic communities and the Monte-Carlo permutation test resulted highly significant ($p < 0.005$).

#figure 4 approximately here#

The graph reported in Figure 4a shows a clear differentiation of the two rivers. Sampling transects in the control river resulted to be highly differentiated within each other, while in the impacted river, transects are very similar, in particular those closer to the quarries. Only the sampling transect L1, located downstream of the entry of the left tributary, showed a clear differentiation. The impacted river mainly characterized by stress-tolerant taxa with respect of both diatom (Figure 4b) and macroinvertebrate communities (Figure 4c). Diatom communities in both streams are characterized by sensitive and pioneer taxa with the dominance of *Achnanthidium*, with some noticeable differences within this genus. In the Luserna stream *Achnanthidium minutissimum* is the dominant taxon, belonging to the low profile ecological guild and characterized by the adnate life form, which give it a high tolerance to physical disturbance. In the control stream, *A. minutissimum* is partly substituted by *Achnanthidium pyrenaicum* and *Achnanthidium lineare*, probably less tolerant to physical disturbance. Moreover it is here noticeable the presence of *Gomphonema pumilum* var. *elegans* (stalked and typical of mature biofilm) and of *Cocconeis lineata*, which is epiphytic thus strictly related to the presence of aquatic macrophytes.

Considering macroinvertebrates, we collected a total of 15,068 specimens belonging to 53 taxa. Comparing the presence of biological and ecological trait groups in the two rivers we noticed interesting differences. Taxa belonging to the '*f*' biological trait group, i.e. medium-sized, monovoltine organisms, mainly crawlers and shredders with aquatic respiration were abundant in the control river while resulted nearby absent in the Luserna. Macroinvertebrates in the impacted river are generally dipterans, belonging to the '*e'* biological trait group, i.e. small and medium-sized organisms, short living and plurivoltine, with various feeding habits. Regarding ecological trait classification, in the control river the macrobenthic community was dominated by organisms belonging to the '*C*' group, i.e. living in rhithronic environments, oligo to β-mesosaprobic, mainly inhabiting mineral substrates such as cobble and sand with important presence of groups '*A*' and '*B*' (both generally rheophilous, orophilous and oligosaprobic, inhabiting coarse substrata). These groups are poorly represented in the Luserna river, where in general the most important is the '*F*' ecological group, i.e. ecologically adaptable organisms living in semi-lentic habitats, eurythermic, mesosaprobic.

DISCUSSION AND CONCLUSIONS

Our study focused on the impacts of quarry activities on some functional and structural parameters of an Alpine stream biota. The occurrence of mining areas in close proximity to streams can impose several distinct stresses at different scales. At reach scale, main alterations refer to water quality (pH, turbidity, fine sediment deposition, concentrations of dissolved metals, deposition of hydrous metal oxides; Niyogi *et al.*, 2002). In this case, the main impact is the increase of fine sediments in the basin. Indeed, 'Luserna gneiss' is a natural stone, and for its extraction only mechanical devices are used. At catchment scale, mining activities imply the removal of riparian vegetation, construction of gravel roads, bank alteration with a significant increase of erosive processes. For such complex impacts, an integrated field-base approach is required. Interestingly, while experimental work is useful to isolate stressor effects or to analyse selected biological targets (Bo *et al.*, 2007; Connolly and Pearson, 2007), they are almost useless to analyse responses from an ecosystem point of view (e.g. considering altogether in- and out-stream energetic inputs, benthic algae, and invertebrate communities).

With this regard, we expressly adopted two statistical tools which are both able to integrate responses from multiple factors.

The path analysis approach highlighted a negative effect of both quarry pressure and bed load amounts on the traits considered (EPT and Shredders abundance), while the total abundance and the specific richness are influenced only by one of these factors. Functional traits seem then to better reflect the integrate impact originating from the presence of quarries in the river basin than community structure metrics like total abundance and specific richness. From a practical point of view, this may represent an applied outcome in the environmental assessments of the anthropic pressure generated by excessive fine sediment concentration. Future management programs should take into consideration macroinvertebrate functional traits in spite of common community metrics to detect impacts caused by the bed load.

As long as energetic inputs are considered, the quarry pressure in the river basin resulted as the key factor determining their patterns. We can then hypothesize the landscape morphological alteration caused by the presence of quarries to be the main responsible of a reduction of energetic inputs. For instance, the elevated amounts of fine sediments in the streambed combined with the higher turbidity in the Luserna, resulted in a lower aquatic primary production, due to the reduced survival possibilities for benthic photoautotrophic organisms, and in a lower CPOM availability, due to the increased uniformity of the substrate and the consequent reduction of the coarse detritus retention capacity.

The differences between the two rivers also emerged from the Co-Inertia analysis, confirming the negative effect of the quarries presence in the Luserna catchment. Indeed, the two rivers are clearly separated, with Luserna transects much more similar between each other than the Comba Liussa ones. Thus, we can suppose that the anthropic land use and the bed load are responsible of a homogenization of both the macroinvertebrate and the diatom communities.

Diatom communities in both streams reflect a good water quality, being composed mainly of β-mesosaprobous *taxa* typical of mountain streams. In general, the biovolumes of the diatom communities colonizing the Luserna stretches are lower than those detected in the control stream. Luserna is characterized by small sized taxa with high reproduction rates, generally low profile and pioneer (Rimet and Bouchez, 2012). Moreover, it is possible to notice a good percentage of motile taxa (belonging the genera *Nitzschia* and *Navicula*) generally considered siltation tolerant (Bahls, 1993). On the contrary, the Comba Liussa hosts a good proportion of stalked taxa belonging to the genus *Gomphonema*, as well as epiphytic taxa such as *Cocconeis*, denoting a certain streambed stability and periphyton maturity. Considering these results, we can conclude that ecological guilds and life forms represent good metrics for the assessment of the unnatural fine sediment impact in mountain rivers, more than commonly used trophic indices.

Regarding the macroinvertebrate communities, benthic coenoses of the control river were composed by *taxa* typical of mountain environments, characterized by coarse substrate, good intake of particulate organic terrestrial material: here organisms were generally characterized by medium to large size, long life cycles, shredder or scraper feeding habits. On the contrary, the anthropic pressure on the Luserna, and particularly the unnatural presence of high amounts of fine sediment, completely altered the macrobenthic community: here the dominant organisms belonged to ubiquitous and euriecious taxa, with rapid life cycles, small size, which prefer fine or muddy substrates and that are generalist collectors of fine organic particles. The situation improved in the most downstream station, where in the community some stenoecious elements reappeared.

Indeed, considering that the responses of the two benthic communities to the bed load are highly correlated, it is plausible that the excessive quantity of fine sediment negatively affects not only macroinvertebrates but also diatoms. Further investigation on the effects of the bed load on the diatom community is highly recommended.

In conclusion, the modelling procedure based on path analysis confirms to be an effective tool in the field of water ecology, particularly when a set of multiple variables must be considered to explain the response of all biological components to an environmental disturbance, as already pointed out by Bona *et al.* (2011).

Our final suggestion is that resource managers should focus particular attention on reducing erosion in stream catchments and sediment load into streams, because of the multiple and severe effects on the aquatic biota.

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Table I. The basis set (B_U) of d-separation statements implied by our path diagram. As we can see, we have just 3 d-separation statements, since we have no causal parents for the pair (V,QT) and their conditioning set Z is thus empty

d-separation statements	Mixed model	Variable whose partial regression slope should be zero
(V,Chl a)|{QT,BL}	*Chl a ~ V + QT + BL + (1|transect)*	*V*
(V,CPOM)|{QT,BL}	*CPOM ~ V + QT + BL BL + (1|transect)*	*V*
(Chl a,CPOM)|{QT,BL}	*Chl a ~ CPOM + QT + BL BL + (1|transect)*	*CPOM*

Table II. Summary of water quality data (transects), bed load and energy inputs (sampling points) of the two streams

	Luserna			**Comba Liussa**		
	N	Mean	SD	N	Mean	SD
Temperature (°C)	7	13.0	0.458	3	14.5	0.072
pH	7	7.1	0.136	3	7.2	0.047
Conductivity (mS cm^{-1})	7	0.037	0.003	3	0.078	0.000
N-NO$_3$(mg L^{-1})	7	0.819	0.127	3	0.733	0.037
SRP (µg L^{-1})	7	12.8	11.5	3	4.7	2.3
BOD (mg L-^{1})	7	0.61	0.442	3	1.38	0.366
TSS (mg L^{-1})	7	147	134	3	0.57	0.120
Turbidity (NTU)	7	37.4	15.0	3	6.70	5.79
Bed Load (g)	42	28.6	19.8	18	3.02	0.565
Chl a total µg (cm^{-2})	42	0.726	0.560	18	3.73	2.08
Chl a diatoms (µg cm^{-2})	42	0.449	0.366	18	3.03	1.95
CPOM (g)	42	0.196	0.286	18	0.416	0.242

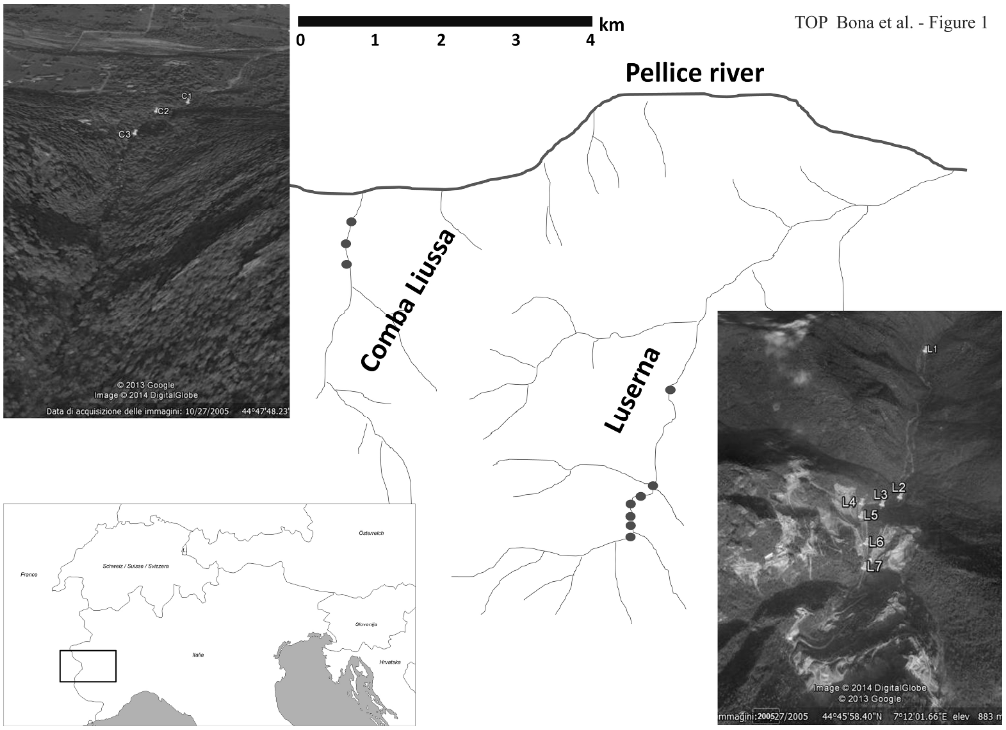

Figure 1. Study area. Google heart images evidence the different anthropic impact in the examined lotic systems: Luserna stream (with important quarry activities) and Comba Liussa stream (utilised as control)
127x91mm (600 x 600 DPI)

Bona et al. – Figure 2

TOP

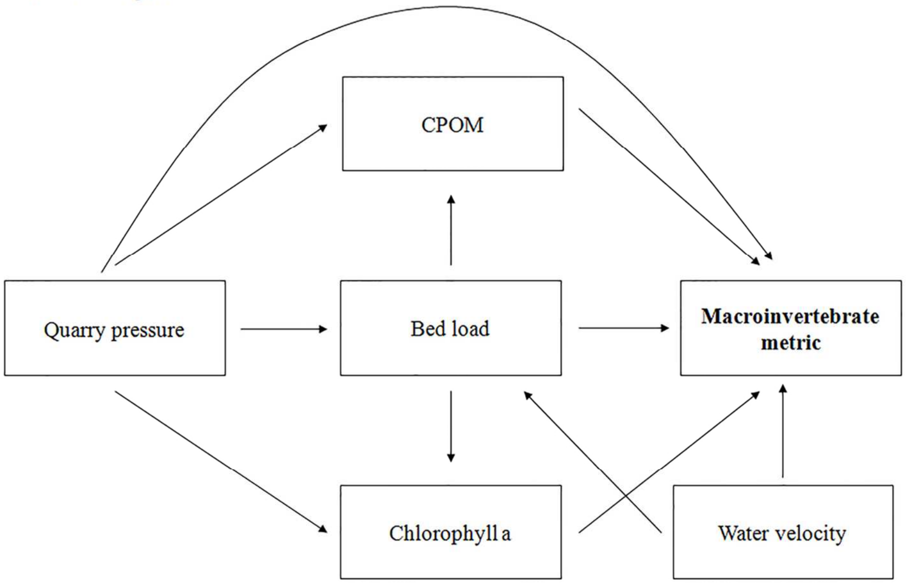

Figure 2. Graph expressing the hypothesized causal model for selected macroinvertebrate metrics. According to this causal model, the water velocity (V) and the quarry pressure (QP) are exogenous variables (their causal parents are not explicitly modeled). Water velocity (V) exerts both a direct and indirect influence, mediated by the bed load (BL), on the macroinvertebrate metrics. Besides affecting macroinvertebrate metrics directly, QP also exerts an indirect influence mediated by the BL, the CPOM and the Chl a. Indeed, the latter variables are endogenous variables (i.e. variables caused by some other variables in the model), affected by V and/or by QP
60x45mm (600 x 600 DPI)

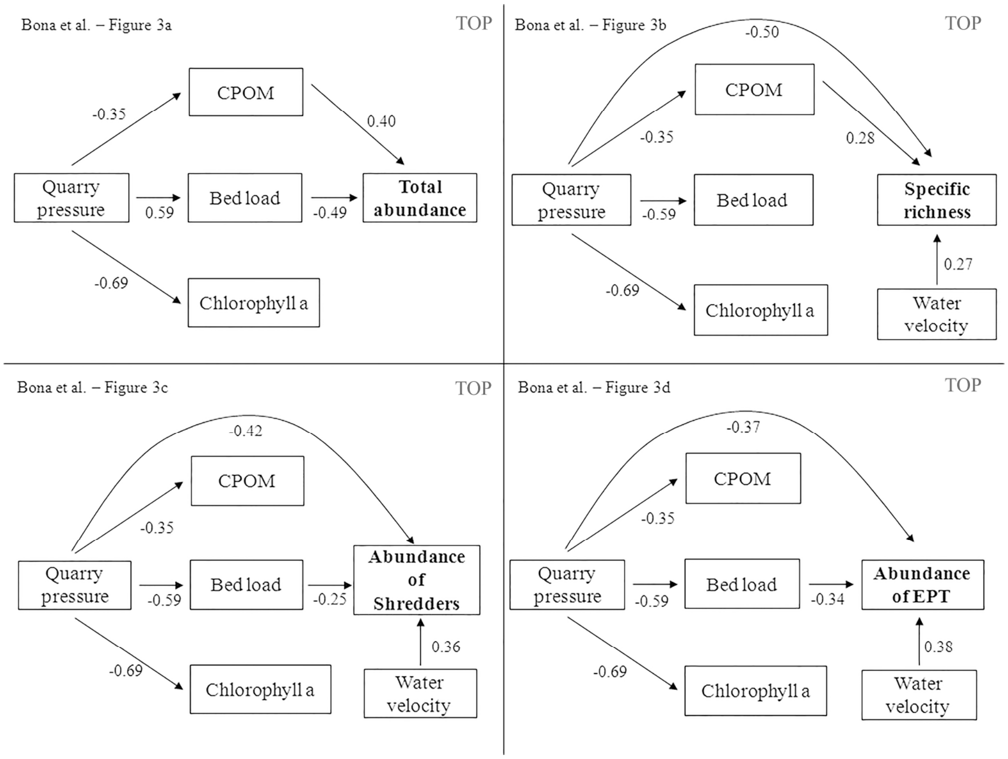

Figure 3. Causal graphs supported by the observed data, with standardized path coefficients (P) for: a) Total abundance: the quarry pressure QP has only an indirect effect on the dependent variable, mediated by the bed load and the CPOM (C = 0.47, df =8); b) Specific richness: QP has both a direct and indirect effect mediated by the CPOM on the dependent variable (C = 0.53, df =16); c) Abundance of Shredders: QP has both a direct and an indirect effect mediated by the bed load on the dependent variable (C = 0.26, df 16); d) Abundance of EPT: QP has both a direct and an indirect effect on the dependent variable mediated by the bed load (C = 0.40, df =16)
120x90mm (600 x 600 DPI)

TOP

Bona et al. – Figure4

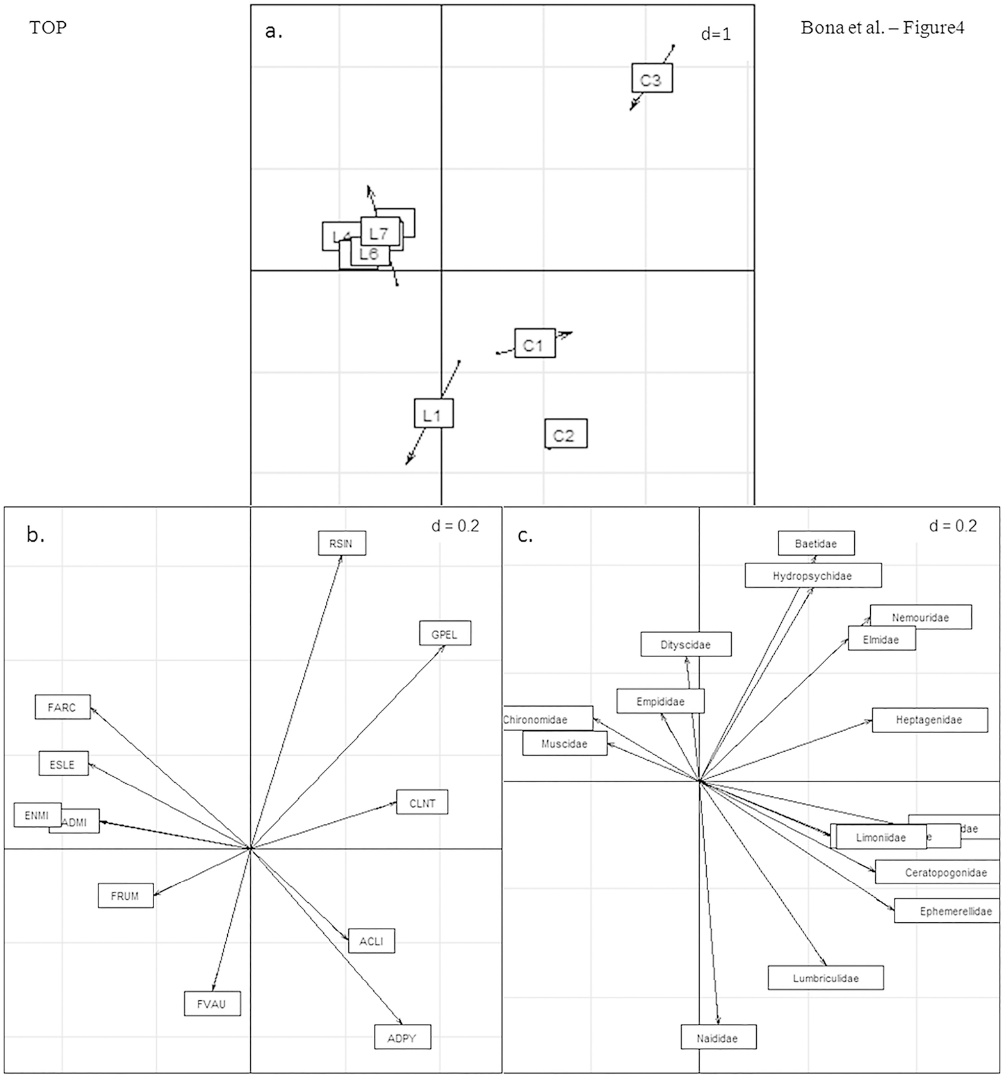

Figure 4. Results of the Co-Inertia analysis with the distribution along of the first two axes of a) sampling transects; b) diatom selected taxa; c) macroinvertebrate selected taxa. ACLI: Achnanthidium lineare, ADMI: Achnanthidium minutissimum, ADPY: Achnanthidium pyrenaicum, CLNT: Cocconeis lineata, ENMI: Encyonema minutum, ELSE: Encyonema silesiacum, FARC: Fragilaria arcus, FRUM: Fragilaria rumpens, FVAU: Fragilaria vaucheriae, GPEL: Gomphonema pumilum var. elegans, RSIN: Reimeria sinuata
171x184mm (300 x 300 DPI)