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Assessment of hydropeaking-induced alterations of benthic communities in experimental flumes

Mauro Carolli[1*], Maria Cristina Bruno[1,2], Bruno Maiolini[1], Luana Silveri[1]

1 Edmund Mach Foundation, Via E. Mach, 1 - 38010 S. Michele all'Adige (TN), Italy

2 Department of Environmental Sciences, Tuscia University, Largo dell'Università - 01100 Viterbo, Italy

** Referente per la corrispondenza: mauro.carolli@iasma.it*

Abstract

The relationships between discharge alterations due to the intermittent discharge of turbinated water downstream of hydropower plants (hydropeaking) and drift of zoobenthos were investigated through the simulation of two different flow increases in artificial flumes, i.e. one similar to natural high-flow events (stepwise increase in discharge 2x), and one to hydropeaking (abrupt increase in discharge 7x). The effects on zoobenthos detected with the artificial flumes were compared with those of a field study of an hydropeaking wave in an alpine stream, in order to assess the validity of the artificial flumes to simulate natural streams in hydraulic manipulation experiments. The research was conducted in the Adige River catchment. The experimental structure of five steel channels with adjustable discharge and slope is located along the Fersina Stream. The hydropeaking wave was studied in natural conditions in the Noce Stream, 0.25 km downstream of Cogolo-Pont hydropower plant. Results showed a strong increase in drift in response to discharge increases; the temporal trend and absolute value of drift in the station downstream of the plant were similar to those of the artificial channels, especially of the channel with abrupt discharge. Taxa responded differently according to their levels of adaptation to flow increases. Differences in drift rates between artificial and natural conditions were probably due to the daily timing of hydropeaking in the Noce Stream, which reduce the consistence of the benthic community. The study also confirms the validity of the artificial flumes to manipulate discharge in order to develop guidelines for an eco-sustainable management of hydropeaking-impacted alpine streams.

KEYWORDS: hydropeaking / drift / experimental flumes / hydropower / Alpine rivers

Valutazione degli effetti dell'hydropeaking sulla comunità bentonica tramite l'uso di un apparato sperimentale

Le relazioni tra alterazioni delle portate determinate da immissioni intermittenti di acque turbinate a valle delle centrali idroelettriche (hydropeaking) e il drift dello zoobenthos sono state investigate tramite la simulazione di un improvviso aumento della portata pari a 7x (simile all'hydropeaking) e uno graduale a 2x (simile a condizioni naturali) in un impianto sperimentale. Gli effetti sulle biocenosi zoobentoniche rilevati nei canali sperimentali sono stati confrontati con quelli ottenuti nello studio di un'onda di hydropeaking in un torrente alpino, al fine di valutare la validità dell'impianto sperimentale a simulare un torrente naturale in esperimenti di manipolazione idraulica. L'area di studio è rappresentata dal bacino del Fiume Adige. La struttura sperimentale di cinque canalette in acciaio, con portata e pendenza regolabili, è situata lungo il torrente Fersina. L'onda di hydropeaking è stata studiata sul torrente Noce, 0.25 km a valle della centrale di Cogolo-Pont. I risultati hanno dimostrato un aumento massiccio del drift in risposta agli aumenti di portata, con andamento temporale e di valore assoluto del drift nella stazione a valle della centrale simile a quello registrato nelle due canalette sperimentali, in particolare a quello della canaletta con aumento improvviso. I taxa hanno risposto in modo diverso a causa dei diversi gradi di adattamento all'aumento della corrente. Differenze quantitative del drift tra la condizione sperimentale e quella nel Noce sono probabilmente dovute alla ripetizione giornaliera dell'hydropeaking nel fiume, che depaupera la consistenza delle comunità bentoniche. L'impianto sperimentale è risultato efficace per manipolare la portata al fine di sviluppare linee guida per una gestione ecosostenibile dei corsi d'acqua alpini impattati da hydropeaking.

PAROLE CHIAVE: hydropeaking / drift / canalette sperimentali / energia idroelettrica / torrenti alpini

INTRODUCTION

In Alpine regions, intermittent hydropower generation has high economic importance. Although it is the most relevant renewable electricity source, with clear advantages for the global CO_2 balance (Bratrich *et al*., 2004), hydropower causes serious ecological alterations to aquatic ecosystems. Benthic communities suffer from the effects of water abstraction, diversion and stocking, and from the abrupt changes in flow regime and water levels due to water releases, i.e. the hydropeaking (Armitage, 1984; Brittain and Saltveit, 1989). The release of turbinated waters may impose dramatic and sudden changes not only in discharge, but also in chemical and physical properties of waters, which propagate over long distances downstream (Friedl and Wüest, 2002; Wüest, 2003). Density and biomass of benthic invertebrates decrease downstream the hydropower outlets (Irvine, 1985; Moog, 1993; Céréghino and Lavandier, 1998a, 1998b; Céréghino *et al*., 2002, 2004), because the intensity of bed scour increases and leads to the catastrophic drift of aquatic organisms (Crisp and Robson, 1979; Brittain and Eikeland, 1988; Gore *et al*., 1989; Troelstrup and Hergenrader, 1990; Cobb *et al*., 1992; Boon, 1993). In parallel, the frequent changes in flow regime and the deposition of fine materials from upstream reservoirs induce riverbed clogging, thus reducing habitat availability for the bottom-dwelling fauna (Blaschke *et al*., 2003; Anselmetti *et al*., 2007).

In streams, drift regulates densities, dispersal, and life cycles of benthic invertebrates (Brittain and Eikeland, 1988; Céréghino and Lavandier, 1998a; Maier, 2001; Mochizuki *et al*., 2006). In temperate streams, drifting organisms are mainly larval stages of Ephemeroptera, Diptera Simuliidae and Chironomidae, Plecoptera and Trichoptera, which are the most common benthic taxa in such habitats (Brittain and Eikeland, 1988). In alpine streams, Chironomidae are the most abundant drifting organisms (Lencioni *et al*., 1999, 2001; Hieber *et al.*, 2003). Catastrophic drift (*sensu* Culp *et al*., 1985) is usually associated with flood conditions, during which the substrate is physically disturbed, as it typically occurs downstream of hydropower plant outlets. Despite the clear role that sediment mobilization plays in initiating drift, considerable drift can also occur in the absence of sediment movement, and the effects of non-scouring increases in flow are not less dramatic for benthic communities than those of catastrophic floods (Imbert and Perry, 2000; Gibbins *et al*., 2005).

Gradual and abrupt increases in flow are two of the most common flow patterns in many stream ecosystems, although their effects on benthic fauna differ: abrupt increases in flow had a stronger effect on invertebrate drift than did stepwise increases in experimental streams (Imbert and Perry, 2000). The use of artificial channels of different typology to study the responses of biological communities to flow manipulation is increasingly becoming a commonly-used tool (Doeg and Milledge, 1991; Imbert and Perry, 2000; Suren and Jowett, 2001; Mochizuki *et al*., 2006; Gibbins *et al*., 2007). Because the efficiency of the artificial flumes used in this experiment in recreating the conditions found during natural or artificial floods had never been tested before, this study represents also a validation of the effectiveness of such experimental setting.

This paper contributes to evaluate the effectiveness of a set of experimental channels for studying natural flood and hydropeaking effects. The study aimed: i) to assess the relationships between discharge and drift; ii) to simulate and compare the effects of two different flow increases, i.e. one similar to natural high-flow events and one representing hydropeaking; iii) to assess the validity of artificial flumes to simulate natural streams in hydraulic manipulation experiments.

MATERIALS AND METHODS

Study area and biological sampling

The impact of hydropeaking on drifting and benthic invertebrate communities was studied in the Adige watershed (NE Italy, Trentino, Fig. 1). We analyzed the responses of different taxa to gradual and abrupt increases in non-scouring flow in experimental, gravel-bed flumes, and responses to an abrupt increase of non-scouring flow (hydropeaking) in a natural stream. The magnitudes of flow changes in the experimental flumes were 2- and 7-folds the baseflow. A 2-fold increase is typical of the heavy short-term rainfall occurring in spring and summer in Alpine streams, which cause abrupt flow increases in natural streams. A 7-fold increase is typical of hydropeaking releases in the Adige watershed (Bruno *et al*., 2009), and occurs

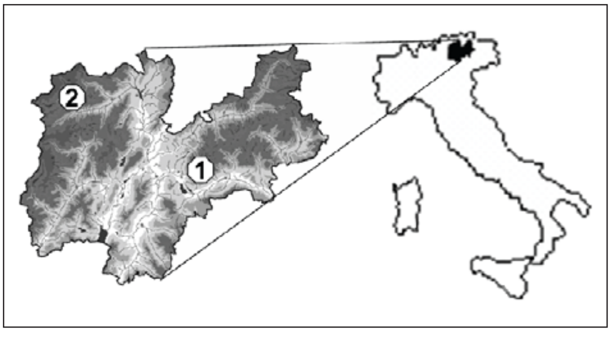

Fig. 1. Study area. 1) Experimental flumes, Fersina Stream; 2) Field site, Noce Stream.

on the Noce Stream in the reach chosen for the field experiment (Bruno *et al.*, 2009) field site.

The experimental flumes are located in the Fersina Stream, a 2nd order stream which is a left tributary of the Adige River, at 630 m a.s.l.. Five 20 m long, 20 cm wide and 20 cm tall metal flumes are located on the riparian area and are directly fed with water diverted from the stream (Fig. 2). The flumes have adjustable longitudinal slope and feeding discharge, and are filled with a 10 cm deep layer of gravel and sand collected from the riverbanks. We used two channels and imposed different experimental changes in non-scouring flow in each channel, abrupt (channel B) and stepwise (channel A), reaching 7- and 2-fold discharge increases, respectively (Table I, Fig. 3). Drift samples were taken with drift nets (mesh size 100 µm) from a plastic pipe connected to the downstream end of each flume. Time intervals between samples are listed in Table I.

Field experiments were conducted on the Noce Stream, a 3rd order stream and a main right tributary of the Adige River. A hydropower plant is located at Cogolo, at 1,208 m a.s.l., which uses waters from the Careser (2,603 m a.s.l.) and Pian Palù (1,850 m a.s.l.) reservoirs. On 24-09-2006, an experimental release was planned with the national company for electric

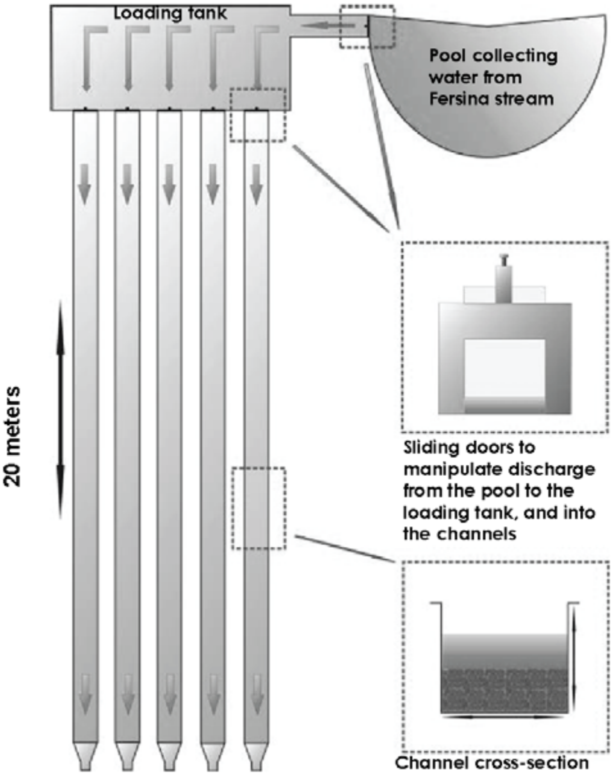

Fig. 2. Scheme of the experimental flumes on the Fersina Stream.

Table I. Experimental setting. Timing and discharge of each sample collected, respectively, for flume A (stepwise) and B (abrupt), and in the natural stream (NB8).

Time intervals from the beginning of the experiment (in minutes)	Sample number	Discharge (m^{3}s^{-1})
0	1A	2.2 x 10^{-3}
15’	2A	2.22 x 10^{-3}
30’	3A	2.22 x 10^{-3}
45’	4A	2.22 x 10^{-3}
48’	5A	3.12 x 10^{-3}
51’	6A	3.12 x 10^{-3}
54’	7A	3.12 x 10^{-3}
57’	8A	3.952 x 10^{-3}
60’	9A	4.12 x 10^{-3}
63’	10A	4.12 x 10^{-3}
88’	11A	4.12 x 10^{-3}
0	1B	12 x 10^{-3}
15’	2B	12 x 10^{-3}
30’	3B	12 x 10^{-3}
45’	4B	12 x 10^{-3}
48’	5B	22 x 10^{-3}
51’	6B	42 x 10^{-3}
54’	7B	5.62 x 10^{-3}
57’	8B	5.652 x 10^{-3}
60’	9B	5.82 x 10^{-3}
63’	10B	62 x 10^{-3}
88’	11B	72 x 10^{-3}
0’	1NB8	1
15’	2NB8	1
30’	3NB8	1
45’	4NB8	1
50’	5NB8	7
55’	6NB8	7
60’	7NB8	7
65’	8NB8	7
70’	9NB8	7
75’	10NB8	7
90’	11NB8	7

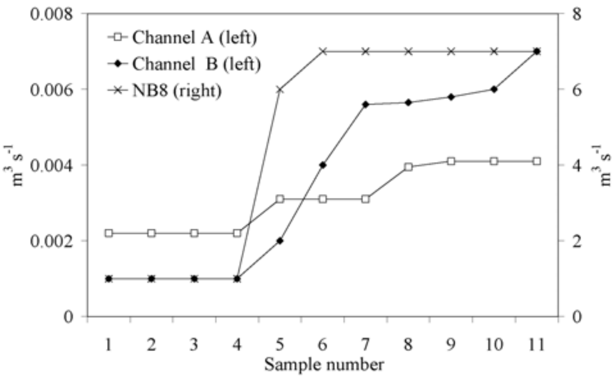

Fig. 3. Values of discharge at the three sampling sites over time (increasing sample number).

power (ENEL). The experiment consisted in no release during the night, followed by a release at maximum turbine capacity, which increased the discharge from 1 to 7 m^3 sec^{-1} in about 10 minutes (Table I, Fig. 3). Station NB8 was located 0.25 km downstream of Cogolo hydropower plant, at 1,197 m a.s.l.; drift samples were collected using three drift nets (mesh size 100 µm, mouth diameter 10 cm, length 1 m) placed side by side on a metal bar that was lowered into the stream from a bridge; the contents of the three nets were pooled together and represented one sample. Sampling timing and discharges are reported in Table I.

For both collections in the experimental flumes and in the stream (hereafter called "sites"), the first four consecutive samples were taken before the water release at each of the three sites (called "before" drift samples herein and labelled "BE"), and seven consecutive samples were taken during the water release (called "during" drift samples herein and labelled "DU"); the fifth sample represented the beginning of the increase of discharge at each of the sampling sites. Invertebrate densities in all drift samples were adjusted for the different collecting times and expressed as ind/m^{-3}. After collection, biological samples were refrigerated and carried to the laboratory, where they were preserved in 75% ethanol. All samples were sorted in the laboratory and organisms identified to order or family taxonomical level.

Statistical analyses

Because drift at NB8 contained a high number of rare taxa, which were not present in the artificial flume samples, we included in the analysis only the common taxa, i.e. those present in all three sites and with more than one individual: Acarina, larvae of Ephemeroptera Baetidae, Plecoptera and Trichoptera, larvae and pupae of Diptera Chironomidae and Simuliidae and other Diptera, aquatic Hemiptera, Nematoda, Oligochaeta, Ostracoda, benthic Copepoda. The resulting matrix, with a total of 33 samples (12 before and 21 during for each site) was first standardized to the total value of each site, and then transformed as $\arcsin\sqrt{x}$. A similarity matrix was then calculated using the Bray-Curtis Similarity Index.

We performed a 2-way nested Analysis of Similarities - ANOSIM (CLARKE, 1993), which tests the null hypothesis that (Hp$_{01}$) there are no differences in drift assemblages between "before" and "during" samples within each site; (Hp$_{02}$) there are no differences between sites (factor BEFORE-AFTER nested within factor SITE).

For those assemblages which proved to be significantly different with the ANOSIM analysis, we assessed the role of taxa in contributing to the separation between two groups of samples, and the closeness of samples within a group by performing a two-way Similarity Percentages analysis (SIMPER), which calculates the mean Bray-Curtis Dissimilarity Index between two groups(CLARKE, 1993).

All analyses were performed using Primer 6 ver. 6.1.6 (PRIMER-E Ltd, 2006) and Statistica ver. 8.1 (StatSoft Inc., 2008).

RESULTS

A total of 1973, 3362, and 535 ind m^{-3} were collected in the drift of channel A, B, and NB8, respectively. The percentage composition was similar for the three sites, but whereas at channels A and B 90% of the total was represented by larvae and pupae of Chironomidae, Simuliidae and larvae of Baetidae, at NB8 the same percentage was due to larvae and pupae of Chironomidae, larvae of Plecoptera and Baetidae, and aquatic Hemiptera (Fig. 4).

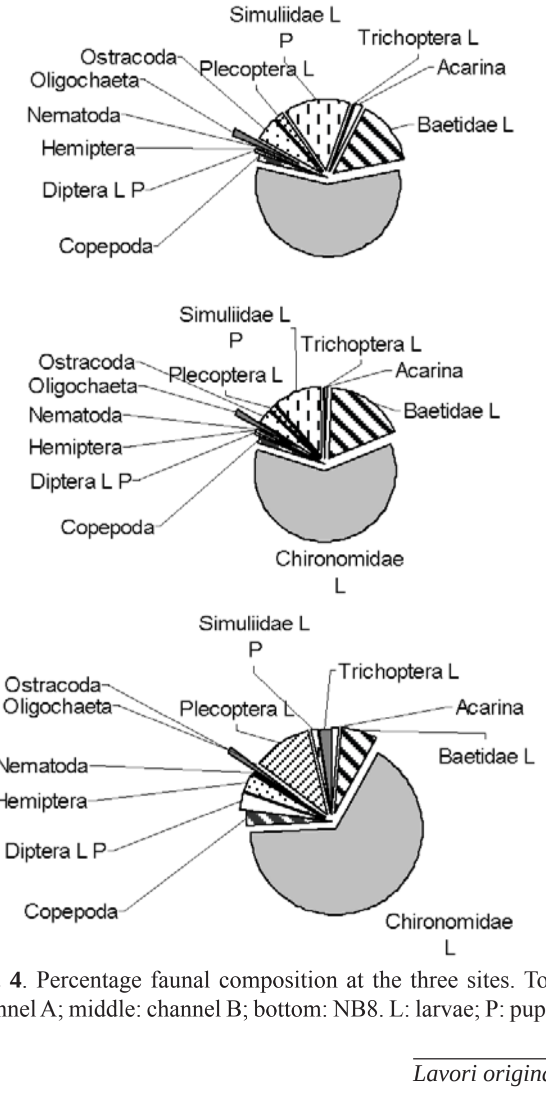

Fig. 4. Percentage faunal composition at the three sites. Top: channel A; middle: channel B; bottom: NB8. L: larvae; P: pupae

The results of the ANOSIM analysis indicated a significant difference in assemblages before and during the hydropeaking within each channel (Hp_{01} R: 0.889 and p=0.001), but the drift recorded in the artificial channels and in the field event did not differ overall (Hp_{02} p=0.3). In fact, densities of drifting invertebrates increased with increasing discharge with a similar temporal trend at the three sites; the increase in density was greater in the artificial channels: the ratio between the total number of drifting individuals collected in samples 1BE-4BE to those collected in sample 5DU was 17 for channel A, 10 for channel B, and 7 for NB8. 92%, 89.7%, and 87.9% of the total drifting individuals were collected "during" at channel A, B, and NB8 respectively. The absolute increase in drift was more similar between channel B and NB8 (Fig. 5), the temporal trends showed the same increase within 3' of the beginning of the discharge increase at the three sites; the subsequent decrease of drift abundance was more similar between channel B and NB8 (decrease in 6'), whereas in channel A the decrease in drift abundance had a slightly different trend (Fig. 5). The increase of drift due to the whole change in discharge, calculated by dividing the total number of individuals collected in samples 1BE-4BE by those in samples 5DU-11DU, gave similar values for the three

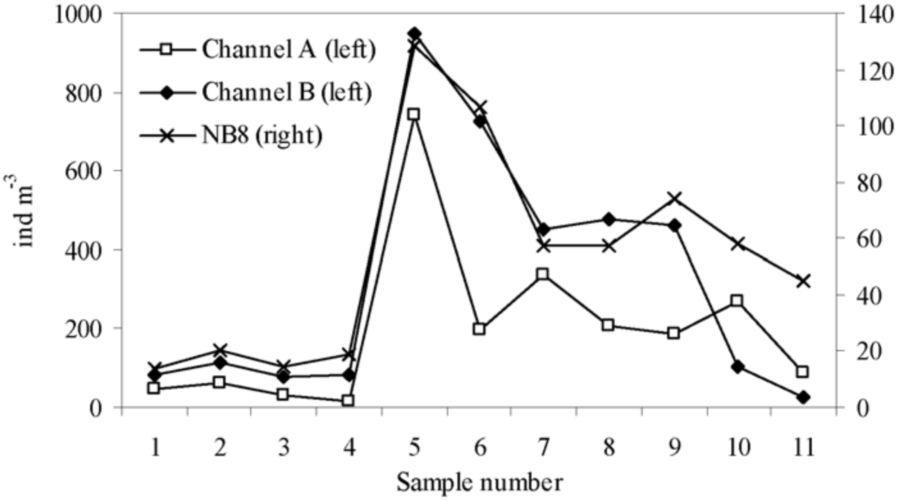

Fig. 5. Total density of drifting invertebrates at the three sampling sites for each drift sample. Channel A: abrupt increase; channel B: stepwise increase; NB8: hydropeaking in field experiment.

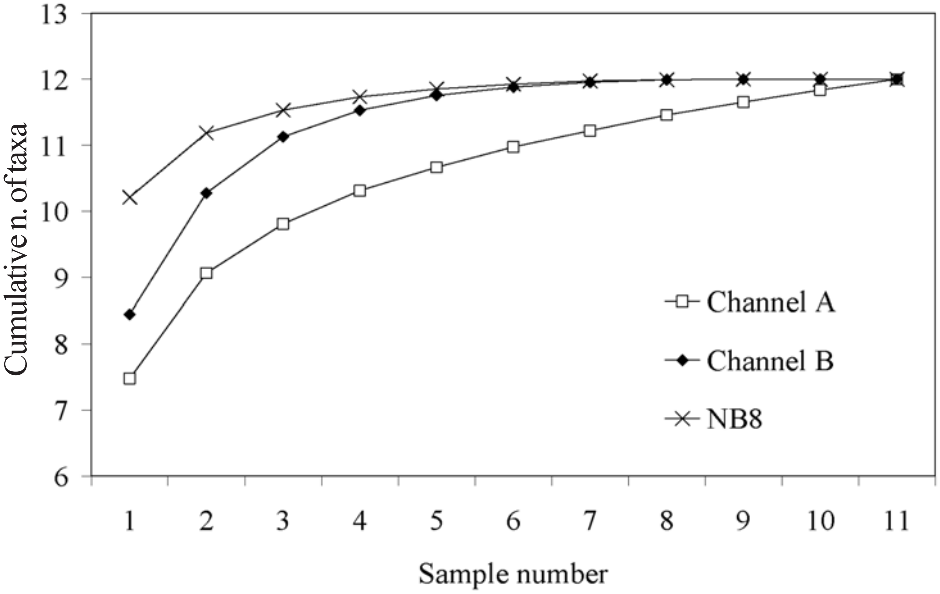

Fig. 6. Cumulative number of taxa against drift sample number. Channel A: abrupt increase; channel B: stepwise increase; NB8: hydropeaking in field experiment.

sites, scoring 7, 5, and 4 respectively for stepwise changes (channel A), abrupt changes (channel B), and NB8. In the case of the artificial channels, at the end of the experiment the drift rate returned to values similar to those recorded before the increase, whereas at NB8 there were several individuals still drifting (Fig. 5).

The cumulative observed number of taxa (Fig. 6) shows that NB8 and channel B reached the asymptotic number of 12 drifting taxa at the 8th sample (i.e. 9 minutes after the beginning of the increase of discharge), whereas channel A, where discharge increased stepwise, the maximum number of drifting taxa was reached with the last sample. The curves of channel A and NB8 differed significantly (Mann-Whitney U-test. P=0.016).

The differences in drift composition were assessed with a one-way SIMPER analysis, run for the factor "before\during"; the results showed an average dissimilarity of "before" and "during" samples, calculated across all 3 site groups, of 39.42%. Many species determined the dissimilarity between the two groups, in fact 90% of the contribution to diversity was due to (in decreasing order of importance): larvae and pupae of Chironomidae and Simuliidae, Ostracoda, benthic Copepoda, larvae of Baetidae, Acarina, larvae of Plecoptera, Oligochaeta, larvae and pupae of other Diptera. The first four taxa accounted for over 50% (Table II), with larvae and pupae of Chironomidae, Ostracoda, benthic Copepoda, and Oligochaeta being the good discriminating taxa. In fact, larvae and pupae of Chironomidae and Oligochaeta significantly increased in abundance in drift with discharge increases, whereas benthic Copepoda and Ostracoda decreased. The average similarity within each group scored 60.03 % for "before", and 77.55% for "during"; the analysis of the contribution of each taxon to similarity (Table III) showed a 90% of the "before" samples due to Chironomidae larvae and pupae, benthic Copepoda, larvae of Baetidae, larvae and pupae of Simuliidae, Acarina, Ostracoda, and 90% of the "during" samples due to larvae and pupae of Chironomidae, larvae of Baetidae, larvae and pupae of Simuliidae, larvae of Plecoptera, benthic Copepoda, Oligochaeta, Ostracoda.

DISCUSSION

Relationships between hydraulic regime and drift

In all three cases, drift increased with increasing discharge, and invertebrates responded to the hydropeaking wave quickly: peaks in drift abundance were recorded during the rising phase, within 5 minutes

Table III. Results of SIMPER analysis. Percentage contribution of each taxon to similarity within the two groups: before, and during the hydropeaking wave. An asterisk marks the good discriminating taxa. L: larvae; P: pupae.

Taxon	before	during
Chironomidae L P	35.18*	47.21*
Benthic Copepoda	16.04*	4.52*
Baetidae L	14.32*	16.53*
Simuliidae L P	10.89	9.5
Acarina	7.77	2.84
Ostracoda	7.45	2.93
Plecoptera L	4.98	6.25
Hemiptera	1.78	1.56
Diptera L P	0.62	2.44
Trichoptera L P	0.6	1.57
Oligochaeta	0.19	4.33*
Nematoda	0.18	0.31

Table II. Results of SIMPER analysis. Breakdown of average dissimilarity between group 1 (before) and 2 (during) into contributions from each species. An asterisk marks the good discriminating taxa. L: larvae; P: pupae.

Taxon	Group 1 Average Abund.	Group 2 Average Abund.	Average Dissimilarity between groups	Dissimilarity /SD	Percentage contribution to dissimilarity	Cumulative percentage contribution
Chironomidae L P	0.68	0.93	7.26	1.83*	18.42	18.42
Simuliidae L P	0.36	0.25	6.30	1.19	15.99	34.41
Ostracoda	0.23	0.11	4.26	1.64*	10.80	45.21
Benthic Copepoda	0.29	0.11	3.73	1.57*	9.47	54.68
Baetidae L	0.31	0.37	3.42	1.51	8.67	63.35
Acarina	0.19	0.08	2.92	1.26	7.41	70.77
Plecoptera L	0.13	0.20	2.91	1.41	7.38	78.15
Oligochaeta	0.02	0.11	2.03	1.88*	5.16	83.31
Diptera L P	0.05	0.09	1.95	1.23	4.94	88.24
Hemiptera	0.08	0.08	1.90	1.22	4.81	93.05
Trichoptera L P	0.04	0.07	1.59	1.14	4.03	97.08
Nematoda	0.04	0.02	1.15	0.67	2.92	100.00

from the beginning of the wave. Most of the invertebrates were washed out within the first 15 minutes, and their abundance and composition returned to base-flow levels after about 20 minutes from the beginning of the wave. A significant drift increase, occurring immediately after discharge rising and followed by a dramatic decrease, has been recorded by several authors in experimental flow manipulations in artificial channels (IMBERT and PERRY, 2000; MOCHIZUKI *et al*., 2006), in natural rivers (ROBINSON *et al*., 2004a), and recently in an extended study by BRUNO *et al*. (2009) which included station NB8. The increase/decrease pattern is attributed to the association of many invertebrates with algae and organic debris which are washed away by the increased discharge (IRVINE and HENRIQUES, 1984; IRVINE, 1985). In our case study, drifting invertebrates peaked together with drifting organic matter (data not shown), and the taxa that discriminated between the samples collected before and during the discharge alterations (larvae and pupae of Chironomidae, and Oligochaeta) in fact feed on detritus or live in it. On the other hand, taxa which can find refuge by dwelling in the sediment due to their morphological and behavioural adaptations, decreased in drift with increasing discharge (i.e. benthic Copepoda and Ostracoda).

The dominance of Chironomidae in our drift samples was expected, because this group is commonly reported in literature as being dominant in drift samples (e.g., GAYRAUD *et al*., 2000; IMBERT and PERRY, 2000; ROBINSON *et al*., 2004b), and responding without delay to increase in discharge (SCULLION and SINTON, 1983; JACOB *et al*., 2003; ROBINSON *et al*., 2004a).

Comparison of the effects of two different flow increases: natural high-flow versus hydropeaking

A similar drift composition was recorded in the two channels, both before and during the discharge manipulations. Overall, less drift was collected in the stepwise experiment, but with a higher drift rate during the discharge increase. However, in this channel, the experiment started from a higher base-flow and the lower drift rate, notwithstanding a higher initial flow, might be due to the possible adaptation of benthic organisms to the higher flow. For instance, by selecting flow-protected areas in the channel bed, less individuals were affected by the discharge increases. Moreover, stepwise increase mobilized less organic matter, and therefore less associated fauna. The higher ratio of drift collected "during" to the one collected "before" recorded in the stepwise increases than in the abrupt one, is probably a bias due to the low number of drifting individuals collected in the "before" samples in the stepwise increase simulation.

Responses of benthos to disturbance was faster in the case of abrupt increases, where all taxa were drifting after 9 minutes, whereas it took 40 minutes in the stepwise increase to mobilize all taxa.

Assessment of the validity of artificial flumes to simulate natural streams in hydraulic manipulation experiments

Drift occurred even without movement of bed sediments. Recently GIBBINS *et al*. (2007) investigated how bed instability can trigger mass drift of invertebrates even at the low bedload rates (similar to those occurring during small floods) which do not mobilize the bed sediments. Consequently, discharge events not considered as disturbances in geomorphic terms may initiate frequent episodes of catastrophic drift. In our study artificial channels operated in a way as effective as the one recorded in a natural stream without bedload mobilization.

The artificial channels performed well to simulate discharge variations, to the point of detail that the simulation of the abrupt change was more similar than the simulation of the stepwise change to the hydropeaking wave in the natural stream as trend and type of benthos response.

The higher catastrophic drift rates recorded in the flumes, compared to those registered during the Noce experiment, are probably due to the fact that in hydropeaking-impacted streams, hydropeaking is a repeated daily event. As a consequence the benthic community is particularly poor and the drifting invertebrates are those few that colonise the impacted reach from undisturbed upstream sites. In the flumes, the community was left to stabilize with constant discharge for a month before inducing the simulated hydropeaking, and thus it reached the maximum environmental carrying capacity.

The artificial channels can not be used to assess the hydropeaking effects on riparian invertebrate communities. In fact, taxa typically living in protected water (i.e. near the banks) such as Hemiptera, which were significant in the drift collected at NB8, were rare in the artificial flumes.

CONCLUSIONS

As such, our results address a theoretical question (i.e. relationships between hydraulics and drift) as well as assessing the validity of simulated responses compared to actual field situations. Manipulation of flow and other parameters (temperature, turbidity) in artificial flumes is a strategic tool in assessing the effects of each hydropeaking-induced alteration, and in testing possible mitigation measures. The results of our research showed that:

- an increase in discharge causes a catastrophic drift of benthic invertebrates; taxa responses depend on their morphological, physiological and behavioural adaptations;
- abrupt increases in discharge have more severe effects than stepwise increases;
- artificial flumes simulate very well natural events, with the restriction that they are not suitable/suited to investigate the effects on riparian fauna.

Further experiments, performed with replicated sampling-design, will be needed to conduct a more detailed comparison between artificial channels and natural streams, possibly including hydropeaking-impacted stream reaches at the same elevation of the experimental structure. However, these first results indicate that the artificial channels can be used to simulate and assess hydrological alterations in natural streams. This is particularly important when studying the hydropeaking-induced impacts on benthic fauna: the release of turbinated water from hydropower plants cause, in fact, not only an increase of discharge, but also significant alterations in the thermal regime (Webb and Walling, 1996; Lessard and Hayes, 2003): in a natural stream it is impossible to separate the two causes of the effect (i.e. catastrophic drift). On the other hand, experimentation in artificial channels allows manipulating such variables and thus to disentangle the effects of discharge and temperature alterations. Such experiments are presently being developed by our research group.

Acknowledgements

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