Multiple drift responses of benthic invertebrates to hydropeaking waves

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ABSTRACT. Sudden instream releases of hypolimnetic water from hydropower plants (*i.e.*, hydropeaking) can cause abrupt temperature variations (*i.e.*, thermopeaking), typically on a daily basis. The propagation of the discharge and thermal waves are asynchronous, causing the benthic community to undergo two distinct but consecutive impacts. Invertebrates are known to respond to sudden increases in discharge with catastrophic drift, and recently have been shown to respond to sudden changes of temperature with drift, which is probably behavioral. Due to the decoupling of the discharge and thermal waves, catastrophic and behavioral drift can occur as distinct events. We analyzed the induction of drift in benthic invertebrates caused by a hydropeaking wave followed by a thermopeaking wave, in two open air flumes directly fed by an Alpine stream. The slight but abrupt increase in discharge caused a maximum 28 and 24-fold peak increases in drift in the two flumes, and the abrupt decrease in temperature caused an increase of 36 and 198-fold in the same flumes. In both flumes drift propensity increased during hydropeaking and thermopeaking simulations, and was higher during the latter.

KEYWORDS: *temperature, hydropower, benthos, streams, Alps.*

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1. Introduction

Hydropower is a primary and strategic renewable energy source in the Alps. Among its advantages is the possibility to respond immediately to peak demands, but the resulting sudden release of water in receiving water bodies (hydropeaking) causes severe consequences on the benthic community and on the whole ecosystem (degradation of the riparian zone, clogging of the substrate, etc.) (*e.g.*, Poff *et al.*, 1997; Fette *et al.*, 2007). Furthermore, hydropeaking downstream of storage plants with high elevation reservoirs and hypolimnetic releases causes not only a change in the flow regime but also in the thermal regime through the sharp temperature variations, *i.e.*, thermopeaking (Carolli *et al.*, 2009, 2011; Zolezzi *et al.*, 2010). Recent studies in Alpine streams (Frutiger, 2004; Zolezzi *et al.*, 2010) showed a resulting thermal alteration up to 4°C, comparable with the diurnal variation, occurring within a notably shorter time interval (about 30 minutes). On a seasonal scale, the daily alterations sum up and in the Alpine streams studied the range is plus 3-4C° in winter and minus 5-6C° in summer (Zolezzi *et al.*, 2010).

Because the hydrodynamic and thermal waves propagate downstream with different velocities, with the discharge wave preceding the thermal one (Toffolon *et al.*, 2010), the biota experience a first disturbance caused by the hydropeaking wave (catastrophic drift), followed by a second one caused by the sudden temperature change (behavioural drift, see Carolli *et al.*, 2011). The time lag between the two events increases with distance from the power station and the magnitude depends on the relative position of the reservoir and the receiving water body.

Aim of this study was to assess the impacts on the benthic community of this sequence of events by simulating one hydropeaking wave followed by a thermopeaking one, in experimental flumes.

2. Material and methods

Experiments were conducted on 28 July 2009 in a set of five 20 m long, 30 cm wide metal flumes situated on the riparian zone of the Fersina Stream (46°04'32"N, 11°16'24"E) at 577 m a.s.l. The Fersina is a 2nd order stream, originating at an altitude of 2 005 m, and joining the Adige River at Trento (Trentino Province, Northeastern Italy). Each flume has an adjustable longitudinal slope and feeding discharge. They are filled with a layer of gravel and sand collected from the riverbank and connected to a loading tank that is directly fed by water diverted from the stream. For this experiment we used two flumes, where we artificially caused a sudden increase of discharge of 2.2 x in flumes B and D (from $5.1*10^{-3}$ to $11.3*10^{-3}$ m^3 s^{-1}) and subsequently we decreased abruptly the temperature of 2.4 (flume B) and 3.5°C (flume D). Thermal manipulations were conducted by using a 0.5 m^3 volume, thermally-isolated water tank, where water was cooled with 250 kg of crushed ice and quickly released simultaneously into the two treatment flumes with rubber hoses through the sluice gates feeding each flume.

Drift samples were collected by filtering the whole volume of water leaving the flumes with drift nets (mesh size 100 micron). For each experiment we collected 4 samples before the experiment for 5 minutes at the beginning of each hour, for the four hours preceding the experiment (four samples for each flume, named BF hereafter); during the hydropeaking wave (10 samples for each flume, HP hereafter) and during the thermopeaking wave (11 samples for each flume, TP hereafter) we collected the drift continuously at 2 minutes intervals. Number of collected individuals were transformed in densities and expressed in n. ind. m^{-3}. Benthic density was measured one day before the experiment by collecting three samples in each flume with a Hess sampler (23.5 cm diameter, 100 µm mesh) and calculating mean densities per flume. Composition of the benthic community in the stream from which the water was diverted into the flumes was assessed bi-weekly from March 2009 to the experiment day using standard methods (Carolli *et al.*, unpublished). Propension to drift was calculated as mean drift density/mean benthic density and expressed as n. ind. m^{-1}. Values were calculated separately for the samples collected before the simulations, during HP, and during TP.

3. Results

The composition of the benthic community in the flumes was similar to that of the adjacent stream. Differences were represented by the higher relative abundance of collectors, scrapers and filterers in respect to predators in the flumes.

The density of drifting invertebrates increased a first time during the hydropeaking simulation, followed by a second increase during the thermopeaking one (Figure 1).

The slight but abrupt increase in discharge caused a maximum 28- and 24-fold peak increases in drift in flumes B and D respectively, while mean increase before and during the hydropeaking simulation experiment was 12- and 10-fold (Table 1). During the TP experiment, more invertebrates drifted, particularly in flume B, which experienced a higher thermal shift: peak increase measured 36 in B and 198 in D, with a mean increase of 23 in B and 56 in D (Table 1).

Drift propensity increased in both flumes during both HP and TP simulations, with higher values in the latter (Figure 2).

We could identify three kinds of drift responses (Figure 3):

a. taxa which tended naturally to drift (*i.e.* they were proportionally more abundant in drift before the simulations than in benthos) and responded to the discharge and/or thermal alterations. This is the case of Chironomidae whose drift propensity increased 15- and 22-fold in flume B for HP and TP respectively, and 11- and 51-fold in flume D, and of Simuliidae, whose propensity to drift increased of 14- and 25-fold in flume B, 8- and 41-fold in flume D. The high abundance of Simuliidae in the benthos could explain their high propension to drift (even in absence of alterations), due to overcrowding, a condition not normally occurring in streams, where they generally have low propensity to drift (*e.g.*, Crossky, 1990; Kiel, 2001).

b. taxa which did not tend to drift (*i.e.* they were proportionally more abundant in benthos than in drift before) but responded to the discharge

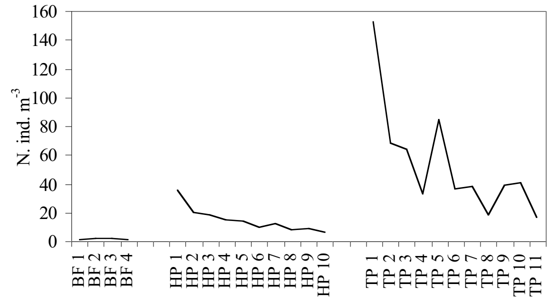

Figure. 1. Densities of drifting invertebrates (as mean between the two flumes) before the simulation (BF), and during the hydropeaking (HP) and thermopeaking (TP) simulations.

Table 1. Main physical and biological parameters of the hydropeaking (HP) and thermopeaking (TP) simulations. Drift values expressed as n. ind. m^{-3}.

	Flume B	Flume D
ΔQ ($l\ s^{-1}$)	2.2	2.2
ΔT (°C)	2.4	3.5
A: mean drift before	1.3	1.4
B: mean drift during HP	15.3	14
C: mean drift during TP	29.8	80.9
B/A: drift increase ratio during HP	11.7	9.7
C/A: drift increase ratio during TP	22.7	56
D: max drift before	1. 8	2.2
E: max drift during HP	36.5	34.4
F: max drift during TP	67.1	285.8
E/A	27.9	23.8
F/A	35.8	197.6

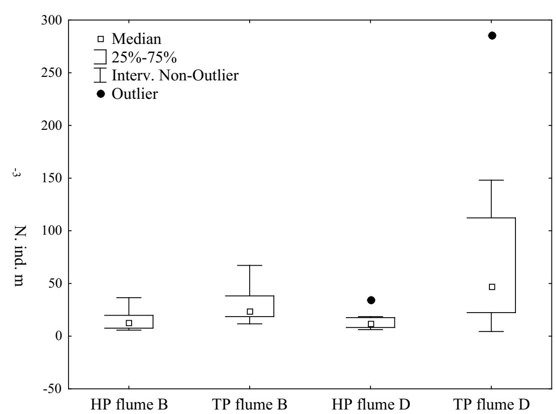

Figure 2. Densities of drifting invertebrates collected in the two artificial flumes (B and D) during the hydropeaking (HP) and thermopeaking (TP) simulations.

and/or thermal alterations by increasing their propensity to drift, *i.e.* Trichoptera, Baetidae, other Diptera, Acarina, Harpacticoida and Oligochaeta;

c. taxa which were not or only slightly affected by HP and TP, such as Heptageniidae and Plecoptera, whose increase in drift propensity was negligible.

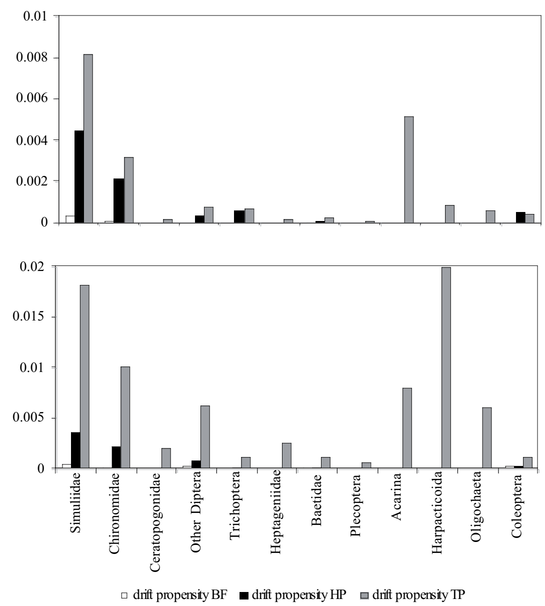

Figure 3. Drift propensity of main taxa in flume B (top) and D (bottom) before simulations (BF), and during hydropeaking (HP) and thermopeaking (TP) simulations.

4. Discussion

Flow and temperature regimes are considered the main drivers in stream ecology (Poff *et al.*, 1997), though the effects of pulsating temperature changes are still little known. Hydropower plants fed by high elevation and stratified reservoirs with hypolimnetic releases are rather common in the Alps and their pulsating releases impact many rivers (Alpine Convention, 2009).
In previous studies in the same flume system (Carolli *et al.*, 2011) we assessed how abrupt changes of temperature induce drift in benthic invertebrates, and how such drift is probably behavioural, whereas the well-known effects of sudden increases of discharge is the induction of catastrophic drift (*e.g.* Céréghino *et al.*, 2002; Hay *et al.*, 2008; Bruno *et al.*, 2010), which was assessed as well in the same flumes (Carolli *et al.*, 2010). The sudden and repeated discharge and thermal waves (hydropeaking and thermopeaking) travel downstream with different velocities and thus, in the short term, the invertebrate community composition in the hydropeaking-impacted reaches changes because invertebrates undergo behavioral drift in response to thermopeaking and catastrophic drift in response to the discharge wave. Behavioral and catastrophic drifts can occur as distinct events. In this study we attempted to reproduce such effect manipulating discharge and temperature in two artificial flumes. Results indicate that the thermal wave following the discharge one may affect the benthos to a higher degree.
The effects of abrupt increases of discharge and changes of temperature may vary according to the time lag of their arrival. In our experiment we tested the case of two separate and subsequent waves. Normally this situation does not occur; in fact, in most cases each hydropeaking event lasts several hours and thus the resulting two waves overlap for a long distance downstream. More recently though, the operation of power plants is increasingly market-oriented and short operational shifts (less than one hour) are becoming frequent. In such cases, the separation of the two waves may occur at relatively short distance from the power plant. As showed by this study, different taxa behave differently in reaction to the sequence of impacts and different communities may be selected by the different operational modes of hydropower plants.
The results of this study may be relevant to forecast the summed effect of multiple stressors that occur in heavily modified water bodies. Further research is needed to verify the role of the time lag between one hydropeaking event and the associated thermopeaking, and their cumulative effect at different time scales.

Acknowledgements

The authors wish to thank the Servizio Bacini Montani, Autonomous Province of Trento, for building and maintaining the flumes; A. Siviglia, G. Zolezzi, M. Salvaro (Environmental and Civil Engineering Department of the University of Trento) for their help in setting and conducting the experiments, and E. Varolo (University of Bolzano) and L. Silveri for helping in the field and for sorting and identifying the invertebrates. This research was conducted partly within the framework of the Interreg IVB project ALP WATER SCARCE - Water Management Strategies against Water Scarcity in the Alps.

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