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Hydroelectric power generation and disruption of the natural stream flow: effects on the zoobenthic community

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SUMMARY - *Hydroelectric power generation and disruption of the natural stream flow: effects on the zoobenthic community* - Hydropower generation impacts the ecological characteristics of rivers and streams during the three phases of the production process: abstraction, storage in reservoirs and release of turbinated waters to the stream. These effects were assessed on abiotic (temperature and hydrological regime, chemistry, solid transport) and biotic (discontinuity of drift, isolation of benthic populations) features of the Noce Bianco stream (de La Mare Valley, Trentino), which was investigated from 2001 to 2005. The most relevant impact was due to the release of turbinated water into the channel, which caused repeated and sudden changes in the physical characteristics of water, which in turn affected the biological community. Hydropeaking regards most of the Italian Alpine streams and often abates the expected benefits of the Minimum Flow and other mitigation measures. Scope of this research was to evaluate the effects caused by hydropower production on the zoobenthic communities, and particularly on Plecoptera,

RIASSUNTO - *Produzione idroelettrica e discontinuità fluviale: effetti sulla comunità zoobentonica* - La produzione di energia idroelettrica condiziona le caratteristiche ecologiche dei corsi d'acqua. Gli impatti riguardano le tre fasi della produzione: captazione, stoccaggio e rilascio di acque turbinate. Dal 2001 al 2005 è stata studiata la comunità bentonica, in particolare l'ordine dei Plecotteri, nel bacino del Noce Bianco (Val de La Mare, Trentino). Nelle tre fasi sono stati rilevati effetti sulla comunità, dovuti in misura diversa a cambiamenti abiotici (regime termico e idrologico, chimismo, trasporto solido) e biotici (interruzione del *drift*, isolamento delle popolazioni bentoniche). L'impatto più rilevante è dovuto alla restituzione delle acque turbinate, soprattutto per il continuo e improvviso variare delle caratteristiche fisiche che provocano una forte riduzione qualitativa e quantitativa delle biocenosi. L'*hydropeaking* interessa la maggior parte dei corsi d'acqua alpini e spesso inficia i benefici attesi dal rilascio del Deflusso Minimo Vitale e da altri interventi di mitigazione. Scopo della ricerca è valutare gli effetti della discontinuità indotta dalla filiera idroelettrica sulla comunità zoobentonica.

Key words: Stoneflies, hydroelectric impact, hydrological regime, stream connectivity, Trentino (Italy)
Parole chiave: Plecotteri, impatto idroelettrico, regime idrologico, connettività fluviale, Trentino

1. INTRODUCTION

The connectivity of streams, rivers and associated ecosystems is altered by the use of water for hydropower production (Boon 1988; Brittain & Saltveit 1989; Petts & Bickerton 1994). The disruption of continuity regards the three phases of hydropower production: water abstraction or diversion, storage in reservoirs, release of turbinated water to the channel. Main effects regard changes in temperature and hydrological regimes, streambed stability, water chemistry and structure of benthic communities (Morgan *et al*. 1991; Moog 1993; Robinson 2002). Hydrological regime, water quality and channel geomorphology are among the most important driving forces of the distribution and abundance of riverine species and vary with stream typology (Poff & Ward 1989; Karr 1991; Cortes 1992; Death & Winterbourn 1995). The natural flow regime is strictly dependent from the geomorphological, climatic and environmental characteristics of the watershed and its natural changes occur over hours, days, seasons and years. It is defined by five critical components: magnitude of discharge, frequency of occurrence of flow, duration of specific high or low flow conditions, timing or predictability of flows and rate of flow change (Poff *et al*. 1997).

Hydropower plants are generally operated only during peak energy requests, producing sudden changes in discharge, current velocity, turbidity, streambed stability and temperature downstream of the power plants (Cushman 1985; Allan & Flecker 1993; Maiolini 2006).

Several studies regarded the impact of water abstraction and diversion (Brittain & Saltveit 1989; Armitage & Petts 1992), but few focused on the effects of hydropeaking (Cereghino & Lavandier 1998; Cereghino *et al.* 2002; Cortes *et al*. 2002). Aim of this research was to evaluate the effects of the three phases of hydropower production on the zoobenthos, with particular regard to the structure and dynamics of the Plecoptera community.

2. STUDY AREA

Eight sampling sites were selected within the Noce Bianco watershed, in the de La Mare Valley (Stelvio National Park, Trentino, NE Italy, 46°N, 10°E) (Tab. 1). The hydropower system "Malga Mare-Pont" includes Pont (1208 m a.s.l.) and Malga Mare (1963 m a.s.l.) plants, and Careser (2603 m a.s.l.) and Pian Palù (1752 m a.s.l.) reservoirs. A pipeline abstracts water from inlets and outlets of the Lungo, Marmotte and Nero lakes, located between 2700 and 2600 m a.s.l., in the eastern part of the valley, and feeds the Careser reservoir. From here, water is turbinated after a 622 m fall and then discharged in the sedimentation basin of the Malga Mare plant. The same sedimentation basin also collects water from the Noce Bianco and its tributaries. Water is turbinated again after a fall of 750 m in the Cogolo-Pont plant, which also uses water from Pian Palù Reservoir. From the Cogolo-Pont plant turbinated water is discharged into the Noce Bianco stream at 1265 m a.s.l.

3. METHODS

The zoobenthic community was sampled in spring, summer and autumn from 2001 to 2004, using a kick net (100 μm mesh size; 5 replicates for each station, in each disturbing 0.1 m^2 for one minute). Samples were preserved in 70% ethanol, and specimens were identified to the genus/species (for Plecoptera) or higher (for other taxa) taxonomic level. Water temperature was measured above (NB7) and below (NB8, NB13, NB15) the Cogolo-Pont power plant with dataloggers (Tiny Talk). The Service for Hydraulic Works of the Autonomous Province of Trento provided discharge and hydrometric level data.

4. RESULTS

A total of 45,442 aquatic invertebrates were collected and identified. Insects resulted the most abundant group in all eight stations. Diptera, represented mostly by Chironomidae, were dominant above the tree-line, followed by Simuliidae, Limoniidae, Empididae and Tipulidae. The percentage of ETP taxa (Ephemeroptera, Trichoptera, Plecoptera) increased with decreasing elevation and became dominant below the tree-line at all stations except NB13, where Chironomidae were dominant (Fig. 1). Abstraction, storage and release were not summed in either of the considered sampling sites, but each experienced one type of impact.

4.1. *Water diversion*

The effects of water diversion were evaluated by comparing the communities upstream (ImL1) and downstream (ImL2) of the abstraction pipeline on the Lungo Lake inlet. Chironomidae increased downstream, and Trichoptera and Plecoptera decreased (Fig. 1). Plecoptera density changed from 141 ind. m^{-2} to 82 ind. m^{-2}, the percentage of predator Plecoptera from 68.1% to 7.3%, and that of herbivore Plecoptera from

Tab. 1 - List of sampling stations names, stream typology, altitude (m a.s.l.), temperature range (°C) and discharge range (m^3 sec^{-1}). Temperature values refer to the period from spring to autumn, Q range to an annual range.

Tab. 1 - Lista delle stazioni di campionamento e delle relative tipologie fluviali, quote, intervalli di variazione della temperatura(°C) e della portata(m^3 sec^{-1}). La lista è riferita al periodo compreso tra la primavera e l'estate, la portata è espressa come range di variazione annuale.

Station	Stream typology	Altitude (m a.s.l.)	T min-max (°C)	Q range (m^3sec^{-1})
ImL1	kreno-rhithral	2730	2.6-4.9	0.02-0.1
ImL2	kreno-rhithral	2600	2.9-7.5	≤0.02
CR2	glacio-rhithral	2642	0.3-6.8	>0.8
CR3	kreno-rhithral	1985	3.6-9.0	0.1-0.2
NB7	kreno-rhithral	1265	5.7-11.6	0.2-0.8
NB8	kreno-rhithral	1197	3.4-8.6	>0.8
NB13	kreno-rhithral	1054	4.4-9.6	>0.8
NB15	kreno-rhithral	988	5.2-10.3	>0.8

31.9% to 92.7%. The predator species most affected by water diversion were *Dictyogenus fontium* (Ris.) (from 84 to 6 ind. m^{-2}) and *Isoperla* sp. (Tab. 2). The herbivorous *Rhabdiopteryx alpina* Kuehtreiber became the dominant species followed by *Leuctra rosinae* Kempny and other *Leuctra* species (Tab. 2).

4.2. Water storage

The effects of water storage in the reservoir were evaluated by comparing the communities at stations CR2 and CR3, which are located respectively upstream and downstream of the Careser dam. The dominant taxon

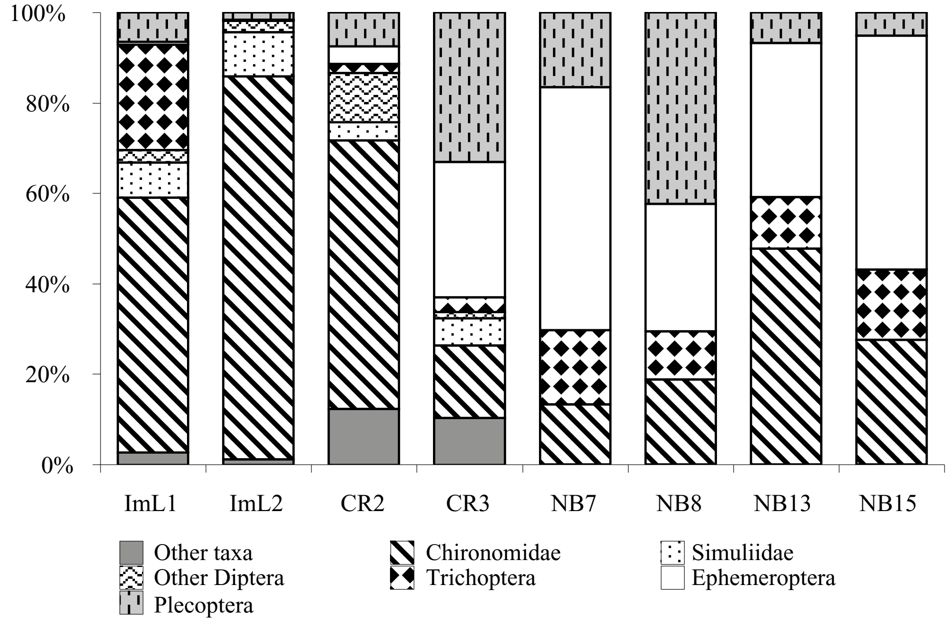

Fig. 1 - Relative composition of zoobenthos in each of the eight sampling station.
Fig. 1 - Composizione relativa dello zoobenthos nelle otto stazioni di campionamento.

Tab. 2 - Density (ind. m^{-2}) of Plecoptera species in the eight sampling stations.
Tab. 2- Densità (ind. m^{-2}) delle specie di Plecotteri nelle otto stazioni campionate.

		ImL1	ImL2	CR2	CR3	NB7	NB8	NB13	NB15
PREDATORS	CHLOROPERLIDAE								
	Siphonoperla sp.				10				
	Siphonoperla torrentium (Pictet)					4			
	PERLODIDAE								
	Perlodidae juv.	4			161	1	4		
	Dictyogenus fontium (Ris)	84	6		4	12			
	Perlodes sp.				3				
	Perlodes intricatus (Pictet)				2				
	Isoperla sp.	8			22	24			
	Isoperla rivulorum (Pictet)				26				
HERBIVORES	TAENIOPTERIGYDAE								
	Taeniopterigtdae juv.	5	3	40	59				
	Rhabdiopteryx alpina (Kuehtreiber)	4	26			2			
	NEMOURIDAE								
	Nemouridae juv.	13	13	1					
	Nemoura sp.				4				
	Nemoura mortoni (Ris)	1			111	6	24	4	
	Protonemura sp.	1	8	1	298	65	60	8	8
	Protonemura brevistyla (Ris)					1			
	Protonemura nimborum (Ris)				1	8			
	LEUCTRIDAE								
	Leuctra sp.	21	25	15	725	1361			
	Leuctra major (Brinck)			18	115				
	Leuctra rosinae (Kempny)		1						

shifted from Chironomidae to Plecoptera: the former were dominant upstream, the latter downstream, together with Ephemeroptera (Fig. 1). Plecoptera density changed from 81 ind. m^{-2} to 8,686 ind. m^{-2}. Only herbivorous Plecoptera were present in the upstream station while they represented 15.1% of the identified stonefly species in the downstream station, where a relevant number of Plecoptera (82.3%) was represented by non identified neanids.

Predator Plecoptera were absent upstream the reservoir but were 2.6% of identified species downstream. The most abundant predator species were *D. fontium*, *Perlodes intricatus* (Pictet), *Siphonoperla torrentium* (Pictet) and *Isoperla* sp. The most abundant herbivorous species in both stations was *Leuctra major* Brinck. In the downstream station *N. mortoni* and *Protonemura nimborum* (Ris) were also abundant (Tab. 2).

The reservoir changed the river typology from a glacial dominated stream to a groundwater fed one, with a rather constant discharge, clear waters, stable channel and warmer summer temperatures. The benthic community switched from a typical kryon to a rhithron. Ephemeroptera, almost absent in upstream of the reservoir, were well present downstream.

4.3. Hydropeaking

The turbinated water release is the phase of hydropower production that most affects the stream ecosystem downstream of the release point, mixing waters of different origin and characteristics. Temperature patterns were changed at the daily and seasonal level by the Cogolo power plant (Fig. 2). In particular, downstream temperature was lower than in the upstream unimpacted reach during summer, warmer in winter, due to contribution of waters pumped from the bottom layer of the stratified reservoir.

The flow regime was severely affected with sudden increases of about six m^2 $sec.^{-1}$ (Fig. 3) The effects of hydropeaking on the benthic community were evaluated by comparing the communities upstream of the Cogolo-Pont plant (NB7) with those downstream (NB8, NB13 and NB15). As a mean value, total density decreased by 13 times downstream; the zoobenthic community immediately downstream (NB8) was dominated by Plecoptera; Chironomidae and Ephemeroptera prevailed at NB13 and Ephemeroptera were dominant at NB15 (Fig. 1).

Density of Plecoptera strongly decreased from 1,642 ind. m^{-2} to 168 ind. m^{-2}; predator species decreased and herbivores increased downstream from the release point, where all the collected specimens were juvenile larvae. The following species disappeared downstream from the release point: *S. torrentium*, *Isoperla rivulorum* (Pictet), *Dictyogenus* sp. and *R. alpina* (Tab. 2).

5. DISCUSSION

As expected, the zoobenthic community was dominated by Diptera Chironomidae above the tree-line, and by EPT at lower elevations (Milner & Petts 1994; Ward 1994; Maiolini & Lencioni 2001).

All three phases of the production process change the physical-chemical and hydrological characteristics of the waterbodies, which in turn strongly alter the structure, trophic relation and dynamics of macrobenthic populations for a long distance downstream of the impacted area (Vinson 2001). Uhelinger & Robinson (2002) found that zoobenthic communities increased in density due to few taxa downstream of a water diversion structure in a non-glacial stream. In the present study total density increased 5 times, mainly for Chironomidae. The increase in density was due to lower solid transport and discharge, with consequent in-

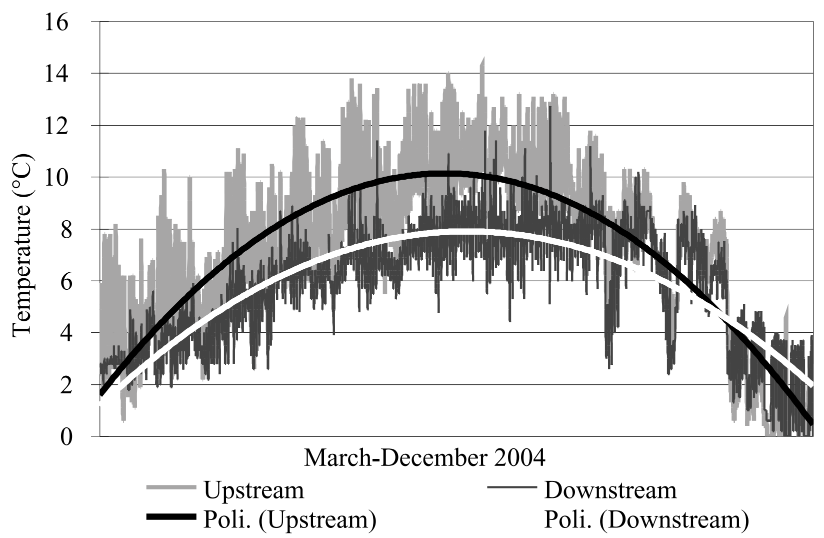

Fig. 2 - Temperatures (°C) recorded from March to December 2004 in a station upstream (NB7) and downstream (NB8) of the turbinated water release point at Cogolo-Pont plant.

Fig. 2 - Temperature (°C) registrate da marzo a dicembre 2004 nella stazione a monte (NB7) e in quella a valle (NB8) del punto di rilascio delle acque turbinate.

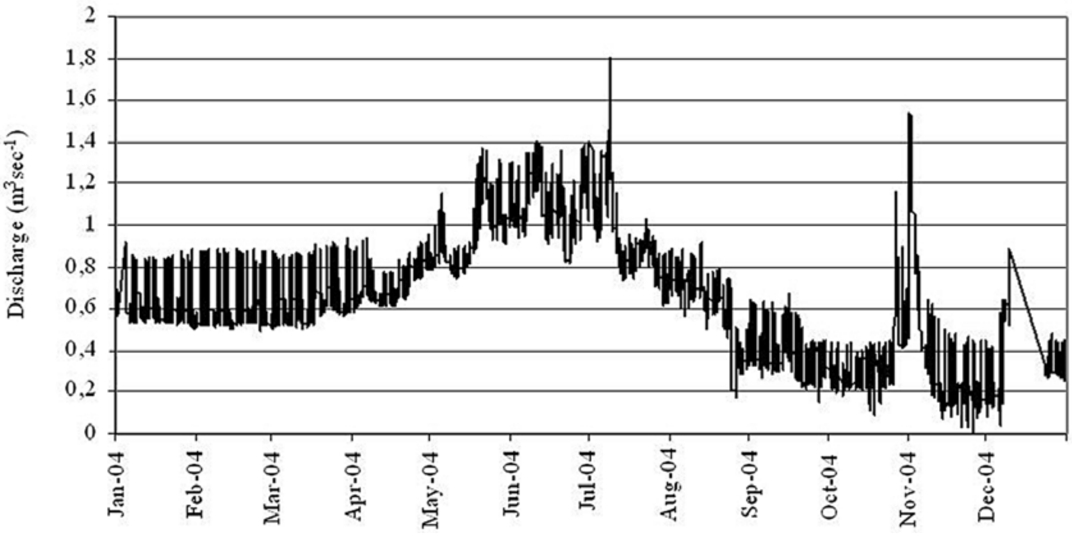

Fig. 3 - Discharge (m^3 sec^{-1}) during hydropeaking regime recorded at the Service for Hydraulic Works Hydrological monitoring stations located at Noce Bianco stream, downstream from Cogolo-Pont hydropower station
Fig. 3 - Portata (m^3 sec^{-1}) misurata presso le stazioni idrologiche Servizio Opere Idrauliche del Torrente Noce Bianco, a valle della stazione idroelettrica Cogolo-Pont.

crease in streambed stability, summer water temperature and phytobenthos development, as also reported by Badino (1994). The effects on the primary production of the reservoir was mainly due to changes of stream typology. The upstream glacial stream had low phytobenthic production due to the unstable habitat and scouring from sediment transport. Downstream of the reservoir, the more mild conditions of the groundwater fed outlet fostered a higher primary production sustaining a more abundant and diverse community. Finally the hydropower release had a consistent "washing effect", continuously dislodging organic matter and most part of the benthic community.

As regards Plecoptera, we recorded a decrease in population densities and a change in community structure: crenobiont taxa decreased in density (*D. fontium*) or disappeared (*Isoperla* sp.), whereas *R. alpina* and Nemouridae increased due to the development of moss and higher water temperature. The change in stream typology produced a shift from a community dominated by Chironomidae, typical of glacial streams, to a community dominated by Ephemeroptera and Plecoptera, typical of mixed fed streams. The Plecoptera community changed as well: both the predator (Perlodidae) and the herbivore (Nemouridae and Leuctridae) components became more diverse downstream, as expected with the change in stream typology and elevation (Brittain *et al*. 2003).

Hydropeaking resulted with the highest impact on the stream ecosystem. Discharge and water temperature downstream from the release point had far from natural annual and daily variations. As a consequence, we recorded a drastic reduction of zoobenthos density and diversity, with effects detectable 10 km downstream, as also found by other authors (Cereghino & Lavandier 1998; Cortes *et al*. 2002) which report a considerable decrease in biodiversity of aquatic and riparian invertebrates and an increase in catastrophic drift. In this study the Plecoptera community changed downstream of the power plant, where only Nemouridae were present, although they were represented mainly by neanids of *N. mortoni* and *Protonemura* sp. The effects on the Plecoptera community are due to the sudden changes of discharge and temperature, and populations in the impacted reaches were represented by early larval stages, more prone to drift and thus to colonize downstream areas. The development and life cycles of the Plecoptera were severely altered as also observed by Cereghino & Lavandier (1998).

6. CONCLUSIONS

Hydroelectric power production causes the interruption of the four dimensions of the river continuum, affecting the zoobenthic communities in different ways during the three phases of the production process: abstraction, storage, and release of turbinated water to the channel; Plecoptera appear to be excellent sentinel species (Consiglio 1980; Fochetti 1994; Mancini & Fochetti 1997) and can be used as bioindicators of different levels of alterations of the river continuity.

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