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PLECOPTERA IN TRENTINO: DISTRIBUTION AND ECOLOGY.

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Riassunto

Il 97% del globo è costituito di acqua, di questa massa solo la parte pi piccola è acqua corrente superficiale, eppure è la parte con cui l'uomo si rapporta di più, utilizzandola per molteplici scopi e spesso compromettendone la qualità.

I corsi d'acqua al di sopra la linea degli alberi, ancora poco conosciuti dal punto di vista ecologico, hanno caratteristiche che variano a seconda della loro origine(*kryal*, *krenal*, *rhithral*).
Il diverso tipo di alimentazione del corso d'acqua determina sensibili differenze nel regime idrogeologico, nelle qualità fisiche dell'acqua e quindi nelle comunità vegetali ed animali che in essi vivono.

Le specie animali tipiche dei vari habitat, attraverso adattamenti morfologici, fisiologici e comportamentali hanno acquisito buone capacità di colonizzazione, resilienza e mobilità nonostante gli stress ambientali. Tra gli invertebrati bentonici i gruppi più rappresentati nei torrenti montani sono: Tricladi, Nematodi, Oligocheti, Idracari, Copepodi, Ostracodi e stadi larvali di Insetti tra cui Efemerotteri, Plecotteri, Coleotteri.
Il taxon dei Plecotteri rappresenta una componente zoologica significativa che contribuisce alla struttura e alla funzionalità dell'ecosistema fluviale la cui distribuzione è limitata dalla caratteristiche ecologiche (stenoeci). Le varie specie ricoprono un ampio spettro di ruoli trofici nei torrenti alpini di alta quota, soprattutto in quelli di origine glaciale, in quanto essi rappresentano, dopo i Ditteri la componente maggiore come numero di specie e biomassa delle comunità zoobentoniche. Sono in grado di colonizzare anche l'habitat iporreico e di dar luogo a fenomeni di colonizzazione valle-monte.
La conoscenza puntuale della distribuzione di questi organismi e la valutazione di quali sono i fattori che regolano la composizione delle varie comunità è importante per studi su fenomeni di tossicità, di biomonitoraggio e di impatto antropico sull'integrità ecologica dei corsi d'acqua.
Oggi si rende necessaria una analisi approfondita e critica delle condizioni ecologiche dei torrenti d'alta quota poiché rappresentano una delle ultime risorse di acqua incontaminata del Pianeta. L'ecoregione Alpina comprende una risorsa di inestimabile valore, i torrenti alpini i quali sono però pesantemente minacciati dallo sfruttamento antropico. Le principali cause antropogeniche del declino ecologico di molti corsi d'acqua alpini sono l'alterazione degli habitat (deflussi controllati, frammentazione, urbanizzazione ecc.), l'inquinamento diffuso e puntiforme, l'invasione da parte di specie esotiche e il cambiamento climatico
Di recente, grazie all'avvicinarsi delle scadenze imposte dalla Direttiva Europea (DIRETTIVA 2000/60/CE DEL PARLAMENTO EUROPEO 23 OTTOBRE 2000) si stanno iniziando a valutare gli effetti sulla struttura comunità zoobentoniche dei torrenti alpini e le implicazioni autoecologiche sui singoli taxa.
Gli obiettivi alla base del percorso di ricerca sono stati: (i) l'indagine delle tassocenosi presenti nelle tipologie fluviali tipiche del trentino attraverso la determinazione delle specie di Plecotteri; (ii) lo studio delle dinamiche trofiche che regolano le comunità zoobentoniche campionate attraverso l'analisi dei contenuti stomacali; (iii) lo studio della funzione dell'ecotone iporreico per la popolazione di Plecotteri ed infine (iiii) la valutazione dell'impatto ambientale della produzione idroelettrica sulla stabilità delle popolazioni, sulla loro capacità di resistenza e di resilienza e sui loro cicli vitali.
La stesura della lista finale delle specie di Plecotteri ha permesso di aggiungere 5 nuove segnalazioni in Trentino e ha confermato la presenza delle 35 specie già segnalate.

Dagli studi condotti sui contenuti stomacali è emerso chiaramente che la dieta dei Plecotteri predatori che hanno modalità attive di predazione è composta per lo più da Ditteri Chironomidi il che è in accordo con la composizione della comunità zoobentonica dei torrenti glaciali, la predazione meno attiva tipica delle specie iporreiche invece comporta una minore scelta delle prede.

A proposito dell'iporreico la ricerca ha confermato come questo ecotone sia abitualmente frequentato da diverse specie di Plecotteri poiché assume la funzione di: area rifugio durante eventi estremi di portata, area rifugio dove trascorrere fasi delicate del ciclo vitale (muta, sfarfallamento), nursery, zona di foraggiamento e predazione e via di colonizzazione valle-monte o verso corsi d'acqua confinanti.

Le comunità di Plecotteri ad ora studiate hanno anche dimostrato la loro grande sensibilità alle modificazioni indotte dai tre momenti dell'uso idroelettrico dei corsi d'acqua. Inoltre appare evidente come il momento del rilascio in alveo delle acque turbinate sia l'evento che maggiormente modifica la comunità zoobentonica, in particolare la comunità di Plecotteri.

Al termine della ricerca sono emerse considerazioni che indicano chiaramente l'importanza dello studio dell'ecologia attraverso la conoscenza dell'autoecologia di specie in grado di fungere da indicatori e sentinelle dello stato di salute dell'ambiente e degli affetti indotti dall'uso antropico delle risorse.

DIRECTIVE 2000/60/CE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL 23rd October 2000 establishing a framework for Community action in the field of water policy

EUROPEAN PARLIAMENT AND THE COUNCIL OF EUROPEAN UNION

Having regard to the Treaty establishing the European Community, and in particular Article 175(1) thereof:

1 Water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such.

HAVE ADOPTED THIS DIRECTIVE:

Article 1

The purpose of this Directive is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater which:

a) prevents further deterioration and protects and enhances the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems;

b) promotes sustainable water use based on a long-term protection of available water resources.

I. INTRODUCTION

About 97% of the water of the planet is salty; the other 3% is represented by freshwater, which in greater part (2%) is stocked in the glaciers. The remaining freshwaters are represented by groundwater (0.6%), lakes (0.02%), atmospheric vapor (0.001%) and rivers (0.000095%) (Allan 1995). Therefore surface running waters are the smaller part of water resources, though it is the most relevant for human societies.

Mountains are a key source of water for human consumption and economic use (irrigation, hydropower and industry) both within mountain regions and in downstream lowlands.

Headwaters are the most sensitive aquatic ecosystems, the focal point of mountain landscapes, supporting unique plant and animal communities and determining the quality and quantity of lowland rivers (Lowe and Likens 2005). In the last decade, growing attention has been demonstrated by the scientific community to the headwater lotic ecosystems, increasing the knowledge for a better preservation of their functionality. Integrity of freshwater ecosystems is becoming a priority request (Leopold et al. 1964, Brittain and Milner, 2001), also considering that the rate of biodiversity decline is five times faster in freshwater ecosystems than in terrestrial and marine ones (Ricciardi & Rasmussen 1999). There is growing evidence that the water quality, biodiversity, and ecological health of freshwater systems depend on functions provided by headwater streams (Kiffney et al. 2000; Peterson et al. 2001; McGlynn and Seibert 2002, Lowe and Likens 2005). High levels of habitat diversity, among and within these small streams, create niches for different organisms, including headwater-specialist species of aquatic invertebrates, amphibians, and fishes. Headwaters also act as refuge for riverine species during specific life-history stages and critical periods of the year, such as warm summer months (Lowe and Likens 2005). Headwaters are critical habitats for rare and endangered freshwater species and healthy ecosystems can supply primary services and goods useful to the human population survival and development (Meyer et al. 2003, Sounders et al. 2002).

Natural rivers are dynamic and complex systems based on different and specific relationships (Tockner and Stanford, 2002, Tockner et al. 2003, Lovett et al. 2005). Freshwater ecosystems exhibit a set of physical (water temperature, current velocity, flow regime, substrate stability and heterogeneity, etc.), biological (riverine vegetation, zoobenthos, fishes, etc.) and chemical (dissolved oxygen, turbidity, suspended solids, conductivity, etc.) characteristics, as well as spatial and temporal variability, which together give the support to the communities and deliver ecosystem services and goods. Therefore the integrity of freshwater ecosystems must be considered as the sum of the integrity of each element (Toth 1995, Allan 1995, Arscott et al. 2002) (Fig. 1.1).

A good level of integrity of the ecosystem has structural complexity, and as consequence higher biodiversity. The main characteristics of functional and healthy freshwater ecosystems can be resumed in:

- natural flow regimes;
- connectivity;
- water quality;
- biodiversity.

The natural flow regime (movement of water and sediments) can be considered a “master variable” that limits the distribution and abundance of riverine species and regulates the ecological integrity of flowing water systems. Five critical components of the flow regime regulate ecological processes in running water ecosystems: magnitude, frequency, duration, timing, and rate of change of hydrologic conditions. The natural flow of a river varies on time scales of hours, days, seasons, years, and decades (Poff et al. 1997).

Connectivity of the four dimensions of running waters (longitudinal, lateral, vertical and temporal) is one of the main elements enhancing the existence of a well diversified patchy habitat (Ward 1992, Ward 1994). Connectivity among each suitable habitat allows the structure and the quantity of microhabitats to develop and promote the existence of food webs and the availability of refuges (from predators and environmental constraints).

The water quality of riverine ecosystems is determined by the geology, climate, and human activities in the drainage basin. Water quality can be measured in terms of suspended sediment, dissolved oxygen, dissolved solids, nutrients, toxins, and temperature.

The biodiversity is an important indicator of functionality and health of ecosystems (Loreau et al, 2001; Giller et al, 2004; Gessner et al. 2004, Hooper et al, 2005; Balvanera et al, 2006) and is related to the ecological processes in the community, as competition (Tilman, 1996), predation (Wimp and Whitham 2001, Raffaelli et al. 2002) and production (Tilman, 1996; Dodson et al. 2000; Mittelbach et al. 2001). Thus biodiversity is a fundamental indicator of the stability of the community (Ives et al. 2000; Carr et al. 2002; Clark and McLachlan 2003). Biodiversity in river corridors is structured along longitudinal, lateral and vertical dimensions (Ward 1989). Various concepts predicting species diversity along river corridors have been developed (Vannote *et al.* 1980; Statzner and Higler 1986; Ward and Stanford 1995; Stanford et al. 1996). One of the first theories was the Stream Zonation Concept (Illies and Botosaneanu 1963), which defined a series of distinct communities along rivers, separated by major faunal transition zones (e.g. the rhithral–potamal transition). The River Continuum Concept (Vannote et al. 1980) followed a more ecolgical perspecitive and proposed maximum biodiversity in middle reaches, where environmental heterogeneity is expected to be maximized. Statzner and Higler (1986) suggested that maximized biodiversity is linked to hydraulic changes associated with geomorphologic transition zones. In extension of the serial discontinuity concept (SDC), Ward and Stanford (1995) included the interactions between the river channel and its flood plain (i.e., lateral dimension). They proposed greatest diversity in transition zones between constrained and braided sections and in the meandering reaches. Stanford et al. (1996) suggested a more complex and extended model, which predicts maximum diversity in floodplain reaches and lowest diversity in geomorphologic transition zones. Spatial and temporal variation in taxa richness, abundance and dominance are important attributes of biotic communities (Arscott et al. 2002, Rosenzweig 1995). Spatial variation could be attributed to habitat characteristics (Brown et al. 1995) while temporal variation in community assemblages can be influenced by habitat seasonality, organism phenology and disturbance (for the stability of community structure and function). Biodiversity and biological integrity includes structure and diversity of benthic fauna and riparian vegetation.

The relevance of riparian vegetation is related to its role as buffer strip between water and land. Riparian strips provide protection of the channel from erosion, they filter surface and subsurface flow from adjacent uplands, provides shade that curbs excessive growth of aquatic macrophytes and regulates water temperature. Furthermore they represent migration corridors for vertebrates and invertebrates and provide important ecosystem goods as denitrification of diffused nitrogen loads (Peterson et al. 2003, Maiolini and Bruno 2007). The presence of macroinvertebrate taxa within streams reflects their ability to withstand disturbance (resistance) and to recover from disturbance (resilience). Resistance elements include physiological adaptations to flow and habitat variability, whilst resilience adaptations include traits such as different life cycle timings, allowing avoidance of unfavourable conditions. Benthic macroinvertebrates (diversity and structure of the invertebrate communities) can be used as indicators of water quality in streams (Gaufin and Tarzwell 1952, Bass and Harrel 1980, Resh and Rosemberg 1993). In order to protect and maintain natural populations of most large freshwater species, we must ensure the integrity of the natural food web to which those populations belong.

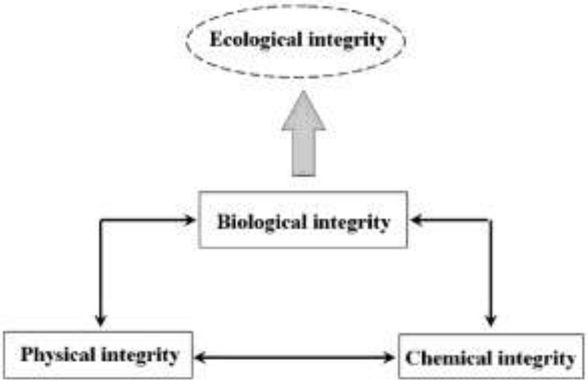


Fig. 1.1.:Model of ecological integrity modified by Resh and Rosemberg 1993

.1. **THE ALPINE LOTIC ECOSYSTEMS*.***

The expression "alpine streams" refers to running waters, flowing between the tree-line and perennial snow. These streams are generally very cold with a turbulent natural flow. Consequently, they are caracterized by a high concentration of dissolved oxygen and substrates are essentially constituted by rocks, pebbles and gravel. Due to the timing of snow and glacier melt, these streams can change their flow regime and the related physical-chemical parameters.

Early studies on the fauna of alpine headwater were performed by Otto Steinböck (1934) and August Thienemann (1936), Kownacka and Kownacki (1975). In the 1990s further studies were carried out in the central-western Alps (Piedmont–Italy and Canton Bern, Switzerland) (e.g., Boggero et al. 1996; Boggero and Nobili 1998; Fjellheim et al. 2000; Lods-Crozet et al. 2001; Burgher 2002; Burgherr and Ward 2001) and in the central-eastern Alps (Trentino-Alto Adige, Italy and Austria) (e.g., Kownacki and Kownacka 1994; Füreder et al. 2001; Maiolini and Lencioni 2001). Notwithstanding its importance, the alpine biome remains to date one of the least studied ecosystems in the world (Bowman and Seastedt 2001).

Many studies have concluded that macroinvertebrate assemblages in streams are closely related to local scale habitat characteristics such as current, substrate, and temperature (Minshall 1984; Allan 1995; Richards et al. 1997; Downes et al. 1998; Minshall and Robinson 1998; Voelz and McArthur 2000; Burgherr and Ward 2000; Melo and Froehlich 2001; Sponseller et al. 2001).

Alpine basins contain multiple water sources so they have been considerated as very complex systems. Water sources such as glaciers, snow, and groundwater act as hydrological stores. Sediment can be eroded, transported and deposited; energy exchanges can affect water temperature. Physicochemical reactions and the mixing of water from various sources can result in water quality variations (Smith et al. 2001). Hydrological regime, water quality and channel geomorphology are the most important parameters that limit the distribution and abundance of riverine species and they vary with stream typology (Poff and Ward 1989; Karr 1991, Cortes 1992; Death and Winterbourn 1995). Consequently, stream communities have to resist and respond to a wide range of dynamic physical processes. In general there is a reduction of biodiversity in running waters from low to high elevation stream traits. This, however, is strongly dependent from primary water sources.

.1.1. ALPINE STREAM TYPOLOGIES.

Interest in high mountain streams and their fauna was high at the beginning of the 20th century (Steinmann 1907, Thienemann 1912, Steinböck 1934, Dorier 1937), most later studies dealt principally with hydrology, glaciology, geomorphology and physical-chemical attributes (e.g. Gurnell and Fenn 1985; Röthlisberger and Lang 1987; Prowse 1994; Gurnell et al. 1999). In contrast, comprehensive studies examining longitudinal distribution patterns of alpine benthic communities are few (e.g. Saethe 1968; Steffan 1971; Kownacka and Kownacki 1972; Kownacki 1991), and typically of limited duration or intensity.

In the past, alpine streams have been grouped in three general stream biotypes; *kryal*, *rhithral*, and *krenal*, based on their origin (glacial, snowmelt, rain and groundwater fed) (Milner and Petts 1994; Ward 1994; Malard et al. 1999; Ward et al. 1999; Füreder et al. 2001). The physical and chemical characteristics of these stream tipologies change downstream of their origin, and the most important drivers are water temperature, substrastre stability, flow regime and solid transport. In particular, temperature ranges play a priority role in defining faunal distributions (Steffan 1971; Ward 1994).

Glacier-melt-dominated streams (*krya*l) occur at high altitude close to the glacier terminus and have the lowest water temperatures.

Downstream of the kryal segment, a *glacio-rhithral* zone, fed by a mixture of water sources, can extend for a considerable distance, with temporal changes in discharge and temperature, reflecting the relative proportion of glacial influence (Füreder 1999). During periods of favourable environmental conditions (spring and late autumn/early winter), invertebrate density and taxa richness peak, and cold-adapted taxa other than Diptera Chironomidae Diamesinae can occur close to the glacier terminus. Such periods are characterized by (i) highly stable stream beds (Füreder 1999, Maiolini and Lencioni 2001), (ii) minimal sediment transport, shear stress and turbidity (Uehlinger et al. 1998), and (iii) accompanied accrual of benthic algae, especially the chrysophyte *Hydrurus foetidus*, enhancing food availability for zoobenthic organisms.

In alpine regions, these zonations are generally applied to headwater streams that lie between the permanent snowline and the tree line (Brittain and Milner, 2001). Alpine lake outlets may be ascribed to a subclass of rhithral or kryal typologies (Uehlinger et al. 1998).

Glacial streams are characterized by (i) year-round low temperatures (Tmax 4 °C) (Füreder 1999, Ward 1994, Smith et al. 2001), (ii) large flow fluctuations in summer with peaks in late afternoon due to glacial melting (Church 1987; Röthlisberger and Lang 1987; Hannah et al. 2000a), (iii) highly turbid water from suspended sediments due to glacial scouring and (iv) usually low channel stability close to the glacier, with frequent channel-shifting disturbances (Milner and Petts 1994), but with increasing stability downstream (Milner and Petts 1994, Burgherr and Ward 2001). Synthesizing the available literature on the ecology of glacial-fed streams, Milner and Petts (1994) proposed a qualitative model that relates longitudinal gradients of zoobenthic communities to temperature and channel stability; both being a function of distance from the glacier terminus and time since deglaciation. Close to the glacier, where summer temperatures typically do not exceed 2 °C, chironomids of the genus *Diamesa* generally dominate, or are the sole animals found. Where maxima temperatures are between 2 and 4 °C, other Diamesinae, Orthocladiinae and Simuliidae are typically present. When water temperatures exceed 4 °C, Baetidae, Nemouridae and Chloroperlidae colonize glacial streams. Further downstream, other Ephemeroptera, Plecoptera and Diptera, as well as Trichoptera, are predicted to appear. Kryal streams are usually subdivided into an upper *metakryal* and lower *hypokryal*.

Rhithral, or seasonal snowmelt and rainfall fed streams, are characterized by intermediate conditions between kryal and krenal (Ward, 1994). The rhithral streams are usually located below the permanent snowline with maximum temperatures reaching between 5 and 10°C (Ward 1994, Poff and Ward 1989). In the Northern Hemisphere, snowmelt-dominated regimes generally show discharge peaks in spring before occurance of glacial runoff, although at high altitudes the peak may be delayed until as late as July (Milner and Petts 1994). A receding snowline and shrinking snow packs during late spring and early summer reduce the influence of snowmelt on alpine stream hydrology (Smith et al. 2001). Normally, snowmelt-dominated streams are very clear and transport little sediment. However, during high flows, they may have high turbidity due to resuspension of fine sediments from the streambed (Milner and Petts 1994). Peaks in stream solute load occur during snowmelt as a result of preferential elution of ions from snow packs (Johannessen and Henriksen 1978; Tranter et al. 1987; Helliwell et al. 1998). Macroinvertebrate communities of these ecosystems are represented by Diptera Chironomidae, Ephemeroptera Baetidae and Heptageniidae, and Plecoptera, specially belonging to Nemouridae, Chloroperlidae, Perlodidae and Leuctridae families. A limited fish fauna may be present, represented above all by Salmonids.

Krenal streams are the watercourses fed by springs and groundwater. They are characterized by stable physical and chemical conditions, by clear waters, and have a constant flowing regime through the year that determine a very stable riverbed. Annual temperatures variations do not exceeded 1-2°C and therefore these streams have a cold winter character. This implicates that in winter they can also be free from ice for long distances from the source, with consequent growth of great quantities of algae and mosses and a zoobenthic community including Plecoptera, Ephemeroptera, Tricoptera, Diptera, Turbellaria, Acarina, Oligochaeta and Nematoda.

Recently, Brown et al. (2003) reviewed the traditional classification system. They suggest nine categories, giving qualitative explanations of the stream type, based on their relative proportions of source waters. Variations in environmental characteristics, with a relevant role of the flow regime changes in each typology, can be equally predicted within the nine categories (Table 1.1). The classification may also be used to describe changes in streams with increasing distance from glacier margins.

Typology	Suspended sediments Concentration	Hydrochemistry	Channel stability	Flow variation
Krenal	Constantly very low <10 mg L^{-1}	High silica, bicarbonate and sulphate	Very stable, straight or gentle meanders, single thread	Constant flow with little diurnal variation
Kreno-nival	Low but >krenal as snowmelt may contribute a small amount	High silica (<krenal) and relatively high chloride (<nival)	Stable, single thread and meandering or straight	Relatively constant flow. Small diurnal variation from snowmelt input
Kreno-kryal	Low concentration due to groundwater dilution. Small diurnal variation likely	High silica (<krenal) and relatively high calcium and sulphate (<kryal)	Relatively stable but glacial sediment inputs may result in some braiding	Base flow relatively constant but glacial influence may cause diurnal variation
Nivo-krenal	Low but slightly <kreno-nival due to greater proportion of snowmelt	High chloride <, nival) and relatively high silica (<krenal)	Stable as low sediment inputs and low discharge variation	Diurnal variations due to snow input (>kreno-nival)
Kryo-krenal	Relatively high but glacial source dominant	High sulphate (<kryal) and silica (<krenal).	Relatively low channel stability due to dominance of glacial source	Glacial source dominant so fairly pronounced diurnal variation
Nival	Low but >krenal. Very low diurnal variation.Possible increase when high flows)	High chloride and nitrate from snow pack elution. Low silica	Typically more stable than kryal	Diurnal cycle <kryal. Building toward late afternoon/early evening
Nivo-kryal	Elevated levels compared to nival due to glacial influence. Diurnal variations	High chloride as snow dominant (, nival) Relatively high sulphate. Low silica	Relatively stable but glacial sediment inputs may result in some braiding.	Diurnal peak intermediate between nival and kryal. <kryo-nival as snow dominant
Kryo-nival	High but <kryal. Pronounced diurnal variations	High sulphate as glacial melt water source dominates. Relatively high chloride and nitrate	Unstable channel. Variety of channel forms as glacial input dominant	Pronounced diurnal peak intermediate between nivokryal and kryal
Kryal	Very high during peak flows with large diurnal range	High sulphate and calcium, low chloride and silica	Very low channel stability. Frequently braided or wandering	Large diurnal cycle related to solar radiation input. Peak late afternoon

Table 1.1: Characteristic physical and chemical variables expected for alpine stream categories based on relative proportions of source water contributions. (Modified by Brown et al 2003).

The outlets of alpine lakes are defined as zones of longitudinal transition among lentic and lotic environments. Usually lakes have a buffer effect on the variations of temperature of the outlets and this can enhance nutrient richness and plankton development and thus an abundance of filtering invertebrates. Normally these streams, compared with the "not-outlets" have higher maxima temperatures, higher annual day-degrees and lower daily temperature variations.

In relation with the typology of the tributaries, outlets can be classified as subclasses of rhithral or kryal. The rhithral outlets show a very stable river bed that fosters a good development of algae and above all of mosses, and therefore a good autotrophic production. The most common invertebrates in this environment are the chironomids and non insect taxa (Oligochaeta, Nematoda and Crustacea Copepoda). The kryal outlets are still influenced by glacial streams; consequently, they show less stable river bed and chemical-physical parameters. Alpine lakes are generally of small dimensions and they strongly influence their outlets.

Some studies demonstrated that the range of spatial-temporal patterns in environmental conditions markedly affect the composition of benthic stream communities in Alpine streams (Milner and Petts 1994, Ward 1994). Species distributions are influenced by elevation and stream typology (Ward, 1994; Sartori and Landolt, 1999) and are related to physical-chemical characteristics (Fig 1.2). Water temperature has long been recognized as a major driver of stream community structure and functioning (Hynes 1970; Vannote and Sweeney 1980; Vannote et al. 1980; Sweeney 1984; Ward, 1985). In glacial streams, water temperature plays a primary role in structuring benthic communities (Milner and Petts 1994, Milner et al. 2001). At the level of individual organisms, water temperature controls growth rates, the timing of life cycles, and rates of primary and secondary production (Hynes, 1970; Allan, 1995). In alpine streams, water sources have a primary influence on water temperature, although climatic factors, such as solar radiation input, can also play an important role. Because stream water temperature may be influenced by factors other than the source, classifying streams on the basis of temperature alone is problematic. In addition, water sources impart a range of other physical and chemical properties that are discussed by current classification approaches (e.g., Ward 1994) but rarely used in practice. Even where water temperature is suitable, channel and bed stability may still inhibit colonization by some taxa (Milner and Petts 1994). For this reason, stability must be considered in conjunction with water temperature when evaluating community composition of glacial rivers (Milner and Petts 1994; Milner et al. 2001). Channel stability is related to channel slope, substratum composition, and stream power (Resh et al., 1988). The increased sediment loads that couple with high flows, and that are characteristic of glacial streams (Gurnell 1987, 1995), may directly affect stream communities through abrasion and reduced light penetration (Castella et al., 2001; Milner et al., 200, Brittain et al 2003).

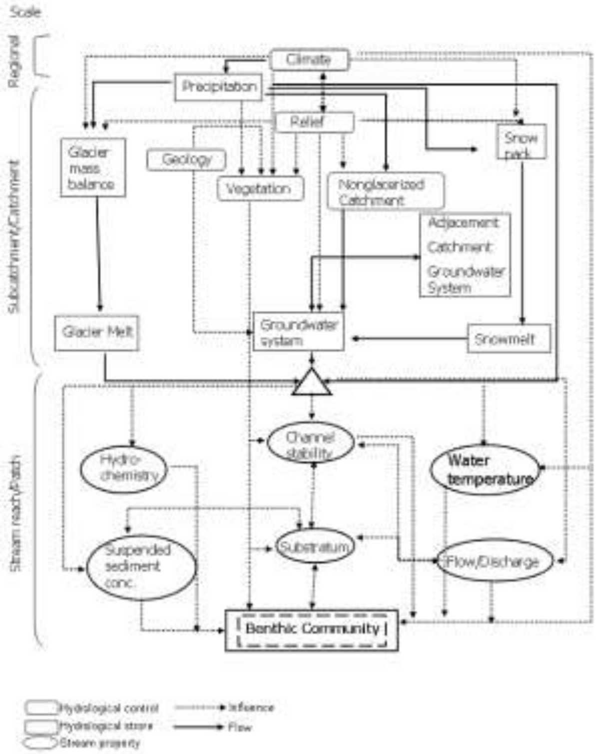


Fig. 1.2: Scheme of a conceptual model of the environmental variables influencing benthic communities in alpine streams at different spatial scales. (modified by Brown et al. 2003).

Harsh environmental conditions of glacier-fed streams result to be highly selective for macroinvertebrate communities. Thus, in particular, benthic stonefly communities are usually less diverse in glacial streams than in non-glacial ones (Brittain et al 2000, Ward 1994).

The milder environmental conditions of non-glacial streams (characterised by transparent and cool waters, with low discharge and low current velocity fluctuations during the day) allow the development of a more diverse and abundant invertebrate community. In these streams dissolved oxygen is generally fully saturated and carbon dioxide concentration can be very high, favouring the development of algae, mosses and liverworts. (Maiolini and Lencioni, 2001).

.1.2. THE HYPORHEIC HABITAT

The hyporheic zone can be considered as a surface-subsurface hydrological exchange zone along which stream water downwells into the sediment, travels for some distance beneath the stream, eventually mixes with ground water, and then returns to the stream (Bencala 2000). From a more ecological perspective it is defined as a dynamic ecotone between surface and ground water (Gibert 2001, Ward et al, 1998); it may be also considered as: ”the saturated interstitial area below the bed of the stream and inside the shores that contain water of river bed” (Ward et al, 1998). As well as extending vertically below a stream, the hyporheic zone reaches laterally into the sediments beside the stream and the floodplain into the parafluvial zone (Stanford and Ward, 1993). Hydrological, chemical and faunal exchanges occur over a wide range of spatial and temporal scales between the hyporheic and neighboring surface, groundwater, riparian, and alluvial floodplain habitats (Boulton 1998, Boulton et al. 1998, Gibert et al 1994a). Anthropic alterations, including soil use and water use for hydroelectric power generation, strongly affect the dynamic balance of hyporheic habitats (Boulton 2000b, Poff et al 1997, Gibert 1992).

The hyporheic systems sustain high densities of meiofauna, with Crustacea, insect larvae, Nematoda, Rotifea, and Oligocheta being the most typical and abundant components (Claret et al. 1999). The structure and diversity of this invertebrate community is strongly dependent from the chemical, physical and biological processes occurring in the hyporheic zone (Dole-Olivier and Marmonier 1992, Strayer et al. 1997, Brunke and Gonser 1999, Fauvet et al. 2001).

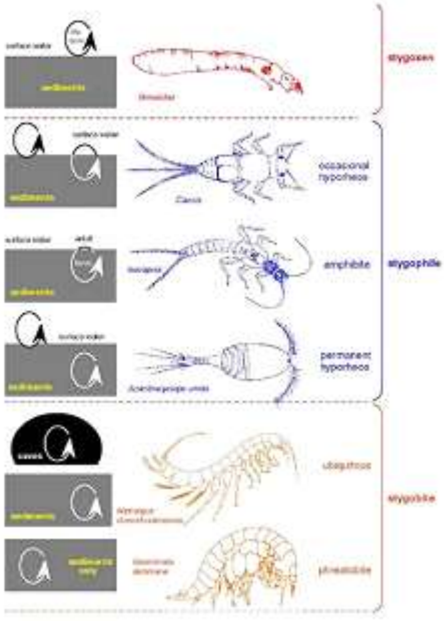


Fig 1.3 classification of groundwater fauna (modified after Gibert et al. 1994b).

Groundwater animal communities comprise species at different stages of adaptation to the subterranean environment. Several classifications of groundwater invertebrates have been used in literature (Thienemann

1925, Christiansen 1962, Bar 1968, Ginet and Décou 1977, Williams and Hynes 1974, Culver 1982, Holsinger 1988, Holsinger and Culver 1988). The classification presented below (Marmonier et al. 1993, Gibert et al. 1994b, Claret et al. 1999) is one of the most diffused. It is organised according to the preferred habitat and resultant behavioural, physiological and morphological features. Three ecological categories are distinguished.

Stygoxenes are organisms that have no affinities with groundwater systems, where they occur only accidentally (Fig.1.3). Stygophiles are further subdivided into three categories. The occasional hyporheos consists mainly of benthic insect larvae, the early instars of which reside in the hyporheic zone. However, the use of the hyporheic zone is not necessary because individuals of the same species can also spend all their life in the surface environment. Amphibite species include a taxonomically variable group of stoneflies, whose life cycle is dependent on the use of both surface and ground water systems (Stanford and Gaufin 1974). The permanent hyporheos consists of many species of Nematoda, Oligochaeta, Copepoda, Ostracoda, Cladocera and Tardigrada that can spend all their life cycle either in subsurface water or in surface water. Stygobites are specialised subterranean forms that complete their whole life cycle exclusively in subsurface water. Stygobite species can be restricted to the phreatic zone in unconsolidated sediments (i.e. phreatobites) or they can exhibit a much wider habitat distribution (e.g. ubiquitous stygobites living in the phreatic zone of unconsolidated sediments, karst ground water, and the hypotelminorheic biotope).

Stygophiles encompass a number of species that actively exploit the resources of the groundwater environment for part of their life cycle.

Plecoptera belonging to the occasional or amphibitic hyporheos (Stanford and Ward 1993). For this taxon, the hyporheic habitat represents a refuge from unfavourable situations in the surface environment, a nursery or a preying area for carnivore taxa. (Williams 1984, Boulton 2000a).

The hyporheic habitat of alpine streams has a key-role for conservation of macrobenthos (Maiolini and Lencioni 2000b, Milner and Petts 1994, Ward 1994). Anthropic alterations as soil use and water use can strongly affect the dynamic balance of the hyporheic habitat (Boulton 2000b. Poff et al 19997, Gibert 1992). The most common disturbance following hydropower generation is clogging; (= obstruction of interstices and a consequently loss of microhabitat and functions such as refuge area for many stigobites and stygophile species). The hyporheic habitat of high altitude alpine streams is still poorly known, notwithstanding its key-role for conservation of macrobenthos (Maiolini et al. 2008, Milner and Petts 1994, Ward 1994).

.1.3. SPRING ECOSYSTEMS

Springs are a natural outflow of groundwater that may create a lotic, lentic or wetland environment. They represent one of the main running water typologies, they constitute an interface between surface and groundwater ecosystems (Webb et al. 1998) and are geographically and functionally relatively isolated from each other (Williams and Williams 1998, Botosaneau 1998, Glazier 1998, Smith at al. 2003). Springs are a common feature of many alluvial flood plains and consequently play an important role in the ecology of the alluvial riverine landscapes (Stanford 1998, Arscott et al. 2000, Burgherr et al. 2002, Ward et al. 2002).

Springs have been differently classified according to their hydrogeology, physicochemistry, faunal and source characteristics (Zollhoefer et al. 2000). The most universally accepted classification was proposed by Steinman (1915) and modified by Theineman (1924) using the terms rheocrene, limnocrene, and helocrene.

The rheocrene, or gushing spring, discharges directly into a stream channel, often forming a distinct stream source; limnocrenes, in contrast, have lentic headwaters, discharging into pools, which may or may not have an outflowing, rheocrenal stream. Finally, helocrenes are characterised by diffused up-welling over boggy or marshy ground (Lindegaard 1998). The three classes are frequently subdivided using a further descriptor, such as a thermal rheocrene (Hayford and Herrman 1998) or alluvial rheocrene (Zollhoefer et al. 2000). According to the “sandglass” model proposed by Cantonati and Ortler (1998), springs can be considered the lowest point of the subterranean hydrographical system and are the origin of surface hydrographical systems (Spitale et al. 2007). Other classifications are based on different physical-chemical parameters, such as temperature classification that groupes springs in thermal (Hayford and Herrman 1998), cold (Erman 1998) and variable (Smith et al. 2003).

The composition of spring macroinvertebrate communities is shaped by historical and geographical factors (Williams and Williams 1998), and by environmental characteristics, including geology (Bonettini and Cantonati 1996), flow permanence (Smith et al. 2003), pH (Glazier 1991), alkalinity and macrophyte cover (Glazier and Gooch 1987). Stable characteristics of the springs provide species-specific conditions, comprisig species diversity and life cycles.

Therefore, any change in species assemblages (e.g. presence or absence) may be interpreted as the effect of external factors (i.e. anthropogenic factors) or species introduction to these habitats. Such physical differences amid these springs also cause differences in chemical and biological structure in each type, resulting in different species assemblages. As such, and due to the relatively limited number and distribution of springs, they support a variety of relatively rare and unusual fauna (Percival 1945, Glazier 1991, Di Sabatino et al. 2003). They provide refuges from disturbance events, a source of colonizers and a permeable ecotone for the interaction of phreatic and surface communities (Stanford and Ward 1988). The benthic invertebrate communities of springs exhibit some recurring, although rarely universal, patterns. At the spring source, communities may be dominated by crenobionts and crenophilus species. Crenobionts comprise immigrants from aquifer dwelling populations, or surface-water species restricted by physical-chemical factors to spring habitats. Further downstream of the spring brook, lotic, lentic and ubiquitous species become more prominent (McCabe 1998).

In the harsh environmental conditions of the Alps, the mild ecological conditions that frequently characterize spring brooks, contribute to maintain and enhance biodiversity. In fact they act as refuge areas for stream biota that here find better conditions during spates or draughts or during particular moments of their life cycles or as specific habitats for strict crenobiont species. The biology of springs is only known from a few areas in the Alps and further research is needed to expand our knowledge on the regional composition and structure of spring biological communities (Cantonati et. al 2006). Adequate knowledge of the biodiversity and habitat structure of different spring types, as well as the habitat preferences of rare and threatened species, is essential for the conservation of springs.

.2. ANTHROPIC USE OF WATER; THE HYDROPOWER PLANTS AND THEIR IMPACTS.

Alpine streams play an important role in river systems throughout the world (Boon 1988, Füreder 1999, Cortes et al. 2002,Robinson et al. 1992, Robinson et al. 2004), and may be more affected by global climate change and anthropogenic impacts than mountain streams at lower altitude (Chapin and Koérner, 1994;

McGregor et al., 1995). Hydropower generation has high economical relevance because it provides the most important renewable and gas free electricity generation with clear advantages for the global CO_2 balance. Today, there are 945000 dams higher than 15 m, with a total capacity of 96500 km^3 of water, or about 15% of the total annual river runoff globally (Nillson et al. 2005). In Alpine regions hydropower plants provide most part of the local energy request. This, however, is often counterbalanced by a strong impact on the ecological integrity of alpine freshwater ecosystems.

The stream longitudinal connectivity is altered by the three phases of hydroelectric power production: water abstraction or diversion, stocking in reservoirs, and release of turbinated water to the channel, starting from high altitude streams (Boon 1988; Brittain and Saltveit 1989; Petts and Bickerton 1994, Troelstrup and Hergenrader, 1990; Morgan et al. 1991; Moog 1993, Cobb et al., 1992, Poff and Hart, 2002). The resulting effects have been reported on abiotic (temperature and hydrological regimes, chemistry, solid transport, etc.) and biotic (disruption of drift, isolation of populations) features of the stream (Armitage, 1984; Gibert 1992, Brittain and Saltveit, 1989; Cereghiño and Lavandier, 1998a, 1998b; Boulton 2000b Cortes et al., 2002). Operation of power plant is followed by sudden, frequent and severe changes in discharge, current velocity, turbidity, streambed stability, and temperature, which represent changes in stream typology, and are completely different from those induced by natural variation of flow regime (Cushman 1985; Allan and Flecker 1993; Poff et al 1997, Maiolini 2006).

Benthic communities are impacted by water abstraction/diversion and reservoirs, and also by the release of turbinated waters (hydropeaking). The loss and the isolation of habitats can reduce species diversity and change community composition through a variety of processes (Klein, 1989; Newmark, 1991; Saunders et al., 1991; Robinson et al., 1992; Andren, 1994; Margules et al., 1994; Zwick, 1992; Allan and Flecker, 1993; Dynesius and Nilsson, 1994; Ward and Tockner, 2001).

II. ORDER OF PLECOPTERA

.1. ORDER OF PLECOPTERA: EVOLUTION, MORPHOLOGY AND ECOLOGY

Plecoptera are a small order of Insects with more than 3400 described species in the world and constitute a significant ecological component of running water ecosystems (Fochetti and Tierno de Figueroa 2008). Approximately 650 species have been described in North America (Stark and Baumann 2005), and 95 and 378 species are present respectively in Central and South America (Heckman 2003). Europe hosts a total of 426 species (Fochetti and Tierno de Figueroa 2004), while 126 species are present in Africa (31 from Mediterranean areas with 12 endemic species, 50 from tropical Africa, 33 from South Africa and 12 from Madagascar island). In Asia a total of 1527 species have been described, with many endemic species restricted to small areas (Sivec et al 1988, Yang et al 2004, Shimizu 2001). In Australia and New Zealand 191 and 104 species have been described respectively (Michaelis and Yule 1988, McLellan 2006).

The order name Plecoptera derives from the Latin *pleco*, meaning plaited, braided, or folded, and the Greek *pteron*, meaning feather or wing, and refers to the ability of adults to fold their wings on their back. Taxonomic classification of Plecoptera:

Kingdom: Animalia
  Phylum: Arthropoda
    Subphylum: Hexapoda
    Class: Insecta
    Subclass: Pterygota
    Infraclass: Neoptera
    Superorder: Exopterigota
    Order: Plecoptera Burmeister 1839
    Suborder: Arctoperlaria
      Antarctoperlaria

Stoneflies constitute an important ecological component of running water ecosystems (Cushing and Allan 2001) both as biomass and as diversity of ecological roles (primary or secondary consumers and prey for other macroinvertebrates and fishes) (Hynes 1956, Illies 1966, Zwick 1973, Baumann et al. 1977, Zwick 2000). Their fossil records extend back into the Permian, about 250 million years ago. Baltic amber from the Miocene (38-54 million years ago) has preserved specimens of several exstinct families (Zwick 2000). While the area of origin of Plecoptera is unknown, the suborder names Antarctoperlaria and Arctoperlaria suggest the distributions of the suborders. Thus, Arctoperlaria occur throughout the Northern hemisphere and Oriental region with a family, Perlidae, widely reaching into the Southern hemisphere and an other one, Notonemouridae, exclusively distributed in the Southern hemisphere. Antarctoperlaria are generally distributed across the Southern hemisphere, but do not have representatives in the Northern hemisphere. The breakup of the landmass Pangea had a major role in the distribution of suborders.

Stoneflies have been the object of scientific studies for a very long time, with the first species being described by Linnaeus in 1758 and placed within the genus *Phryganea* of the Trichoptera. Burmeister first proposed the order name Plecoptera in 1839. Plecoptera constitute a monophyletic group within the Neopterous (wings folded flat over back) insects and have recently been reviewed by Zwick (2000). This overview primarily follows Zwick (2000) but much of the phylogeny of Plecoptera is under debate and alternative phylogenies have been proposed (Nelson 2005, Thomas et al. 2000, Uchida and Isobe 1989;

Zwick 1973).

Plecoptera are hemimetabolous insects (incomplete metamorphosis with no pupal stage) with aquatic nymphs and winged terrestrial adults. Stonefly nymphs moult from 12 to 33 times (Hynes 2000) and may be univoltine (one generation per year), or semivoltine (one generation every 2 or 3 years), and only exceptionally multivoltine (more than one generation per year) (Hynes, 1976). Water temperature and other environmental factors control the rate of growth and development. Some species are euriecious and occupy a wide range of habitats, other have strict ecological demands and thus are restricted to specific habitats. Behavioural drift rates in Plecoptera nymphs are relatively low, but catastrophic drift can occur in relation to anthropic disturbances.

As regards morphology, the nymphs have a distinct head, thorax and abdomen (Fig. 1a and b). The head contains the mouthparts and sensory structures (long antennae and simple and compound eyes). The thorax is composed by the prothorax, mesothorax and metathorax, each bearing a pair of legs (composed of five segments: coxa, trochanter, femur, tibia and tarsus). The dorsal surface of the meso- and metathoracic segments bear wing pads in the mature nymphs. The abdomen is composed by 10 segments (urites) with vestiges of the eleventh, and at the end of the last urite there are two long cerci (“tails”).

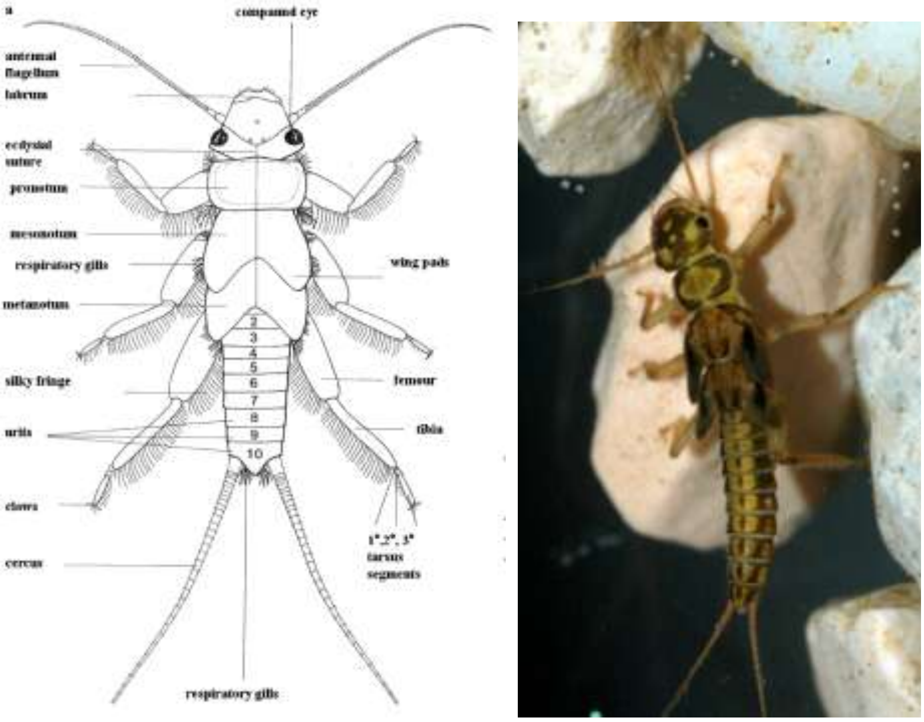


Figure 1: **a**) Habitus of nymphs of Plecoptera (modified by Campaioli et al. 1987 **b)** Nymph of *Isoperla* sp. *(photo by B. Maiolini).*

Emergence of Plecoptera species requires the right cues (i.e. temperature, day length, and growth hormones). Emergence of a generation may occur rapidly within a short time period (synchronous), may last several weeks (extended), or may take place at nearly any time of the year (asynchronous) (DeWalt and Stewart 1995). Nymphs migrate to the stream margins and climb on an emerging surface. This last nymphal stadium ends when the nymphal skin splits and the imago emerges from the top of the thoracic segments.

Adults (Fig. 2a and b) generally have a terrestrial short life (from several days to some weeks). For example, some winter species have longer longevity than spring ones (DeWalt and Stewart 1995). Usually they feed on pollen, lichens, cyanobacteria, etc, although some big-sized species do not ingest food during the imaginal stage (Tierno de Figueroa and Fochetti, 2001). Adults exhibit a complex mating behaviour, usually employing vibration calls (produced by drumming, rubbing, tremulation or combination of them) (Stewart 1994). Dispersion ability varies widely among species; some remain close to the stream, others fly away for several meters from emerging place. Oviposition occurs by flying over the waterbody and dropping an egg mass, or by crawling to the shoreline and dipping the abdomen and egg batch into the water. Less frequently, eggs are laid singolarly.

Zwick (1973; 2000) has recognized 16 families within two monophyletic suborders, the Antarctoperlaria and the Arctoperlaria. The Antarctoperlaria has a Southern hemisphere distribution and comprise four families: Austroperlidae, Diamphipnoidae, Eustheniidae, and Gripopterygidae. The Arctoperlaria include 12 families: Capniidae, Chloroperlidae, Leuctridae, Nemouridae, Notonemouridae, Peltoperlidae, Perlidae, Perlodidae, Pteronarcyidae, Scopuridae, Styloperlidae, and Taeniopterygidae. All Arctoperlaria occur in the Northern hemisphere, with the two exceptions: Notonemouridae, which is found only in the Southern hemisphere, and Perlidae, which is found in both hemispheres.

A total of seven families, 34 genera, and 426 species, are present in Europe (Fochetti and Tierno de Figueroa 2004). The greatest species diversity occurs within Leuctridae and Nemouridae families, with nearly 62 percent of the total European species (Fochetti 2004). The species belonging to the genera *Nemoura*, *Protonemura*, and *Leuctra* are the most prevalent in the Southern countries of Europe (Fochetti 2004).

In Italy, first researches on Plecoptera were conducted by Antonio Festa, followed by the outstanding contribution of Carlo Consiglio (until the beginning of the eighties). From the seventies to now, Carlalberto Ravizza and Elisabetta Ravizza-Dematteis made a considerable contribution to the knowledge of stoneflies, mainly in Northern Italy. From the beginning of the eighties, Paolo Nicolai and Romolo Fochetti actively researched on Plecoptera and the latter holds a preminent position in the field of Plecopterologist studies in Italy. More recently, mainly in the present century, other authors as J. Manuel Tierno de Figueroa, Stefano Fenoglio, Tiziano Bo dedicated at least a part of their researches to stonefly biology. All these authors have provided valuable information on taxonomy, distribution and ecology of stoneflies both in the Alps and in the Apennines.

The Italian fauna comprises 157 species of Plecoptera, divided in 7 families and 22 genera. In the Trentino Province a total of 61 species of Plecoptera result from the Ckmap (Ruffo and Stoch 2006), belonging to 6 families and 14 genera.

Species richness and endemisms present in Mediterranean countries (especially Spain and Italy) are probably due to the presence of mountain regions (Pyrenees, Betic system, Apennines, Italian Alps that represent a good environment but also an important barrier for dispersion), and to the effect of glaciations (as favoured factors for isolation and speciation processes) (Fochetti and Tierno de Figueroa 2006). Nevertheless, species richness generally decreases in these countries from North to South (Sanchez-Ortega and Tierno de Figueroa 1996; Fochetti et al. 1998) due to the well-known peninsular effect (Simpson 1964).

Due to the increasing pollution of running waters (from sewage, agricultural, and industrial waste), to habitat fragmentation of streams and the narrow ecological requirements of stoneflies, many species are vulnerable or threatened with extinction. Several of them are in fact reduced to small isolated populations or already extinct (see for instance Ravizza and Nicolai 1983; Zwick 1992; Sanchez-Ortega and Tierno de

Figueroa 1996). As described by Fochetti and Tierno de Figueroa (2006), in Europe the entire stonefly fauna of lowland rivers can be considered threatened. The risk of disappearance of the whole stonefly fauna is shown by ~~a~~ the example of endangered Plecoptera from Italy: 22 species out of 144 are considered threatened of extinction in Italy, islands included (Fochetti 1994), and some species, such as *Brachyptera trifasciata*, *Isogenus nubecula*, *Isoperla obscura*, and *Perla abdominalis* Burmeister, 1839 are considered already extinct in Italy (Fochetti et al. 1998).

Taeniopteryx araneoides (Klapalek, 1902) and *Oemopteryx loewi* (Albarda, 1899), once common in large Central European rivers, are now extinct (never collected in the last 100 years) (Zwick 1992, 2004). *Isogenus nubecula* (Newman, 1839) was exceedingly common in major European rivers, but it was considered extinct from Western and Central Europe since the second half of the 20th century (Zwick 1992). Neverthless, there are recent records of this species from Hungary, Austria, and Slovakia (Juha´sz et al. 1998; Kovács et al. 2001; Derka et al. 2002), but these populations could be isolated and endangered. *Agnetina elegantula* (Klapalek, 1905) is almost extinct in Central Europe as well; this species is presently known from very few localities (Graf 1997; Kovacs and Ambrus 2000). *Marthamea vitripennis* (Burmeister, 1839) is today extinct in most of its geographical range (Zwick 1984a, 2004). Its congener, *M. selysii* (Pictet, 1841), is a rare West European species of lowland rivers, threatened throughout its range; but it has been collected recently in a few localities in Spain (Luzon-Ortega and Tierno de Figueroa 2004). Several other species [e.g. *Brachyptera trifasciata* (Pictet, 1832), *Isoperla obscura*.(Zetterstedt, 1840), and *Brachyptera braueri* (Klapalek, 1900)] have become rare (Zwick 1992).

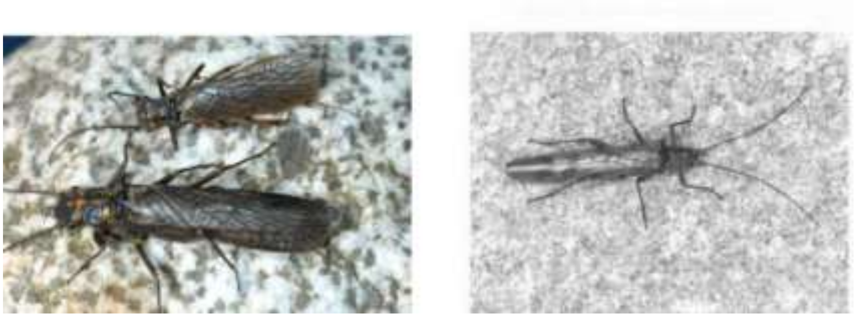


Fig 2a: Adult male and female of Perlodidae (photo *B. Maiolini*) **2b**: Adults of *Brachyptera risi* (from Ravizza & Fochetti 1998).

.2. PLECOPTERA AND IMPACTS OF HYDROPOWER PRODUCTION

When the four dimensions of river connectivity and physical-chemical water qualities are preserved, stonefly communities may occupy most of the available habitats, with a resulting high diversity along the entire stream. Some parameters, as a specific range of water temperatures and high dissolved oxygen, are particularly required by many stonefly species (Ward 1992, Malmqvist 1999, Bradt et al. 1999). The most sensitive species have very specific requirements and are found as isolated, widely scattered populations in unique watersheds, stream types, or habitats (Maiolini and Lencioni 2001, Lods-Crozet et al 2001). These species are normally the most sensitive to disturbance, and are the first to disappear from a region because of anthropogenic impacts. Due to their distribution along the entire length of rivers and to their sensitivity to environmental stress, stoneflies may be used as bioindicators to asses the water quality and aquatic ecosystems health (Consiglio 1980, Metcalfe 1989, Brittain 1991, Fochetti 1994).

Characteristics of macrobenthic organisms that make them especially useful for water quality studies include:

1) long life cycles, which may reflect conditions for an extended period of time,

2) low motility,

3) various ranges of tolerance to changing environmental conditions,

4) occupancy of central positions in aquatic food webs (Keup et al. 1966, Bass 1995). The aquatic ecosystems of high altitude are characterized by an elevated sensibility to different types of natural alterations human induced (Chapin et al. 1994; Brittain et al. 2000) and as such as valid environmental indicators, and for a short and long time environmental danger (McGregor et al., 1995).

Hydropower production produces severe impacts on the ecological characteristics of rivers and streams during the three phases of the production process: abstraction, stocking in reservoirs, and release of turbinated waters to the stream. Several studies assessed the impact of water abstraction and diversion (Brittain and Saltveit 1989; Armitage and Petts 1992), but few focused on the effects of hydropeaking (Cereghiño and Lavandier 1998, Cortes et al. 2002). So it results to be very important improve the knowledge on the effects of the three phases of hydropower production with particular emphasis to the third phase (i.e. hydropeaking), on alpine streams zoobenthos, and on the structure and dynamic of the Plecoptera community. All the three phases of hydropower use of water can strongly affect the Plecoptera community, by the most recent literature effects can be summarize as:

- Alteration of biodiversity and of food webs role of the Plecoptera, upstream and downstream of each interruption (Bradt et al. 1999, Cereghiño and Lavandier 1998)
- Alteration of the life cycle of some stenoecies species due to the alteration of water temperature (Cereghiño and Lavandier 1998, Cortes et al. 2002);
- Alteration of resistance and resilience of communities due to induced catastrophic drift
- Alteration of community structure due to the change of avalaible food sources (Anderson and Cummins, 1979; Moor and Janecek, 1991).

III. SCOPE OF THE RESEARCH

This thesis is based on findings arising from three different projects (CRYOALP, REPORT and CRENODAT) developed within the Natural Science Museum of Trento. The main arguments of this thesis can be summarized as follows:

- review and update of the list of Plecoptera species in Trentino in different freshwater typologies (springs, glacial-crenal and rhithral streams) and in different habitats (benthic and hyporheic habitats);
- analysis of the life cycles of some Plecoptera species living in different habitats;
- analysis of the feeding habits of some Plecoptera species;
- a preliminary study on the environmental impact of hydropower production on the stability of populations, especially on the resistance and the resilience of the communities.

The first project is CRYOALP (Role of the Alpine criosphere in the water cycle, 2003-2006, co-funded by the Italian Institute for Mountain Research IMONT). Within this project the Section of Hydrobiology has focused on the ecology of Alpine glacial streams and the resilience of the benthic communities.

The second project is REPORT (Regulation of flow regimes in hydropower impacted river systems, 2005-2008, co-funded by the Adige Water Authority).

The main focus is the quantification of hydropower impacts on the development of guidelines for a sustainable management.

The last one is CRENODAT (Biodiversity assessment and integrity evaluation of springs of Trentino, 2004-2007, funded by the Autonomous Province of Trento). The role of the hydrobiological section regarded the taxonomy of Ephemeroptera, Trichoptera and Plecoptera.

Other material has been examined from the MTSN collections.

IV STUDY AREA

.1. THE VAL DE LA MARE AND THE NOCE BIANCO STREAM

The Val De la Mare is located in the Northern part of the Pejo valley (Trentino, South-Eastern Alps). The highest elevation is 3769 m a.s.l. (Mount Cevedale) and the lowest is 1160 m a.s.l. (Cogolo). It has a surface of 68 km2 and a length, from the Forcola pass (3032 m a.s.l.) to Cogolo, of 7 km. The geological substrate is represented by metamorphic rocks (paragneiss, micaschists and fillads) derived by a succession of sedimentary rocks. The Val De la Mare is located in a transitional climate zone between a Northern continental zone, with a summer precipitation peak, and a South Mediterranean climate zone, with mainly spring and autumn precipitations. The copresence of these two different climatic zones increases winter, autumn and spring precipitations and gradually decreases summer ones.

In the valley there are 5 glaciers with a total surface of 13,7 km^2: Vedretta De la Mare (4,55 km^2), originating the Noce Bianco stream, Careser glacier (3,55 km2) originating the Rio Careser stream, Vedretta Venezia (1,71 km^2), Vedretta Rossa (1,24 km^2) and Vedretta Cavaion (0,26 km^2) (Comitato Glaciologico italiano, Sezione SAT-CAI 2006). Between the De la Mare and Careser glaciers lies a non glaciated sub basin; the Val Lagolungo basin with three Alpine small shallow lakes of glacial origin: Lake Marmotte (2705 m a.s.l.), Lake Lungo (2550 m a.s.l.) and Lake Nero (2621 m a.s.l).

In Val De la Mare the tree line is located around 1800-2000 m a.s.l. The wooded vegetation is dominated by *Picea excelsa* and *Betula alba*. From 1600 m a.s.l other species can be found (i.e. *Pinus cembra* and *Larix decidua*). At higher elevation (above 2000 m a.s.l.) bushes of rusty-leaved alpenrose (*Rhododendron ferrugineum*), green alders (*Alnus viridis*), loniceres (*Lonicera nigra*, *L. caerulea*), elder (*Sambucus racemosa*), juniper (*Juniperus nana*) and willows (*Salix erbacea* and *Salix helvetica*) prevail. In Pian Venezia peat bogs (Caricetum fuscae association) are present in the lower part of the floodplain.

The Val De la Mare includes the headwaters of the Noce Bianco stream (21,4 km^2) and of the Careser stream (14,5 km^2). Land coverage of the Noce Bianco basin is represented by bare rock (50%), glaciers (34%) and pasture (16%).

The Vedretta De la Mare snout is about 2800 m a.s.l., and it generates the Noce Bianco glacial stream, a left tributary to the Noce stream, which is in turn a major tributary of the Adige River. Two kilometres downstream of its source, the Noce Bianco reaches the alluvial plain of Pian Venezia (2270 m a.s.l.), where it receives the contribution of the Rio Larcher, fed by snowmelt and groundwater.

In 1935 the Val De la Mare was included in the Stelvio National Park. This contributed to maintain large part of this area in natural conditions.

The Val De la Mare valley has thus a high variety of stream typologies, ranging from glacial dominated streams, to lake outlets, snowmelt and rain dominated streams and springbrooks. Part of the valley is interested by the hydropower system of Cogolo Pont, with abstraction pipelines, the Careser dam and Malga Mare sedimentation basin. Other impacts regard a rather low tourist summer presence (Larcher mountain hut) and little summer grazing by cattle.

For these reasons the valley offers many possibilities to study the biodiversity of high elevation Alpine stream typologies and the effect of different (direct and indirect) anthropic impacts.

.2. THE COGOLO-PONT HYDROPOWER SYSTEM

The hydropower system “Malga Mare-Pont” (pictures below show all the components of Cogolo power plant – Photos by B. Maiolini) includes Pont (1208 m a.s.l.) and Malga Mare (1963 m a.s.l.) hydropower plants, Careser dam (2603m a.s.l.) and Pian Palù (1752 m a.s.l.) reservoirs. This system is located in the Noce Bianco watershed. In 1947 the Cogolo-Pont plant was inaugurated, while the dam of Pian Palù was built between 1948 and 1959, (height of 52 m and water volume capacity of 15,58*103 m^3) (Longo and Visintainer 2008). The waters coming from Pian Palù arrive to Cogolo-Pont through galleries.

A pipeline abstracts water from inlets of Lungo, Marmotte and Nero lakes. The pipelines runs at about 2680 m a.s.l., in the eastern part of the valley, and feeds the Careser reservoir. The Careser dam is one of the most elevated of Europe with a volume of 15,58 million m^3 (dam dimensions: height 66 m and depth 44 m). The Careser basin is connected to Malga Mare hydropower plant (1964 m s.l.m. and volume of 150000 m3) by a forced pipe (water jump=622 m). 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 the turbinated water is discharged into the Noce Bianco stream at 1265 m a.s.l. The hydropower system of Val di Pejo can produce an annual mean of 190000 MW/h, with 15000 hours of operation (Bernardi, 1993).

Cogolo-Pont hydropower plant

Malga Mare basin

Abstraction Pipeline

Careser dam

Release point

.3. SAMPLING STATIONS

Selected sampling stations are representative of all the different stream typologies: (kryal, rhithral, and mixed) present in the Noce Bianco watershed (Fig 2.1). Four sampling stations were chosen to study community structure and diversity, life cycle and feeding habits of Plecoptera (Fig 3.1):

NB3: (kryal station, Noce Bianco stream) located 2 km downstream the glacier source. The riverbed is highly unstable and substrate is dominated by stones and pebbles. The river margins are partially covered by herbaceous vegetation. Water velocity was ≈ 2,0 ± 0,5 m/s and summer mean temperature varied between 3.9°C and 1,4°C, while winter temperature was low (from 0.6°C to 0.4°C).

NB3bis: (rhithral station, Rio Larcher), located 2.5 km from source. It is characterized by stable substrate with pebbles and stable river margins with herbaceous vegetation and mosses. Water temperature varied between 5.1°C and 1.8°C in summer and 1,9 ± 0,8°C in winter. Water velocity was 0,7 ± 0,2 m/s, lower respect to the glacial station.

NB4: (mixed station) located after the confluence of the two streams. Substrate is strongly influenced by the glacial fed stream and results unstable and dominated by gravel and pebble. All the chemical and physical characteristics result a mix of the glacial and rhithral ones.

EmM2: (outlet of the Marmotte Lake) the Rio Marmotte is fed by the lake, by a great number of small sources and then contributes to the Rio Larcher. It has a constant but low discharge and the substrate is dominated by pebbles, gravel and silt.

Other eight sampling station were selected to study the effects of hydropower water use on Plecoptera communities.

Water abstraction:

ImL1: (Rio Lago Lungo; inlet of Lungo lake) located at 150 m upstream of the pipeline for water abstraction. This stream flows in a rocky valley with variable, rapid and turbulent flow. Substrate is composed by pebbles, rocks and gravel.

ImL2: (Rio Lago outlet of Lungo Lake) located 30 m downstream of the abstraction pipeline and 150 m upstream of Lungo Lake. This stream originates from a series of springs and consequently shows constant values of discharge and fast flow in relation with the slope. The substrate is dominated by pebbles, gravel and stones.

Storage in dam:

CR2: (Rio Careser), located about 100 m upstream the Careser dam and downstream the confluence with the glacial stream and its main non glacial tributary (Rio Larcher).The substrate is dominated by pebbles and gravel and results highly unstable.

CR3: (Careser dam outlet, Rio Careser) located downstream of the Careser dam, it is the first sampling station located below the tree line, at the confluence of Rio Careser and Rio Lago Lungo. Discharge and flow result very constant.

Release of turbinated water:

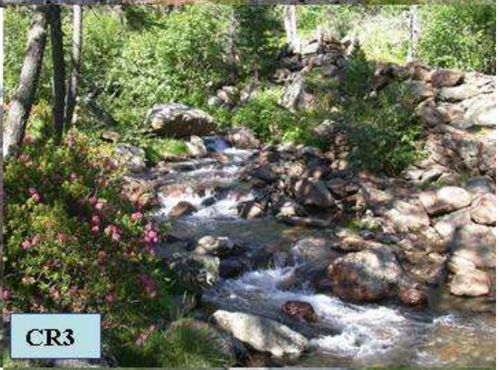
NB7: (Noce Bianco stream) located 250 m upstream of the Cogolo plant. This reach can be defined as kreno-rhithral with a stable riverbed composed by pebbles, gravel and silt. Temperature, discharge, water velocity and flow are constant. Sometime discharge and chemical parameters can be disturbed by casual landslides or by cleaning of Malga Mare basin.

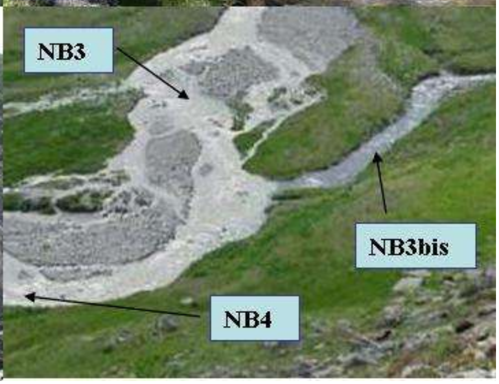
NB8: (Noce Bianco stream) located 0,25 km downstream from the Cogolo power plant. The discharge is strongly dependent by the release of turbinated waters. Consequently current velocity is variable and the riverbed is stable due to the armouring of stones and pebbles by the repeated hydropeaking events.

NB13: (Noce Bianco stream) located 6 km downstream from the power plant. This sampling station is characterized by lower current velocity and consequently the stream has a stable riverbed with some silty areas.

NB15: (Noce Bianco stream) located 8 km, downstream from the plant. It is the last and lower elevation sampling station, with substrate dominated by stones and pebbles and silty riverbanks.

All selected sampling stations are illustrated in the pictures below (*photos by B. Maiolini*)






NB5


NB7


NB8


NB13


NB15

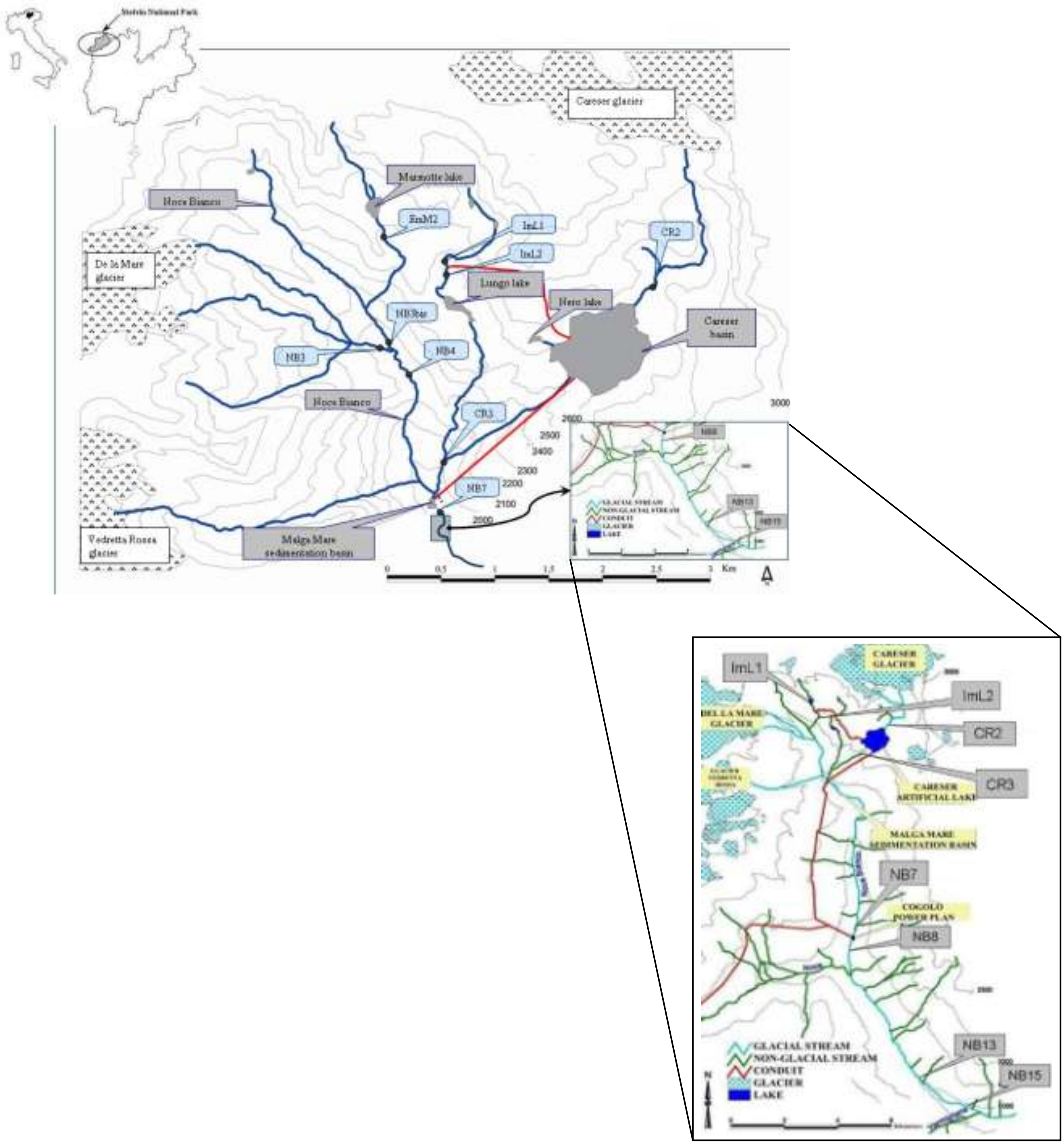


Fig. 2.1: Map of study area with sampling stations and enlarged map of Cogolo-Pont power plant and sampling stations.

Tables 1 and 2 display other characteristics of each sampling station. For the discharge classes; 1=0-20; 2=20-100; 3=100-200; 4=200-400; 5=400-600; 6=600-800; 7=>800 (l/s). Chemical parameters are missing for some of the stations.

watershed	Careser	Careser	Careser	Careser	Careser
sampling station	**CR2**	**CR3**	**EmM2**	**ImL1**	**ImL2**
stream order	3	3	1	1	1
reach type	glacio-rhithral	kreno-rhithral	outlet	kreno-rhithral	kreno-rhithral
altitude m a.s.l.	2642	1985	2620	2700	2600
water depth (min/max)	9,2-18	8,6-20			
water velocity (min/max)	0,31-1,7	0,03-1,08			
distance from source (m)	1841	1750	20	1361	1589
slope	0,03	0,06	0,08	0,06	0,07
Pfankuck	52	30	20	25	15
BPOM (min/max)	1,64	9,5-64,6	1,4-7,8	3,38-8,3	2,7-16,4
T_{mean} (°C)	2,04	4,62		1,84	4,60
T_{min} (°C)	0,17	3,19		1,33	2,95
T_{max} (°C)	6,04	7,02		2,48	7,50
discharge (categories)	7	3	2	2	1
pH20°C (min-max)	6,4-7,2	6,5-7,1	6,4-7,0	6,6-6,8	6,7-6,9
conductivity µS/cm (min-max)	41-149	33-59	71-82	73-98	69-90
alkalinity mg/l(min/max)	3,4-16,6	4,1-7,5	1,8-7,8	4,5-6,8	3,8-5,4
N-NO_3µg/l (min/max)	80-210	90-295	192	280-326	250-297
N-NH_3µg/l (min/max)	23-100	<20-40	10	10	10
P-PO_4µg/l (min/max)	0,9-3	0,9-2,5	0,9	0,9-1	0,9-1
SiO_2mg/l (min/max)	1,31-3,48	2,27-3,35	3,65	2,9-3,3	2,95-3,36
HCO_3mg/l (min/max)	4,2-20,2	5,56-9,09	9,516	5,4-8,3	4,6-6,6
SO_4mg/l (min/max)	13,5-35,4	9,9-17,2	24,1	27-37,4	25-34,7
suspended sediments	6,1-292,3	0,95-28,1	1,95	4,7-8,4	2,7-3,6

watershed	Noce Bianco	Noce Bianco	Noce Bianco	Noce Bianco	Noce Bianco	Noce Bianco	Noce Bianco	Noce Bianco
sampling station	**NB3**	**NB3bis**	**NB4**	**NB5**	**NB7**	**NB8**	**NB13**	**NB15**
stream order	2	2	3	3	3	3	3	3
reach type	kr	kr-rh	gl-rh	gl-rh	kr-rh	impa	imp	imp
altitude m a.s.l.	2270	2270	2257	1950	1265	1197	1054	988
water depth (min/max)	0,7-17.4	0,6-22-4	0,5-18	9,4-30				
water velocity (min/max)	0,35-16,6	0,4-12.3	0,4-12,2	0,04-1,08				
distance from source (m)	2250	2514	2660	3861	14560	15510	21510	23510
slope	0,02	0,01	0,03	0,07				
Pfankuck	50	28	42	55				
BPOM (min/max)	0,09-7,9	3,8-60,6	0,23-23,49	0,12-8,48				
T_{mean} (°C)	3,20	3,92	3,28	4,31				
T_{min} (°C)	0,84	1,44	0,83	1,81				
T_{max} (°C)	7,18	8,24	7,61	8,06				
discharge (categories)	6	3	7	7	7	7	7	7
pH 20°C (min-max)	6,0-6,7	6,1-6,6	6,1-6,7	6,3-7,1	7,1-7,6			
conductivity µS/cm (min-max)	52-193	84-164	58-158	86-113	74-121			
alkalinity mg/l(min/max)	1,0-6,3	1,4-5,0	5,3	112,9	9-31,3			
N-NO_3µg/l (min/max)	100-330	140-240	95-280	15-300	171-738			
N-NH_3µg/l (min/max)	10	10,0-24	10,0-76	10,093	15-61			
P-PO_4µg/l (min/max)	0.9-3,5	0,9-3,45	0,9-3,5	0,9-1,5	1,0-37			
SiO_2mg/l (min/max)	1,2-4,2	6,18	1,46-4,85	1,56-5,65	0,3-6,4			
HCO_3mg/l (min/max)	2,3-7,6	2,07-5,4	2,01-6,42	4,12-10,51				
SO_4mg/l (min/max)	21,42-65,1	33,4-65	22,5-51,8	28-68,4	15,6-44,0			
suspended sediments		0,05-23,5	199,395	9,5-685,4				

.4. SPRINGS OF THE TRENTINO PROVINCE

A total of 600 springs were counted in the Trentino Province by the Geological Service in 1993. Part of these springs, representative of the territory, were chosen for the CRENODAT project The most important criteria for the preliminary selection of springs were; 1) mainly permanent springs, ii) habitat not affected by heavy direct impacts, iii) representative of the lithologies of the study area (ranging from limestones and dolomites to schist and gneisses and to different types of granites), iv) all altitude intervals (from 100 to 2500 m a.s.l.), v) all districts of the Province, especially protected areas, biotopes and Natural Parks. After this pre-selection a total of 108 springs were chosen.

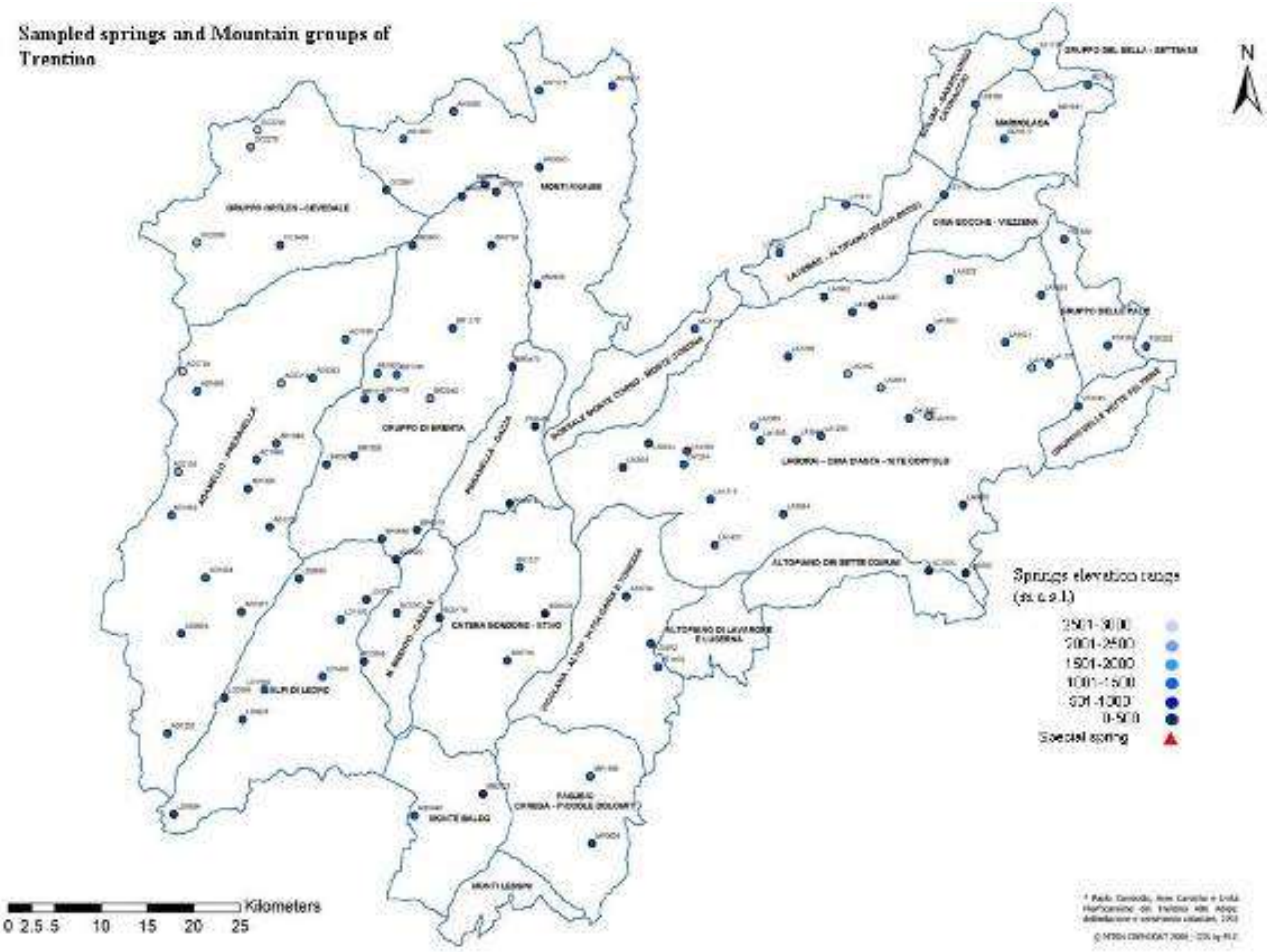


Fig. 2.2: Sampled springs grouped by elevation range and mountain groups.

The selected springs are located in 20 different mountain groups (fig 2.2) and in different geological substrates (carbonates and crystalline). The higher elevation springs are in metamorphic and magmatic massives (Lagorai, Adamello and Stelvio groups), while springs in carbonate mountains, due to the higher permeability of rocks, originate generally at lower altitude ranges.

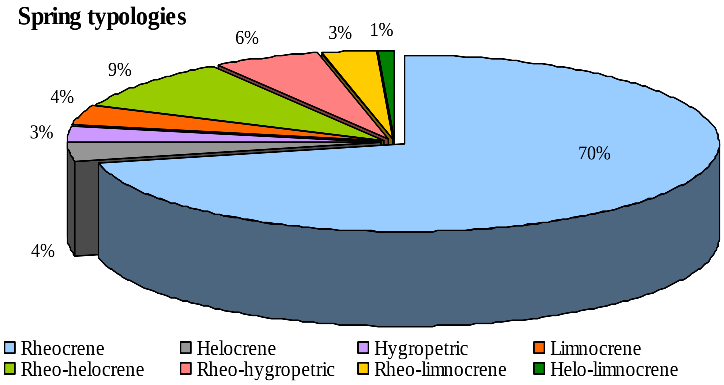


Fig 2.3: Spring typologies (percentage) selected for the CrenoDat project.

All sampled springs can be grouped in eight typologies and are located from 170 m a.s.l. to 2792 m a.s.l. (Fig. 2.3). As illustrated in Fig. 2.3 the great number of springs are rheocrene (77), followed by rheo-helocrene (10), rheo-hygropetric (6), limnocrene (4) and helocrene (4), hygropetric (3) and rheo-limnocrene (3) and only one is a helo-limnocrene spring.

The physical and chemical characteristics of the sampled springs are listed in table 1.1, appendix 1

V. MATERIAL AND METHODS

Samples collected seasonally for CRYOALP (stations: NB3, NB3bis, NB4, ImL1, ImL2, CR2, CR3 and EmM2) projects were used to study the biodiversity of hyporheic and benthic Plecoptera community, life cycles and feeding habits of some species of Plecoptera. Samples collected for the CRENODAT project were used to investigate the diversity and the assemblages of Plecoptera communities in 108 Trentino springs.

Benthic macroinvertebrate communities were collected seasonally from 2003 to 2005 with the kick-sampling method. For every station five zoobenthos samples have been collected using a d-frame net (100µm of mesh) (Fig. 3.1) disturbing a surface area from 0.1 to 0.3 m^2, representative of all microhabitats of each station. Other methods as direct collection, Malayse, light and emergence traps were used to collect adults specimens. Samples were preserved in 75% ethanol in the field, specimens were identified to the genus/species or higher (for other taxa) taxonomic level. Plecoptera larvae have been identified to the species level.

During the REPORT project the last four stations (NB7, NB8, NB13 and NB15) were sampled to investigate the effects of water release from hydropower plants. The impact of hydropeaking was tested by a field experiment conducted on the Noce Bianco stream. On 24-09-2006, an experimental release (no release during the night, followed by a release at maximum turbines capacity, increasing discharge of 7-fold) was arranged with the managing agency (ENEL).

At stations NB8, NB13, and NB15, quantitative 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 bridges; the contents of the three nets were pooled together and represented one sample.

Results from this experiment are currently been analyzed and will be presented in a paper.

.1. HYPORHEOS

Different sampling methods have been adopted to study the hyporheos:

- bottle neck traps,
- Bou-Rouch pump,
- artificial substrates

With these methods, qualitative samples of the hyporheic communities have been seasonally picked. Samples were preserved in 75% ethanol in the field, specimens were identified to the genus/species (for Plecoptera) or higher (for other taxa) taxonomic level.

Bottle neck traps are plastic bottles (in PVC with 1 l of capacity) with the third superior cut and inserted again upside-down. The bottle traps were buried 30 cm in the river bed in vertical position (a group of 6 traps for each station) and changed monthly. The abundance was expressed as number of individuals/m^2.

The Bou-Rouch pump is a hand piston pump inserted in the riverbed and used to collect interstitial samples. The pump is fixed on the top of a steel tube (perforated at its lower end) which is inserted into the riverbed to a depth of 40 cm. For each monthly sample 10 l of water were filtered. Abundance was expressed as number of individuals/m^3.

Artificial substrates are pipes of 1 m of length and 15 cm of Ø, open towards downstream and positioned one beside the other in the river bed. In each pipe three bags, constituted by a net of 1 cm mesh filled with pebbles and gravel, were positioned. The substrates were inserted in the sediment to a depth of 15 cm. The abundance was expressed as number of individuals/m^2. Differently from northern Europe (Williams and Wiliams, 1993) and North America (Williams and Hynes, 1976; Baer et al 2001; Mackay, 1992), the study of hyporheos with artificial substrates is not very diffused in Italy, especially for high altitude streams (Rossaro 1985; Matthaei et al.,1996; Rodriguez et al. 1998; Fenoglio et al. 2002; Maiolini et al. 2004).

All the sampling methods used to sample are illustrated below (*photos by B. Maiolini*).

.2. SPRINGS

Springs were sampled seasonally from 2005 to 2006. Basic physical and chemical parameters were recorded for each spring. The main problems to sample springs were constituted by the reduced dimensions and the heterogeneity of the habitats. Consequently, to study the diversity of Plecoptera species, different sampling methods for each microhabitat were chosen.

- rocky and stony habitats were sampled by brushing and scraping,
- gravel and sandy habitats were sampled by digging and washing of the sediments,
- macrophyte and mosses were squeezed and washed and eventually a selection of specific parts of plants for laboratory analysis were taken.

Samples were sorted in the field and preserved in 75% ethanol.

Fig. 3.1: Used sampling methods.

.3. FEEDING HABITS AND LIFE CYCLE; LABORATORY PHASES

A dissection microscope (Leica MS5 50X) was used for taxonomic identification of Plecoptera species following the dichotomic keys by Aubert, Consiglio, Campaioli et al.

Measures of the body length (from the head to the last urite) and head dimension (length and width) were taken with an ocular micrometer. We run a correlation analysis (Spearman R using StatSof8 with $p< 0.05$) between the measurements to determine if these parameters could be used independently for each other (i.e. if there was no correlation among them). We used measures of mean, standard deviation and range of head width to analyse the life cycle. We also considered the size of the wing pads and the wing development level to define these classes, corresponding to different stages of nymphal development, as follows: I class (newly-emerged neanids), II class (neanids), III class (neanids with traces of wing pads), IV class (nymphs with well-developed wing pads) and V class (nymphs ready to emerge).

Fig. 3.2: Analysis of gut content with gut exctraction *(photo by L. Silveri)*.

For the gut content analysis we followed two different methodologies (Fig.3.1):

- i) gut content analysis with the extraction of the gut of predatory species (Peckarsky 1996) and the identification of preys identifying undigested chitinouse parts (especially head capsules).
- ii) the clarification method used by several authors (Tierno de Figueroa and Sánchez-Ortega, 1999; Derka et al., 2004), based on the methodology of Bello and Cabrera (1999). Single specimens were first stored in vials with Herwitgs´ liquid (a variation of Hoyer´s liquid) and then heated at 65ºC for 30 hours. The cleared specimens were mounted on a slide, and the gut contents were observed with an Olympus optic microscope at 400x.

IV RESULTS

.1. DISTRIBUTION OF PLECOPTERA IN TRENTINO PROVINCE

In table 1 were reported all the Plecoptera species found in the studied stations. For each species we recorded the presence in the different stream typologies, the altitude range (minimun and maximum record in m a.s.l.), the presesence in the Trentino province of each species according to the Italian Ckmap and the presence of species in the hydropower impacted stations. Many early instars could not be identified to species level.

species	cren	kry	kry-rhith	kren-rhith	rhith	elevation	ckmap (tn)	HP
Chloroperla susemicheli Zwick 1967	x		x	x	x	1435-2153	x	x
Rhabdiopteryx alpina Kuehtreiber, 1934		x	x	x	x	988-2700		
Brachiptera risi (Morton, 1836)		x		x		1190-2700	x	
Dictyogenus alpinus (Pictet 1842)	x		x	x	x	1077-1880	x	
Dictyogenus fontium (Ris 1896)	x			x	x	950-2270	x	
Perlodes microcephalus (Pictet 1833)	x		x	x		1300-1990	x	
Perlodes intricatus (Pictet, 1841)			x	x	x	2270	x	
Isoperla rivulorum (Pictet, 1842)				x		2270	x	
Isolerla grammatica (Poda, 1761)				x		1190	x	
Isoperla saccai (Festa 1939)	x					656-1379		
Isoperla cf. *andreinii* (Festa 1938)	x					1115-1379		
Dinocras ferreri (Pictet 1841)	x			x		170-972	x	
Amphinemura sulcicollis (Stephens 1836)	x			x		419-658	x	
Nemoura cinerea (Retzius, 1783)	x			x		250-1853	x	
Nemoura flexuosa Aubert, 1949	x			x		250-2240	x	
Nemoura mortoni (Ris, 1902)	x	x	x			250-2153	x	
Nemoura cf. *obtusa* (Ris, 1902)	x					1435	x	
Nemoura cf. *sinuata* (Ris, 1902)	x			x		419-2153	x	
Protonemura cf. *auberti* Illies, 1954	x					753-2153	x	
Protonemura brevistyla (Ris, 1902)	x			x		470-2153	x	
Protonemura intricata (Ris, 1902)	x					1358-2153	x	
Protonemura lateralis (Pictet, 1836)	x		x	x		474-1990	x	
Protonemura cf. *nimborum* (Ris, 1902)	x	x	x	x		453-2153	x	
Protonemura cf. *nitida* (Pictet, 1836)	x					686-2153	x	
Nemurella pictetii Klapálek, 1900	x			x		250-2182	x	
Capnia vidua Klapálek, 1904			x	x	x	2257-2270	x	
Leuctra braueri Kempny, 1898	x			x		250-2051	x	
Leuctra hippopus Kempny, 1899	x					1358	x	
Leuctra helvetica Aubert, 1956	x					1300-1358	x	
Leuctra niveola Schmid, 1947	x					1300		
Leuctra rosinae Kempny, 1900	x	x	x	x		1358	x	
Leuctra cf. *alpina* Kuehtreiber, 1934	x		x	x		1300	x	
Leuctra inermis Kempny, 1899	x			x		656-1300	x	
Leuctra cf *rauscheri* Aubert, 1957	x					1358	x	
Leuctra cf. *teriolensis* Kempny, 1900	x					1605	x	
Leuctra fusca (Linnaeus, 1758)	x					735-905		
Leuctra major Brinck, 1949	x	x	x	x		720-2270	x	x
TOT	31	6	11	24	6		32	2

.2. ECOLOGY OF PLECOPTERA; LIFE CYCLE, FEEDING HABITS AND USE OF HYPORHEIC ZONE

.2.1. LIFE CYCLE OF *CHLOROPERLA SUSEMICHELI* ZWICK 1967(CHLOROPERLIDAE)

A total of 71 speciments of *C susemicheli* were measured. All three measures were highly correlated (R= 0.75 for body length *vs.* head length; R= 0.76 for body length *vs.* head width; R= 0.82 for head length *vs.* head width; all with p< 0.05). Thus, only head width (in cm) was used for life cycle definition as illustrated in figure 2.1 below.

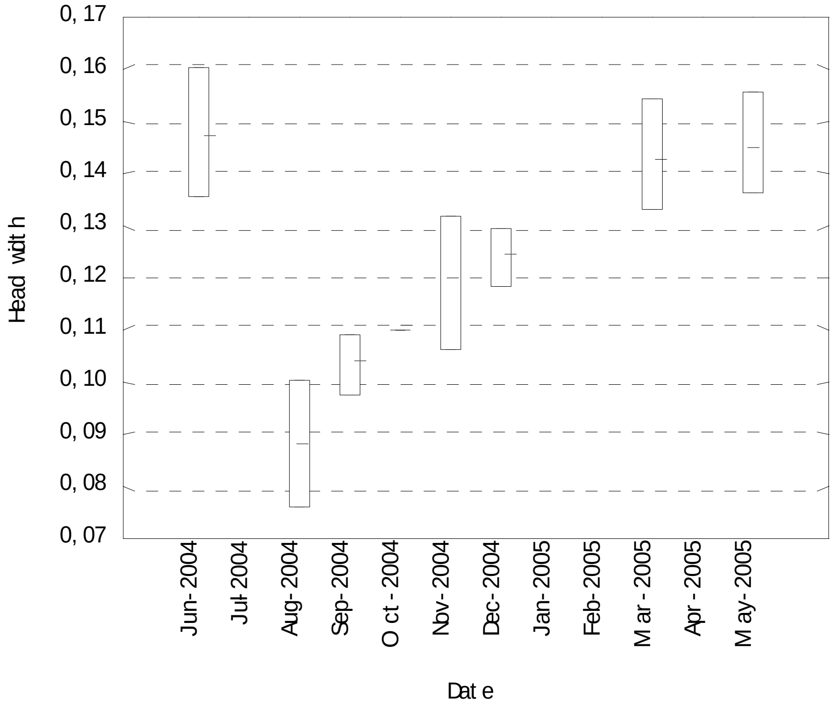


Fig.2.1: Life cycle of *C. susemicheli* (head width in cm).

.2.2. LIFE CYCLE OF *NEMOURA MORTONI* RIS 1902 (NEMOURIDAE)

A total of 62 nymphs of *N. mortoni* were measured. All the mesures were higtly correlated (R values for each measures are shown in tab 2.1) Thus we choose the femour width to describe the life cycle as illustrated in Fig. 2.2

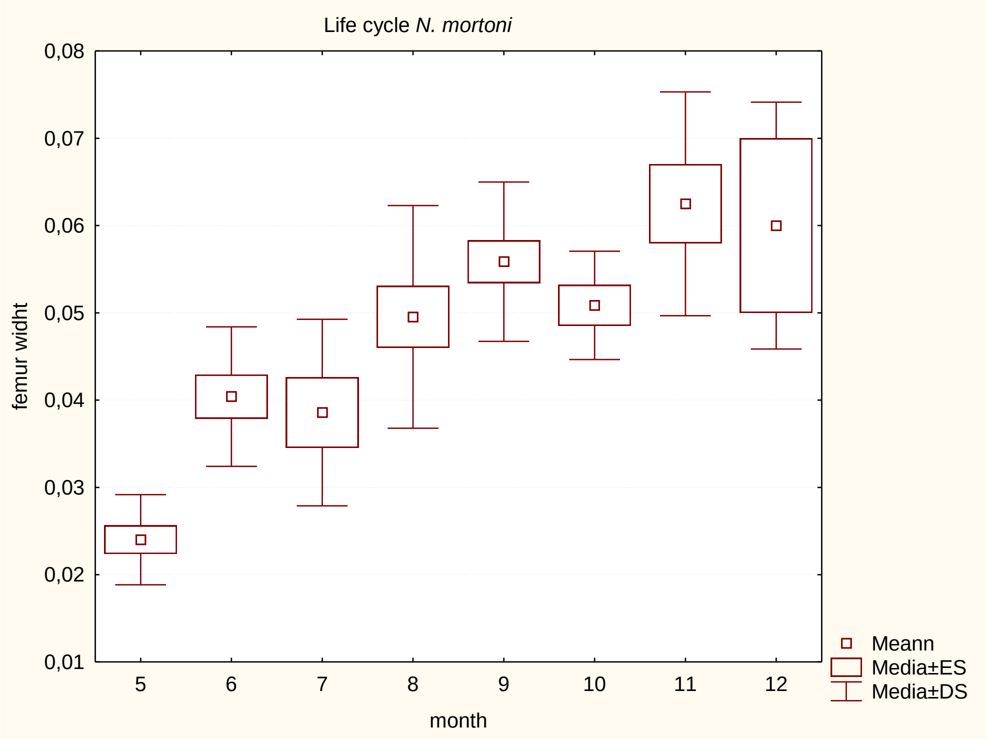


Fig. 2.2: Life cycle of *N. mortoni* (femour width in cm).

	month	body length	head base	head length	pronotum base	pronotum heigth	femur length
month	1	0,507077	0,387661	0,489968	0,460965	0,488313	0,43291
body length	0,507077	1	0,859581	0,943095	0,921504	0,953368	0,900064
head base	0,387661	0,859581	1	0,878924	0,903836	0,864837	0,867781
head length	0,489968	0,943095	0,878924	1	0,927577	0,980573	0,887448
pronotum base	0,460965	0,921504	0,903836	0,927577	1	0,92742	0,885629
pronotum heigth	0,488313	0,953368	0,864837	0,980573	0,92742	1	0,905751
femur length	0,43291	0,900064	0,867781	0,887448	0,885629	0,905751	1

Tab. 2.1: Spearman Correlation values p <0,5000.

.2.3. FEEDING HABITS OF DICTYOGENUS FONTIUM (RIS 1896) (PERLODIDAE)

60 nymphs of *D. fontium* collected from three sampling stations, representative of three different stream typologies and located in the same area were selected for gut analysis. 44 resulted with undigested chitinouse parts in the gut. The benthic comunity composition, the Plecoptera species assemblages and the items found in the guts are presented in figures 2.3 a, b and c.

In station EmM2 the community was well diversified. Diptera represented 80% of the community with Chironomidae as dominant family in every season (mean 78%). Plecoptera, Tricoptera and Ephemeroptera accounted for 5%, 3% and 0.5% of the benthic community respectively (Fig. 2.3a). *D. fontium* was the most abundant stonefly (61%) and was the only predator species, followed by *Leuctra* sp. (36%) and *Rhabdiopteryx alpina* (Kuehtreiber, 1934) (2%), both herbivorous species (Fig 2.3b).

Ten *D. fontium* nymphs were selected for analyses from this station. Body length of the nymphs ranged between 28 mm and 3 mm. Three nymphs had chitinouse parts in the gut. 80% of the preys were Chironomid larvae (20 of 25 items). Other preys were Simuliidae (2 larvae), Limoniidae (2 larvae) and Limnephiliidae (1 larva) (Fig.2.3c).

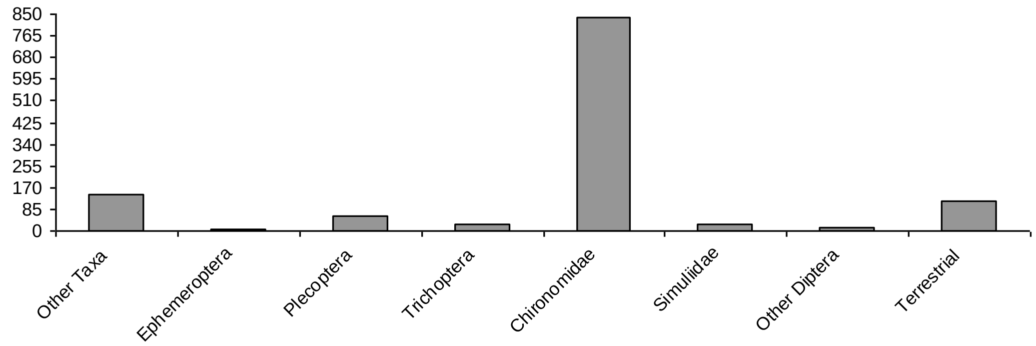


Fig. 2.3 a: Taxa present in EmM2 sampling station (ind*m^{-2}).

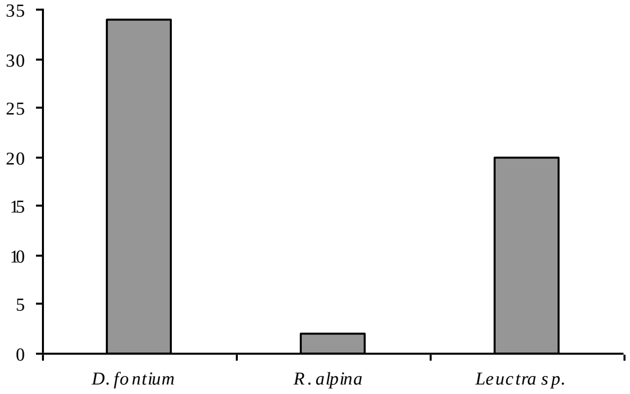


Fig. 2.3b: Pleoptera community of EmM2 sampling station (ind*m^{-2}).

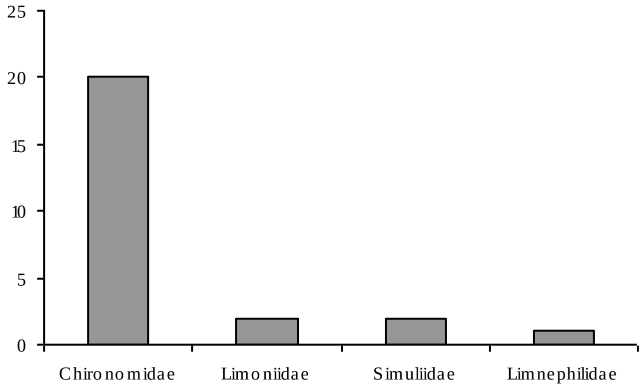


Fig. 2.3c: Gut content of *D. fontium* nhympsh in EmM2 sampling station (n°of items).

ImL1 presented a well structured benthic community, Diptera were 73% of the total community with Chironomidaes (62%) and Simulidae (8.5%) as most abundant families. Within EPT, Tricoptera was the most represented (16%) followed by Plecoptera (7%) and Ephemeroptera (0.6%) (Fig. 2.4a). The Plecoptera community was well diversified with the predator species *D. fontium* (58%) and *Isoperla rivulorum* (Pictet, 1842) (7%) and the herbivorous *Leuctra* sp. (17%), *Nemoura* sp. (5 %), *R. alpina* (3%), *Nemoura mortoni* (0.8%) and *Protonemura* sp. (0,8%), (Fig. 2.4b). In this station, 37 nymphs of the 44 analyzed had chitinouse residues and their body length ranged between 17,1 mm and 2,2 mm. Chironomidae (especially Diamesae and *Ortocladius* sp.) were the most preyed organisms. In one nymph we found 36 Chironomid cephalic capsules. Residues of Athericidae, Limoniidae, Tricoptera Limnephilidae and Plecoptera were also found (Fig. 2.4c).

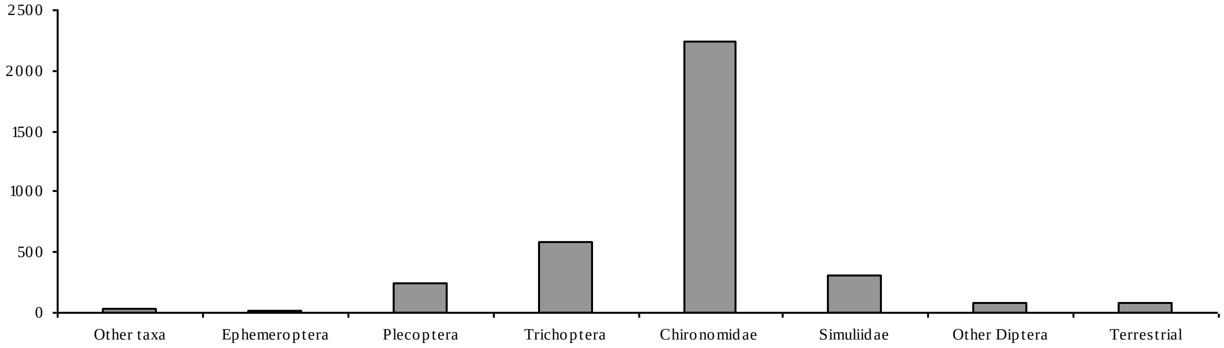


Fig. 2.4 a: Taxa present in ImL1 sampling station (ind*m^{-2}).

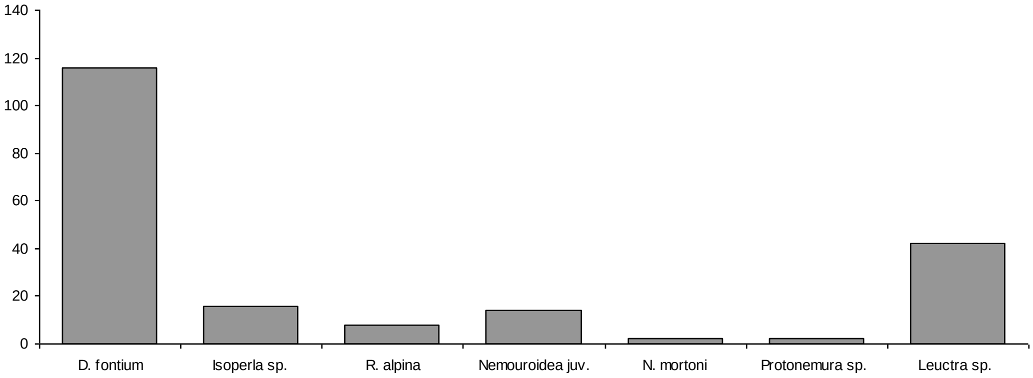


Fig.2. 4b: Pleoptera community of ImL1 sampling station (ind*m^{-2}).

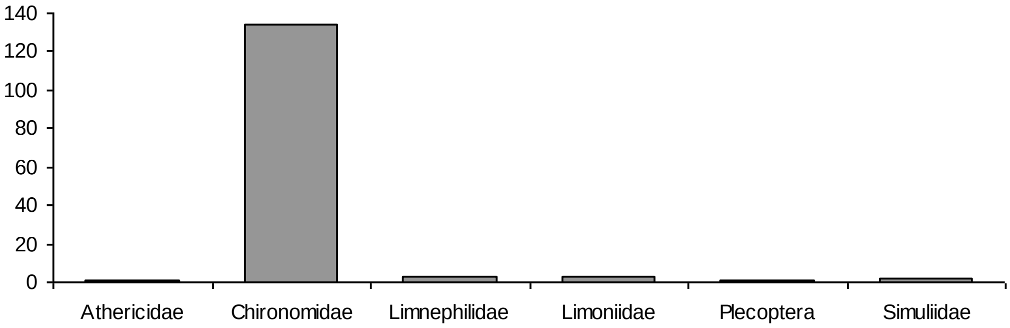


Fig. 2.4c: Gut content of *D. fontium* nhympsh in ImL1 sampling station (n° of items).

Finally in ImL2 the community was dominated by Chironomidaes (92%) followed by Simulidae (4%), Tricoptera (0.1%), Ephemeroptera (0.03%) and Plecoptera (1%) (Fig. 2.5a). The Plecoptera community was diversified with the predatory species *D. fontium* (12%) and the herbivorous ones *R. alpina* (21%), *Nemoura* sp (39%), *Protonemura* sp (24%). and *Taenoipteryx* (3%) (Fig. 2. 5b). Four nymphs of *D. fontium*, with body length between 23 mm and 1.7 mm, were analyzed from ImL2: two had no preys and other two had undigested parts of Chironomidae (7 organisms) and one springtail (Fig. 2.5c).

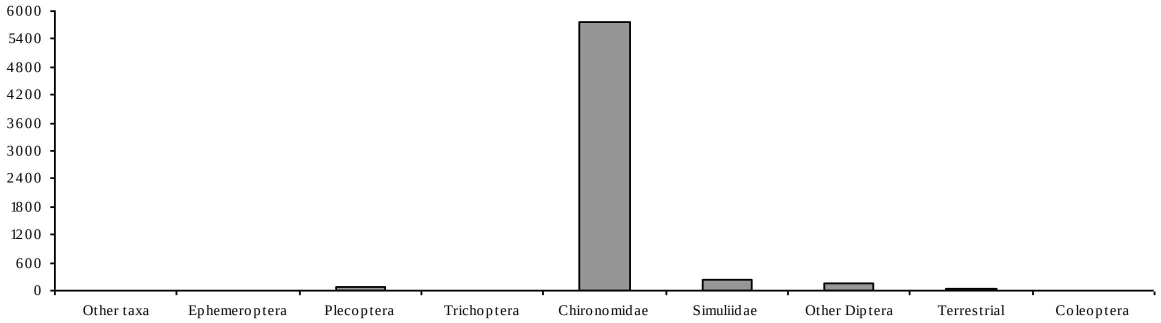


Fig. 2.5 a: Taxa present in ImL2 sampling station (ind*m^{-2}).

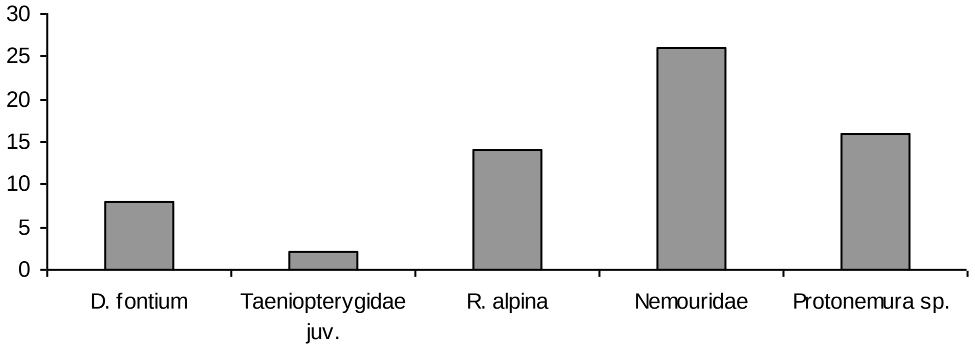


Fig. 2.5b: Pleoptera community of ImL2 sampling station (ind*m^{-2}).

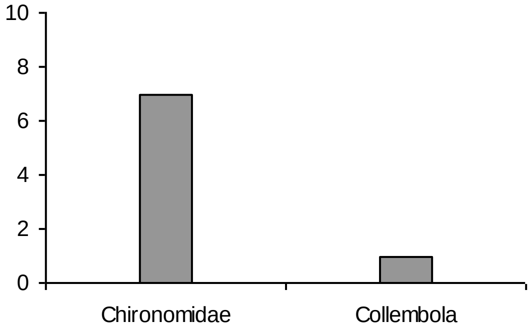


Fig. 2.5c: Gut content of *D. fontium* nhympsh in ImL2 sampling station (n° of items).

.2.4. FEEDING HABITS OF *CHLOROPERLA SUSEMICHELI* (RIS 1896) (CHLOROPERLIDAE)

Forty nine speciments of *C. susemicheli* (representing all size ranges) were analysed for the gut contents. Only six individuals had no gut content. According with the results (Table 2.2), *C. susemicheli* belongs to the predator functional feeding group (engulfer-carnivorous *sensu* Cummins & Merritt 1996). The high presence of mineral matter and detritus (present in 42 of the 43 studied individuals with gut content) could be explained by the feeding mechanism of this species, which usually ingests whole animals (engulfers).

Items	Valid N	Mean	Min.	Max.	Std.Dev.	Presence [%]
Chironomidae	43	1,67	0	8,00	2,09	26 [60.5%]
Plecoptera	43	0,07	0	1,00	0,26	3 [7.0%]
Efemeroptera	43	0,02	0	1,00	0,15	1 [2.3%]
Not identified animal mat	43	0,26	0	2,00	0,49	10 [23.3%]
Mineral mat. + detritus [%]	43	0,59	0	1,00	0,33	42 [97.7%]
Algae [%]	43	0,03	0	0,95	0,15	5 [11.6%]

Table 2.2: Gut content of *C. susemicheli* nymphs. Presence indicates the number of individuals containing that item (% of the total individuals).

.2.5. PLECOPTERA AND THE HYPORHEIC HABITAT

A total of 464 larvae were collected; 230 of them were identified to species level. They belonged to six families: Chloroperlidae, Pelodidae, Taeniopterygidae, Nemouridae, Leuctridae, Capnidae. The species list and feeding habits are presented in Table 2.3.

The analysis of the distribution of the families in benthic and hyporheic habitats of each station shows that in the glacial station NB3 (Fig. 2.6) the family Nemouridae is dominant in benthic communities (81,8% of the total), followed by Taeniopterygidae (8,2%), Leuctridae (6,8%), and Perlodidae (2,5%). The hyporheos of the same station is more diverse: Nemouridae are dominant again (43,6%), followed by Leuctridae (25,6%), Perlodidae (12,8%), Chloroperlidae (10,3%), Capnidae (5,1%), and Taeniopterygidae (2,6%).

The dominant family in benthic communities of the rhithral station NB3bis (Fig. 2.6) was Leuctridae (62,2%) followed by Nemouridae (21,7%), Taeniopterygidae (7,8%), Perlodidae (5,1%), Chloroperlida (1,7%), and Capnidae (1,4%). The hyporheic community was characterised by an increase of predator taxa such as Perlodidae (9,5%) and Chloroperlidae (7,6%), by a decrease in Leuctridae (9.9%). Nemuridae were dominant (54,4%), followd by Taeniopterygidae (12%), Capnidae were present as 6,5%.

As regards the mixed creno-rhithral station NB4 (Fig. 2.6), Nemouridae (55,3%) were dominant, followed by Taeniopterygidae (37,9%), Leuctridae (4,5%), and Perlodidae (1,8%). Rare taxa were represented by Chloroperlidae (0,3%) and Capnidae (0,1). Hyporheos was mainly composed of Nemuridae (59,5), Leuctridae (21,6), Capnidae (13,5%). Perlodidae (2,7%) and Chloroperlidae (2,7%) were rare.

A more detailed analysis showed that the species of the Nemouridae genus *Protonemura* were the most abundant in the hyporheic habitat of all three stream typologies. In particular, *P. nimborum* was always present in both benthic and hyporheic communities. Other herbivorous species collected both in benthic and hyporheic samples were *L. major*, *L. braueri* and *C. vidua*. Among predators, *C. susemiheli* and *P. intricatus* were always abundant in the hyporheic habitat.

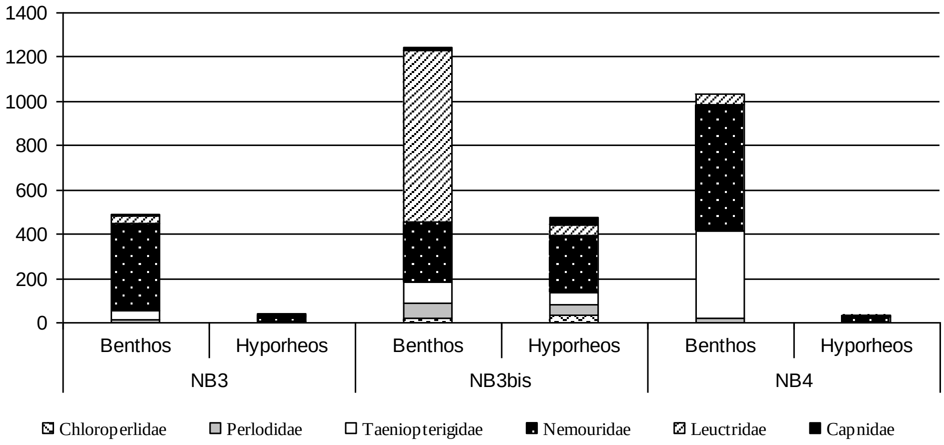


Fig.2.6 Relative composition of stonefly communities in the benthos and in the hyporheos.

The analysis of the larval measurements led to the definition of five classes, which we related to five larval developmental stages as follows:

- **I class:** newly-emerged neanid,
- **II class:** neanid,
- **III class:** neanid with traces of windbuds,
- **IV class:** nymph with well-developed windbuds,
- **V class:** nymph ready to emerge.

Neanids (classes I, II, II) of *P. nimborum* were the most abundant herbivorous species in glacial station NB3. The other herbivorous species (*L. major*, *C. vidua* and *R. alpina*) were present with neanids of the same classes. On the contrary, the predators *P. microcephalus* and *P. intricatus* were collected in the hyporheos at later developmental stages (classes IV and V).

The hyporheic habitat of rhithral station NB3bis was characterised by a more complex larval distribution. As regards herbivorous species, *P. nimborum* was present at all stages of larval development, although it was more abundant as mature nymph, as shown by the 65 larvae of *P. nimborum* and 11 larvae of *P. brevistyla* all ready to emerge. *Nemoura morton*i was rare and always as neanid (I and II classes). *R. alpina* was present in hyporheic habitats in the early and intermediate phases of larval development; in fact, 28 neanids and 19 neanids with traces of windbuds were collected (classes II and III, respectively). *C. vidua* was abundant, with very early larval stages (22 neanids class I) and almost mature nymphs (7 larvae class IV and 2 of class V). All the species of *Leuctra* were at intermediate developmental stages (II, III and IV classes). As regards predator species, several unidentified nymphs of *Perlodes* (13 neanids) were collected at NB3bis. Young larvae of *I. rivulorum* were present in the hyporheic (I, II and III classes). *P. microcephalus* and *P. intricatus* were distributed similarly to the other Perlodidae, but in later development stages (IV and V classes).

The mixed creno-rhithral station NB4 was characterised by *P. nimborum* in late developmental stages (III and IV classes). *L. major*, *L. braueri* and *C.vidua* were present in the hyporheic habitat at intermediate developmental stages (III class). Only one predator species, *S. torrentium*, was colected at this station so far, with a quite mature larva (IV class).

	Sites	Species	I	II	III	IV	V
Shredders	**NB3**	*R. alpina*			1		
		Protonemura sp.		1			
		P. nimborum	7	7	3		
		Leuctra sp.	4				
		L. major		1			
		C. vidua		2			
	NB3bis	*R. alpina*	7	28	19	3	
		Nemoura sp.	1		1		2
		N. mortoni	5	3	1	1	
		Protonemura sp.		11	1	3	37
		P. nimborum	6	5	14	18	65
		P. brevistyla		2	8	8	11
		Leuctra sp.	30		3		
	NB4	*L. braueri*	2	1			
		L. major			9	2	
		C. vidua	22	2		7	2
		N. mortoni	4				
		Protonemura sp.		1			
		P. nimborum		1	5	4	
		Leuctra sp.		1	1		
		L. braueri			1	1	
		L. major		1	1	3	
		C. vidua		2	1		
Predators	**NB3**	Perlodidae	1				
		P. microcephalus				3	
		P. intricatus					2
	NB3bis	*I. rivulorum*	2	2	2	1	
		Perlodes sp.	13	2	1		
		P. microcephalus		2	1	2	
		P. intricatus		2	8	3	1
	NB4	*S. torrentium*				1	

Tab 2.3: List of species collected in the hyporheic habitat, grouped by station, and classified according to developmental stages and feeding habits.

A total of 75 nymphs of *D. fontium, P. intricatus* and *I. rivulorum* and 22 juvenile Perlodinae belonging to the hyporheic habitat of glacio-rhitharal, kryal and kreno-rhithral, were analyzed. For these species the life cycle in the hyporheic habitat was studied using development classification and feeding habits.

In figure 2.7 the presence of preadatory species of Plecoptera in the hyporheic habitats of high altitute stations is presented.

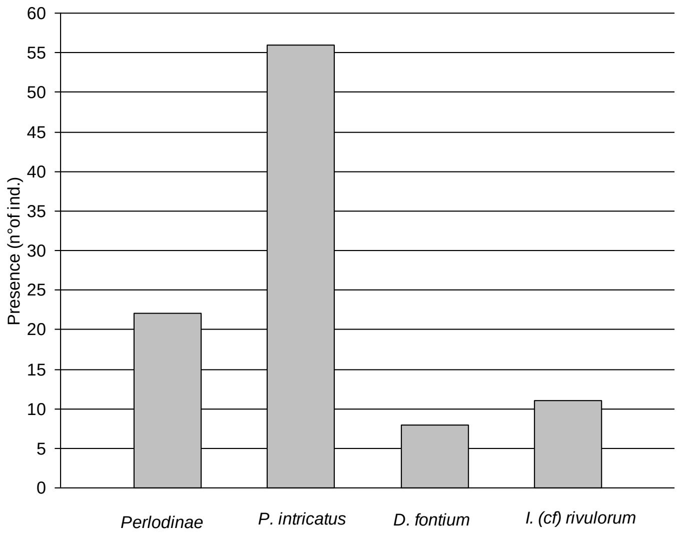


Fig. 2.7: Relative presence of predatory Plecoptera in the hyporheic community.

Measurements of body length (from the head to the last urite) and head dimension (length and width) were taken with an ocular micrometer microscope.

All three measures were highly correlated (for *D. fontium*: Spearman R= 0.79 for body length *vs.* head length; Spearman R= 0.82 for body length *vs*. head width; Spearman R= 0.92 for head length *vs*. head width, N= 67; for *I.* (cf) *rivulorum*: Spearman R= 0.79 for body length *vs*. head length; Spearman R= 0.81 for body length *vs*. head width; Spearman R= 0.91 for head length *vs*. head width N=7 and for *P. intricatus*: Spearman R= 0.97 for body length *vs*. head length; Spearman R= 0.96 for body length *vs*. head width; Spearman R= 0.85 for head length *vs*. head width N=89; all with $p< 0.05$). Thus, we choose to use only head width to define five size ranges for each species. We also considered the size of the wing pads and the wing development level to define these classes, corresponding to different stages of nymphal development. In Figure 2.8 the Perlodidae species collected in the hyporheic habitat and their classification according to the five developmental stages is shown.

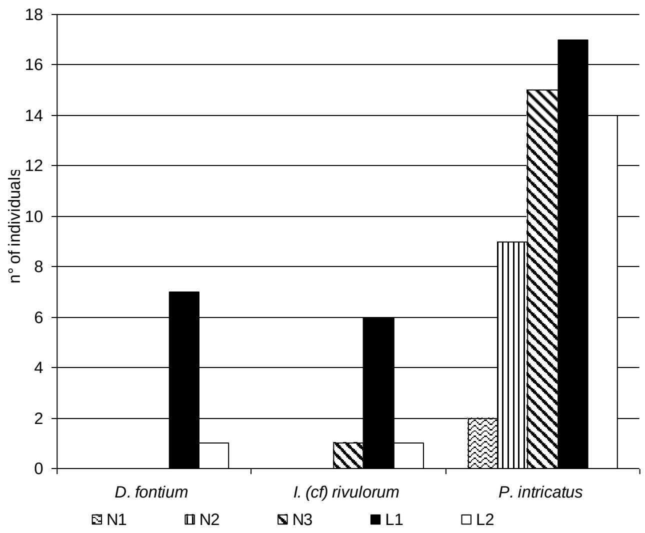


Fig. 2.8: Distribution of the five size classes of the nymphs of three species.

The gut contents of the three analyzed stonefly species is shown in Figure 2.9.

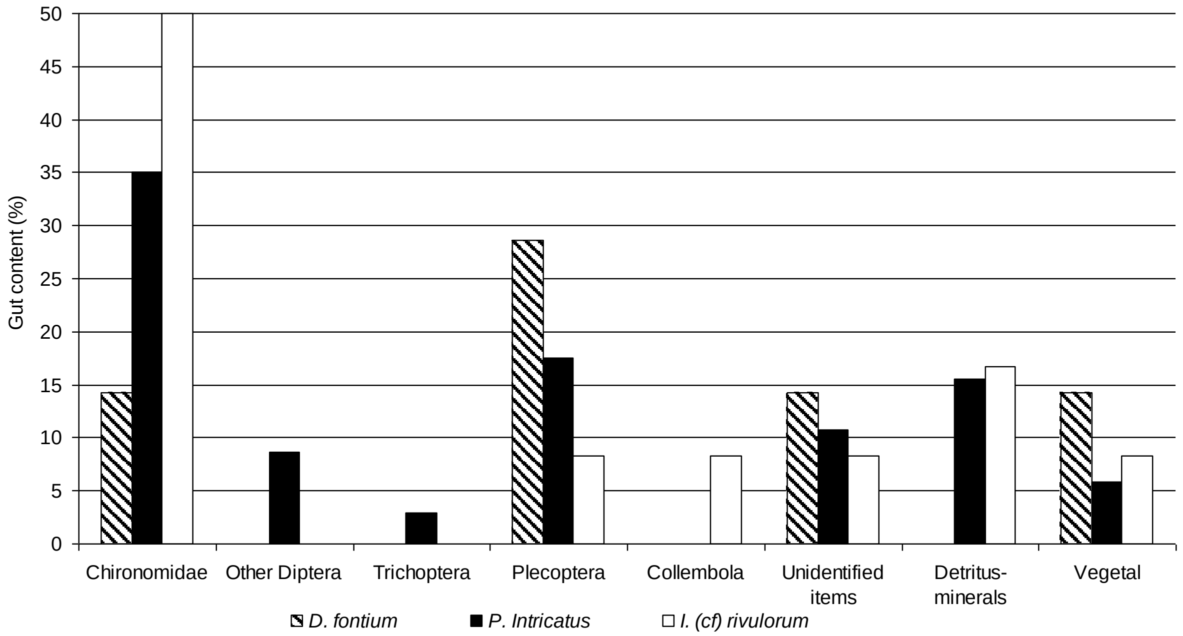


Fig. 2.9: Percentage of items found in the gut contents of the three studied Perlodidae species

Seven of the eight studied *D. fontium* had gut contents (Table 2.4).

Items	Mean	Min-Max	SD	Presence
Chironomidae	0,25	0.00-1.00	0.46	2 (25%)
Plecoptera	0,50	0.00-1.00	0.53	4 (50%)
Unid. prey	0,25	0.00-1.00	0.46	2 (25%)
Veg. Mat. (%)	12,50	0.00-60.00	23.75	2 (25%)

Tab 2.4: Gut content of *D. fontium* (N=8).

Fifty two of 56 studied *P intricatus* had gut contents (Table 2.5).

Items	**Mean**	**Min-Max**	**SD**	**Presence**
Simuliidae	0.04	0.00-1.00	0.19	2 (3.57%)
Limoniidae	0.12	0.00-2.00	0.38	6 (10.71%)
Chironomidae	4.36	0.00-35.00	6.92	36 (64.29%)
Other Diptera	0.02	0.00-1.00	0.13	1 (1.78%)
Trichoptera	0.05	0.00-1.00	0.23	3 (5.36%)
Plecoptera	0.46	0.00-4.00	0.87	18 (32.14%)
Unid. prey	0.20	0.00-1.00	0.40	11 (19.64%)
Detritus (%)	11.96	0.00-100.00	25.68	16 (28.57%)
Veg. Mat. (%)	2.41	0.00-65.00	9.53	6 (10.71%)

Tab. 2.5 Gut content of *P. intricatus* (N=56).

All seven analyzed individuals of *I. rivulorum* had gut contents but four were severely damaged and thus gut analyses were not possible. Table 2.6 illustrates the content of the seven analyzed speciments.

Items	Mean	Min-Max	SD	Presence
Chironomidae	2.00	0.00-4.00	1.41	6 (85.71%)
Plecoptera	0.29	0.00-2.00	0.76	1 (14.29%)
Collembola	0.14	0.00-1.00	0.38	1 (14.29%)
Unid. prey	0.14	0.00-1.00	0.38	1 (14.29%)
Detritus (%)	13.75	0.00-6.00	24.27	2 (28.57%)
Veg. mat. (%)	2.86	0.00-20.00	7.56	1 (14.29%)

Tab. 2.6: Gut content of *I. rivulorum* (N=7).

.3. HYDROELECTRIC POWER GENERATION, ALTERATION OF THE NATURAL STREAM FLOW AND EFFECTS ON THE PLECOPTERA BENTHIC COMMUNITY

A total of 45442 aquatic invertebrates were collected and identified. Insects were the most abundant group in all eight stations. In particular, Diptera were dominant above the tree-line (1800 m a.s.l.); represented mostly by Chironomidae, 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.

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. The percentage of Chironomidae increased, and those of Trichoptera and Plecoptera decreased (Fig. 3.1).

Plecoptera density changed from 141 ind*m^{-2} to 82 ind*m^{-2}, the percentage of predator Plecoptera changed from 68,1% to 7,3%, and that of herbivore Plecoptera from 31,9% to 92,7%. The predator species most affected by water diversion were *D fontium* (whose density changed from 84 to 6 ind*m^{-2}), *Isoperla* sp. and the juvenile stages of Perlodidae (Tab. 3.1). The most affected herbivore species was *R. alpina*, which became the dominant species; *Leuctra* spp. increased as well, especially *L. rosine* (Tab. 3.1).

Higher summer water temperature and improved channel stability in the downstream reach enhanced periphyton development, favouring the herbivorous components of the community.

The effects of water stocking 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 shifted from Chironomidae to Plecoptera: the former were dominant upstream, the latter downstream, together with Ephemeroptera (Fig. 3.1).

Plecoptera density changed from 81 ind/m^2 to 8,686 ind*m^{-2}. Herbivorous Plecoptera were the only species present in upstream station and 15,1% of the stonefly community in the downstream station. Predator species were absent upstream the reservoir but were 2,3% downstream. The most abundant predator species were *D. fontium*, *P. intricatus*, *S.torrentium* and Isoperla *sp.*; the most abundant herbivorous species in both stations was *L. major* and downstream *N. mortoni*, *L. major* and *P. nimborum* were also abundant (Tab. 3.1). Relevant was the high quantity of juvenile Plecoptera in the upstream station (81,2% of stonefly community).

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 the first, were well present in the second.

The turbinated water release is the phase of hydropower production that most affects the stream ecosystem downstream of the release point, where waters of different origin and characteristics are mixed. Values of daily and yearly variations in temperature and discharge measured on the Noce Bianco watershed in an hydropeaking-impacted area in respect to a non-impacted one (Fig. 3.2a,b) and in the downstream sampling station (Fig. 2a) sensibly differ from the natural ones (Figs. 3.2a, 3.2b). In particular, downstream temperature (Fig. 2b) was lower than in the upstream un-impacted reach during summer, warmer in winter, due to contribution of waters pumped from the bottom layer of the stratified reservoir.

The effects of hydropeaking on the benthic community were evaluated by comparing the station upstream of the Cogolo-Pont plant (NB7) with those downstream (NB8, NB13 and NB15). Total density decreased by 13 times downstream; the zoobenthic community immediately downstream (NB8) was dominated by Plecoptera, by Chironomidae and Ephemeroptera at NB13, and by Ephemeroptera at NB15 (Fig. 3.1).

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 individuals were represented by juvenile larvae. The following species disappeared downstream from the release point: *S. torrentium*, *I. rivulorum*, *Dictyogenus* sp and *R. alpina* (Tab. 3.1).

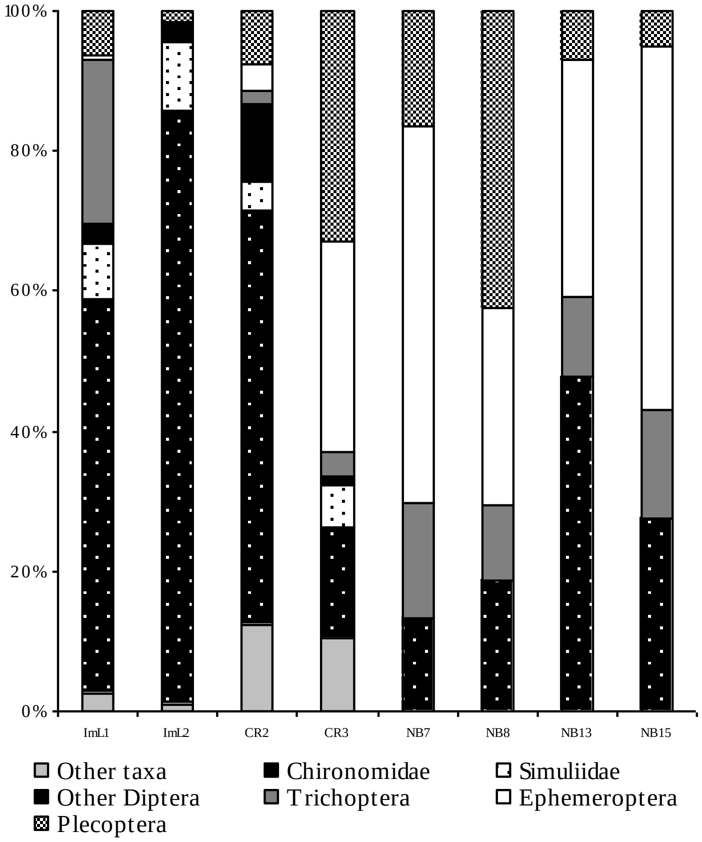


Fig.3.1 Relative composition of zoobenthos in each of the eight sampling station.

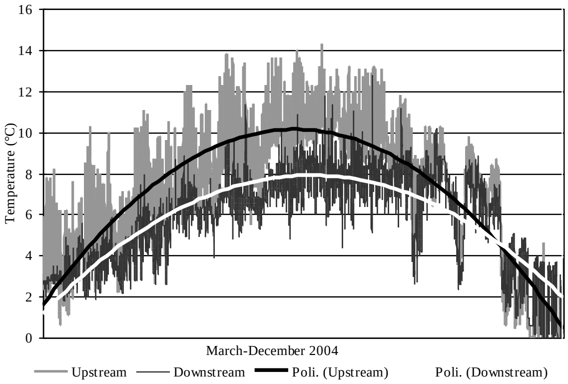


Fig.3.2: Temperature (°C) recorded from March to December 2004 in a station upstream (NB7) and one downstream (NB8) of the turbinated water release point at Cogolo-Pont plant.

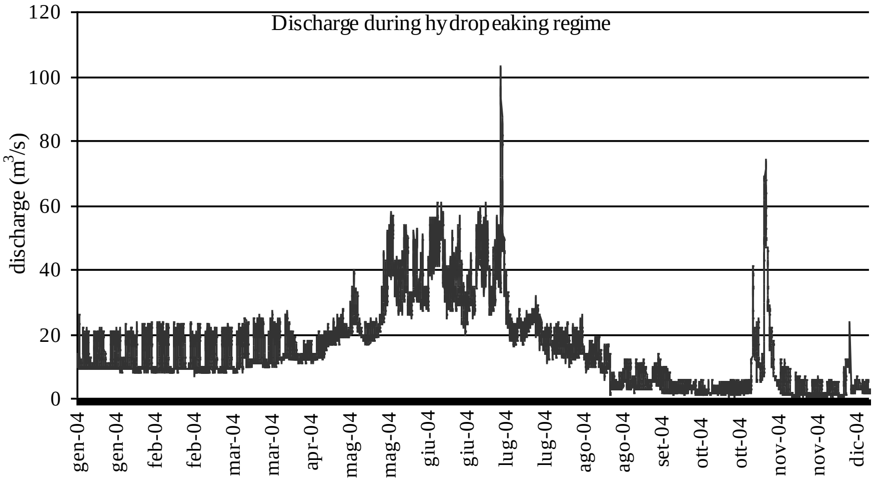
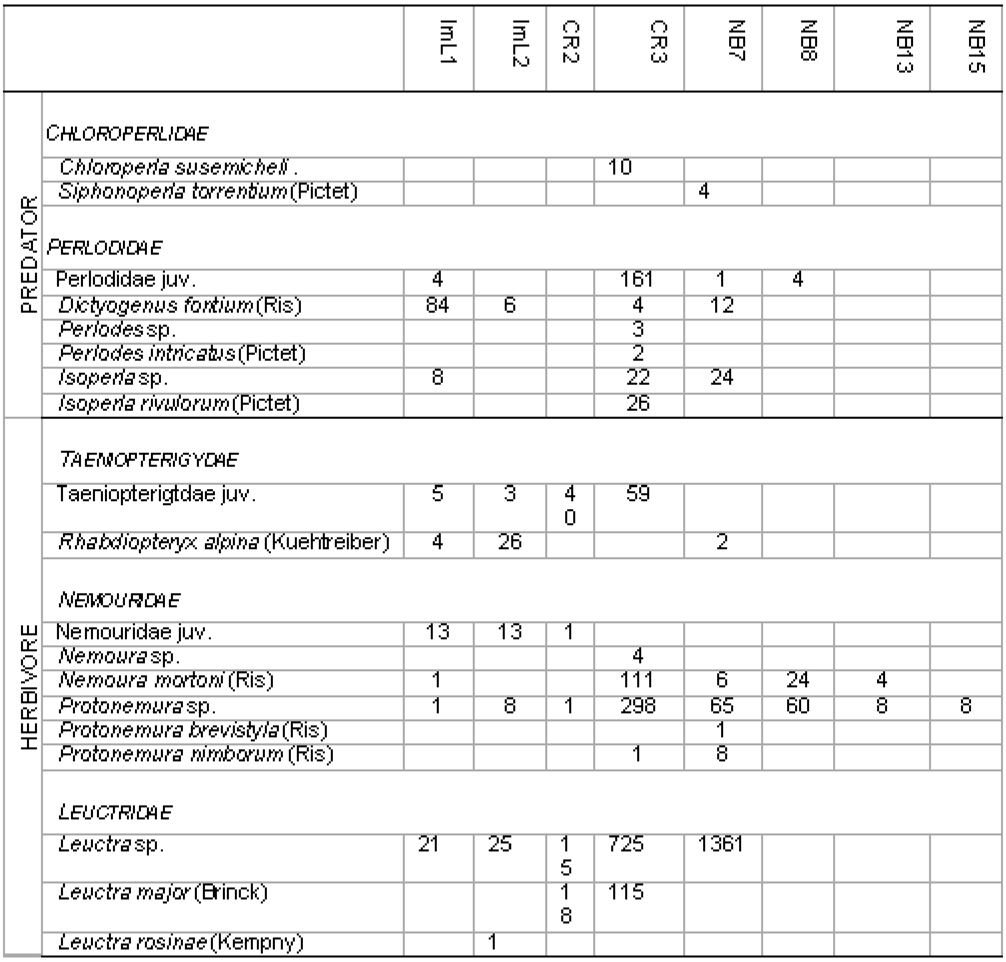


Fig. 3.3: - Discharge ($m^3 sec^{-1}$) recorded by the Service for Hydraulic Works Hydrological monitoring stations located at Noce Bianco stream, downstream from Cogolo-Pont hydropower plant.



		ImL1	ImL2	CR2	CR3	NB7	NB8	NB13	NB15
PREDATOR	*CHLOROPERLIDAE*								
	Chloroperla susemicheli .				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				
HERBIVORE	*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						

Tab 3.1 Density (ind* m^{-2}) of each species Plecoptera in the eight sampling stations.

VII. DISCUSSION

.1. THE PLECOPTERA SPECIES OF ALPINE STREAMS AND SPRINGS IN THE TRENTINO PROVINCE*.*

The recently updated *FaunaEuropaea* highlights that Italy has the largest number of animal species in Europe. This remarkable primacy however poses serious questions about the best way of conserving this irreplaceable heritage, which is further enhanced by the high percentage (about 30%) of endemic species, or species that live wholly or mostly in Italy. The *Checklist of the Species of the Italian Fauna*, which lists about 56,000 animal species, and the *CKmap* database, with about 538,000 entries on the distribution of over 10,000 land and fresh water species, provide the basis upon which to plan the conservation of the Italian fauna.

According to the list of Plecoptera species of Ckmap, the Trentino porvince counts a total of 54 Plecoptera species divided in: 7 species of Perlodidae (*Dyctiogenus*, *Isoperla* and *Perlodes* genera), 4 species of Perlidae (*Dinocras* and *Perla* genera), 3 species of Chloroperlidae (*Chloroperla*, *Siphonoperla* and *Xantoperla* genera), 4 species of Taeniopterigidae (*Brachiptera* and *Rhabdiopterix* genera), 18 species of Nemouridae (*Nemurella, Nemoura, Protonemura and Amphynemura* genera), 1 species of Capniidae (*capnia* genus) and 17 species of Leuctridae (*Leuctra* genus).

From this research we record the presence of 35 species with some new records for Trentino: two for the genus *Leuctra* (*Leuctra niveola* and *Leuctra fusca*), two for the genus *Isoperla* (*Isoperla saccai* and *Isoperla andreini*), one for the genus *Rhabdiopterix* (*Rhabdiopterix alpina*).

Krenal habitas, as aspected, results the most adapt to enhance and preserve the diversity. Our results shown as in Trentino province 31 of the 35 species of Plecoptera were found in springs and in krenal streams. A total of 24 species of Plecopetera were found in kreno-rhithral habitats. This suggest as the mild charatheristics of these habitats can support a good level of species divesity. An intermediate condition between the kryal and rhitral result to preserve a good diversity as suggested by the 11 species found in our kryo-rhithral sampling stations. The less suitable habitats for Plecoptera results to be the kryal streams where only 6 species of Plecopetra were collected. Our result shown also the role of human imapcts for the decrease of number of species present.

.2. ECOLOGY OF PLECOPTERA; LIFE CYCLE, FEEDING HABITS AND USE OF THE HYPORHEIC ZONE

"There is no discipline in hydrobiology that does not require a study of the feeding and nutrition of aquatic animals." (Monakov 2003)

Studies on the feeding habits of aquatic macroinvertebrates have increased in the last ten years, due to theyr importance for a better understanding of the trophic structures of stream communities (Mihuc 1997, Resh & Rosemberg 1984). Predator species have a very important role because they exert a top-down control on the structure of the macroinvertebrate communities (Molles & Pietruszka 1987). In the last decades there was a strong impulse to the study of feeding habits of stoneflies of the Northern hemisphere (Allan 1982, Stewart & Stark 1988). One recent issue is the linking of single species feeding habits with ecological processes at the population and community level (Williams et al.1993). It is known that in Alpine streams the community structure is strongly affected by the harsh conditions of these habitats, especially low temperatures, channel instability, low nutrient availability (Maiolini & Lencioni 2000). In Alpine low order streams most predator species belong to the orders Plecoptera and Tricoptera. To date, the studies on predatory Plecoptera suggest the existence of different feeding preferences in relationship with stage of development, ability to handle inactive and active preys, and dimensions of the nymphs (Walde & Ronald 1987). In fact it has been demonstrated that there is a shift from an herbivorous/detritivorous habit in the first instars, to a strictly carnivorous diet in mature nymphs (Fuller & Stewart 1977) Knowledge of possible variation in diet is very important to understand the biology of a species and in defining its role in community dynamics. Gut content analyses has proved to be a reliable method to study the feeding habits of predator stoneflies in the field, as it allows the identification of the preys by the presence of undigested chitinous parts (Peckarsky 1996, Allan 1995). This is possible because Plecoptera engulf preys without chewing, and thus the chitinous parts are still complete in the gut.

.2.1. LIFE CYCLE OF CHLOROPERLA SUSEMICHELI ZWICK 1967(CHLOROPERLIDAE)

According to our results, *C. susemicheli* presents a univoltine life cycle that could be catalogued as “slow seasonal cycle” according to Hynes (1976). Nymphs were present in the hyporheos for ten months. Emergence (and flight period) occurred in spring-summer, slightly earlier than the period usually reported in literature [Fochetti et al. in press]. This was probably due to the high altitude and relatively low temperature of our study area, with a short summer period ending in mid-August. Hatching occurred in July-August. Growth was constant in autumn and winter (from September to March), in contrast with the findings by Hynes (1962) for *C. tripunctata,* that presents a semivotine life cycle with growth restricted to the summer of each year. The annual life cycle with constant growth shown by the studied species could be a consequence of the stability of the hyporheic habitat. According to literature, the nymphs of the Chloroperlidae family can have univoltine [Hynes 1941, Lavandier & Dumas 1971] or semivoltine [Hynes 1941, 1962, 1976] life cycle.

It is remarkable that all the life cycle of *C. susemicheli* occurred in the hyporheic habitat. This could be related to the fact that this species (and in general all macroinvertebrates) seems to be particularly sensitive to the hydrological regime variations (Knispel & Castella 2003, Fenoglio et al. 2007), and the hyporheic zone is a habitat with stabile environmental conditions. Other species, such as *P. intricatus* and *D. fontium*, only occupy hyporheic habitats for a phase of their life cycle, specially using it as a refuge (Maiolini & Silveri 2006).

.2.2. LIFE CYCLE OF NEMOURA MORTONI RIS 1902 (NEMOURIDAE)

The genus *Nemoura* Latreille, 1796 includes about 175 species, 55 of them present in Europe (Fochetti & Tierno de Figueroa, 2006, 2008), living in different aquatic habitats, mainly in streams and rivers but also in lakes. In Italy, Nemoura counts 17 species, 13 of which are typical of Alpine and Pre-Alpine areas. *N. mortoni* is one of the most abundant species in the Alps. In Italy, this species presents an altitudinal range comprised between 200 and 2300 m a.s.l. and a spring flight period, from April to June or beginning of July, (Consiglio, 1980; Fochetti et al., in press), but there is no data on its life cycle.

Our data suggests that *N. mortoni* has a univoltine life cycle. The data show a spring flight period, mature nymphs were present in the last days of March and the absence of nymphs in April confirm this consideration. The presence of earlier nymphs in May suggest an earlier summer egg hatching period.

During summer, nymphs shown a clear and constant growth till the end of autumn. Our data prove that *N. mortoni* in general had a slow growth with constant incremental growth range during summer and autumn. The absence of nymphs in January and February is due to the harsh environmental conditions that prevent field sampling at high elevation.

It is known that some *Nemoura* species, with univoltine life cycles in low altitude and/or middle latitude areas, present longer cycles in colder areas, while others can complete their life cycles in these areas in only one year despite the unfavourable conditions (Lillehammer, 1986, 1988). Also, the gradualism of growth can vary according with temperature or remain approximately constant along the year, although it is usually accepted that at low temperatures the growth is slow and gradual (Lillehammer, 1986). In relation to this, we want to remark the importance of studies on life cycles and other aspects of stonefly biology at species level, given that it is not possible to infer this information from the general patterns obtained from some other species that, living in different conditions, may behave in a different way.

.2.3. FEEDING HABITS OF DICTYOGENUS FONTIUM (RIS 1896) (PERLODIDAE)

D. fontium is widespread in the Italian Alps, where it populates rhithral streams even at high elevation. In Trentino it was recorded up to 2700 m a.s.l. (Lencioni et al 2001). Nymphs have an annual life-cycle with mature larvae from 15 to 25 mm long, adults emerge from June to September (Consiglio 1980). *D. fontium* is one of the biggest predatory stoneflies present in Alpine streams but its feeding habits are still poorly known. Studies regarding carnivorous species allow investigating the food chains that regulate the structure of stream communities (Allan 1995). Unfortunately, there are few studies on the predatory Plecoptera living in Alpine environments, probably due to the relative recent interest towards these ecosystems.

Of the 60 examined nymphs, 16 had empty guts, probably due to their larval stage. In fact Perlodid and Perlid nymphs stop feeding during the last instars or near moults (Elliot, 2000, Fenoglio 2003, Fenoglio and Tierno de Figueroa 2003, Tierno de Figueroa and Fochetti 2001). In two cases the absence of preys was probably due to bad health conditions of the nymphs, visibly wounded.

32 nymphs had ingested individuals belonging to only one taxon, 11 had ingested two different prey taxa. In one case a mature nymph (28 mm length, station EmM2) was found with gut residues. This is also the only case in which one nymph ingested preys belonging to three different taxa (Chironomidae, Tricoptera Limnephilidae and Simulidae). The choice of one or more prey taxa appeared not to be associated with dimensions and developmental stages of the nymphs. More data are needed to investigate statistical correlations.

Fenoglio and Bo (2004) found that *D. alpinus* living at lower elevations in the Western Italian Alps (1500 – 2000 m a.s.l.) had a rather clear prey preference for Chironomidae and Baetidae, not strictly dependent on the available preys and in some cases the diet was integrated with vegetal fragments. Other studies (Dudgeon 2000; Fenoglio 2003) show a clear link between prey selection and composition of the local benthic community. Our results indicate that *D. fontium* in high elevation Alpine streams feed mainly on Chironomid larvae, which are the most abundant preys and that other preys, though present, are not actively selected. The second preferred prey were blackfly and caddiesfly larvae, which were also the second and third abundant taxa in the benthic community. Thus predation in high elevation habitats with low macroinvertebrate densities seems driven by relative availability of possible preys.

The knowledge about the life cycles of many macroinvertebrate species results very important, especially in the last decade, to evaluate the effects of environmental stress.

.2.4. FEEDING HABITS OF CHLOROPERLA SUSEMICHELI ZWICK 1967 (CHLOROPELIDAE)

C. susemicheli behaves as an opportunistic predator. The main preys were Chironomid larvae (found in 26 individuals), the most abundant macroinvertebrate in glacial hyporheic habitat (Burgher & Ward 2001, Milner et al. 2001, Maiolini & Lencioni 2001). Chironomidae larvae have the adequate size for being ingested by *C. susemicheli*, due to the relatively small size of this predator, and the high abundance of Chironomids in the hyporheos assemblage suggests that there is probably no strong competition with other predatory species such as Perlodidae, also present in the same habitat. Other macroinvertebrates, such as Ephemeroptera (found in only one case) and Plecoptera (in three individuals) were scarcely present in *C. susemicheli* gut content.

We did not detect variation in the diet following nymphal growth (although we did not analyze statistically the differences among size classes due to the low number of individuals). Vegetal matter, usually cited as a common component of the diet of Perloidea early nymphal stages (for instance Hynes, 1941), was almost absent in all size classes. This fact could be a consequence of living in high altitude Alpine streams where aquatic macrophytes and allochtonous leaves are scarce or absent. This could explain the similar situation recorded for *D. fontium* studied in the same area (Maiolini & Silveri 2005). Moreover, detritus was not more common in small nymphs than in large ones, differently from findings in other Perloidea (Hynes 1976).

.2.5. PLECOPTERA OF HYPORHEIC HABITAT

In general, benthic stonefly communities are less diverse in glacial streams than in non-glacial ones in response to the harsh environmental conditions in this habitat (Brittain et al 2000, Ward 1994). From the results of this study, it appears that the same situation applies to the hyporheic communities. However, our results show that hyporheic stonefly communities in glacial streams are more diverse than the corresponding benthic ones. This fact is probably due to the use of the hyporheic as a refuge from the adverse conditions in surface water, as nursery, and as feeding area as suggested by Varricchione 1999 and Boulton 2000a.
Three species of Plecoptera, *L. major* and *S. torrentium* and *C. susemicheli* are considered typical of the hyporheic habitat (Standford & Ward 1988, Allan 1995,Boulton et al 1992) and our results confirmed this ecological preference. Other species such as *P. nimborum*, *C. vidua* and *L. braueri* were often present in this habitat as well, suggesting that, in the harsh environmental conditions represented by glacial streams, some sensitive species (such as those belonging to the genera *Leuctra*, *Capnia* and *Perlodes*) may choose a less-variable habitat moving from the benthic to the hyporheic habitat.

The presence of many larval exuviae suggest that stoneflies use the hyporheic habitat in particularly sensitive phases of the larval development. The role of hyporheic zones as refugia is confirmed by the numerous larvae of typically benthic species ready to emerge and there collected.

The hyporheic habitat as nursery refugia (Boulton 1998 and Brunke & Gonser 1999): was also confirmed by the large number of neanids collected probably to more safely complete their larval development, escaping adverse conditions of glacial surface water.

In the investigated streams, the hyporheic habitat was used as feeding area as well, as shown by the presence of the typical predator *C. susemicheli* and, more rarely, of *S. torrentium*, and of other Perlodidae with particular high abundances in the hyporheic habitat when compared to the benthic one of the same stream reach.

.2. THE IMPACT OF HYDROPOWER PRODUCTION ON PLECOPTERA COMMUNITIES.

The connectivity of streams and 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, and release of turbinated waters 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). Hydrological regime, water quality and channel geomorphology are among the most important driving forces of the distribution and abundance of riverine species and they 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; Maiolini et al 2008).

Several studies regarded the impact of water abstraction and diversion (Brittain & Saltveit 1989; Armitage 1992), but few focused on the effects of hydropeaking (Cereghino & Lavandier 1998, Cortes et al. 2002). Hydroelectric power production causes the interruption of the four dimensions of the river continuum, affecting the zoobenthic communities in different ways, according to the three phases of the production process; these differences should be taken into account when developing public water management plans. Plecoptera are excellent sentinel species (Consiglio 1980, Fochetti 1994) and can be used as bio indicators of different levels of alterations.

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). In particular, downstream of a water diversion structure in a non-glacial stream, zoobenthic communities increase in density due to few taxa (Uhelinger and Robinson 2002); in this study, total density increased 5 times, mainly by Chironomidae. The increase in densities was due to a decrease in substrate granulometry, solid transport and discharge, with consequent increase in streambed stability and water temperature. Our results indicate that water diversion causes a downstream increase of primary production with development of phytobenthic species, favoured by warmer summer temperatures and more stable substrate, due to the minor discharge.

The effects on the primary production of the reservoir was mainly due to changes of freshwater tipology. The upstream glacial stream had low phytobentic 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 richer and more 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. Higher stability implied an increase in taxa which prefer low water flow and stable substrates, whereas those taxa which are adapted to turbulent water and instable substrates decreased.

More considerable changes occurred between stations separated by the stocking/sedimentation basin, which implies a change in stream typology. In fact, we observed a shift from a community dominated by Chironomidae, typical of glacial streams, to a community dominated by Ephemeroptera and Plecoptera, typical of mixed, non-glacial streams. The Plecoptera community changed as well: both the predator (Perlodidae) and the herbivore (Nemouridae and Leuctridae) components become more diverse, as it is expected with the change in stream typology and elevation (Brittain et al. 2003).

Flow and temperature regimes are two primary factors controlling the structure and dynamics of stream invertebrates (Cereghiño and Lavandier, 1998b), directly by increasing animal transport (Waters, 1965; Cereghiño and Lavandier,1998a, 1998b) and/or indirectly by increasing the spatial-temporal variability of stream habitats (Feminella & Resh, 1990; Robinson et al., 1992) and determining the available food resources (Moog & Janecek, 1991). The flow regime alterations associated with sharp fluctuations in water levels when water is released form the hydropower plants into the streams (*hydropeaking*) modifies the specific composition and longitudinal zonation of invertebrate populations below the outlet. Direct impacts are due to scouring, which removes the fauna through drift (Boon, 1988, 1993; Troelstrup and Hergenrader, 1990; Cobb et al., 1992), and clogging, which reduces the available habitat for the bottom-dwelling fauna; indirect impacts are the reduction of growth and development of instream algae and macrophytes, and riparian vegetation (Stromberg & Patten, 1990; Robinson et al., 2004b), which change the food sources available to macroinvertebrates (Anderson and Cummins, 1979; Moog & Janecek, 1991). Consequently hydropeaking is the phase with highest impact on the stream ecosystem. In our study, 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.

VIII. CONCLUSION

- After ten years from the last sampling of the Trentino province, the list of species of Plecoptera result to be improved. This suggest the relevance of a periodical review with increasing number of sampling station.
- In the harsh environmental conditions typical of alpine streams, the hyporheic ecotone assumes an inmportant role as nursery, feeding area for most sensitive predaceus species and refuge area. In hydropower impacted stations such role is particulrly relevant to escape the effects of the repated physical–chemical changes occurring in the river bed. Unfortunally the availabilty of hyporheic habitats is reduced downstream of power plants by clogging of the interstices, a known effect of hydropeaking.
- The knowledge about the life cycles of many macroinvertebrate species results very important to evaluate the effects of environmental stress in alpine environments suffering from human alteration and consequences of climate change.
- 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) and can be used as bioindicators of different levels of alterations of the river continuity.
- Consistently with other studies regarding ecological effects of hydropeaking (Cereghino and Lavandier 1998; Cortes et al. 2002) we found a considerable decrease in biodiversity of aquatic and riparian terrestrial invertebrates, and an increase in catastrophic drift, which prevents the establishment of stable zoobenthic communities dowstream of power plants. In this study the Plecoptera community changed downstream from the turbinated water release point, 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 unnatural variations of discharge and temperature which have effects on spatial distribution, 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 and Lavandier (1998).

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