The use of benthic invertebrate production for the definition of Ecologically Acceptable Flows in mountain rivers

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Abstract Through benthic habitats occurrence, a link between secondary production and discharge has been established, to enable the definition of Ecologically Acceptable Flows (EAFs) in mountain rivers. The procedure, named BENHFOR (BENthic Habitat FOR optimum flow reckoning), supports the identification of optimum and minimum flow conditions for macroinvertebrate communities. Production values for the four habitats identified (pool, riffle, transition habitat and bedrock), and flow-production relationships for the whole community and for selected taxa are presented. For the mayfly *Ecdyonurus helveticus*, the production curve was separated seasonally, to take into account the different developmental generations and thus produce a more sensitive and seasonally adjusted discharge regime. Examples of optimum and minimum flow values for single taxa and community production are presented. The general applicability of the method is discussed.

Key words instream habitat; flow; secondary production; BENHFOR; invertebrate; mayfly; mountain rivers

INTRODUCTION

The selection and development of simple, economically acceptable and ecologically sound hydroecological methods are now required for Italy, as new national rules regulating water abstractions are being set. In Italy, the definition of Ecologically Acceptable Flows (EAFs) has a short history (Viganò *et al.*, 1998), as legislative guidelines and operational rules have only recently been proposed. This has led to a delay, both in the application of existing hydroecological methodologies and in the development of new methods suitable for the Italian geographical and socio-economical situation. Many commonly used hydrological methods to set standard flows (e.g. Matthews & Bao, 1991; Tennant, 1976) cannot be utilized in Italian rivers because hydrological data are lacking, while existing biologically based methodologies to define optimum or minimum flows (e.g. Bovee, 1982; Ginot, 1995; Milner *et al.*, 1985) cannot be generally applied, primarily because of uncertainties regarding ecological assumptions and target species selection. In parts of Europe and the USA, fish biomass estimates are often selected for use in hydroecological assessment methods (Stalnaker, 1993) because many species (mainly salmonids) are commercially important. In Italy, very few salmonid species are present and their populations can be very artificial because of extensive management. Additionally, exotic taxa are frequently introduced to inland waters, compromising fish community integrity (Gandolfi *et al.*, 1990). Alternative ecological targets may therefore be needed for assessing flows, particularly when fish data are not suitable. Macroinvertebrates are an appropriate alternative biological target, as expertise on their collection, identification and analysis is widespread throughout Italy and Europe and they offer a large amount of information on the state of the aquatic environment. Furthermore, invertebrate communities are inherently worth protecting, if biotic integrity and ecosystem functioning is to be maintained (Gore, 1989).

Secondary production is a measure of ecosystem functioning, integrating the overall response at population, community and ecosystem levels, and is considered to be the most comprehensive representation of success for any population (Benke, 1993). Production should be assessed taking habitat abundance into account (e.g. Smock *et al.*, 1985; Lugthart & Wallace, 1992), in order to fully evaluate total stream productivity. Such an approach potentially links with traditional methods for assessing instream flows, such as PHABSIM (Bovee, 1982), which involve detailed habitat evaluation. Numerous papers used invertebrates in instream flow studies (e.g. Armitage, 1989; King & Tharme, 1994). The author is unaware, however, of any studies utilizing macroinvertebrate production to assess Ecologically Acceptable Flows.

The initial aim of this paper is to quantify invertebrate habitat occurrence in different flow conditions and to derive habitat and production *vs* discharge relationships for a range of flows, in an Italian mountain river characterized by a high degree of ecological integrity (Buffagni & Comin, 2000). A link between flow and benthic production will then be established for the whole community and for selected taxa. Finally, a method based on the definition of these relationships—named BENHFOR (BENthic Habitat FOR optimum flow reckoning) that can be used when assessing environmentally acceptable flows, is presented.

STUDY SITE, MATERIALS AND METHODS

The study was conducted on the Pioverna River, a typical mountain stream of the Italian Alps, located in Valsassina (Pasturo, Lecco, north Italy). It flows between 2300 and 418 m a.m.s.l. and its waters run for about 20 km before running into the Como Lake, near Bellano. The study site, close to the city of Pasturo, is a pristine river stretch about 500 m long and 3–6 m wide at baseflow, at about 800 m a.m.s.l. The river here is characterized by good water and environmental quality (Buffagni & Comin, 2000). To estimate macroinvertebrate production, monthly sampling (18 dates between April 1996 and September 1997 inclusive) was performed. The minimum discharge during the invertebrate collecting period was observed in April 1997 (0.011 m^3 s^{-1}), while the maximum was observed in July 1997 (0.241 m^3 s^{-1}). The studied stretch had a predominantly stony or rocky substratum, with water velocity varying from 0 to approximately 2 m s^{-1}. Maximum water depth was approximately 1.5 m. No aquatic macrophytes were present. Water temperature ranged from 3.5°C in December 1996 to 15.6°C in August 1997 (annual average: 7.8°C), and the studied river reach is of a good biological quality (Buffagni & Comin, 2000). Production of benthic invertebrates and habitat mapping were assessed for the four functional habitats, as described by Harper *et al.*, 1992, previously identified in the Pioverna River (Crosa & Buffagni, 1996; Buffagni & Comin, 2000) by means of TWINSPAN (Hill, 1979). Habitats were defined by the composition and abundance of the benthic community (Crosa & Buffagni, 1996) and four distinct types were recognized: "riffle", "pool", "transition" and "bedrock". The term "transition" is used to label highly dynamic habitats showing somewhat intermediate attributes between pools and riffles. Transition habitats often occur in stream areas where physical features are likely to change with small variations in discharge (e.g. lateral runs and marginal, still water, areas). The habitats identified, differ from each other mainly with regard to water velocity (pool and transition *vs* riffle and bedrock), depth (pool *vs* the other habitats), physical substratum features (bedrock *vs* the others) and substratum roughness (pool and bedrock *vs* transition and riffle).

The field surveys to map river habitats were conducted on single dates between April 1997 and June 1999. In the field, river habitats were identified, quantified using a measuring tape (Harrelson *et al.*, 1994) and by visual assessment (for short distances) and mapped along the river stretch. This procedure was repeated for eight measured flows ranging from 0.01 to 1.2 $m^3 s^{-1}$. On average, the mapping procedure took less than one hour for 100 m using two trained surveyors and one assistant. Habitat identification, tape measuring and visual assessment of distances may be subject to some investigator error (e.g. Hannaford et al., 1997; Spencer et al., 1998). Thus, a ring test was conducted to evaluate the consistency of the habitat assessment among the trained surveyors who performed the mapping (Friedman and Tukey's tests were applied to the collected data). No differences were found between the surveyors, although some differences were noted between them and untrained field operators, mainly regarding the "transition" habitat occurrence. Within the framework of the methodology proposed here, other procedures to estimate benthic habitat occurrence may be used as well.

A total of 115 Surber samples (area 0.15 m^2, mesh size 0.45 mm) were collected at monthly intervals to facilitate secondary production estimates for the most abundant taxa present at the study site. To define life cycles and assess production, body lengths of selected taxa were measured. The production values per square metre were considered constant within habitats for any taxa, given the difficulty of evaluating the effects on the production estimates, for example there may possibly be size-dependent movement of nymphs between habitats and changes in habitat patch dimensions. To estimate production (dry weight) the methods of removal-summation, instantaneous growth and size-frequency were used (see Benke, 1984; 1993, for details). Results presented hereafter refer to average values. Details on field sampling, sorting and identification of macroinvertebrates and production estimates are reported in Buffagni & Comin (2000).

The stages required for applying BENHFOR can be summarized as follows:

(a) Identify which and how many benthic invertebrate functional habitats with a proved ecological distinctiveness and meaning are present in the study reach (from the literature, if possible).

(b) Estimate secondary production of benthic invertebrate taxa and assemblages for each functional habitat, either entirely from primary data, or by partly using literature sources.

(c) Quantify the occurrence of functional habitats by direct mapping in different flow conditions and derive functional habitat/discharge relationships for a range of flows.
(d) Predict the expected secondary production (for the whole community or for single taxa and guilds) by combining values of production for the functional habitats, with the relative occurrence of habitat at different flows. Details on single cohorts should be provided, where feasible.
(e) Where possible, identify notable points of change on the resulting curves, which correspond to optimum and minimum acceptable flow values for invertebrate production.

That not considered in the present paper is:
(f) Assess the variation of expected production resulting from flow changes by developing habitat and production time series for alternative flow management options.

RESULTS

Benthic production varied between the four instream functional habitats identified in the Pioverna River (Table 1). The taxa with highest abundance and production belong to the Plecoptera, Ephemeroptera, Diptera and Trichoptera (also see Buffagni & Comin, 2000). The riffle habitat had the highest secondary production, while bedrock habitat had the lowest. Pool and transition habitats attained intermediate production values. The mayfly species, *Ibisia marginata* and the plecopteran family Nemouridae, gave the highest contribution to total production. *I. marginata* and *Amphinemura* sp. exhibited a relatively high production in all habitats except bedrock, while the other taxa showed more variability between habitats. Some taxa were more productive in riffles (*Baetis alpinus*, *Ecdyonurus helveticus* and *Rhithrogena* spp.), others in pools (*Leuctra* sp. and *Habroleptoides* sp.) while only one taxon showed peak production in the transition and bedrock habitats, *Alainites muticus* and *Baetis melanonyx* respectively.

Table 1 Annual production of the main benthic invertebrate taxa in the Pioverna River for the four functional habitats during 1996–1997.

	Taxon	Secondary production ($g\ m^{-2}\ year^{-1}$): Pool	Transition habitat	Riffle	Bedrock
Plecoptera	*Leuctra* sp.	0.141	0.027	0.029	0
	Amphinemura sp.	0.151	0.177	0.303	0
	Protonemura sp.	0.027	0.025	0.110	0
Ephemeroptera	*Alainites muticus*	0	0.003	0.002	0
	Baetis alpinus	0	0	0.310	0.096
	Baetis melanonyx	0	0	0.042	0.137
	Baetis rhodani	0	0.176	0.202	0
	Habroleptoides sp.	0.059	0	0	0
	Ecdyonurus helveticus	0	0.020	0.267	0
	Rhithrogena spp.	0	0	0.234	0
Diptera	*Ibisia marginata*	0.288	0.191	0.257	0
Trichoptera	Hydropsychidae	0	0.029	0.098	0
	Total production	0.667	0.650	1.853	0.234

The habitat/discharge relationships for the four functional habitats are reported in Fig. 1 for the studied reach of the Pioverna River. As a general tendency, occurrence of the riffle habitat increased with flow. The bedrock substratum quickly peaked then remained relatively constant even at higher flows. The transition habitat showed maximum occurrence with intermediate/low flows, while the pool one was maximal at relatively low flows. The potential sensitivity of biota to habitat change due to flow variation was evaluated using benthic production estimates for single taxa as well as for the whole benthic community, deriving production/discharge relationships for a range of flows (Fig. 2). The amount of expected production for each flow value was calculated by summing the contribution from the four habitats considering their total area along the whole stretch. A few taxa did not display relevant modification of their potential production (excluding values of flow close to zero) with varying flows (e.g. *I. marginata*, Fig. 3). All the others exhibited apparent increasing (e.g. *Baetis* spp., *E. helveticus*; Figs 4 and 6) or decreasing (*Leuctra* sp., Fig. 5) trends of expected production. For *E. helveticus*, the production curves for the observed development

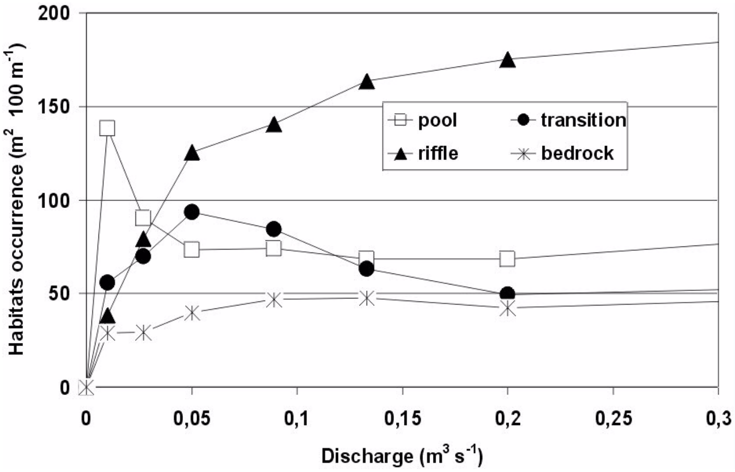

Fig. 1 Relationships between habitat occurrence and discharge for the studied reach of the Pioverna River (this and following figures focus on lower flows).

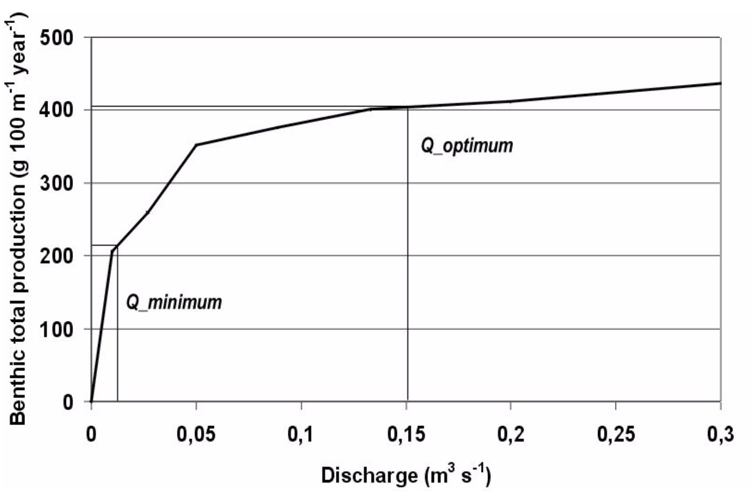

Fig. 2 Expected trend of secondary production for the whole community at different discharge values in the Pioverna River.

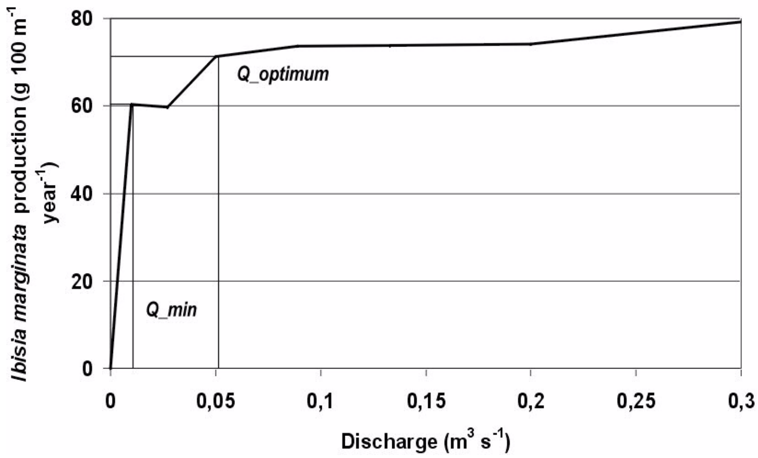

Fig. 3 Expected trend of secondary production for *I. marginata* at different discharge values in the Pioverna River.

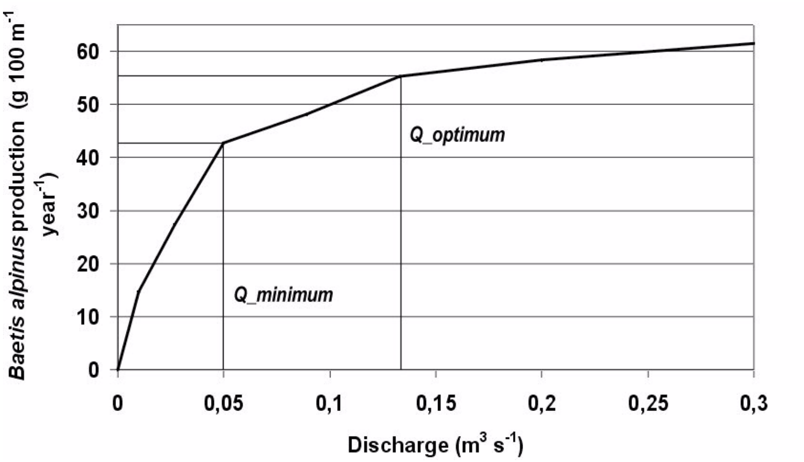

Fig. 4 Expected trend of secondary production for *B. alpinus* at different discharge values in the Pioverna River.

generations (here labelled "winter", "spring" and "summer" cohorts: Buffagni, unpublished data) contributing to the species life cycle, are shown in Fig. 6, together with the yearly curve. Lines corresponding to the average discharge of the period during which each cohort developed are drawn, and the consequent production values are defined on the *y*-axis. The dotted lines approaching the axis refer to the annual mean discharge, in this case the corresponding expected total production is close to the sum of the values from estimations for the single cohorts (horizontal line on the *y*-axis). Hypothesized optimum and minimum flow values for taxa and community production are graphically presented in these figures (except in Fig. 6), based on notable points of change on the defined curves. The points of change have been identified for pure demonstrative purposes (i.e. no water abstraction takes place from the Pioverna River) according to two main criteria. Minimum flow values would correspond to points situated immediately after the first steep portion of the curves, while optimum flow values would be placed where the curves reach the lowest/nearest area of a plateau section (if present) or at the production peak, if the curve decreases. Their soundness should always be carefully evaluated according to river management priorities and ecological targets.

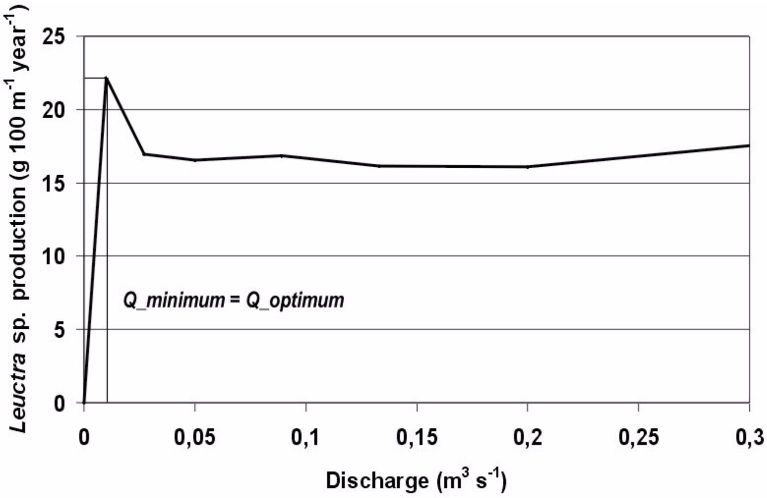

Fig. 5 Expected trend of secondary production for *Leuctra* sp. at different discharge values in the Pioverna River.

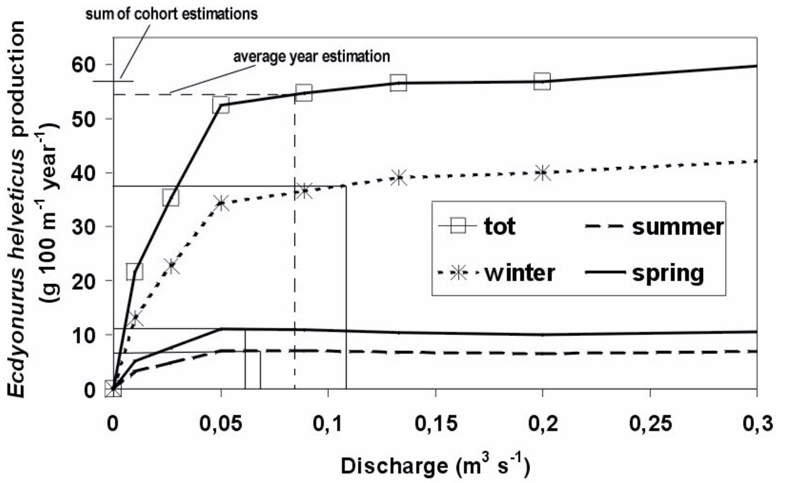

Fig. 6 Expected trend of secondary production for *E. helveticus* at different discharge values in the Pioverna River, separated for the three different generations.

DISCUSSION

The joint use of biological metrics with a system of habitat classification, has considerable merit, since distinct habitat can be readily recognized and assessed, whereas ecological functioning is entirely more complex (Harper *et al.*, 1995). Moreover, the establishment of a link between habitat occurrence and biological response is a useful tool, whenever habitat variation can be associated with flow, because it allows hydrological change to be tied to ecological function (e.g. secondary production). It can additionally be argued that conserving the river habitats themselves is a cost-effective surrogate for conserving the invertebrate community (Harper *et al.*, 1992). Future studies for estimating secondary production should be habitat-oriented (Smock *et al.*, 1985; Buffagni & Comin, 2000), and this will necessitate an accurate listing of all instream habitats within a river reach. If this procedure is successful, a good basis for using benthic production data within the flow management schemes, will result.

During the present study, quantitative physical habitat was estimated using rapid assessment techniques. This is considered to be a cost-effective procedure for small and medium-sized rivers.

Growth rates and production of invertebrates in unimpacted streams are primarily controlled by water temperature, food availability and physical habitat (Benke, 1993). A reduction in usable habitat will therefore directly affect the actual (and, to a lesser extent, the subsequent) population abundance. Invertebrate density and production will also be influenced by extreme events experienced by the populations during their life cycles (Lavandier & Decamps, 1984). In this context, man-induced modifications (e.g. water quality) or natural events (e.g. spates and droughts) can be important in accounting for expected invertebrate production, as they can greatly influence invertebrate populations. In rivers with highly variable flows, for example, the current-related resources and habitat distribution relationships can easily be disrupted (Poff & Ward, 1989; Céréghino & Lavandier, 1998). Such environments should, however, host taxa adapted to withstand wide variation in flow regime, or to recover after disturbance. On the other hand, patches of stable habitat along river stretches can enable taxa to persist in the face of very variable flows. In general, the functional habitats whose production are likely to be less affected by hydrological variations, are those bearing benthic assemblages adapted to harsh local hydraulic conditions (i.e. riffle and bedrock habitats). Yet, a fall in global production would likely occur as flows increase to critical levels. The estimation of expected production on the basis of habitat availability, as performed in the present paper, does not account for such extreme hydrological events, which should be considered independently.

If applying BENHFOR in fish streams, invertebrate production values can be selectively employed depending on the fish species present and management purposes. If fish catches and fisheries need to be enhanced, together with specific fish oriented options (e.g. the identification of spawning areas), the frequency of the most productive habitats (i.e. riffle in mountain rivers in the Alps) could be maximized. Furthermore, if the flow is set for increasing production of drift feeding fish, invertebrate taxa recognized as "drifters" (e.g. *Baetis* spp.: McIntosh *et al.*, 1999; Brittain & Eikeland, 1988) should be mainly considered for determining instream flow optimum values. Alternatively, if fish species or stages are mainly feeding on benthic prey, value selection could consider invertebrate taxa more strictly anchored to substrate (e.g. *Rhithrogena* spp., Grandi, 1960) or confined to interstices (e.g. *Ibisia marginata*).

The identification of critical points on the production/discharge curves, corresponding to optimum and minimum flows, can help formulate flow management options. Assessing flows based on the secondary production of benthos and on the occurrence of functional habitats could be particularly beneficial in fish-poor rivers, where macroinvertebrates may be the only biota reliably available for sampling and prediction. In its last step, the procedure presented here is close to the concepts embodied within biological response modelling techniques, such as PHABSIM, as it assumes that river biomass and secondary production can be related to flow (e.g. Milhous *et al.*, 1989) and that critical discharge values, of ecological value, can be identified (e.g. Orth & Leonard, 1990). Methods like PHABSIM, require hydrological simulation, however, a procedure that is difficult in some river types. Approaches like BENHFOR may overcome these problems, since flow is related to distinct habitat occurrence and not to single taxa preferences for simulated water depth, velocity and substratum type. Invertebrate production/flow relationships reported in this study (Figs 2–5), could be used as general tools for managing flows in the Pioverna River. As flows will always vary annually and seasonally, environmentally acceptable discharges should be prescribed considering habitat time series for the most productive habitats and taxa. More precise analysis and definition may be possible. Figure 6 for example presents details on the production of single cohorts of a dominant benthic species, *E. helveticus*. The splitting of the taxa annual production into their cohort production, in this case, can enable the setting of more sensitive and seasonally adjusted discharge values. In the case of *E. helveticus*, the most important generation season is winter, with nearly 70% of the annual production. The two remaining generations make a minor contribution to overall production. When managing flows to sustain optimal levels of this taxon's production, therefore, attention should primarily be paid to habitat availability for the winter generation. Similar cohort analysis should ideally be undertaken for all species contributing to production, so that season or month-specific discharges, corresponding to optimum or minimum values for the benthic community, can be identified.

Defining EAFs for rivers often requires the application of time-consuming procedures. Estimating secondary production can be arduous too, and will not always provide a worthwhile return for the time and field effort invested. This is certainly true for poorly studied areas and rivers, although in situations where adequate data are available, information from the literature (e.g. the annual *Production/Biomass* ratios or multiple regression models) can be combined with mean biomass and other readily measured variables to estimate production (Waters, 1977; Lapchin & Neveu, 1980, Poff & Huryn, 1998). This would give production/flow studies increased attractiveness, reducing analytical time and costs and simplifying calculations. Taxa and functional habitat data can also be obtained from the existing literature and this again would reduce field and laboratory effort when applying BENHFOR. Once taxa and habitat lists and production reference parameters (e.g. see Benke, 1993; Buffagni & Comin, 2000) have been defined for one river sector, they could be easily employed in streams of similar type, within an ecoregion. Nevertheless, extreme caution should be exercised to derive directly production values from literature sources (Gore & Nestler, 1988), since site specific variations can be conspicuous.

When defining a regime for river management, optimum and minimum acceptable flows for selected taxa and benthic assemblages represent only one step in determining a streamflow hydrograph able to sustain the ecological integrity of whole river ecosystem (Petts *et al.*, 1996). The approach outlined here could play an important role in this process, as well as providing invaluable information to help conserve key species and communities.

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