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DOWNSTREAM EFFECTS OF A NEW HYDROPOWER IMPOUNDMENT ON MACROPHYTE, MACROINVERTEBRATE AND FISH COMMUNITIES

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ABSTRACT

The downstream effects of Valparaíso Reservoir (Río Tera, north-western Spain) on macrophyte, macroinvertebrate and fish communities are examined by comparing their respective structures before (1986) and after (1990–1991) the creation of this hydropower impoundment. A single sampling station was selected 2·4 km below the dam. Macrophytes significantly ($p < 0{\cdot}05$) decreased their total biomass, although the species composition remained dominated by two species (*Myriophyllum verticillatum* and *Ranunculus fluitans*). The macroinvertebrate community, on the other hand, exhibited a significant ($p < 0{\cdot}05$) decrease in taxonomic richness, total density and total biomass. In general, planarians, ephemeropterans, coleopterans, plecopterans and trichopterans disappeared or decreased their abundances. Scrapers (as relative biomass) were the functional feeding group most adversely affected by the new flow regulation. With regard to the fish community, the most significant change was the absence of all resident coarse fishes (cyprinids, primarily) at the sampling site during the 1990 and 1991 sampling surveys. Conversely, salmonids (*Salmo trutta*) persisted; the trout population was dominated by individuals of the 0+ age group ($\leqslant 1$ year old) both before and after the construction of Valparaíso Dam. It is concluded that short-term flow fluctuations induced by hydroelectric power generation were the main factor causing the observed adverse effects. In this respect, some management measures to minimize these effects are recommended.

KEY WORDS Hydropower impoundments Macrophytes Fish Macroinvertebrates Species composition

INTRODUCTION

Although the downstream effects of water pollution on freshwater biota have been investigated in detail, comparatively little attention has been paid to the effects of short-term flow fluctuations induced by hydroelectric power generation. This type of river regulation can produce important adverse effects on fluvial communities (Ward and Stanford, 1979; Brooker, 1981; Ward, 1982; Lillehammer and Saltveit, 1984; Petts, 1984; Armitage *et al.*, 1987; Boon, 1988; Garcia de Jalon *et al.*, 1988; Camargo and Garcia de Jalon, 1990; Voelz and Ward, 1991). In general, unnaturally rapid increases and decreases in water volume downriver from hydropower impoundments cause changes in species composition, decreases in species richness, modifications of life cycle patterns and alterations in population abundances.

In Spain, hydroelectric power generation has led to the impoundment and regulation of a large number of rivers and streams (Garcia de Jalon, 1987). The regulated Río Tera constitutes a clear example of this process. Eight hydropower impoundments were built along its headstreams between 1953 and 1962. The main channel was first impounded in 1969 by Cernadilla Reservoir, which is used for agricultural irrigation and hydroelectric production (Casado *et al.*, 1989). The Valparaíso Reservoir, created just below Cernadilla Dam for the same purposes, was completed in 1989.

The present study examines the downstream effects of Valparaíso Reservoir on macrophyte, macroinvertebrate and fish communities by comparing their respective structures before (1986) and after (1990–1991)

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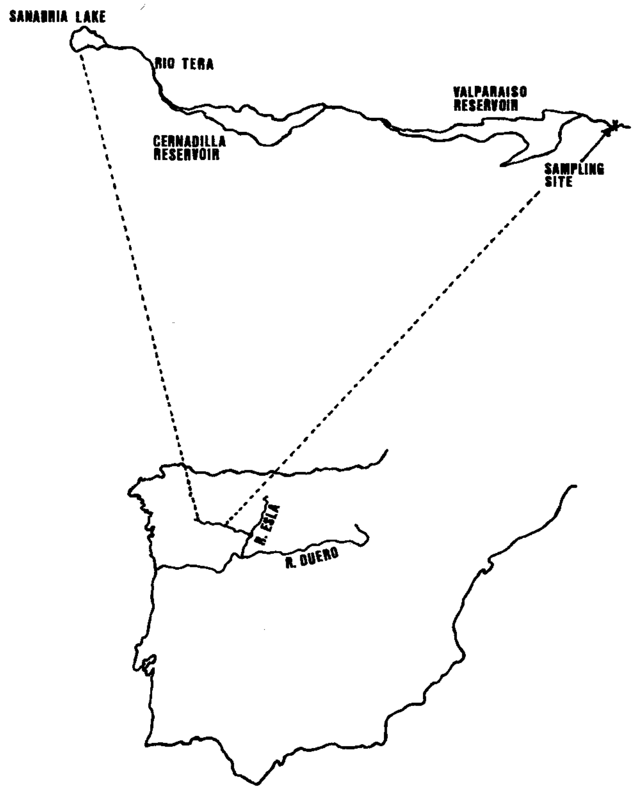

Figure 1. General diagram of the Río Tera (north-western Spain) showing the location of Cernadilla Reservoir, Valparaíso Reservoir and sampling site (2·5 km below Valparaíso Dam)

the creation of the impoundment. Similar comparative approaches have been applied to studies of other regulated rivers (see, for example, Armitage, 1978; Crisp *et al.*, 1983; Craig and Kemper, 1987; Boon, 1993), and it seems to be appropriate for assessing structural responses of aquatic communities after the start of hydroelectric power generation although the limitations of a single 'baseline' survey (1986) are fully appreciated. In addition, some management measures to minimize the adverse effects and accelerate the ecological recovery are recommended.

STUDY ZONE AND FLOW REGULATION

The Río Tera is located in north-western Spain (Zamora) within the Duero basin. It arises from Sanabria Lake, which receives waters from the mountains of the 'Sierra de la Culebra' (more than 2000 m a.s.l.), and drains into the Río Esla, which is the major affluent of the Río Duero (Figure 1). The watershed of the Río Tera is mainly underlain by siliceous rocks (e.g. granite, gneiss). This induces the formation of soft waters with a low ionic content. According to Casado *et al.* (1989), the Río Tera's natural flow regime before 1969 was characterized by maximum monthly mean flows during February–March and minimum flows during August–September, with an average annual flow of 20 $m^3 s^{-1}$. However, after the construction of Cernadilla Dam, the previous extreme values between winter and summer seasons were reduced.

Valparaíso Dam is located in the middle Río Tera (Figure 1), impounding a bottom outlet reservoir with a capacity of $169 \times 10^6 m^3$, a maximum depth of 64 m and a surface area of 1224 ha (MOPU, 1988). Hydroelectric power is generated by discharging hypolimnial waters through two turbines. Each turbine can discharge an average volume of 70 $m^3 s^{-1}$. Additionally, the dam has a surface spillway that is used when the reservoir becomes overfull as a consequence of important floods.

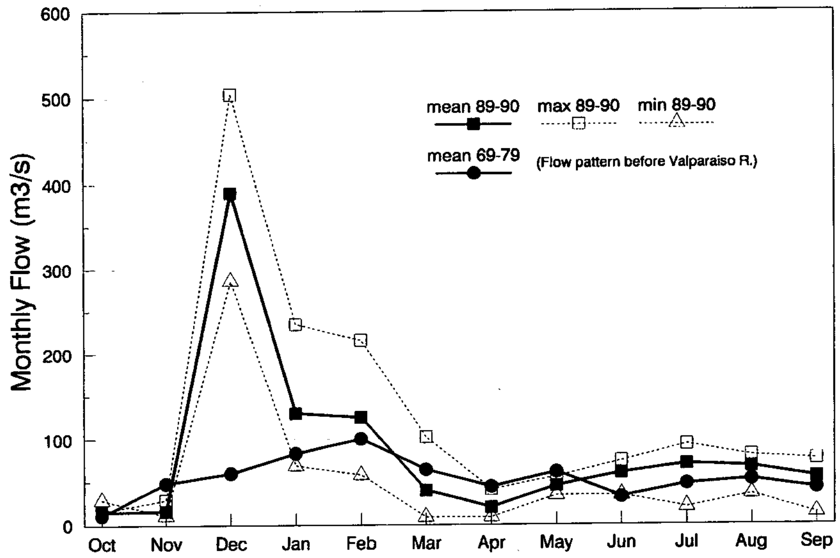

Figure 2. Monthly flow pattern at the sampling station (2·5 km below Valparaíso Dam) for the hydrological year 1989–1990 and for the pre-dam (1969–1979) period

The Río Tera's regulated flow regime (monthly flow pattern) downriver from Valparaíso Dam for the hydrological year 1989–1990 is shown in Figure 2. There was an unusually rainy winter, with great floods taking place. However, after the winter, monthly mean flows were similar. Figure 3 shows two typical types of daily flow pattern over a one-week period downriver from Valparaíso Dam. In winter (March), turbines often work once a day with huge flow fluctuations (from 10 to 210 $m^3 s^{-1}$). By contrast, in summer (July), turbines usually work five times a day, the flow fluctuations being smaller (from 15 to 110 $m^3 s^{-1}$). This seasonal difference is due fundamentally to variations in the demand for hydroelectric power.

METHODOLOGY

To examine the downstream effects of Valparaíso Reservoir on macrophyte, macroinvertebrate and fish communities, a single sampling station was selected 2·4 km below Valparaíso Dam (and 24 km below Cernadilla Dam). This study reach (Figure 1) is located at an altitude of 776 m a.s.l., has an average width of 40 m and an approximate area of 1500 m^2; it corresponds to a fourth-order stream (scale map 1 : 50 000). The river bottom was mainly stony with boulders, pebbles and gravel.

The macrophyte community was sampled using a cylinder with a sampling area of 0·1 m^2. Sampling surveys were undertaken in September 1986 and 1990, collecting three to four replicates in each survey. After identification, macrophytes were dried in an oven at 60°C for eight hours to estimate the biomass (dry weight).

The benthic macroinvertebrate community was sampled using a Hess cylindrical sampler, which enclosed a sampling area of 0·1 m^2 and was equipped with a 0·5 m net with a mesh size of 250 μm. Six sampling surveys were undertaken: the first in September of 1986 and the rest during 1990 (July, September, November) and 1991 (February, May). Six to ten riffle bottom replicates were collected in each survey, being preserved in 4% formalin until laboratory analysis. After identification and counting, quantitative samples were dried in an oven at 60°C for 24 hours to estimate biomass (dry weight). Four macroinvertebrate functional feeding groups (predators, collectors, scrapers and shredders) were assigned in accordance with Cummins and Klug (1979), Tachet *et al.* (1981) and Garcia de Jalon and Gonzalez del Tanago (1986). Relative abundances of functional feeding groups were calculated on the basis of biomass estimates.

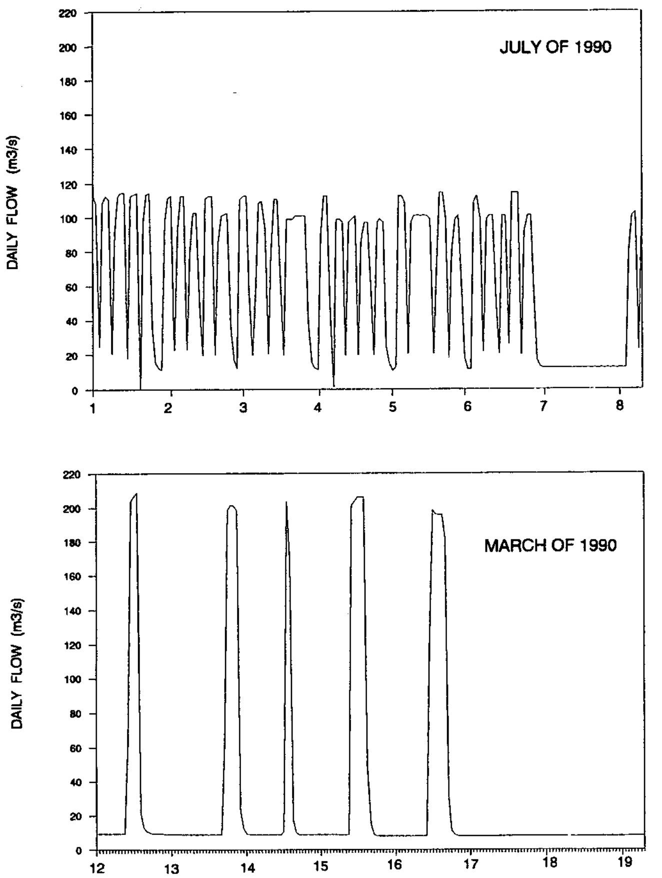

Figure 3. Daily flow pattern over a one-week period at the sampling station (2·5 km below Valparaíso Dam) in March and July 1990. Minimum flows were at night and during weekends

The fish community was sampled using an electrofishing technique with a direct current of 440 V and 0·7 A. Sampling surveys were undertaken in 1986 (September), 1990 (September) and 1991 (July). On each sampling date the study reach was delimited by nets and three successive captures at constant effort were accomplished. After identification, trout were measured (fork length) and weighed (alive), and their scales read for age determination.

Statistical differences between community structures before and after the construction of Valparaíso Dam were determined by a two-sample t-test in accordance with the method of Sokal and Rohlf (1981). It was assumed that biological parameters were normally distributed with homogeneous variances throughout the study.

RESULTS

Macrophytes

In both sampling surveys, the species composition was dominated by the same two species; *Myriophyllum verticillatum* and *Ranunculus fluitans*. Nevertheless, the value of total biomass (dry weight) significantly ($p < 0{\cdot}05$) decreased from 260·5 g m^{-2} in 1986 to 68·0 m^{-2} in 1990. Furthermore, *M. verticillatum* increased its relative abundance (from 73·9% to more than 90%) at the expense of *R. fluitans*, which was more adversely affected by flow regulation.

Table I. Mean values of density (individuals m^{-2}) estimated for each macrobenthic taxon at the sampling site (2·4 km below Valparaíso Dam) in 1986, 1990 and 1991

	Sep 1986	Jul 1990	Sep 1990	Nov 1990	Feb 1991	May 1991
Planariidae	63	0	0	0	0	0
Dugesia sp.	0	0	0	0	3	1
Tubificidae	619	102	291	1292	298	204
Erpobdella sp.	43	24	35	50	72	21
Pisidium sp.	3	0	0	0	0	0
Ancylus fluviatilis	3	6	2	13	8	3
Epeorus torrentium	386	0	0	0	0	0
Rithrogena diaphana	14	0	0	0	0	0
Ecdyonurus sp.	89	0	0	0	0	0
Baetis rhodani	1593	33	38	2	0	3
Baetis muticus	3	0	0	0	0	0
Ephemerella ignata	6	225	37	0	5	29
Serratella albai	60	0	0	0	0	0
Eulectra geniculata	720	0	0	0	0	0
Leuctra sp.	0	61	65	25	7	190
Protonemoura sp.	167	0	0	0	0	0
Protonemoura hispanica	6	0	0	0	0	0
Elmis aenea	12	0	0	0	0	0
Limnius opacus	158	0	0	0	0	0
Oulimnius sp.	2	0	0	0	0	0
Hydraena sp.	3	0	0	0	0	0
Rhyacophila munda	26	0	0	0	0	1
Rhyacophila relicta	101	0	8	2	12	5
Hydropsyche pellucidula	2261	0	0	3	5	1
Hydropsyche siltalai	43	0	0	0	0	1
Polycentropus flavomaculatus	20	0	0	0	0	0
Psychomia pusilla	3	0	0	0	0	0
Tinodes waeneri	0	0	1	2	0	3
Lepidostoma hirtum	26	0	0	0	0	0
Sericostoma sp.	17	0	0	0	0	0
Allogamus ligonifer	0	0	0	0	7	6
Mystacides azurea	0	0	0	2	0	0
Brachycentrus subnubilus	3	0	0	0	0	0
Chironomidae	596	579	1148	913	265	340
Simuliidae	1256	1133	36	23	5	2656
Athericidae	6	0	0	0	0	0
Empididae	6	0	0	5	2	1
Tipulidae	0	0	3	0	0	0

Macroinvertebrates

The taxonomic composition and abundances (individuals m^{-2}) for each taxon are presented in Table I. The most significant change after the creation of the new hydropower impoundment was the replacement of *Eulectra geniculata* by *Leuctra* sp. An additional 19 taxa also disappeared: *Planariidae*, *Pisidium* sp., *Epeorus torrentium*, *Rithrogena diaphana*, *Ecdyonurus* sp., *Baetis muticus*, *Serratella albai*, *Protonemoura* sp., *Protonemoura hispanica*, *Elmis aenea*, *Limnius opacus*, *Oulimnius* sp., *Hydraena* sp., *Polycentropus flavomaculatus*, *Psychomia pusilla*, *Lepidostoma hirtum*, *Sericostoma* sp., *Brachycentrus subnubilus* and *Athericidae*. Other taxa, such as *Baetis rhodani*, *Rhyacophila relicta* and *Hydropsyche pellucidula*, significantly ($p < 0{\cdot}05$) decreased their abundances downriver from Valparaíso Dam. Conversely, *Dugesia* sp., *Tinodes waeneri*, *Allogamus ligonifer*, *Mystacides azurea* and *Tipulidae* were only collected in 1990 and 1991.

Values of taxonomic richness, total density and total biomass are presented in Table II. These biological parameters significantly ($p < 0{\cdot}05$) decreased after the creation of Valparaíso Reservoir. However, a

Table II. Values of biological parameters estimated for the benthic macroinvertebrate community at the sampling site (2·4 km below Valparaíso Dam) in 1986, 1990 and 1991. Density and biomass values are expressed in individuals and milligrams per square metre, respectively

	Sep 1986	July 1990	Sep 1990	Nov 1990	Feb 1991	May 1991
Taxonomic richness	32	8	11	12	12	16
Total density	8314	2163	1664	2332	689	3465
Total biomass	2889	605	509	213	309	402

recovery of taxonomic richness is suggested by the data. The trophic structure of the benthic macroinvertebrate community is shown in Figure 4. Scrapers, organisms that feed on periphyton, were the least abundant functional feeding group on each sampling date, showing a tendency to decrease after the creation of the impoundment. Conversely, collectors (gatherers and filterers), organisms that feed on fine sedimentary detritus or on organic material suspended in the water column, were the dominant functional feeding group during all sampling surveys. Shredders, organisms that feed on coarse sedimentary detritus, and predators did not show a clear tendency to increase or decrease after the construction of Valparaíso Dam.

Fisheries

The most significant change after the construction of Valparaíso Dam was the absence of all resident coarse fishes. In 1986, the species composition of the fish community was dominated by the salmonid *Salmo trutta* (trout), the cobitid *Cobitis calderoni* ('colmilleja') and several cyprinids such as *Leuciscus carolitertii* ('cacho'), *Rutilus arcasii* ('bermejuela'), *Gobio gobio* (gudgeon) and *Barbus bocagei* (barbel). Nevertheless, in 1990 and 1991, only trout were collected.

Allometric characteristics of the trout population in September of 1986 and 1990 are presented in Table III. The age structure was dominated by individuals of the 0+ age group during both sampling surveys, the 1+ age group being abnormally scarce with respect to the 2+ age group. Average values of fork length and a live weight at different age groups were compared, and no statistically significant ($p > 0.05$) difference was

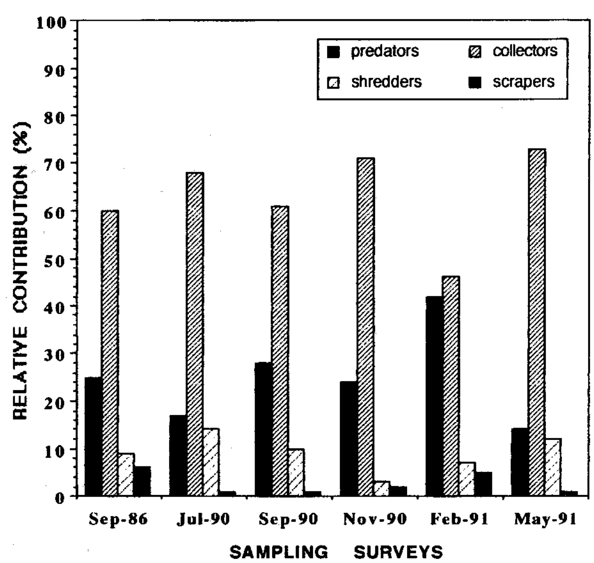

Figure 4. Relative contributions (%) of macroinvertebrate functional feeding groups on each sampling date. These contributions were calculated on the basis of biomass estimates (mg m^{-2})

Table III. Allometric characteristics of the trout population at the sampling site (2·4 km below Valparaíso Dam) in September 1986 and 1990. A = Percentage (%); B = average fork length (millimetres); and C = average live weight (g)

Age structure	September 1986			September 1990		
	A	B	C	A	B	C
0+	86	87·1	6·5	73	81·4	3·9
1+	2	165·0	50·5	5	167·1	60·7
2+	9	200·5	94·4	18	207·0	103·7
3+	1	312·0	270·0	4	246·7	191·3
4+	2	386·0	510·0	0	–	–

found between the two sampling surveys. However, it is important to remark that the older trout (more than three years old) tended to be larger (in length and weight) before (1986) than after (1990) the creation of Valparaíso Reservoir.

DISCUSSION

Previous studies on the downstream effects of hydropower impoundments on aquatic communities have emphasized the importance of short-term flow fluctuations in adversely affecting the natural population dynamics of freshwater organisms. Hence, in this study, it is not surprising to observe some major changes in taxonomic composition, taxonomic richness and abundance of taxa within macrophyte, macroinvertebrate and fish communities after the construction of Valparaíso Dam. Although, in some instances, hydropower impoundments can cause an overall favourable environment for the development of downstream flora (Ward, 1976; Holmes and Whitton, 1981; Carmago and Garcia de Jalon, 1990), in other instances hydroelectric power generation may significantly reduce the abundance of macrophytes downriver from dams (Casado *et al.*, 1989). In this instance an increase in water turbidity (personal observations) as a consequence of hypolimnial releases from the new hydropower impoundment may have contributed to the significant decrease in macrophyte biomass.

The observed alterations in the structure of the benthic macroinvertebrate community are similar to those observed downriver from other hydropower impoundments. In general, planarians, plecopterans, ephemeropterans, coleopterans and trichopterans tend to disappear or reduce in abundance because of the environmentally catastrophic conditions caused by short-term flow fluctuations (Armitage, 1978; Ward and Stanford, 1979; Brooker, 1981; Ward, 1982; Crisp *et al.*, 1983; Lillehammer and Saltveit, 1984; Petts, 1984; Armitage *et al.*, 1987; Craig and Kemper, 1987; Boon, 1988; Garcia de Jalon *et al.*, 1988; Casado *et al.*, 1989; Camargo and Garcia de Jalon 1990; Voelz and Ward, 1991). Reductions in living space during low flow periods and the deposition of silt during receding spates alter the substrate composition and reduce the heterogeneity of the river bottom, resulting in a macrobenthic depletion. Moreover, sudden changes in current velocity can increase the rate of macrobenthic drift (Moog, 1993).

It is evident from Table I that macroinvertebrate species such as *Epeorus torrentium*, *Eulectra geniculata*, *Baetis rhodani*, *Rhyacophila relicta*, *Hydropsyche pellucidula* and *Limnius opacus* were sensitive to the environmental conditions induced by Valparaíso Reservoir. Significant reductions in the abundance of *H. pellucidula* have already been observed in other regulated rivers (Boon, 1987; Camargo, 1993). The decrease in the relative abundance of scrapers can be explained considering the reduction of macrophyte biomass after the start of hydroelectric power generation. It is well known that macrophytes usually support an important biomass of periphyton on which scrapers feed. In this connection, Irvine and Henriques (1984) showed that benthic macroinvertebrates associated with periphyton tend to be more susceptible to fluctuating flows. However, their results were inconclusive and, consequently, further studies on this subject are needed.

With regard to the fish community, the fact that all resident coarse fishes were absent at the sampling site under the regulated flow regime, whereas trout populations persisted, agrees once more with results found elsewhere (Garcia de Jalon *et al.*, 1988; Casado *et al.*, 1989). However, in the Río Duratón (northern Spain), Camargo and Garcia de Jalon (1990) found the opposite effect; downriver from Burgomillodo Dam (used for hydroelectric production) cyprinid populations persisted or even increased, whereas trout populations disappeared. The environmental reasons justifying this difference are hard to define, but they must depend on dam management, dam location along the river and the particular ecological characteristics of each regulated reach. To explain the smaller size (in length and weight) of the older trout (more than three years old) after the creation of Valparaíso Reservoir, we need to look not only at the significant decrease in macrobenthic biomass, but also at the total absence of other fish species. It is well known that a depletion of benthic macroinvertebrates can induce decreases in the body size and population density of fish species. Additionally, adult trout often feed on smaller cyprinids when both groups of fishes coexit in the same geographical territory (Garcia de Jalon *et al.*, 1989; Clapp *et al.*, 1990).

CONCLUSIONS AND RECOMMENDATIONS

There is little doubt that the downstream effects of Valparaíso Reservoir on macrophyte, macroinvertebrate and fish communities were due essentially to short-term flow fluctuations. Because of this, and following to Moog (1993), we recommend a number of operational and constructional measures to minimize the adverse effects of the new hydropower impoundment and to encourage the ecological recovery of the Río Tera: (1) pulse release operations should be avoided or reduced; (2) ecologically acceptable minimum flows during periods of turbine shutdown (at night and during weekends, primarily) have to be mandated; (3) better co-ordination of the hydroelectric production via interconnected power pools; (4) alternative flow regimes and discharge constraints based on natural patterns; and (5) the construction of special river bed structures to provide and improve refuge areas, substrate heterogeneity and lotic zones.

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