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THE DOWNSTREAM IMPACTS OF THE BURGOMILLODO RESERVOIR, SPAIN

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ABSTRACT

The Burgomillodo Dam, located in the middle Rio Duraton (north Spain, Duero Basin), has created a small eutrophic reservoir with a capacity of 15×10^6 m^3 and a maximum depth of 40 m. Burgomillodo Reservoir is solely used for producing hydroelectric power. The regulated flow pattern of hypolimnial waters is characterized by higher daytime flows than those by night, with low flows at weekends all the year round. The environmental impact generated by this hydropower scheme on the river downstream was assessed by comparing physiochemical characteristics and aquatic communities of an upstream site (reference station) with those of three downstream stations, which were located 0·2, 2·5, and 7·6 km below the dam.

Water temperature, pH and dissolved oxygen were significantly lower downstream from the reservoir. Hardness, alkalinity, suspended inorganic matter, and conductivity had reduced annual variability below the dam. Photosynthetic activity was directly involved in the recovery of dissolved oxygen and pH values.

Species richness and abundance of macrophytes increased just below the dam. Macrobenthic and fish communities were composed of higher numbers of potamic species. Number of taxa, density, biomass, and diversity were higher at the reference site, recovering their values as the distance below the reservoir increased. Macrobenthic trophic structure was changed by an increase in predators and filter feeders and a decrease in shredders. Environmental impact values for the macrobenthic community living just below the dam were higher than those for the fish community.

It is concluded that the main physiochemical factors involved in environmental impacts were dissolved oxygen deficit and short-term flow fluctuations for the macrobenthic community, and oxygen deficit for the fish fauna. Benthic macroinvertebrates appear to be the best aquatic organisms for detecting changes and for reflecting the spatial recovery of environmental conditions.

KEY WORDS Hydropower eutrophic reservoir Environmental impacts Fish Macrophytes Macroinvertebrates

INTRODUCTION

Stream regulation is one of the principal human activities causing important adverse effects on fluvial communities (Ward and Stanford, 1979a; Ward, 1982; Petts, 1984). Particular problems can arise when hydroelectric power generation induces short-term downstream flow fluctuations with maximum flows during the daytime and minimum flows at night or at weekends (Ward, 1976a; Armitage, 1984; Petts, 1984). Sudden rises in discharge may cause the removal of benthic species (Statzner, 1981; Irvine and Henriques, 1984), decreasing density, diversity, and biomass of macroinvertebrate communities (Ward and Stanford, 1983; Garcia de Jalon *et al.*, 1988). In addition, changes in water quality conditions, such as temperature regimes (Ward, 1976b; Ward and Standford, 1979b; Garcia de Jalon *et al.*, 1988), suspended particulate materials (Brye *et al.*, 1979; Armitage, 1984) and dissolved oxygen concentrations (Young *et al.*, 1976; Scullion *et al.*, 1982) may directly contribute to modifying the functional structure of zoobenthic communities.

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On the other hand, short-term fluctuations can have significant effects on the composition of fish communities, because daily variable downstream-levels may contribute to the decline in endemic fishes (Holden and Stalnaker, 1975). Nevertheless, a modification in water temperature regimes can be the principal environmental factor influencing fish changes (Edwards, 1978, Pasch *et al.*, 1980). To this effect, Garcia de Jalon *et al.*, (1988) have suggested that a reduction in water temperatures during the summer might explain lower growth rates and productivity of trout populations living below a hydropower reservoir. In other cases, the release of anoxic hypolimnial waters has generated extensive fish mortalities downstream from dams (eg. Bŕadka and Rehacková, 1964). However, low oxygen levels might only have a local effect, because dissolved oxygen can be rapidly replaced by the turbulence of stream waters (Petts, 1984). In addition, the fish fauna may also be affected by hydroelectric regulation as a consequence of the decrease in its food resources (Petts, 1984; Garcia de Jalon *et al.*, 1988).

In this paper, the environmental impact caused by a hydropower eutrophic reservoir on its downstream ecosystem has been assessed. The major aims of this research were: (1) to document the responses of macroinvertebrate and fish communities to the instream changes produced by this hydroelectric regulation and (2) to determine and quantify the main environmental factors responsible for such responses. In addition, the effects of this eutrophic reservoir on downstream communities are evaluated in order to improve the dam management so as to prevent future environmental impacts.

STUDY AREA AND SAMPLING SITES

The Rio Duraton is located in northern Spain (Segovia) within the Duero basin. It arises in the mountains of the 'Sierra de Guadarrama' (more than 1600 m a.s.l.) and flows for about 110 km draining a basin of 1450 km^2 before entering the Duero (Figure 1). The watershed of the Rio Duraton is mainly underlain by

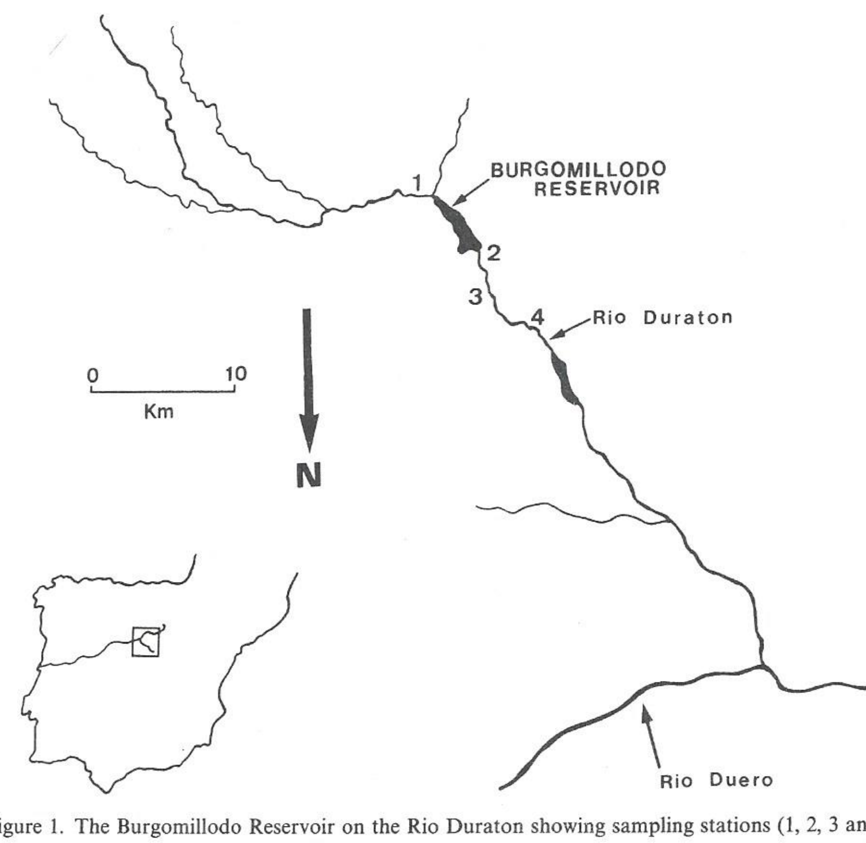

Figure 1. The Burgomillodo Reservoir on the Rio Duraton showing sampling stations (1, 2, 3 and 4)

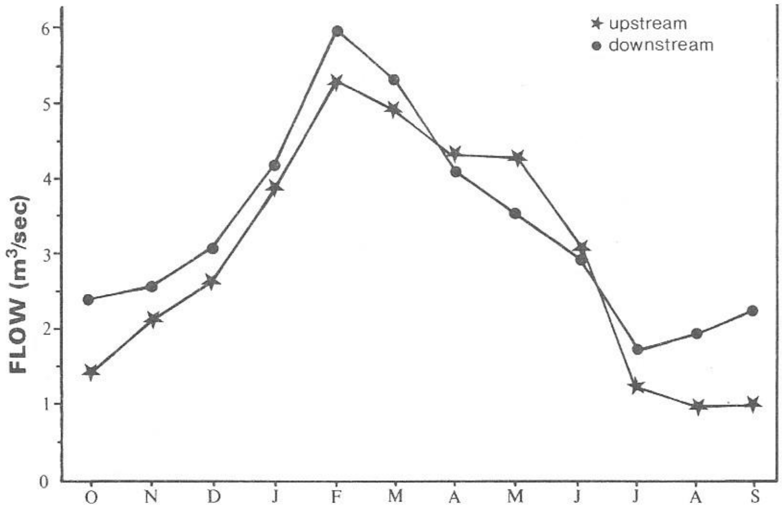

Figure 2. Mean monthly flow values (1968–1980) in the Rio Duraton, upstream and downstream from Burgomillodo reservoir

calcareous rocks, like limestones, which induce the formation of hard water with high ionic content. An ecological description of the Rio Duraton has been presented by Garcia de Jalon and Gonzalez del Tanago (1986) and Camargo (1989).

The Burgomillodo Dam is located in the middle Rio Duraton, making a small reservoir with a capacity of 15 hm^3, a maximum depth of 40 m and a surface area of 46 Ha (MOPU, 1988). Burgomillodo Reservoir was built in 1953 and is solely used for producing hydroelectric power by discharging hypolimnial waters through three turbines. Its annual production reaches $4{\cdot}6 \times 10^6$ kwh (MOPU, 1988), causing daily and weekly flow fluctuations with minimum flows at night and at weekends, and maximum ones during the daytime from Monday to Friday. Instream flows can range daily from 0·35 to 10·5 $m^3 s^{-1}$.This small reservoir is described as a eutrophic one due to its physico-chemical and biological characteristics (MOPU, 1980).

The Rio Duraton's natural flow regime upstream from Burgomillodo Reservoir is characterized by maximum monthly means flows during February–March and minimum ones during August–September (Figure 2), with a mean annual flow of 2·9 $m^3 s^{-1}$. Nevertheless a similar flow regime is maintained about 15 km downstream from Burgomillodo Dam, with a mean annual flow of 3·3 $m^3 s^{-1}$.

The cross-section of the river channel is more or less U-shape, so the flow fluctuations cause only changes in depth; the river bed is most exposed at low flows.

In order to assess the environmental impact of Burgomillodo Reservoir on its downstream ecosystem, four sampling stations were selected in the middle Rio Duraton (Figure 1). An unregulated station (S–1) situated upstream from the reservoir was used as a reference site. Second (S–2), third (S–3), and fourth (S–4) sampling stations were respectively situated 0·2, 2·5, and 7·6 km below Burgomillodo Dam. The reaches corresponded to 4th order streams (scale map 1:50 000), and their environmental characteristics were very similar except for the different influence of stream regulation. All four stations were located at similar elevations (835–900 m a.s.l.) at stony riffles, with low slope and little riparian vegetation. There are no other significant human activities which influence freshwater communities at the sites in the study area (Camargo, 1989).

METHODOLOGY

Physico-chemical parameters

Six extensive sampling surveys were undertaken during 1987 to 1988. The first four surveys during the start of summer (July) in 1987, the fifth at the end of the autumn (December) in 1987, and the last survey at the end of the spring (June) in 1988. Fourteen physico-chemical parameters were analysed once only at each sampling station per survey, using standardized methods described by APHA (1980) and Rodier (1981). Alkalinity, conductivity, pH, dissolved oxygen, and water temperature were measured *in situ*. Hardness, ammonia, nitrite, nitrate, chloride, sodium, potassium, oxygen saturation, and suspended inorganic matter (SIM) were analysed in the laboratory within 48 hours of sampling, preserved to 4 °C.

In addition, an intensive sampling survey was undertaken on 23 July of 1987 in order to document suitably the hourly variation of pH, dissolved oxygen, and water temperature below the dam. For that, these three physico-chemical parameters were measured every $1\frac{1}{2}$ hours for 24 hours at S–2, S–3, and S–4 sites.

Macroinvertebrates

Three sampling surveys were undertaken coinciding with the fourth (summer), fifth (autumn) and sixth (spring) physico-chemical surveys. Benthic macroinvertebrates were sampled using a cylinder sampler (Hellawell, 1986) as a sampling unit, 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. Five benthic sampling units were collected at each sampling site per survey. Each sampling unit was preserved in 4 per cent formalin until its separation, determination, and counting. Specimens were identified to species or genus, except aquatic earthworms and some midge larvae (identified to family). Afterwards quantitative samples were dried in an oven at 60 °C for 24 hours. Densities and biomass (dry-weight) were estimated for each taxonomic group. Four functional feeding groups were assigned in accordance with Cummins and Klug (1979), Edington and Hildrew (1981), and Garcia de Jalon and Gonzalez del Tanago (1986).

Fishes

A single sampling survey was undertaken during the summer (July) of 1987. Electrofishing was used to estimate fish populations, working with direct current at 220 volts and 0·7 amps. Densities were estimated for reaches delimited by handnets by successive captures. Each isolated reach had an approximate area of 100 m^2 and was fished three times. Some specimens were preserved in 10 per cent formalin for accurate identification in the laboratory.

Data Analysis

In addition to density and biomass, species richness and diversity were estimated by calculating number of taxa and Shannon's index. The percentage of environmental impact on fish and macrobenthic communities was quantified by calculating the environmental impact index (*EI*) performed by Camargo (1989, 1990):

$$EI = \frac{(2A - B - C) \times 50}{A}$$

where A is the number of taxa upstream from the disturbance point, B is the number of taxa downstream from the disturbance point, and C is the number of common taxa to both places.

Statistical differences between sampling sites for water quality conditions, abundances of specific taxa, and ecological parameters were determined by a t-test according to Sokal and Rohlf (1981). When it was necessary, the relationships between physico-chemical parameters were examined by linear correlation analysis.

RESULTS AND DISCUSSION

Water physicochemistry

Results of water analyses obtained at each sampling station during extensive surveys are presented in Table I. There are significant ($p < 0.05$) differences between the reference station (S–1) and downstream sampling sites for alkalinity, hardness, conductivity, suspended inorganic matter (SIM), water temperature, dissolved oxygen and oxygen saturation, pH, nitrites, and nitrates mainly because the Burgomillodo Reservoir is a stratified eutrophic one. Nevertheless, those significant differences for these water parameters

Table I. Water physiochemical parameters at each sampling station (1, 2, 3, 4). A = mean values and their standard deviations (n = 4) for summer surveys; B = values for the autumn survey; C = values for the spring survey; b.d. = below detection (<10 $\mu g\ l^{-1}$)

	S–1			S–2			S–3			S–4		
	A	B	C	A	B	C	A	B	C	A	B	C
Sampling time	7·2 (1·8)	13	10	7·5 (0·4)	7	11	9·1 (0·2)	10	14	9·5 (0·4)	12	15
Alkalinity mg l^{-1} $CaCo_3$	552·5 (55·6)	140	230	365·0 (25·2)	310	350	402·5 (35·0)	330	340	410·0 (30·0)	360	380
Hardness mg l^{-1} $CaCo_3$	225·9 (10·3)	49	89	158·8 (11·5)	95	108	165·2 (12·3)	105	117	179·4 (6·0)	110	127
Conductivity μmhos cm^{-1}	317·5 (13·2)	65	130	202·5 (9·6)	120	165	223·8 (4·8)	140	180	260·0 (10·0)	160	200
Potassium $\mu g\ l^{-1}$ K^+	146·0 (65·0)	162	120	116·0	212	135 (44·0)	117·0	218	114 (49·0)	115·0	29	130 (40·0)
Sodium mg l^{-1} Na^+	1·87 (1·35)	1·5	2·9	1·97 (1·50)	1·2	2·9	2·04 (1·56)	1·2	2·8	2·13 (2·00)	1·3	3·2
Chloride mg l^{-1} Cl^-	4·66 (2·99)	4·3	6·9	4·77 (3·16)	7·8	8·6	4·78 (2·90)	5·5	8·1	6·38 (3·55)	5·7	8·0
SIM mg l^{-1}	3·73 (1·32)	9·6	—	1·33 (0·62)	2·9	—	2·65 (1·95)	2·2	—	2·60 (2·21)	2·55	—
Water temperature °C	16·20 (0·90)	8·6	14·4	14·45 (0·53)	7·4	14·1	15·08 (0·49)	8·1	15·8	16·00 (0·30)	8·3	16·2
Dissolved oxygen mg l^{-1}	8·70 (0·62)	12·1	10·2	4·05 (0·81)	7·5	7·1	6·48 (0·30)	8·4	8·2	7·17 (0·42)	8·9	8·5
Oxygen saturation %	92·1 (7·5)	107	104	41·3 (8·0)	64	71	64·7 (1·3)	73	86	74·7 (3·7)	78	90
pH	8·14 (0·02)	7·9	7·8	7·59 (0·07)	7·6	7·5	7·69 (0·14)	7·8	7·6	7·80 (0·06)	7·8	7·7
Nitrate mg l^{-1} N	3·06 (0·71)	3·1	—	1·75 (0·47)	1·4	—	2·15 (0·56)	1·9	—	2·27 (0·43)	2·0	—
Nitrite $\mu g\ l^{-1}$ N	17·0 (4·0)	b·d·	—	38·0 (3·0)	9·0	—	25·0 (4·0)	8·0	—	21·0 (6·0)	9·0	—

gradually decrease as the distance to the dam increases. Ammonia was never detected ($<10\ \mu g\ l^{-1}$) at any of the sampling stations. The spatial of physico-chemical conditions may be due to environmental factors like turbulence of stream waters, dissolution of carbonates and bicarbonates from stream bottom, hours of sunlight, and photosynthetic activity of macrophytes and benthic algae.

The daily discharge of hypolimnial waters, which are cooler and have an oxygen deficit (low redox potential), results in a reduction in temperature, oxygen, pH, and nitrate values downstream from Burgomillodo Reservoir, increasing, in contrast, nitrite values. Although it has been stated that summer cool and winter warm conditions characterize temperature regimes in streams below deep-release reservoirs (Ward, 1982, 1985), in this study water temperatures tend to be cooler downstream most of the year.

The reduction in the redox potential, which is commonly associated with the release of many ions like Ca^{2+}, Mg^{2+}, Mn^{2+} and HCO_3^- from the hypolimnial bottom segments (Margalef, 1983; Petts, 1984), would explain the higher conductivity, alkalinity, and hardness values at sampling stations below the dam during fall and spring surveys. To this effect, Wetzel (1975) predicted that Ca^{2+}/Na^+ ratios might increase in streams receiving hypolimnial releases. However, during the summer time, when the influence of phreatic waters with very high ionic content is greatest on the surface waters on the Rio Duraton (Camargo, 1989), values of these parameters are higher at the reference station (S-1) than those at sampling sites below the dam. In addition, the continuous sedimentation of suspended inorganic materials into Burgomillodo Reservoir results in a reduction in SIM values downstream from the dam all the year round. In this way, the regulation by Burgomillodo Dam results in an annual stabilization of water-quality at sampling sites below the reservoir, mainly in alkalinity, conductivity, hardness, and SIM parameters.

The hourly variations of each physico-chemical parameter (pH, O_2 and T °C) analysed downstream from Burgomillodo Reservoir during the intensive survey are shown in Figure 3. Mean daily values of these water parameters increase gradually with the distance from the dam. In addition, the spatial recovery of dissolved oxygen is faster than those of pH and water temperature. However, the mean daily value of oxygen saturation did not exceed the eighty per cent at S-4. Coefficients of linear correlation between hourly variations of pH, dissolved oxygen, and water temperature were significant ($p < 0{\cdot}05$ $r^2 > 0{\cdot}489$) at each sampling site, suggesting that their hourly recovery would be fundamentally due to photosynthetic activity and hours of sunshine. A similar relation between pH values and photosynthesis has been suggested by Rader and Ward (1988) for a recovery site below Granby Reservoir in the upper Colorado River.

Macrophytes

The number of species and their per cent cover was greatest just below the dam. Macrophytes were uncommon in the other sampling sites. *Ranunculus fluviatilis*, *Myriophyllum spicatum*, *Potamogeton crispus*, and *Groenlandia densa* were all abundant at S-2; but *Ranunculus fluviatilis* was the only macrophyte at S-1, S-3, and S-4. This agrees with previous studies in which it has been suggested that hypolimnetic release reservoirs may cause an overall favourable environment for downstream flora (Ward, 1976b; Holmes and Whitton, 1981), even though, in some case, macrophytes may not be favoured by short-term flow fluctuations (Casado *et al.*, 1989).

Benthic macroinvertebrates

Density mean values of each taxonomic group are shown in Table II. Many species were either absent or rare below Burgomillodo Dam whereas others were rare or absent upstream. In general, plecopterans, coleopterans, and trichopterans were the most affected taxonomic groups.

Dugesia gonocephala, *Echinogammarus calvus*, *Oligoneuriella rhenana*, *Protonemura meyeri*, *Hydraena sp.*, *Agapetus laniger*, *Chimarra marginata*, *Hydropsyche sp.*, *Cheumatopsyche lepida*, *Brachycentrus subnubilus* and *Nanocladius sp.*, were not found at S-2, S-3, and S-4 sampling sites, and the densities of *Baetis rhodani*, *Ecdyonurus sp.*, *Taeniopteryx schoenemundi*, *Capnia bifrons*, *Rhyacophila meridionalis*, *Hydropsyche pellucidula*, and the families *Elmidae* and *Simuliidae* were significantly ($p < 0.05$) reduced downstream at the reservoir, mainly at S-2. A significant reduction in abundance and species richness of net-spinning caddisflies (Brooker and Morris, 1980; Ward, 1987), heptageniid mayflies (Ward, 1982; Armitage *et al.*, 1987), stoneflies

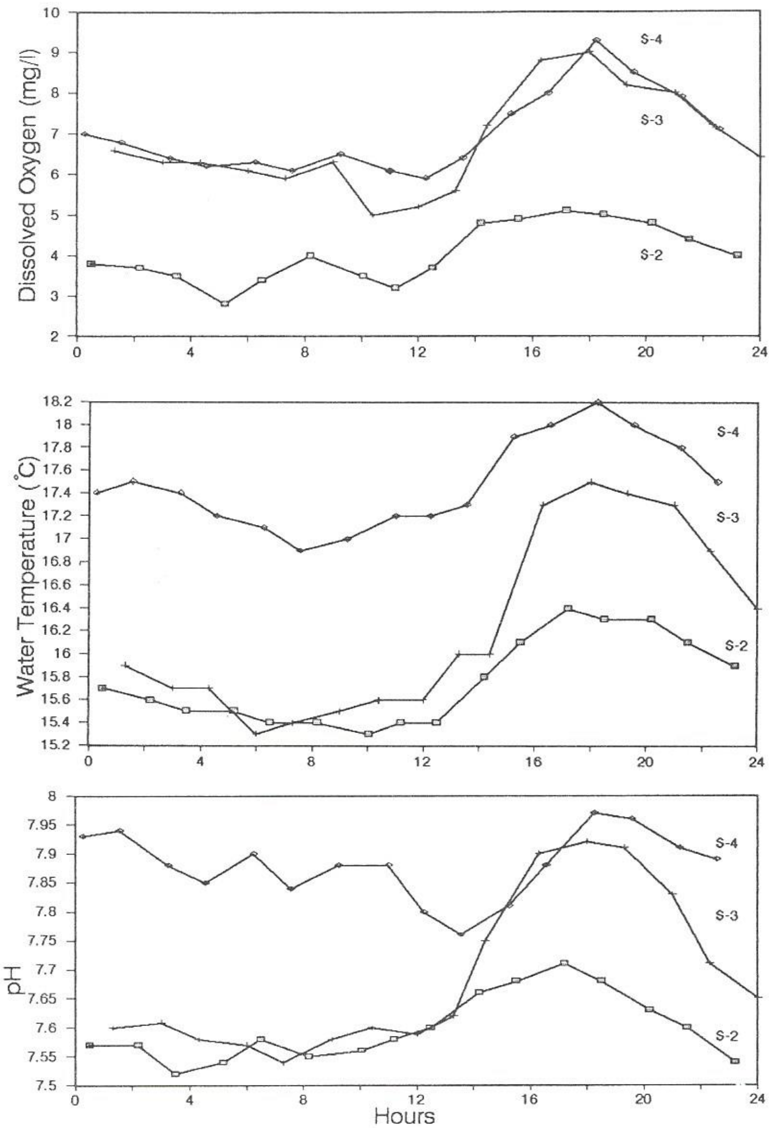

Figure 3. Hourly variation of dissolved oxygen, water temperature and pH parameters at 2 (squares), 3 (crosses) and 4 (rhombs) sampling stations. Minimum (0·35 $m^3 s^{-1}$) and maximum (9·8 $m^3 s^{-1}$) hypolimnial releases were respectively between 0 and 6 and between 10 and 13 hours

(Zimmermann and Ward, 1984; Rader and Ward, 1988), gloososomatid caddisflies (Radford and Hartland-Rowe, 1971; Casado *et al.*, 1989), and families *Elmidae* (Armitage *et al.*, 1987; Rader and Ward, 1988) and *Simuliidae* (Bass and Armitage, 1987) has often been observed in regulated streams, particularly just below hydropower dams with hypolimnial release. However, in some cases, the observed behaviour for a species varies from place to place. Thus, Armitage (1978) found high densities of *Brachycentrus subnubilus* below the Cow Green dam in the River Tees, whereas Casado *et al.* (1989) observed a significant reduction in abundances of this species downstream from Cernadilla reservoir in the Tera stream.

In contrast to the taxa above, species like *Erpobdella monostriata*, *Potamanthus luteus* and *Polycentropus flavomaculatus* were only found at sampling sites below the dam, and others like *Baetis fuscatus*, *Ephemerella ignita*, *Caenis moesta*, *Rhyacophila munda*, *Hydropsyche exocellata*, *H. bulbifera* and *H. siltalai*, together with the majority of chironomids, showed significant ($p < 0.05$) increases in their respective densities downstream

Table II. Density mean values (n = 5) of macrobenthic taxonomic groups (individuals m^{-2}) at each sampling site (1, 2, 3, 4). A = summer survey in 1987; B = autumn survey in 1987; C = spring survey in 1988

	S–1			S–2			S–3			S–4		
	A	B	C	A	B	C	A	B	C	A	B	C
Dugesia gonocephala	84	24	50	—	—	—	—	—	—	—	—	—
Ancylus fluviatilis	82	136	72	84	98	52	106	88	58	66	110	118
Tubificidae	6	—	—	18	—	32	10	—	—	8	—	8
Erpobdella monostriata	—	—	—	200	118	64	8	34	14	12	20	32
Echinogammarus calvus	110	156	190	—	—	—	—	—	—	—	—	—
Baetis fuscatus	162	—	46	74	—	250	78	16	82	416	64	418
Baetis rhodani	354	118	240	44	—	102	8	80	46	114	216	74
Oligoneuriella rhenana	1086	—	598	—	—	—	—	—	—	—	—	—
Ecdyonurus sp.	142	94	136	—	—	—	—	40	70	26	210	130
Ephemerella ignita	148	24	186	176	16	110	258	104	124	286	140	146
Caenis moesta	84	14	24	538	276	386	78	64	40	20	30	90
Potamanthus luteus	—	—	—	32	—	8	66	186	18	28	84	66
Taeniopteryx schoenemundi	—	50	—	—	—	—	—	4	—	—	6	—
Protonemura meyeri	60	66	134	—	—	—	—	—	—	—	—	—
Capnia bifrons	148	—	214	—	—	—	64	—	72	24	—	68
Drectochilus villosus	32	46	14	—	—	—	—	14	26	14	28	42
Elmis maugetii	112	174	140	—	—	—	30	80	24	72	258	68
Esolus angustatus	80	12	82	—	—	—	—	—	10	30	—	56
Limnius intermedius	100	230	170	—	—	—	24	92	82	86	334	60
Limnius opacus	20	62	36	—	—	—	18	32	—	34	62	—
Dulimnius troglodytes	104	246	146	—	—	—	42	84	54	78	102	136
Hydraena sp.	—	40	4	—	—	—	—	—	—	—	—	—
Rhyacophila meridionalis	20	—	8	—	—	—	2	—	—	14	—	—
Rhyacophila munda	4	2	6	—	—	—	16	2	20	32	8	16
Rhyacophila relicta	12	6	16	—	—	—	10	8	10	24	14	4
Agapetus laniger	14	—	84	—	—	—	—	—	—	—	—	—
Hydroptila sp.	2	8	—	6	—	—	—	—	—	4	—	—
Chimarra marginata	266	106	46	—	—	—	—	—	—	—	—	—
Hydropsyche bulbifera	58	34	26	24	—	—	260	78	28	178	68	16
Hydropsyche exocellata	20	20	88	6	—	—	148	140	102	94	100	118
Hydropsyche lobata	6	4	—	—	—	—	2	—	—	—	2	—
Hydropsyche pellucidula	290	108	70	—	—	—	10	—	—	18	—	—
Hydropsyche siltalai	2	14	38	—	—	—	154	404	240	168	336	186
Hydropsyche sp.	8	66	10	—	—	—	—	—	—	—	—	—
Cheumatopsyche lepida	34	126	80	—	—	—	—	—	—	—	—	—
Polycentropus flavomaculatus	—	—	—	74	16	4	62	60	20	16	54	28
Psychomyia pusilla	34	—	28	—	—	—	36	—	72	80	—	76
Brachycentrus subnubilus	32	18	20	—	—	—	—	—	—	—	—	—
Allogamus ligonifer	4	—	4	—	—	—	—	—	—	—	—	6
Tipula sp.	2	—	—	4	2	2	4	—	—	6	—	—
Eusimulium sp.	198	172	64	10	20	—	18	28	32	24	40	54
Odagmia sp.	554	196	80	54	16	—	134	10	20	112	36	56
Ablabesmyia sp.	8	—	10	12	—	8	—	—	—	—	—	—
Prodiamesa olivacea	12	—	2	24	4	22	6	—	2	6	—	—
Diamesa sp.	10	—	8	12	—	24	8	—	16	22	—	16
Potthastia sp.	12	—	—	6	—	—	6	—	—	8	—	—
Orthocladius sp.	144	112	90	146	156	208	140	94	60	274	124	158
Cricotopus sp.	80	44	82	152	86	178	90	58	44	250	86	114
Camptocladius sp.	86	34	76	30	78	192	40	24	40	86	20	62
Nanocladius sp.	16	—	—	—	—	—	—	—	—	—	—	—
Eukiefferiella sp.	16	10	54	24	—	28	6	—	108	26	—	140
Rheotanytarsus sp.	26	—	10	6	—	24	4	—	28	2	—	16
Tanytarsus sp.	36	14	2	30	24	110	8	24	68	4	6	24
Pentapedilum sp.	4	—	6	32	6	74	4	—	6	2	—	8
Polypedilum sp.	14	3	14	50	16	108	6	14	10	4	10	10
Glyptotendipes sp.	—	—	—	14	—	—	—	—	—	—	—	—
Empididae	8	—	—	—	—	—	—	—	—	6	—	—
Anthomyidae	—	—	—	2	—	—	—	—	—	—	—	—

from Burgomillodo reservoir, although *Rhyacophila* and *Hydropsyche* species were almost invariably absent at S–2. A significant increase in *Ephemerella* and *Caenis* populations (Petts, 1984; Casado *et al.*, 1989), chironomid densities (Ward, 1982; Petts, 1984; Armitage *et al.*, 1987; Rader and Ward, 1988) and abundances of some *Hydropsyche* species (Müller, 1981; Boon, 1987) has often been found downstream from water storage reservoirs. Boon (1987) found that trichopteran species diversity was mainly reduced below a dam in the River North Tyne by a disproportionate increase in numbers of *H. siltalai*. This *Hydropsyche* species being favoured at the expense of *H. pellucidula*. It has been reported (Becker 1987) that the physiological efficiency of *Hydropsyche pellucidula* decreased rapidly with falling oxygen concentration, so that development into an imago was no longer possible below 85 per cent oxygen saturation. At sites below Burgomillodo reservoir oxygen saturation values were frequently less than 85 per cent and may have affected development of some species.

In general, all these changes in species composition reflect a substitution of rhithonic species for potamonic species downstream from Burgomillodo reservoir. Thus, *Baetis rhodani*, *Rhyacophilia meridionalis*, and *Hydropsyche pellucidula* are replaced, as dominant species within respective taxonomic genera, by *B. fuscatus*, *R. munda* and *H. bulbifera* and *H. exocellata*, which are, together with *Caenis moesta*, *Ephemerella ignita*, *Polycentropus flavomaculatus Potamanthus luteus*, and *Erpobdella monostriata*, characteristic species of the potamon in the Duero basin (Garcia de Jalon and Gonzalez del Tanago, 1986). The observed reduction in dissolved oxygen concentrations may be the principal cause for this 'potamonization' (enhancement of potamic conditions) in zoobenthic composition. In addition, most intensive short-term flow fluctuations may have contributed to the total disappearance, mainly just below the dam, of other zoobenthic species like *Chimarra marginata*, *Echinogammarus calvus*, and *Cheumatopsyche lepida*, which have been found in the potamon of rivers of Duero Basin (Garcia de Jalon and Gonzalez del Tanago, 1986). High flows coincide with hydropower releases from bottom outflows which are never aerated, so dissolved oxygen is minimum. These intermittent high flows associated with most anoxic waters may contribute to create potamon-like conditions, as oxygen recovery may not be completed at low flows, and the food supply in the form of FPOM seston is favoured.

The structure of the macrobenthic community at each sampling station is shown in Table III. In general, number of taxa, density, biomass, and Shannon's diversity were significantly ($p < 0.01$) superior in the reference site (S–1) during the three seasonal surveys. Values of these four ecological parameters gradually improved with distance from the dam. This is well reflected in the percentage values of the ecotoxicological index (EI) which indicate that the environmental impact at each sampling site decreases with distance from Burgomillodo Reservoir. The sampling station located just below the dam presented a much more simplified structure. Seasonal variations of these ecological parameters were very similar in all sampling stations (Table III).

Table III. Macrobenthic community structure at each sampling site (1, 2, 3, and 4); mean values and their standard deviations (n = 5) for number of taxa, individual density, biomass (dry-weight) and diversity. EI = environmental impact; A = summer survey; B = autumn survey; C = spring survey

	S–1			S–2			S–3			S–4		
	A	B	C	A	B	C	A	B	C	A	B	C
No. Taxa	40·4	30·2	36·0	21·8	12·2	17·8	25·8	23·4	26·8	30·8	23·8	29·6
	(2·70)	(0·84)	(1·87)	(1·30)	(1·10)	(0·84)	(1·64)	(0·89)	(1·79)	(0·84)	(0·45)	(1·14)
Density	4948	2592	3500	1902	932	1994	1968	1880	1650	2962	2566	2620
(ind m^{-2})	(618·8)	(245·6)	(437·7)	(185·7)	(90·9)	(222·7)	(271·6)	(194·0)	(259·5)	(290·5)	(263·1)	(269·5)
Biomass	8·5	3·0	5·6	2·4	1·3	1·5	4·2	3·1	4·5	4·6	3·5	5·0
(gr m^{-2}	(2·79)	(0·29)	(0·61)	(0·54)	(0·25)	(0·38)	(0·83)	(0·45)	(0·93)	(1·16)	(0·29)	(0·55)
Shannon's	4·31	4·43	4·52	3·62	2·93	3·60	4·08	3·97	4·30	4·25	4·03	4·39
diversity	(0·21)	(0·05)	(0·14)	(0·15)	(0·18)	(0·08)	(0·08)	(0·07)	(0·13)	(0·04)	(0·10)	(0·10)
EI (%)	—	—	—	47·1	65·3	57·8	28·4	30·6	30·0	22·5	27·8	27·8

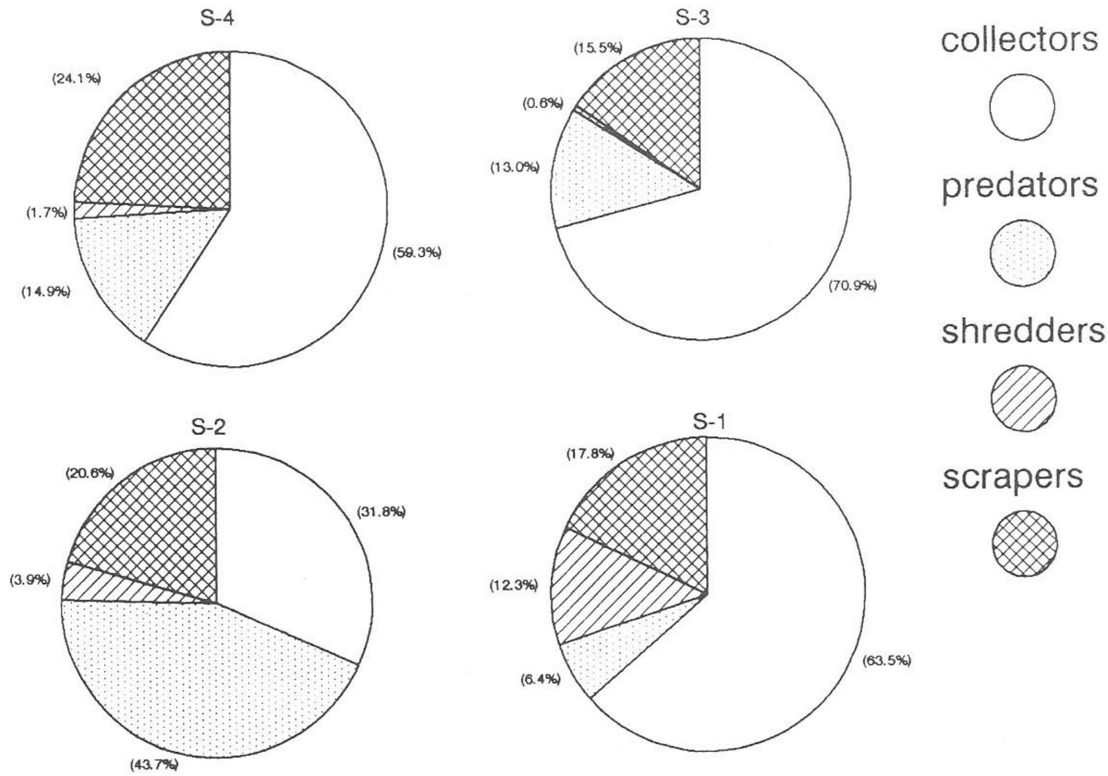

Figure 4. Relative abundance of macroinvertebrate functional feeding groups based on biomass estimates at each sampling station

The trophic structure was altered by stream regulation (Figure 4) and the shredders were the trophic group most adversely affected. The reduction in the relative abundances of shredders has been previously observed by authors (Garcia de Jalon, 1980; Ward and Stanford, 1984; Rader and Ward, 1988). The dominant abundance of collectors in the reference station (S–1) was reduced just below the dam, and this was accompanied by an increase in the relative abundance of predators. The disappearance below the dam of *Oligoneuriella rhenana* (gathers) and *Hydropsyche* species (filterers), which were dominant collectors at S–1 during spring–summer and autumn–winter times respectively, and the high abundance of the predator *Erpobdella monostriata* accounted for the decrease in collectors and the significant increase in predators at S–2. However, collectors recovered their dominance at S–3 and S–4 due to the abundance of hydropsychid filterers. The principal predators in the unregulated station were *Dugesia gonocephala*, *Protonemura meyeri*, and *Rhyacophila* species. The slight increase in predators at S–3 and S–4 was due to the presence of *Erpobdella monostriata*, *Polycentropus flavomaculatus*, and *Rhyacophila* species. The scraper *Ancylus fluviatilis* was the dominant species within its trophic group.

Thus, the main effects of this hydroelectric regulation were a significant reduction in the relative abundance of shredders, an increase in the relative importance of filterers within the collectors, and an increase in the relative biomass of predators, mainly of non-insect taxa. This is in general agreement with the theoretical model of trophic benthic structure along the stream longitudinal gradient (Vannote *et al.*, 1980), and reflects a potamonization in the trophic structure of macrobenthic communities downstream from Burgomillodo Reservoir.

Fisheries

The number of individuals of each fish species is presented in Table IV. The most abundant species at all sampling sites were barbel (*Barbus barbus bocagei*), gudgeon (*Gobio gobio*), and 'bermejuela' (*Rutilus arcasii*). Trout species (*Salmo trutta fario* and *Salmo gairdneri* were not found at S–2, S–3, and S–4. In contrast, the

Table IV. Number of individuals of each fish species at sampling stations (1, 2, 3 and 4) during the summer fish survey

	S–1	S–2	S–3	S–4
Salmo gairdneri	1	—	—	—
Salmo trutta fario	2	—	—	—
Barbus barbus bocagei	8	2	6	3
Gobio gobio	6	18	9	10
Rutilis arcasii	10	13	4	11
Cobitis maroccana	—	5	2	3

cobitid 'lamprehuela' (*Cobitis maroccana*) a characteristic fish species of the potamon in many rivers from the Iberian Peninsula (Garcia de Jalon *et al.*, 1989), was only captured at stations downstream of Burgomillodo Reservoir. It is probable that the reduction in dissolved oxygen concentrations of hypolimnial waters released by the dam were the main cause of this 'potamonization' (enhancement of potamic conditions) in fish composition, because salmonid species are more sensitive to oxygen deficit than other freshwater fish species (Alabaster and Lloyd, 1980). On the other hand, trout species do not seem to be directly affected by sudden flow fluctuations generated by hydroelectric regulations (Garcia de Jalon *et al.*, 1988).

The percentage of environment impact (*EI*) was equal to 30% in all sampling sites below the dam. This would indicate that the fish community has a lesser capacity than macrobenthic one for detecting and reflecting the spatial recovery of environmental conditions downstream from a hydropower eutrophic reservoir.

CONCLUSIONS

The environmental impacts of Burgomillodo Reservoir on its downstream ecosystem may be described as adverse, inducing a general potamonization in the composition of fish and zoobenthic communities, and a decrease in species richness, density, biomass, and delivery of this last community. However, species richness and abundance of macrophytes increase just below the dam.

The main physiochemical factors involved in impacts below the dam are oxygen deficit and short-term flow fluctuations for macrobenthic community and oxygen deficit for fish fauna.

Hardness, alkalinity, suspended inorganic matter, and conductivity experience an annual stabilization downstream from Burgomillodo Reservoir, and photosynthetic activity is directly involved in the recovery of dissolved oxygen and pH values. In addition, benthic macroinvertebrates appear as the best aquatic organisms for detecting and reflecting the spatial recovery of environmental conditions.

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