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EFFECTS OF HYDROELECTRIC SCHEME ON FLUVIAL ECOSYSTEMS WITHIN THE SPANISH PYRENEES

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ABSTRACT

The effects on faunal communities of a high head, low capacity hydroelectric power project are evaluated for the River Cinca, a Pyrenean tributary of the River Ebro (North East of Spain). The macrobenthic fauna of the regulated Cinca river is compared with the unregulated River Ara. Colder summer water temperatures in the River Cinca are shown to have caused a reduction in species richness of the macrobenthic community as a consequence of the elimination of thermophilous species. Reduced temperatures may also explain the lower growth rate and productivity of the trout populations. Sudden flow fluctuations caused by hydropower generation influence the downstream macrobenthic communities; their populations are less abundant (reduction in densities and biomass) and their structure is less diverse. Although trout fisheries do not seem to be directly affected by sudden flow fluctuations, the limitation of their food resources (benthos), has reduced trout production and turnover ratio.

KEY WORDS Hydropower Macrobenthic communities Trout

INTRODUCTION

It has been suggested that flow regulation below hydroelectric power dams has considerable effects on running water communities (Armitage, 1984), particularly where power-peaking operations generate short-term flow fluctuations with maximum flows during the daytime and minimum flows during night or at weekends. The effects of rapid short-term flow fluctuations on the macrobenthos have been reviewed by Ward (1976), Langford (1983), Armitage (1984), and Petts (1984). Generally, hydroelectric regulation produces a decrease in the diversity and density of the macroinvertebrate communities, because few species are able to withstand conditions of strong current alternating with drought periods or slow flow (Trotzky and Gregory, 1974). A sudden rise in discharge can cause the removal of macroinvertebrates (Brooker and Hemsworth, 1978; Statzner, 1981; Gaschignard and Berly, in press) and especially those associated with macrophytes and periphyton (Radford and Hartland-Rowe, 1971; Irvine and Henriques, 1984).

If daily flow fluctuations are large, macrobenthic disturbances may be extreme (Ward and Stanford, 1983; Donald and Mitch, 1980). On the contrary, Gregoire (1983) found that daily variation of flow caused by hydropower plants did not change significantly the diversity of mayfly communities. Kraft and Mundahl (1984) found increased macrobenthic biomass downstream of hydroelectric plants, but

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decreased faunistic richness. Species able to migrate to the interstitial zone (Powell, 1958; Ward, 1976; Henricson and Muller, 1979) may come to dominate the community.

Fish communities are also affected by hydroelectric regulation as a consequence of the reduction of their food resources. Barnes *et al.* (1984) found in *Coregonus* populations living below hydroelctric turbines, decreases in growth, reproductive inhibition, and a general stressed state.

In this paper we analyse the effects on fluvial communities of intensive regulation below a small capacity, but high head, hydroelectric power dam. In order to evaluate these effects, two rivers in the Spanish Pyrenees are compared: River Ara (unregulated) and River Cinca (regulated). The composition and structure of the macroinvertebrates and fish communities are analysed, together with their interrelations, in two reaches near the confluence of the two rivers where the structure of the channel bottoms is very similar.

STUDY AREA

The Ara and Cinca rivers are located in the Aragon's Pyrenees (N.E. Spain) within the River Ebro basin. The rivers rise at an altitude of 2700 m and 3000 m respectively. The River Cinca at its confluence with the River Ara drains a basin of 827 km^2 and the Ara, 664 km^2 (Figure 1). Both basins are underlain by limestones and, in the lower reaches, by marls. Small granitic sifts are also present.

The mean annual flow of the River Cinca is 35·2 m^3s^{-1}, double that of the River Ara (18·2 m^3s^{-1}). Annual runoff from both catchments is high in relation to other rivers (Hughes and Omernick, 1983). The nivo-pluvial flow regime (Figure 2A) is characterized by a snow-melt maximum in May–June and a rainfall maximum in autumn, usually in October-November.

The River Ara is not regulated, but along the River Cinca there are five small reservoirs for hydroelectric energy production (Figure 1). Their total storage capacity is $8{\cdot}5 \times 10^6$ m^3, less than one per cent of the annual runoff. Their annual hydroelectricity production reaches 345×10^6 kwh (M.O.P.U., 1986).

Two sampling stations were selected about 1 km upstream of the confluence at 590 m altitude, near Ainsa (Figure 1). The reaches correspond to 4th order streams (scale map 1/50 000) and their morphological characteristics are very similar. The rivers flow through open valleys, without riparian vegetation; slopes are low, the unstable braided channels have a total width of 40–60 m, the substrate is of stones about 15 cm in diameter, and macrophytes are absent.

METHODOLOGY

Three sampling surveys were undertaken during 1985. The first on the 15th and 16th February (winter); the second on the 7 and 8 September (summer); and the last on 14 and 15 December (Autumn). Physical variables and pH were measured *in situ*. Water chemical parameters were analysed in the laboratory with conventional methodology within 48 hours of sampling.

The organic content of seston was determined for different fractions following the methdology described by Hawkins and Sedell (1981) and Cummins *et al.* (1983). The coarse particulate organic matter (CPOM) was collected in a net of 1 mm mesh size, during one hour in the swiftest zone of the stream. The fine fraction (FPOM) was collected in a 50 m mesh net during ten minutes. The ultrafine fraction (UPOM) was determined by filtering five litres of water through a net of 0·45 m mesh size.

Benthic macroinvertebrates were sampled in lotic reaches using a sampling box 50 cm high with a square base of 34 cm side and 250 mm mesh net. Each quantitative sample consisted of three samples, but other qualitative samples were taken. Samples were conserved in Formalin (4 per cent) until their separation, determination, and counting. Afterwards quantitative samples were dried in an oven at 60 °C for 20 hours. Densities and biomass (dry-weight) were determined for most populations.

Drift was sampled in an 0.1 m^2 net of 0·75 mm mesh size located in the swift current during a period of half an hour.

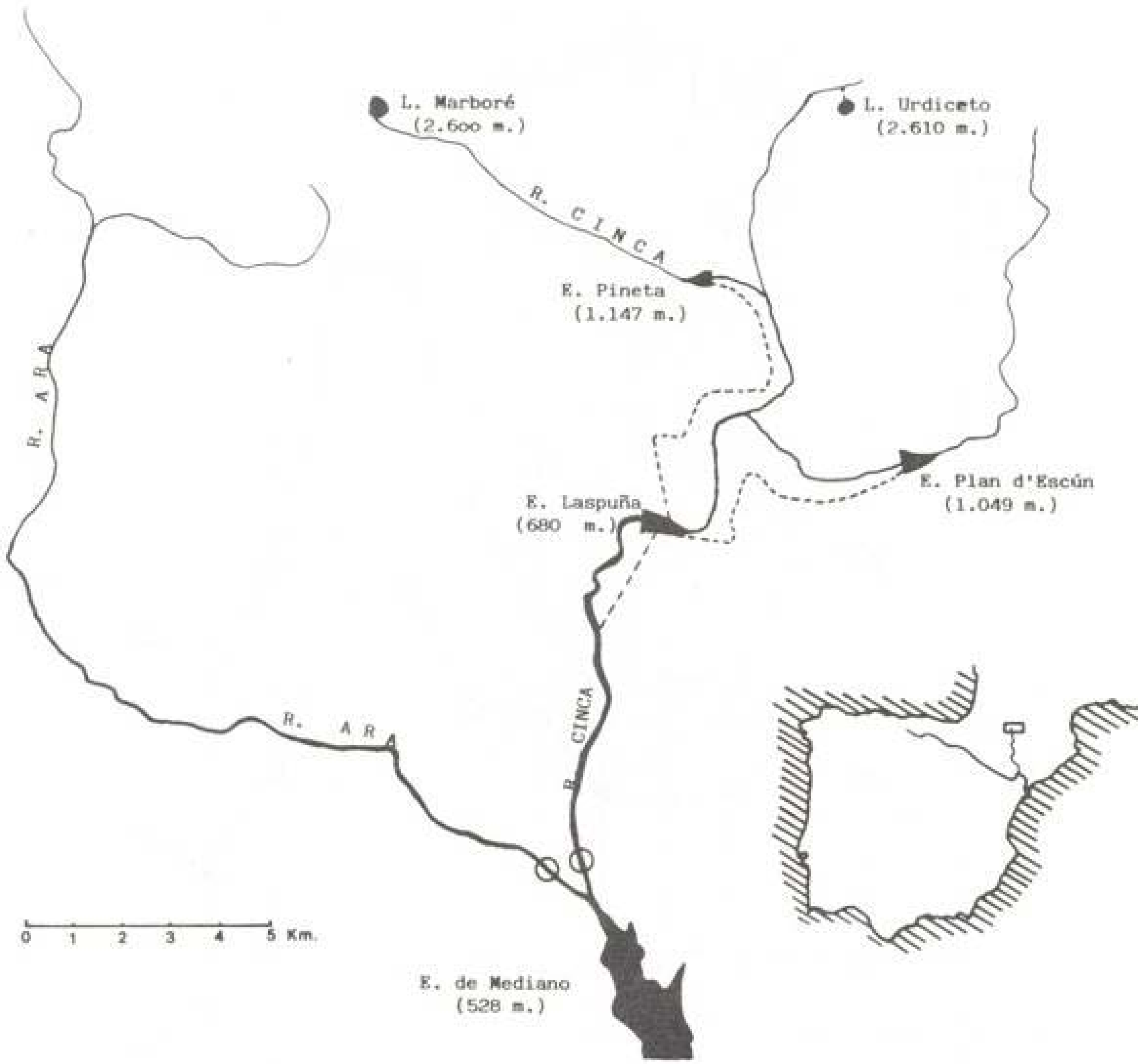

Figure 1. Map of Ara and Cinca rivers, showing sampling locations

An electro-fishing technique was used for estimating fish populations, working with direct current at 220 volts and 0·7 amps. Surveys were undertaken in February and December only. Fish population densities were estimated for reaches defined by nets by successive captures at constant effort. Each isolated reach had an area of 500–900 m^2 and was fished three or four times in each sampling. The efficiency of the capture effort was calculated through Laurent and Lamarqu (1975) regression curves and the population densities were estimated by Moran (1951) formula. More exhaustive explanation on the method used can be found in Garcia de Jalon *et al.* (1986).

The fishes caught were measured (fork length) and weighed (alive) and their scales read for age determination. Von Bertalanffy (1938) growth models have been adjusted to different populations using the Walford (1946) method. Survival rates were estimated using the Robson and Chapman (1961) method and the mortality rates were calculated from them. Annual production was estimated by the method developed by Garcia de Jalon *et al.* (1986) based on Von Bertalnffy growth models. The total production was estimated as the addition of each cohort production, without including annual recruitment.

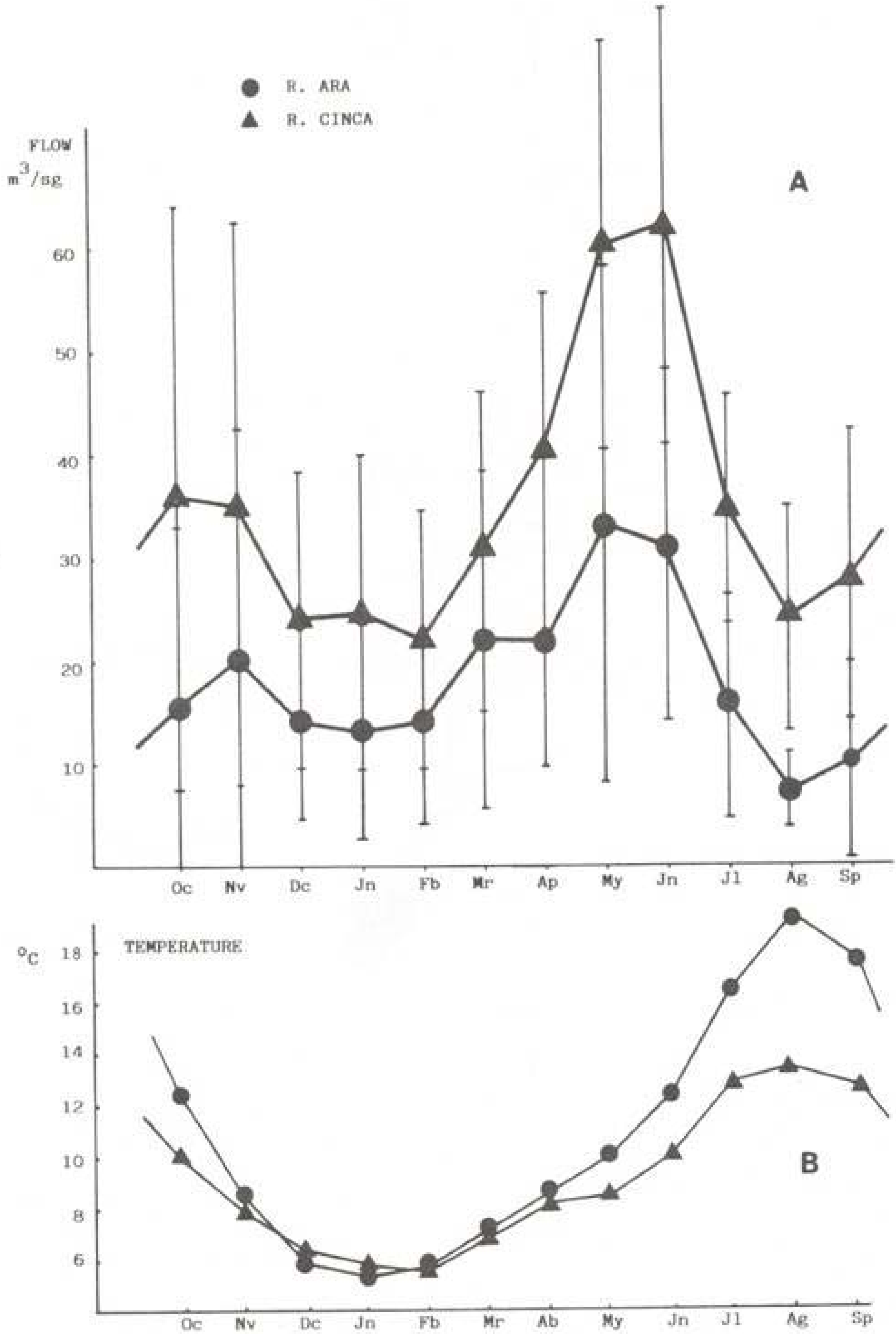

Figure 2. (A) Monthly mean discharges of Ara and Cinca rivers with standard deviations; (B) Monthly mean values of water temperature. Flow measures correspond to the period 1954–1982. Water temperatures correspond to 1976–1984. Base data given by Iberduero S.A. and ICONA

The stomach content of trout populations was analysed using trout captured during the February sampling. Fish were killed immediately they were captured and preserved in Formalin. Only the content of the anterior part of the digestive tract was studied in order to avoid disturbances caused by the different digestability of macrobenthic species (Ellison, 1977).

The sizes of analysed trout correspond mainly to one year old, a few to two or three years old. The number of fish analysed was 25 in the River Cinca and 15 in the River Ara. The analyses of the contents have been done to a wide taxonomical level including species of similar shape, size, and behaviour, between which we suppose trout do not differentiate: eg. Perlidae includes *Perla bipunctata* and *Dinocras cephalotes*, and Heptageniidae with *Ecdyonurus* sp., *Epeorus* sp. and *Rithrogena* sp. However, this ability is yet to be demonstrated.

RESULTS

Physico-chemical characteristics

The results of the water analyses during the three sampling periods in both rivers are presented in Table I. As it can be seen there are no important differences between the rivers Cinca and Ara, neither spatially nor temporally. The water-chemical parameters are characteristic of salmonid rivers (Nisbet and Verneaux, 1970) and indicate a low primary production by phytoplankton (Nieto, 1970). Only the temperature regimes present significant differences in summer. Lower summer temperatures in the River Cinca result from underground pipe flow. In September the daily thermal fluctuation in the River Cinca was 16–21 °C, while in the River Ara it was 18–26 °C.

Benthic Communities

The species compositions, density, and biomass of macrobenthic communities are shown in Table II for each sampling. Community composition is dominated by species belonging to the orders Diptera and

Table I Water physico-chemical characteristics of Cinca and Ara Rivers

	River Cinca			River Ara		
	Winter	Summer	Autumn	Winter	Summer	Autumn
Water Temperature	8·0	21·5	5·5	9·5	19·0	4·5
Conductivity µS cm^{-1}	210	240	260	230	180	275
pH	7·99	7·72	8·28	7·8	7·75	8·2
Alkalinity meq l^{-1}	2·48	2·1	2·1	2·16	2·8	2·7
Chloride mg l^{-1}	7·0	10·0	11·0	6·0	5·0	10·0
Calcium mg l^{-1}	39·28	26·4	29·6	44·0	22·8	28·0
Magnesium mg l^{-1}	9·67	7·65	12·15	12·15	8·7	8·7
Hardness °F	13·8	9·75	12·6	16·0	9·3	11·8
Disolved oxygen (mgl^{-1})	10·6	9·4	10·8	11·0	10·2	11·8
Orthophosphates g-at P-PO_4 l^{-1}	0·1	--	0·06	0·2	0·08	0·03
Nitrates mgN-NO_3 l^{-1}	0·69	0·40	0·6	0·44	0·30	0·8
Nitrites mgN-NO_2 l^{-1}	0·003	0·04	0·009	0·004	0·04	--
Ammonia mg l^{-1}	0·03	0·13	0·01	0·02	0·13	0·02
Silicam g-at.Si–SiO_2 l^{-1}	3·98	1·92	--	3·64	4·5	--
Flow m^3 s^{-1}	5·48	--	5·8	2·5	--	1·3
Water velocity ms^{-1}	0·50	--	0·90	0·62	--	0·76
Chlorophile 'a' mg m^3	0·45	0·25	0·84	0·33	0·36	0·72
Margalef's index D_{430}/D^{665}	2·43	6·00	3·10	6·17	4·00	4·23
N/P ratio	7·23	--	10·30	2·32	5·87	27·33
CPOM mg l^{-1}	$1{\cdot}6{*}10^{-5}$	$7{\cdot}4{*}10^{-4}$	$3{\cdot}5{*}10^{-5}$	$0{\cdot}8{*}10^{-5}$	$2{\cdot}3{*}10^{-5}$	$4{\cdot}2{*}10^{-5}$
FPOM mg l^{-1}	$0{\cdot}9{*}10^{-5}$	$1{\cdot}4{*}10^{-4}$	$2{\cdot}4{*}10^{-5}$	$3{*}10^{-5}$	$2{\cdot}8{*}10^{-5}$	$0{\cdot}5{*}10^{-5}$
UPOM mg l^{-1}	$0{\cdot}4{*}10^{-3}$	--	--	$0{\cdot}6{*}10^{-3}$	--	--

Table II Macrobenthic communities composition expressed in terms of density (individuals m^{-2}) and biomas (g)

	R. Cinca						R. Ara					
	Density			Biomass			Density			Biomass		
	Winter	Summer	Autumn	Winter	Summer	Autumn	Winter	Summer	Autumn	Winter	Summer	Autumn
Hydracarina	—	—	—	—	—	—	4·3	34·6	—	·0003	·0129	—
Oligochaeta	—	11·5	—	—	·0017	—	12·9	17·3	11·5	·0647	·0033	·0022
Baetis gr. alpinus	144·7	5·8	184·5	·0551	·0011	·0205	—	—	1366·8	—	—	·1527
Baetis rhodani	—	937·1	187·4	—	·2044	·0481	21·	348·9	187·4	·0037	·0390	·0773
Baetis fuscatus	—	72·1	—	—	·0156	—	—	498·8	—	—	·0557	—
Baetis muticus	—	2·9	—	—	·0006	—	—	—	—	—	—	—
Baetis vardarensis	—	60·5	—	—	·0133	—	—	966·0	—	—	·1079	—
Epeorus torrentium	2·9	14·4	112·5	·0184	·0066	·0461	—	20·2	28·8	—	·0014	·0044
Ecdyonurus sp.	—	149·9	80·7	—	·0257	·0208	311·4	124·0	112·5	·0539	·0158	·0229
Rhithrogena sp.	490·2	14·4	242·2	·1358	·0052	·0490	186·0	83·6	—	·0515	·0059	—
Oligoneuriella rhenana	—	14·4	—	—	·0299	—	—	17·3	—	—	·0299	—
Caenis rhenicola	2·9	2·9	2·9	·0041	·0001	·0001	121·1	11·5	605·6	·1703	·0005	·0246
Ephemerella ignita	—	8·6	—	—	·0040	—	—	—	—	—	—	—
Torleya mayor	11·5	—	2·9	·0017	—	·0006	77·8	2·9	5·8	·0115	·0006	·0013
Ephemera danica	—	—	—	—	—	—	—	—	2·9	—	—	·0001
Habrophlebia fusca	—	—	—	—	—	—	—	—	2·9	—	—	·0001
Potamanthus luteus	—	—	—	—	—	—	—	—	11·5	—	—	·0025
Onychogomphus sp.	—	—	—	—	—	—	—	2·9	5·8	—	·0170	·0232
Perla bipunctata	46·1	34·6	11·5	·2659	·2108	·2287	17·3	8·6	2·9	·2736	·0307	·1515
Dinocras cephalotes	17·3	43·2	28·8	·0037	·0917	·0450	116·8	207·6	20·2	·5276	·5069	·0846
Protonemura sp.	—	8·6	—	—	·0014	—	—	—	—	—	—	—
Leuctra sp.	—	23·1	—	—	·0058	—	—	—	—	—	—	—
Capnia nigra	2·9	—	—	·0072	—	—	—	—	—	—	—	—
Orectochilus villosus	—	5·8	—	—	·0346	—	17·3	77·8	46·1	·1384	·0400	·0427
Riolus cupreus	—	—	—	—	—	—	—	5·8	—	—	·0006	—
Elmis maugetii	—	—	—	—	—	—	34·6	88·8	24·5	·0071	·0177	·0044
Elmis rioloides	—	—	—	—	—	—	—	355·2	24·5	—	·0708	·0044
Esolus parallelelpipedus	34·5	—	—	·0035	—	—	51·9	—	—	·0035	—	—
Esolus angustatus	—	8·6	2·9	—	·0003	·0003	—	302·8	262·4	—	·0145	·0097
Limnius opacus	—	—	—	—	—	—	—	40·4	2·9	—	·0091	·0009
Hydraena sp.	—	—	—	—	—	—	—	2·9	—	—	·0003	—
Rhyacophila denticulata	—	40·4	11·5	-	·0432	·0014	—	103·8	40·4	-	·8557	·0044
Agraylea sp.	—	—	—	—	—	—	—	—	5·8	—	—	·0004
Hydropsyche dinarica	49·0	49·0	5·8	·2457	·1626	·0150	—	—	—	—	—	—
Hydropsyche pellucidula	—	—	—	—	—	—	138·4	222·0	43·2	1·1687	·4812	·1662
Hydropsyche pictetorum	—	—	—	—	—	—	21·6	—	—	·2885	—	—
Polycentropus flavomaculatus	—	2·9	—	—	·0011	—	—	—	43·2	—	—	·0470
Psychomyia pusilla	2·9	17·3	2·9	·0087	·0011	·0003	220·6	112 ·5	170·1	·6635	·0080	·0121
Metalype fragilis	—	—	—	—	—	—	—	—	8·6	—	—	·0006
Chironomidae	1917·5	726·6	2831·6	·1574	·0585	·2307	354·7	1121·7	1487·9	·0294	·0902	·1198
Ceratopogonidae	—	—	—	—	—	—	—	17·3	—	—	·0043	—
Simuliidae	2·9	40·4	92·3	·0031	·0032	·0075	—	57·7	80·7	—	·0046	·0065
Limoniidae	5·8	2·3	—	·0066	·0003	—	—	—	—	—	—	—
Tipulidae	—	—	—	—	—	—	—	—	17·3	—	—	·1709
Tabanidae	—	—	—	—	—	—	—	—	5·8	—	—	·0066
Ephydridae	—	2·9	—	—	·0003	—	—	—	—	—	—	—
Empididae	2·3	8·6	5·8	·0054	·0011	·0003	17·3	31·7	43·2	·0325	·0040	·0055

Ephemeroptera in the River Cinca (90 per cent in numbers), while in the River Ara dominance is shared by Ephemeroptera, Diptera, Trichoptera, and Coleoptera. The number of species in the River Ara (18–28) is always superior to the number in the River Cinca (16–27) during the three seasons that were sampled.

The fluctuation of species richness during the year also differs between the rivers. In the River Ara the minimum number of taxa is registered in winter after the autumn floods, following a strong increase in taxa from September to December. In the River Cinca very few taxa are found from December to February, while in September the faunistic richness is greatly increased.

In the River Ara benthic densities (Table III) fluctuate markedly from winter ($1730\,m^{-2}$) to summer ($4940\,m^{-2}$). In the River Cinca these changes are less important, with a maximum in December ($3806\,m^{-2}$) and a minimum in September ($2310\,m^{-1}$). The seasonal homogenity of the River Cinca communities is again shown by their biomass (Table III), which is practically constant ($0{\cdot}81$–$1{\cdot}10\,g\,m^{-2}$) while in the River Ara the biomass decreases strongly from February ($3{\cdot}5\,g\,m^{-2}$) to December ($1{\cdot}17\,g\,m^{-1}$). Also it can be asserted that the benthic biomass in the River Ara is always higher than in the River Cinca, especially in summer ($P<0{\cdot}1$).

The frequency in occurrence of different taxa indicate that the River Cinca communities present a simplified structure, dominated by chironomids which constitute 70 per cent. Only in September were other taxa codominant: *Baetis rhodani* (39·4 per cent. Chironomidae (30·5 per cent), *Ecdyonurus* sp. (6·3 per cent) and *Baetis fuscatus* (3 per cent). In contrast, the River Ara presents a much higher structural complexity (no taxon represents more than 35 per cent) during the whole year. Shannon diversity index (Table III) reflects the same pattern: in the River Ara diversity values fluctuate between 2·87 and 3·58 and in the River Cinca are between 1·55 in February and December to 2·64 in September. Also the community eveness evolves similarly, with the River Cinca values being always smaller and with a maximum in summer.

The trophic structure of the benthic communities is shown in Table IV. Seasonal fluctuations are more marked among all trophic groups in the River Ara than in the River Cinca. Collectors are the most abundant group, representing 50 per cent of the biomas in the River Cinca, while in the River Ara they oscillate from 34 per cent to 68 per cent. In both rivers predators represent one third of the total biomass with greatest numbers in summer and grazers represent 15 per cent of the biomass for most of the year, except in summer when numbers fall to less than 5 per cent.

Both rivers are clearly heterotrophic with fine particulate organic matter (FPOM) providing the main energy source. Comparing the collectors' biomass with the quantity of FPOM in the water, only in the River Cinca is there a significant correlation ($P<0{\cdot}05$). However, comparing shredders' biomass with CPOM, only in the River Ara is there a significant correlation ($P<0{\cdot}1$). Finally, grazers biomass is not correlated with chlorophyll content or with the Margalef index. It appears that the qualitative characteristics of energy inputs are the main controls of the macrobenthic trophic structure.

Table III. Macrobenthic community structure in Rivers Ara and Cinca (mean values and standard derivations for number of taxa, individual density, biomass, diversity and evenness)

		R. Ara			R. Cinca		
		Winter	Summer	Autumn	Winter	Summer	Autumn
No. Taxa	$\bar{x}$	15·5	25	20	10·7	19·7	12
	(σ)	(3·5	(4·4)	(3·5)	(2·1)	(0·6	(1)
Density ind.m^{-2}	$\bar{x}$	1730	49939	4671	2742	2396	3806
	(σ)	(726·2)	(2344·4)	(994·6)	(2779·9)	(585·9)	(1260·8)
Biomass (gm^{-2})	$\bar{x}$	3·5	2·37	1·17	1·10	0·97	0·81
	(σ)	(3·63)	(0·84)	(0·31)	(0·37)	(0·33)	(0·49)
Diversity	$\bar{x}$	3·30	3·58	2·88	1·51	2·64	1·56
Evenness (%)	$\bar{x}$	82·39	73·75	59·69	37·83	56·81	39·08

Table IV. Macrobenthic community trophic structure, in biomass terms, from rivers Ara and Cinca

Trophic groups	R. Ara Winter %	g m^{-2}	Summer %	g m^{-2}	Autumn %	g m^{-2}	R. Cinca Winter %	g m^{-2}	Summer %	g m^{-2}	Autumn %	g m^{-2}
Predators	30	1·05	60	1·40	27	0·30	31	0·34	39	0·41	38	0·32
Grazers	3	0·11	1	0·02	16	0·19	17	0·19	4	0·04	15	0·13
Collectors	68	2·38	34	0·81	55	0·64	51	0·56	49	0·51	43	0·36
Shredders	0	0	5	0·12	2	0·02	1	0·01	8	0·08	4	0·03

Drift during the daylight hours presents lower density values in the River Ara ($\bar{x}$ = 0·77, σ = 0·18) than in the River Cinca ($\bar{x}$ = 1·32, σ = 1·98). Drift composition (Table VI), as it is in the macrobenthos, is much more homogeneous between seasons in the River Cinca and is dominated by Chironomidae (more than 60 per cent). In contrast, in the River Ara the composition changes during the year: Chironomidae and *Psychomyia pusilla* are most abundant in February; *Baetis vardarensis*, *Psychomyia pusilla* and Chironomidae are dominant in September; and Diptera (Simuliidae and Chironomidae) dominate in December.

In order to study the changes of macrobenthic communities in space and time, a presence-absence matrix was generated by a Correspondences Analysis and Cluster Analysis (Dixon and Brown, 1982). The results are presented in Figure 3. The first two axes of the Correspondences analysis account for 57·4 per cent of the variance. The projections of the samples in the plane created by the first axis defines the seasonal pattern (Summer–autumn–winter) of the macrobenthos for both rivers (Figure 3). There are two parallel bands in which summer samples have the greatest values (positive) in both axes and winter ones the lowest (negative).

The similarity between samples is illustrated by the cluster dendrogram (Figure 3). At the xx′ level three groups are formed corresponding to: (1) River Ara in summer, (2) River Ara in autumn, (3) A heterogeneous mixture of all samples of the River Cinca wih the River Ara in winter. This last group (yy′) can be distinguished from the following subgroups: (1) River Cinca in summer; (2) River Ara in winter; (3) the rest of the River Cinca. Therefore, we may conclude that within each river the benthic community changes gradually through the year: the communities in the two rivers change in differnet ways and the greatest contrast is in summer. The River Cinca community is relatively homogeneous throughout the year. Temperatures seems to be the main factor controlling benthic compositions: higher summer temperatures in the River Ara promote a seasonal succession that enriches the macrobenthic composition.

Fish communities

The Ara and Cinca river fisheries are dominated by trout (*Salmo trutta fario* Linnaeus, 1758) accompanied by barbel (*Barbus barbus bocagei* Steindachner, 1865), soiffe (*Chondrostoma toxostoma* Vallot, 1837), and stone loach (*Noemacheilus barbatulus* Linnaeus, 1958).

This study concentrates on trout populations because they are the most abundant and because of their social and economic importance. The results of the biomass evaluation in the fisheries indicate that the relative proportion of cyprinids fluctuates from 27 per cent (autumn) to 7·4 per cent (winter) in the River Cinca, while in the River Ara the proportions vary from 7·7 per cent (autumn) to 24 per cent (winter).

Biomass and density values of trout populations are represented in Table V. Biomass decreases from autumn to winter, especially in the River Cinca, while density increases during the same period. The explanantion of this fact can be found in the upstream migration for spawning of trout populations from Mediano Reservoir (located below the sampling sites) in late autumn.

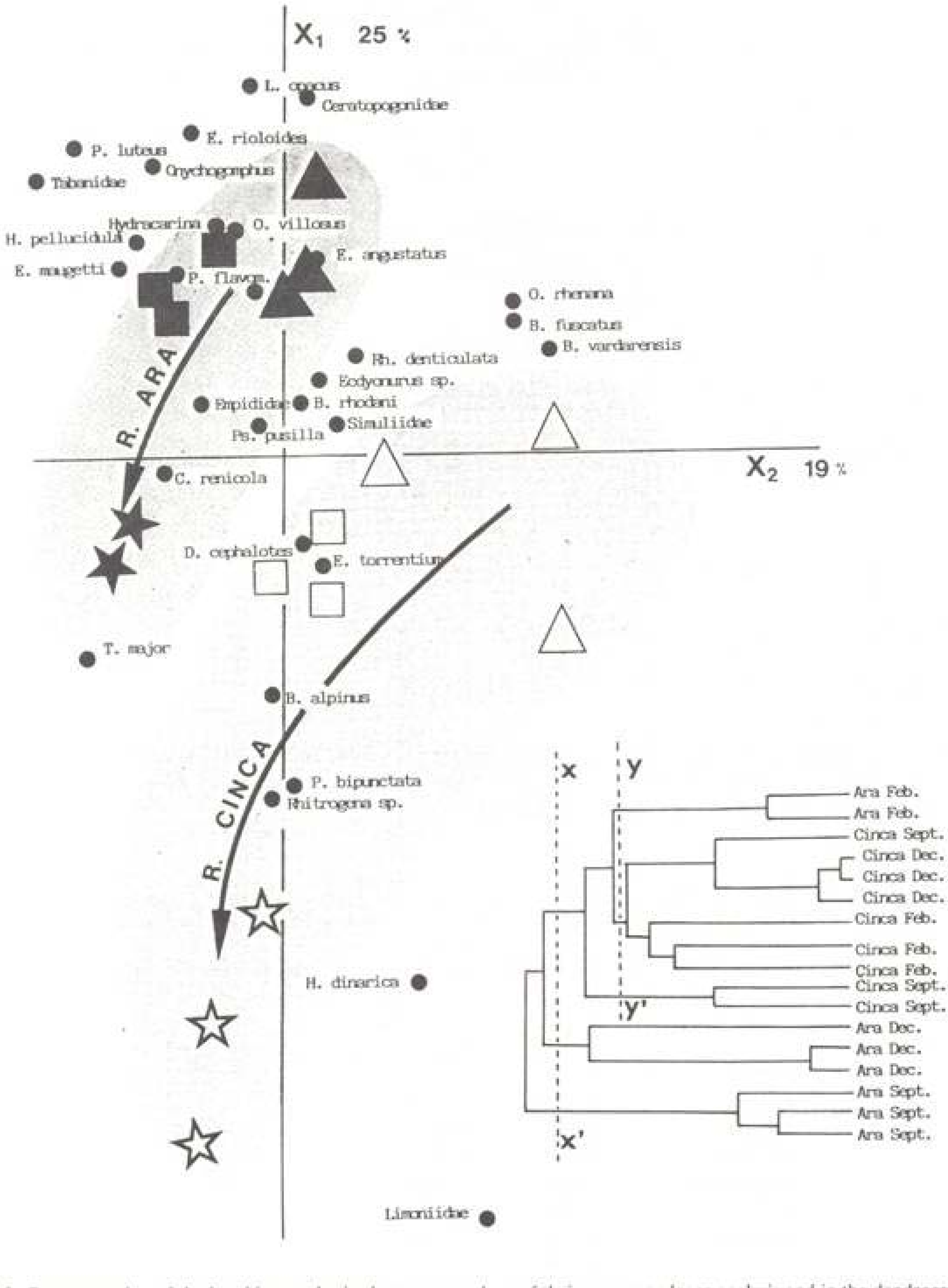

Figure 3. Representation of the benthic samples in the two axes plane of their correspondence analysis and in the dendrogram of their cluster analysis (Dixon and Brown, 1982). Triangles represent summer, squares autumn; and stars are winter.

Survival and mortality rates corresponding to age-structures of trout populations are presented in Table V. The structures are adjusted using the Robson and Chapman (1961) model with positive significant X^2 values with a confidence interval of 95 per cent. The River Ara mortality rates are constant in both samplings, while in the River Cinca these rates oscillate markedly from minimum values in autumn to maximum in winter.

The weight/length relationships for each of the trout populations studied are described by the following equations:

RIVER ARA

Autumn: $W = 7{\cdot}925 \times 10^{-6} \times L^{3{\cdot}050}$ $(r = 0{\cdot}993)$

Winter: $W = 27{\cdot}200 \times 10^{-6} \times L^{2{\cdot}841}$ $(r = 0{\cdot}993)$

RIVER CINCA

Autumn: $W = 1{\cdot}118 \times 10^{-6} \times L^{3{\cdot}000}$ $(r = 0{\cdot}995)$

Winter: $W = 88{\cdot}000 \times 10^{-6} \times L^{2{\cdot}624}$ $(r = 0{\cdot}864)$

where W is the weight in grammes and L is length in mm.

Growth-curves of Ara–Cinca trout populations follow Von Bertalanffy equations;

RIVER ARA

Autumn: $L = 409{\cdot}7\ [1 - e^{-0{\cdot}247(t+0{\cdot}236)}]$ $(r = 0{\cdot}950)$

Winter: $L = 444{\cdot}5\ [1 - e^{0{\cdot}333)(t+0{\cdot}236)}$ $(r = 0{\cdot}950)$

RIVER CINCA

Autumn: $L = 839{\cdot}99\ [1 - e^{-0{\cdot}090(t+0{\cdot}386)}]$ $(r = 0{\cdot}980)$

Winter: $L = 209{\cdot}6\ (1 - e^{-0{\cdot}910(t+0{\cdot}400)}]$ $(r = 0{\cdot}964)$

where t is time expressed in years.

The annual production values of trout populations are presented in Table V. Autumn values are similar for both rivers, indicating once more a common origin, while in winter the River Ara production is doubled and the River Cinca production is halved.

Table V. Mean values of trout population characteristics (biomass, density, survival and mortality rates, production and turn-over) for the rivers Ara and Cinca

		River Ara $\bar{x} \pm \sigma$	River Cinca $x \pm \sigma$
Biomass	autumn	1·85 ± 0·005	2·59 ± 0·01
g m^{-}	winter	1·66 ± 0·03	1·12 ± 1·32
Density	autumn	3·09 ± 0·01	2·27 ± 0·009
ind 100m^{-2}	winter	4·80 ± 0·08	3·60 ± 4·24
Survival rate	autumn	0·25	0·56
	winter	0·26	0·15
Mortality	autumn	1·39	0·58
	winter	1·33	1·91
Production	autumn	1·003	1·335
gm^{-2}y^{-1}	winter	2·070	0·610
P/B	autumn	0·54	0·52
(year^{-1})	winter	1·24	0·54

Trout-benthos Interrelations

The results of stomach content analyses of trout captured during February sampling are present as frequency of occurrence in Table VI. We have compared the macrobenthic composition with the stomach content using frequency analysis (χ^2) because numerical analysis was too variable (see Hynes, 1950 or Hyslop, 1980). Differences were significant in the River Ara but insignificant in the River Cinca (P<0·001); 26·5 per cent of the benthic individuals from the River Ara belong to species are not present in its trout stomachs, while in the River Cinca 97·1 per cent of species were common to both. The terrestrial component of the diet varied between the rivers. In the River Cinca 5·3 per cent of the stomach contents were terrestrial insects and arachnids while in the fish from the River Ara no terrestrial arthropods were found.

Analysis of the stomach contents in relation to drift and benthic data (Table VI) suggest that the trout prefer large predators such as *Rhyacophila* spp. and Perlidae supplemented by drifting Heptageniidae, and *Baetis* spp. Other species are apparently avoided: these include Hydracarina, *Torleya major*, Elmidae, and Orthocladinae.

Table VI. A comparison of the percentage composition of food items in trout stomachs with that in the benthos and drift in the Rivers Ara and Cinca. The significance of the results is tested with X^2 (following Windell and Bower, 1978)

	R. Cinca			R. Ara		
	Fish	River		Fish	River	
	% composition	Benthos	Drift	% composition:	Benthos	Drift
Hydracarina			4 –			–
Baetis	12	8·7 ns	2 +++	14	1·7 +++	
Heptageniidae	23	23·3 ns	0·3 +++	11	22 –	1 +++
Torleya mayor						1 ns
Perlidae	13	3·1 +++		18	7·3 +++	
Elimidae				4	36 –––	
Rhyacophila	5	0·9 +++	0·3 +++	14	0·3 +++	1 +++
Hydropsyche	5	3·6 ns	0·6 +++	11	9·3 ns	
Psychomyia	7	0·1 +++	0·9 +++	7	2·7 ++	45 +++
Hexatoma	2	0·9 ns				
Orthocladiinae	32	57 –	92 –––	21	21·3 ns	48 –––
Simuliidae						1 ns

Significantly rejected: – P<0·05; –– P<0·01; ––– P<0·001
Significantly selected: + P<0·05; +++ P<0·01; +++ P<0·001
ns: difference not significant.

DISCUSSION

Although the data relate to a limited sampling programme the study represents the first interdisciplinary investigation of the effects of hydroelectric dams on rivers in Spain. At a time when the number of dams is growing rapidly data are needed urgently in order to improve the management of existing schemes and to mitigate adverse ecological effects of the new ones. Notwithstanding the above, several general conclusions and points for discussion may be raised. Even under natural conditions within these rivers the environment is unfavourable for biotic communities because of the important autumn and spring floods and the instability of the branched river channel which also prevents the development of riparian vegetation. Thus, the densities and biomass of benthic and fish communities are lower than in other Pyrenean streams (Garcia de Jalon *et al*, 1986). Nevertheless, the introduction of a small capacity hydroelectric plant on the River Cinca upstream of Ainsa, has reduced summer water temperatures (Figure 2b) and introduced sudden flow fluctuations within the river downstream of the dam. The stressed nature of the macrobenthos in the River Cinca in comparison to the River Ara is reflected by the ecological parameters (Table III).

The contrasting summer temperatures of the Cinca and unregulated Ara rivers are reflected in the macrobenthic composition (Table IV). Cryophilic species like *Hydropsyche dinarica*, *Baetis*gr. *alpinus*, and *Capnia nigra* dominate the River Cinca. In the River Ara *Hydropsyche pellucidula* and *H. pictetorum* (Garcia de Jalon, 1986) or potamic species like *Potamanthus luteus*, *Metalype fragilis*, *Agraylea* sp., *Orectochilus viillosus*, *Elmis maugetii*, *Limnius opacus*, or *Onychogompus* sp. characterize the warmer waters. As a consequence, species richness of the macrobenthos is lower in the regulated River Cinca (Table III(because of the elimination of thermophilous species by competitive disadvantage. Similar conclusions have been reached by other authors: e.g. Ward (1976) and Armitage (1984). Colder summer temperatures in the River Cinca also affect fish communities by causing a slower growth rate and lower productivity than in the River Ara.

Fish populations living in reservoirs often invade the streams and rivers that flow into them (See Langford, 1983 for references). In the case of the Mediano Reservoir (downstream from the sampling sites) these invasions are associated with spawning and occur at the end of autumn for trout and at the end of spring for barbel and soiffe. The results of autumn sampling reflect the migration of reservoir populations, while the winter sampling data are representative of the upstream reaches of the rivers. Therefore, assessment of the effects of hydroelectric production is based on the results of winter sampling (Table V). Although there are no significant differences between trout population density and biomass in the rivers Cinca and Ara, production is markedly inferior in the River Cinca ($0{\cdot}61\,g\,m^{-2}y^{-1}$) in comparison to the River Ara ($2{\cdot}07\,g\,m^{-2}y^{-1}$). This is also the case for the turn-over ratio (P/B): $0{\cdot}54\,y^{-1}$ in the River Cinca against $1{\cdot}24\,y^{-1}$ in the River Ara. Values under $1{\cdot}5\,y^{-1}$ for salmonids is characteristic of less productive waters (Chapman, 1978). The observed *P/B* ratios for combined cohorts tend to decrease rapidly with increasing age and differences between the rivers may reflect age-structure differences rather than stress effects. However, this in not the case because winter age–structure is younger in the River Cinca than in the River Ara.

One measure of stress suffered by winter trout populations in the River Cinca is reflected in the analysis of their food items (Table VI), as macroinvertebrates are found in their stomachs in the same proportion as in the benthos. In contrast, in the River Ara, trout actively select the more desirable species. Furthermore, in the River Cinca trout complement their diet with terrestrial anthropods, which is not the case in the River Ara. It is clear that the scarcity of food is the limiting factor for the regulated Cinca trout populations. Comparing macrobenthos biomass (dry-weight) with trout biomass (fresh weight) reveals a coefficient of less than one, while in the River Ara this coefficient is greater than two. Trout populations do not seem to be directly affected by sudden flow fluctuations caused by hydroelectric demands but they are stressed as a result of changes in the trophic chain.

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