Effects of a Small Hydropower Station Upon Brown Trout Salmo Trutta L. in the River Hoz Seca (Tagus Basin, Spain) One Year after Regulation

Article *in* Regulated Rivers Research & Management · September 1999

DOI: 10.1002/(SICI)1099-1646(199909/10)15:53.0.CO;2-B

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REGULATED RIVERS: RESEARCH & MANAGEMENT
Regul. Rivers: Res. Mgmt. **15**: 477—484 (1999)

Short Communication

EFFECTS OF A SMALL HYDROPOWER STATION UPON BROWN TROUT *SALMO TRUTTA* L. IN THE RIVER HOZ SECA (TAGUS BASIN, SPAIN) ONE YEAR AFTER REGULATION

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ABSTRACT

A small hydroelectric power station was built in 1993 on the River Hoz Seca (Tagus basin, central Spain). Pre- and post-regulation studies provided the opportunity to test the early effects of this disturbance on the brown trout *Salmo trutta* L. population. Before and after comparisons of population density and biomass, age composition, growth and production were made upstream and downstream of the diversion dam. The effects of disturbance on benthic macroinvertebrates were also analysed but no changes in abundance were detected. The downstream estimated population densities and biomass of trout showed a decrease of about 50 and 43%, respectively, following regulation. Examination of length-for-age tables revealed no obvious change in growth but a significant difference in age structure. The main consequence of the imposed fluctuating flow regime was a serious reduction in trout production caused by a loss of suitable habitat and a loss of juveniles. Copyright © 1999 John Wiley & Sons, Ltd.

KEY WORDS: hydropower; *Salmo trutta;* Tagus basin

INTRODUCTION

Flow modification is one of the most widespread human disturbances of stream environments. Discharge regime and the related physical effects are modified with increasing frequency by catchment management, especially by activities such as river regulation and transfer, drainage works, afforestation and deforestation (Milner *et al.,* 1981). In general, the most adverse effects of flow regulations are likely to result from substantial, intermittent flow variations periodically exposing large arcas of the channel bed (Brooker, 1981). Bain *et al.* (1988) and Travnichek *et al.* (1995) identified these artificial flow fluctuations from hydroelectric dams as a disturbance that can degrade fish habitat and reduce the complexity of the fish community. It seems obvious that the effects of flow peaking on aquatic systems below dams are important considerations in hydropower development and the management of regulated rivers (Heggenes, 1988).

Despite all major rivers in Spain being regulated by more than 1100 dams (Nicola *et al.,* 1996), to date there have been few attempts to study the consequences of river regulation upon fish communities (García de Jalón *et al.,* 1988; Casado *et al.,* 1989; Camargo and García de Jalón, 1990; García de Jalón *et al.,* 1994). Furthermore, Blanco and González (1992) and Elvira *(1996)* considered dams to be one of the main negative factors affecting Spanish fishes. Specifically, Almodóvar and Burgaleta (1993) considered water regulation as an important cause of the decline of brown trout in Spain.

The Hoz Seca is the first tributary of the River Tagus and supplies the greatest proportion of flow to this upper part of the basin. Since autumn 1993 this stream has been regulated by a small hydropower station *(700* kW). This paper evaluates the impacts of this recent disturbance on an indigenous brown trout population. In order to assess changes in the trout population related to alterations in their food

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CCC 0886-9375/99/050477-08$17.50

Received 14 May 1998
Revised 19 March 1999
Accepted 23 March 1999

supply, the benthic communities were also analysed, since macroinvertebrates are important food items for brown trout (Elliott, 1967).

METHODS

Study area

This study was conducted on the lower reaches of a first-order tributary of the River Tagus. The River Hoz Seca has a basin area of 175.76 km' and its altitude ranges from 1620 m at the yource to 1250 m at its confluence with the Tagus. The mean discharge is highest in winter (2 m^3 s -') and decreases in summer (0.4 m^3 s -'). The river flows over a limestone catchment with an average channel slope of 12.7%. The water chemistry can be characterised as a non-polluted headstream, with low concentrations of organic matter and high levels of dissolved salts. The ionic balance shows a dominance of HCO3 (266 mg L -', 534 tS cm' conductivity) and Ca^e ± (40 mg L -'). The water temperature ranges from a low of 8°C in winter to a high of 14°C in summer, with a pH of 7.6. Stream-bed material was dominated by boulders and bedrock. Substantial proportions of gravel and sand were also present. The availability of cover for fish was high, mainly due to boulders. The bank vegetation at the site was dominated by some riparian deciduous vegetation *(Salix* spp., *Rosa* spp., *Prunus spinosa* L., *Crataegus monogyna* Jacq., *Rubus ulmifolius* Schott. and *Berberis hispanica* Boiss. & Reuter) and pine *(Pinus sylvestris L.).* The aquatic vegetation consisted primarily of *Chara vulgaris L., Groenlandia densa (L.)* Fourr., *Zannichellia contorta* (Desf.) Chamisso & Schlech, *Ranunculus peltatus* Schrank and *Cratoneurum commutatum* (Hedw.) Roth. Brown trout is the only fish species present in this stream, which has never been stocked. Two sampling sites were chosen (see Figure 1), with similar sizes and habitat conditions; site 1 was located near the mouth of the river, about 500 m downstream of the diversion dam; site 2 was a reference sector situated approximately 3 km upstream of the power plant.

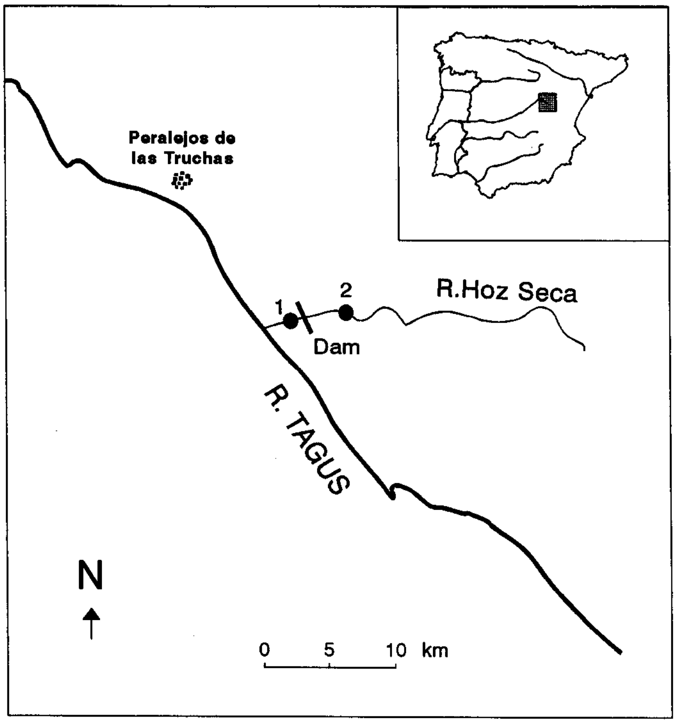

Figure 1. Map of the study area showing sampling sites and the position of the diversion dam

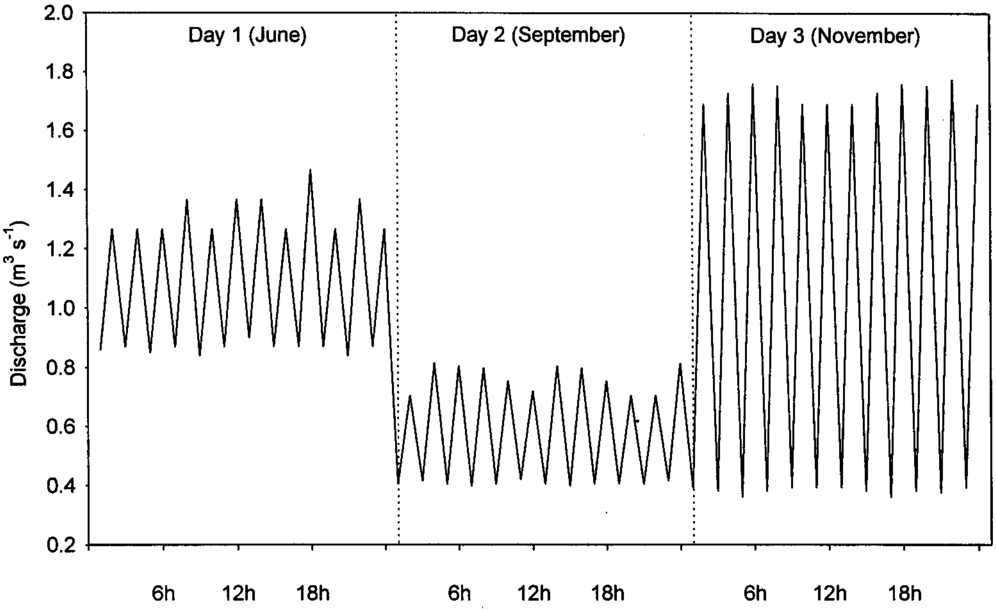

Figure 2. Mean hourly discharge per day in the downstream section of the River Hoz Seca with minimum (June and September) and maximum flow periods (November)

The hydroelectric power station in the River Hoz Seca produces frequent and strong daily flow fluctuations. This effect is especially notorious in autumn when the daily fluctuations range from 0.4 to 1.7 m s -' on average, in spite of being the period of the year with maximum flow (Figure 2). Thus, the water depth in the downstream site increases 0.3 m on average in a matter of minutes whenever the discharge from the power station arrives there, continually changing the location of the shoreline.

Benthic macroinvertebrates

Benthic macroinvertebrates were sampled in riffles every two months from January 1993 to November 1994. Three replicate samples per site, taken progressively upstream of each other, were collected on each sampling date with a Neil cylinder with a 250 µm mesh net. Invertebrate samples were preserved in 10% formalin for later laboratory identification, sorting and counting. Specimens were dried in an oven at 60°C for 24 h and densities and biomass (dry weight) were determined. Each taxonomic group was assigned to one of five major functional feeding categories: predators, scrapers, shredders, filterers and collectors (Cummins, 1973).

Brown trout

Fish were also sampled every 2 months from January 1993 to November 1994 at each site by electrofishing using a 220 W DC generator. Fish caught were anesthetised with tricaine methane-sulphonate (MS-222 SANDOZ) and their fork lengths (to within 1 mm) and weights (to within 1 g) were measured. Scales were taken for age determination. Trout density was estimated by applying the three catch removal method (Zippin, 1956). Standing crop was calculated following the formula proposed by Mahon *et al.* (1979). Population estimates were carried out separately for each year class. The mean instantaneous growth rate (G) was calculated as:

$$G = \ln W_2 - \ln W_1 / t_2 - t_1,$$

where W_1 and W_2 (in grams) were the mean weight of each year class of fish at times t_1 and t_2 (in days). Production was calculated using Allen's graphic method (Allen, 1951) for each year class. A t-test was used to compare both total densities and biomass of trout before and after regulation. The same procedure was also employed to test the mean number of trout caught of each age group.

RESULTS AND DISCUSSION

Benthic macroinvertebrates

In general, the results did not show any drastic change in benthic invertebrate communities below the dam after the hydroelectric power station was put into operation. Furthermore, the opening of the power station did not seem to have a negative effect on benthos with regard to total density or biomass (Table I). On the contrary, the benthic fauna had a slight increase in spite of the flow disturbances. Similar results have been found by Armitage (1989) in 50 regulated sites in Great Britain and by Petts *et al.* (1993), who noted that the regulation did not impoverish the invertebrate fauna but induced subtle changes in faunal composition. The contribution of each feeding group to community structure was equivalent in both sampling sites. Collectors were by far the dominant group (around 44%), followed by predators (around 25%), shredders (15%), scrapers (9%) and filterers (7%). Moreover, frequencies of functional feeding groups did not differ significantly through the sampling period in either site. On the whole, the functional organisation of the macroinvertebrate community in the River Hoz Seca corresponds with that predicted for headwater streams by Vannote *et al.* (1980). However, the frequencies did not seem to follow the hypothetical co-dominance of shredders with collectors in forested headwaters streams (Cummins, 1974; Vannote *et al.,* 1980). Maybe shredders were more abundant in other habitats such as pools (not sampled in this study), where coarse-particulate organic matter (CPOM) could accumulate (Bunn, 1986).

Brown trout

In relation to trout population, there was a rapid response to regulation in terms of decreasing density and biomass. From 1993 to 1994, the estimated population density and biomass showed a significant decrease of about 50% ($t = 6.30$, $p < 0.05$) and 43% ($t = 2.69$, $p < 0.05$), respectively. However, these two parameters remained practically unchanged in the upstream section. Thus, the variations in density from 1993 to 1994 were not significant ($t = 1.57$, $p > 0.05$) and the biomass did not exhibit significant ($t = 0.11$, $p > 0.05$) changes across the sampling period aboye the dam. Also, the recruitment of the individual cohorts showed a progressive fall from 1993 to 1994, which was more evident in 0 + and 1 + year classes.

In Table II the mean number of trout caught by age group in both pre- and post-regulation periods are compared. There was a significant decrease in the catches of 0 + and 1 + trout at the downstream site following regulation and a minor but also significant decrease in 2 + and older trout. Accordingly, the structure of the population became dominated by older fish, probably as a result of flow regulation, since this was not observed in the non-regulated upstream site. Furthermore, the adverse flow conditions in the Hoz Seca possibly prevented adult fish from migrating upstream to spawn. These observations agree with those of Cowx and Gould (1989) for the River Clywedog, where recruitment of brown trout declined over successive years after extensive regulation began. Hvidsten (1985), working in the regulated river Nidelva, detected a similar poor recruitment and suggested that the main reason for deficiencies in the number of 0 + trout was that trout usually remain in their river bed habitats and the frequent changes in water level generated by flow regulation led to increased mortality as a result of stranding.

Since streamflow seems to be the environmental variable likely to exert the greatest influence on populations of young salmonids (Solomon, 1985; Elliott, 1987), it is worth noting that the loss of recruitment in the Hoz Seca could be induced by the downstream displacement of 0 + trout as a result of the violent fluctuations in the water level of the river. Several authors (e.g. Ottaway and Forrest, 1983; Heggenes and Traaen, 1988; Crisp and Hurley, 1991a,b) have experimentally proved the vulnerability of salmonid juveniles to downstream removal due to increasing water velocities. In contrast, Heggenes (1988), testing the response of induced peaking on movement and habitat use of brown trout in a small

Norwegian stream, concluded that trout with a mean length of at least 67 mm were not washed out due to sudden high water flows, provided that coarse substrata supplying cover and low-velocity microhabitat were present. The area of the Hoz Seca subjected to hydropower operations suffers frequent fluctuations of water level leading to a repeated drowning and drying up of sections near the riverbanks. This latter

Table I. Mean density (*D*, individuals m^{-2}) and mean biomass (***B***, g dry weight m^{-2}) of each group of macroinvertebrates for each section (upstream/downstream) within the pre- (1993) and post-regulation (1994) periods

	Upstream				Downstream			
	D		***B***		*D*		***B***	
	1993	1994	1993	1994	1993	1994	1993	1994
Turbellaria	1.785	1.782	0.0019	0.0030	52.595	40.115	0.3462	0.2603
Oligochaeta	5.350	112.772	0.0094	0.0960	11.145	45.465	0.1703	0.1483
Hirudinea	1.785	3.567	0.0009	0.0166	44.575	16.047	0.0339	0.0130
Gastropoda	10.700	14.707	0.0091	0.0650				
Crustacea	80.230	52.150	0.1473	0.0575				
Insecta								
Ephemeroptera								
Baetidae	310.225	193.000	0.1389	0.0835	151.100	390.460	0.0715	0.1496
Heptageniidae	67.750	30.310	0.1210	0.0358	60.175	49.475	0.1426	0.0301
Ephemerellidae	258.520	28.525	0.1281	0.0191	67.750	6.687	0.0358	0.0040
Caenidae		7.132		0.0027		58.835		0.0114
Leptophlebiidae	7.130	36.550	0.0007	0.0242	30.755	5.350	0.0313	0.0031
Ephemeridae	12.480	12.927	0.1847	0.0218	8.465	2.675	0.0107	0.0259
Odonata								
Calopterigidae					1.335	4.012	0.0001	0.0044
Gomphidae	5.350		0.0030		60.175	5.347	0.0474	0.0191
Aeshnidae	1.785		0.3665		1.335	5.347	0.0001	0.3116
Cordulegasteridae		2.675		0.0001		9.360		0.2959
Plecoptera								
Nemouridae	16.045	19.612	0.0051	0.0032	6.685	69.535	0.0013	0.0113
Leuctridae	131.935	168.485	0.0287	0.0563	15.155	29.417	0.0018	0.0072
Perlidae	137.285	67.307	0.5611	0.6755	12.035		0.0275	
Coleoptera					73.100	48.140	0.2369	0.4930
Dytiscidae	90.930	0.892	0.0349	0.0010				
Elmidae	110.540	20.950	0.0089	0.0118	58.390	42.790	0.0212	0.0123
Helodidae	41.005	7.577	0.0107	0.0009	1.785	1.337	0.0002	0.0001
Megaloptera								
Sialidae	3.570	8.025	0.0085	0.0045		6.685		0.0084
Diptera								
Limoniidae	1.785	1.337	0.0032	0.0011	1.335	1.337	0.0012	0.0001
Simuliidae	281.700	4.905	0.0836	0.0008		14.707		0.0043
Chironomidae					22.730	93.602	0.0013	0.0071
Ceratopogonidae					4.460	4.012	0.0003	0.0001
Stratyomyidae	46.355	8.470	0.1219	0.0151	44.575	13.372	0.1455	0.0556
Trichoptera					1.335	2.675	0.0137	0.0002
Rhyacophilidae		2.675		0.0297	1.785	4.012	0.0002	0.0009
Glossosomatidae		48.140		0.0710	1.785	10.697	0.0012	0.0151
Hydropsychidae	10.695	2.230	0.0324	0.0002	8.025	2.675	0.0291	0.0009
Polycentropodidae					6.685		0.0045	
Psychomiidae	8.915		0.0030			2.675		0.0001
Limnephilidae	12.480	62.847	0.0089	0.0802	1.785	2.675	0.0002	0.0005
Sericostomatidae	133.720	109.202	0.2936	0.1952	124.805	141.742	0.1501	0.2467
Total	1790.050	1028.758	2.3167	1.5719	875.860	1131.268	1.5270	2.1410

Table II. Mean number of trout caught for 0+, 1+ and 2+ and older age group for each section (upstream/downstream) within the pre- and post-regulation periods

Site	Period	0+		1+		2+ and older	
		Mean	p	Mean	p	Mean	p
Upstream	Pre-regulation	18	>0.10	27	>0.10	8	>0.10
	Post-regulation	20		25		9	
Downstream	Pre-regulation	20	<0.001	33	<0.001	55	<0.01
	Post-regulation	9		9		34	

The means were compared through a t-test and the results are shown in the table.

resulted in an important shift within the habitat of 0 + trout, which mostly prefer shallow waters with a low water velocity (e.g. Heggenes *et al.,* 1990; Hubert *et al.,* 1994).

Growth was first examined by assessing the mean length of each age class on different sampling occasions. Growth in length took place throughout the year but was faster between May and September. Since growth in trout populations virtually ceases by September, the observed lengths-for-age in November/December were considered as the mean yearly growth. No significant differences ($p > 0.05$) were detected in the annual growth increments of trout between sites before and after regulation. Nevertheless, a more precise examination of changes in the growth rate was made using the mean instantaneous growth rate in length. A slight but not significant increase in this growth rate was observed in the downstream site during the year following regulation for 1 + , 2 + and 3 + year classes, whereas in the upstream site the growth rates remained mostly the same after the disturbance.

The impact of regulation in the River Hoz Seca was also evident in the annual production for trout. Thus, considerable differences were found in the downstream total production between years, whereas in the upstream site only a slight difference was detected (Table III). The observed decline in the downstream site was probably a function of recruitment loss, since no significant change was noticed in growth rate. Crisp *et al.* (1983) and Cowx and Gould (1989) obtained comparable results in the annual production values for salmonids as in growth rate.

In summary, the results suggest that the changes within the downstream trout population were not induced by a scarcity of food resources. Factors closely linked to water discharge such as water velocity and habitat modification seem to be responsible for changes in trout population. Water velocity could be the reason for the observed loss of recruitment by removing of juveniles downstream but alteration to the habitat involves other changes within physical features of the river like depth, cover or substratum composition, which could alter the habitat requirements of young trout.

Table III. Percentage of total trout production (kg ha' year-') contributed by each year class and mean biomass (kg ha-') for each section (upstream and downstream) within the pre- (1993) and post-regulation (1994) periods

Site	Year	1994	1993	1992	1991	1990	1989	1988	Total production (kg ha-' year-')	Mean biomass (kg ha-')
Upstream	1993	–	6.97	32.75	31.06	23.03	6.13	–	47.334 ± 4.8937	68.992 ± 6.8628
	1994	11.97	19.93	44.65	23.29	–			30.907 ± 3.3679	56.3850 ± 5.4015
Downstream	1993	–	1.64	7.44	14.62	50.68	22.95	2.65	79.320 + 4.4533	116.026 + 9.2063
	1994	1.35	6.98	34.23	41.66	15.77	–	–	44.402 ± 15.3051	60.226 + 12.0442

ACKNOWLEDGEMENTS

This work was funded by the project SC-95/005 of the Spanish INIA. We are grateful to J. Cubo and J.L. Castañeras for their assistance in the field and to Dr B. Elvira, Dr M. Díaz, Dr D. García de Jalón and Dr J. Camargo for their helpful advice and comments on the manuscript.

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