90

# Structural and Trophic Changes in a Riverine Macrobenthic Community Following Impoundment for Hydroelectric Power Generation

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## ABSTRACT

Structural and trophic changes in a benthic macroinvertebrate community downriver from Valparaíso Reservoir (northwestern Spain) were compared before (1986) and after (1990-1991) the creation of that hydropower impoundment. The number of taxonomic groups, total biomass and total density significantly declined under the influence of the new flow regulation, with scrapers (as relative density) being the functional feeding group most adversely affected. The environmental impact decreased with time after the construction of the dam. Taxonomic richness and diversity of predators appeared to be the most sensitive biological indicators of the progressive recovery of the macrobenthic community.

## INTRODUCTION

Benthic macroinvertebrates are a critical pathway for the transport and utilization of energy in fluvial ecosystems (Newbold et al. 1982). Nevertheless, at present, human activities are altering the pristine environmental conditions of river systems and thereby modifying the functional structure of macrobenthic communities. Particular problems arise when hydroelectric power generation induces short-term flow fluctuations. In general, unnaturally rapid increases and decreases in water volume downriver from hydropower impoundments can cause alterations in the number, composition and abundance of macroinvertebrate taxa (Ward and Stanford 1979, Lillehammer and Saltveit 1984, Petts 1984, Craig and Kemper 1987).

The present study examines structural and trophic changes in a riverine benthic macroinvertebrate community downriver from Valparaíso Reservoir by comparing its functional structure before (1986) and after (1990-1991) the creation of the impoundment for hydroelectric power genetration. The construction of the dam occurred during the period 1987-1989.

## THE STUDY AREA

Field studies were conducted in the Río Tera (Duero basin, northwestern Spain). The watershed of the Río Tera is mainly underlain by siliceous rocks, such as granite and gneiss, which induce the formation of soft waters with low ionic content. At the end of 1989, Valparaíso Dam was placed in operation for generation of hydroelectric power. This dam created a bottom outlet reservoir with a capacity of 169 x $10^6$ $m^3$, a maximum depth of 64 m, and a surface area of 1.224

Ha (MOPU 1988). Hydroelectric power is generated by discharging hypolimnial waters through two turbines, with maximum flows during the daytime and minimum flows at night and during weekends. In winter, turbines often work once a day with huge flow fluctuations (from 10 to 210 $m^3 s^{-1}$). By contrast, in summer, 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.

In order to examine structural and trophic changes in the macrobenthic community following the commencement of hydroelectric power generation, a single sampling station was selected 2.4 km below Valparaíso Dam. This study reach is located at an altitude of 776 m a.s.l., exhibits an average width of 40 m and corresponds to a fourth order stream. The river bottom was mainly stony with boulders, pebbles and gravel, with Myriophyllum verticillatum and Ranunculus fluitans being the only two species of macrophytes at the sampling site.

## METHODS AND MATERIALS

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 0.25 mm. 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 per survey, being preserved in 4% formalin until laboratory analysis. All organisms were identified to the family level, and some abundant taxa were identified to genus or species. Following identification and counting, five macroinvertebrate functional feeding groups (predators, collector-filterers, collector-gatherers, scrapers and shredders) were assigned in accordance with Cummins and Klug (1979), Tachet et al. (1981), and García de Jalón and Gonzalez del Tánago (1986). The relative contribution of each functional feeding group was calculated on the basis of density estimates. In addition, quantitative samples were dried in an oven at 60°C for eight hours to estimate total biomass (dry weight).

The percentage of environmental impact (EI) generated by the new flow regulation on the entire macrobenthic community was quantified using Camargo's (1990) index:

$$EI = (2A - B - C)\ 50 / A$$

where A represents the total number of taxonomic groups before (1986) the creation of the dam, B represents the total number of taxonomic groups after (1990-1991) the construction of the dam, and C represents the total number of taxonomic groups common to both periods of time. Taxonomic groups were considered at two different taxonomic levels: family and order.

Camargo's (1992) diversity (D') was estimated for each functional feeding group as follows:

$$D' = S - \sum_{}^{K} |p_i - p_j|$$

where S is taxonomic richness (number of macroinvertebrate families in this investigation), $p_i$ is the relative abundance of the ith taxonomic group, $p_j$ is the relative abundance of the jth taxonomic group, and K is the maximum number of possible binary subtractions between taxonomic groups, being $K = S(S-1)/2$. This index of species diversity is based on the personal perspective that the concepts of evenness (e), dominance (d), diversity (D) and uniformity (U), as parameters of community structure, conform two different unifying relationships in interspecific

competition (e+d=1 and DxU=1), these unifying relationships being theoretically interrelated through the composite measurement of species diversity (D=S-Sd) (see Camargo 1995). Other diversity measures in common use (e.g., Shannon-Wiener's function, reciprocal of Simpson's index) were not applied in this study because their values depend largely upon the relative abundances of the most common taxa in the community (Camargo 1993), giving little weight to taxonomic richness.

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

Table 1. Mean densities (individuals $m^{-2}$) estimated for each macroinvertebrate family at the sampling site (2.4 km below Valparaíso Dam) in 1986, 1990 and 1991.

| | Sep-86 | Jul-90 | Sep-90 | Nov-90 | Feb-91 | May-91 |
|---|---|---|---|---|---|---|
| Planariidae | 63 | 0 | 0 | 0 | 0 | 0 |
| Dugesiidae | 0 | 0 | 0 | 0 | 3 | 1 |
| Tubificidae | 619 | 102 | 291 | 1292 | 298 | 204 |
| Erpobdellidae | 43 | 24 | 35 | 50 | 72 | 21 |
| Sphaeriidae | 3 | 0 | 0 | 0 | 0 | 0 |
| Ancylidae | 3 | 6 | 2 | 13 | 8 | 3 |
| Heptageniidae | 489 | 0 | 0 | 0 | 0 | 0 |
| Baetidae | 1596 | 33 | 38 | 2 | 0 | 3 |
| Ephemerellidae | 66 | 225 | 37 | 0 | 5 | 29 |
| Leuctridae | 720 | 61 | 65 | 25 | 7 | 190 |
| Nemouridae | 173 | 0 | 0 | 0 | 0 | 0 |
| Elmidae | 172 | 0 | 0 | 0 | 0 | 0 |
| Hydraenidae | 3 | 0 | 0 | 0 | 0 | 0 |
| Rhyacophilidae | 127 | 0 | 8 | 2 | 12 | 6 |
| Hydropsychidae | 2304 | 0 | 0 | 3 | 5 | 2 |
| Polycentropodidae | 20 | 0 | 0 | 0 | 0 | 0 |
| Psychomyiidae | 3 | 0 | 1 | 2 | 0 | 3 |
| Lepidostomatidae | 26 | 0 | 0 | 0 | 0 | 0 |
| Sericostomatidae | 17 | 0 | 0 | 0 | 0 | 0 |
| Limnephilidae | 0 | 0 | 0 | 0 | 7 | 6 |
| Leptoceridae | 0 | 0 | 0 | 2 | 0 | 0 |
| Brachycentridae | 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 |

## RESULTS

Mean densities of macroinvertebrate families on each sampling date are presented in Table 1. Planariidae, Sphaeriidae, Heptageniidae, Nemouridae, Elmidae, Hydraenidae, Polycentropodidae, Lepidostomatidae, Sericostomatidae, Brachycentridae and Athericidae were absent during 1990 and 1991. Within those absences, it is interesting to note that Epeorus torrentium, Protonemura sp. and Limnius opacus were relatively abundant in 1986. Other macroinvertebrate families, such as Baetidae, Leuctridae, Rhyacophilidae and Hydropsychidae, significantly ($P < 0.05$) decreased in abundance after the construction of the dam, with Baetis rhodani, Eulectra geniculata, Rhyacophila relicta, and Hydropsyche

pellucidula being the species most adversely affected. Conversely, the families Dugesiidae, Limnephilidae, Leptoceridae and Tipulidae were not collected in the sampling survey of 1986.

Values of taxonomic richness, total density and total biomass are presented in Table 2. These biological parameters declined significantly ($P < 0.05$) after the creation of the reservoir. However, a gradual recovery tendency with time was apparent for taxonomic richness. As an outcome of that tendency, the highest values of environmental impact (EI) generated by the new hydropower impoundment on the macrobenthic community were estimated in July of 1990, whereas the lowest values were estimated in May of 1991 (Figure 1). In general, the shift in EI values was due chiefly to a reduction in taxonomic richness rather than to a change in taxonomic composition.

Table 2. Values of taxonomic richness (as numbers of families and orders), total density (individuals $m^{-2}$) and total biomass (milligrams $m^{-2}$) estimated for the whole macrobenthic community at the sampling site (2.4 km below Valparaíso Dam) in 1986, 1990 and 1991.

| | Sep-86 | Jul-90 | Sep-90 | Nov-90 | Feb-91 | May-91 |
|---|---|---|---|---|---|---|
| Number of families | 23 | 8 | 11 | 12 | 12 | 14 |
| Number of orders | 10 | 6 | 7 | 7 | 7 | 8 |
| Total density | 8314 | 2163 | 1664 | 2332 | 689 | 3465 |
| Total biomass | 2889 | 605 | 509 | 213 | 309 | 402 |

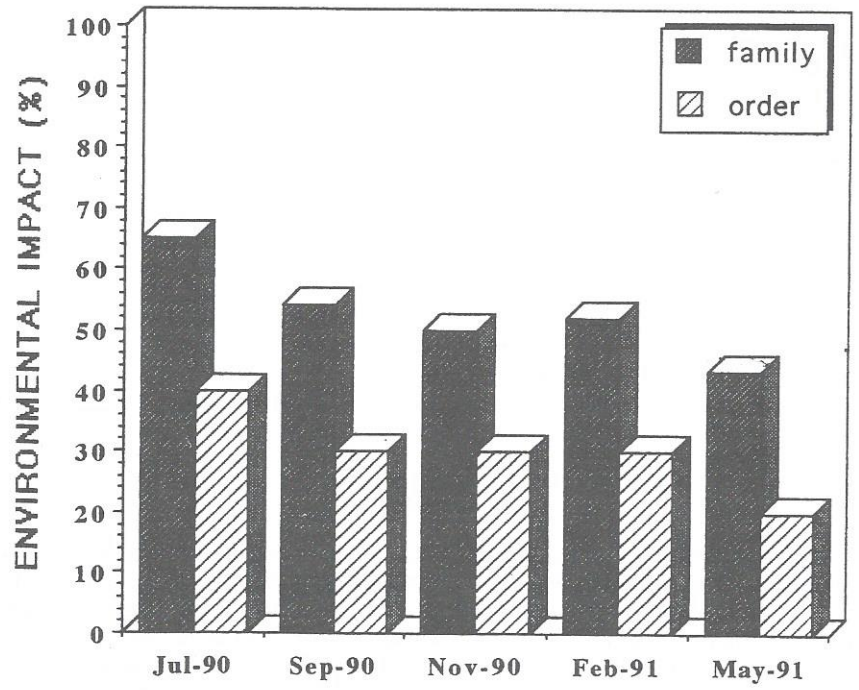


Fig. 1. Percentages of environmental impact (EI) induced by Valparaíso Dam on the macrobenthic community. EI values were calculated at two different taxonomic levels: family and order.

The trophic structure of the benthic macroinvertebrate community is shown in Figure 2. The functional feeding group most adversely affected by the creation of the reservoir was scrapers. Conversely, collector-gatherers and collector-filterers were the dominant functional groups during all sampling surveys, with their relative abundance increasing in 1990 and 1991. Shredders and predators did not exhibit a clear tendency to increase or decrease after the construction of Valparaíso Dam. Diversity (D') values for each macroinvertebrate functional feeding group are shown in Figure 3. D' values markedly decreased within all groups under the influence of the new flow regulation. Predators as a group exhibited a gradual recovery of its diversity values (Figure 3); the other functional feeding groups did not.

## DISCUSSION

Previous studies on downstream effects of hydropower impoundments have emphasized the importance of flow regulation in adversely affecting the population dynamics of benthic macroinvertebrates. In general, planarians, plecopterans, ephemeropterans, coleopterans and trichopterans tended to disappear or reduce their abundances because of the environmental conditions caused by short-term flow fluctuations (Ward and Stanford 1979, Lillehammer and Saltveit 1984, Petts 1984, Craig and Kemper 1987). Therefore, it is not surprising to observe comparable changes in taxonomic composition, taxonomic richness and abundance of taxonomic groups after the creation of Valparaíso Reservoir. Furthermore, the observed changes may be described as transient states leading to the progressive recovery of the macrobenthic community and, ultimately, to the temporal stabilization of its functional structure. In this connection, Petts et al. (1993) have indicated that some ecological adjustments induced by river regulation may occur over a period of 10-100 years. In our case, it is evident that the biological parameters of taxonomic richness and diversity of predators are the most sensitive indicators for assessing the progressive recovery of the macrobenthic community following the commencement of hydroelectric power generation. This fact indirectly suggests that benthic macroinvertebrates comprising the predator group are not very selective with regard to their prey, at least after some environmental perturbation.

There is little doubt that the marked alteration in the trophic structure of the macrobenthic community after the construction of Valparaíso Dam was due essentially to a decrease in the relative abundance of scrapers (e.g., Heptageniidae, Elmidae) and an increase in the relative abundance of collectors (e.g., Simuliidae), despite the fact that some collectors such as Baetidae and Hydropsychidae were nearly absent during 1990 and 1991 sampling surveys. This trophic modification along with the reduction in taxonomic richness probably are the consequences of loss of habitat heterogeneity rather than changes in food resources. Ward (1976) stated that a decrease in the number of macroinvertebrate taxa downstream from impoundments might be the result of a reduction in substrate heterogeneity caused by the smoothing out of flow instabilities. Moreover, unnaturally rapid rise and fall in water levels and flow velocities downriver from hydropower impoundments produce environmental conditions to which few benthic macroinvertebrates are adapted.

We conclude that the observed structural and trophic changes (or transient states) in the macrobenthic community were due essentially to short-term flow fluctuations following the commencement of hydroelectric power generation. In this respect, ecologically acceptable minimum flows during periods of turbine shutdown and alternative flow regimes based on natural patterns are recommended to minimize the adverse effects of the new hydropower impoundment and thereby accelerate the progressive recovery of the functional structure of the macrobenthic community.

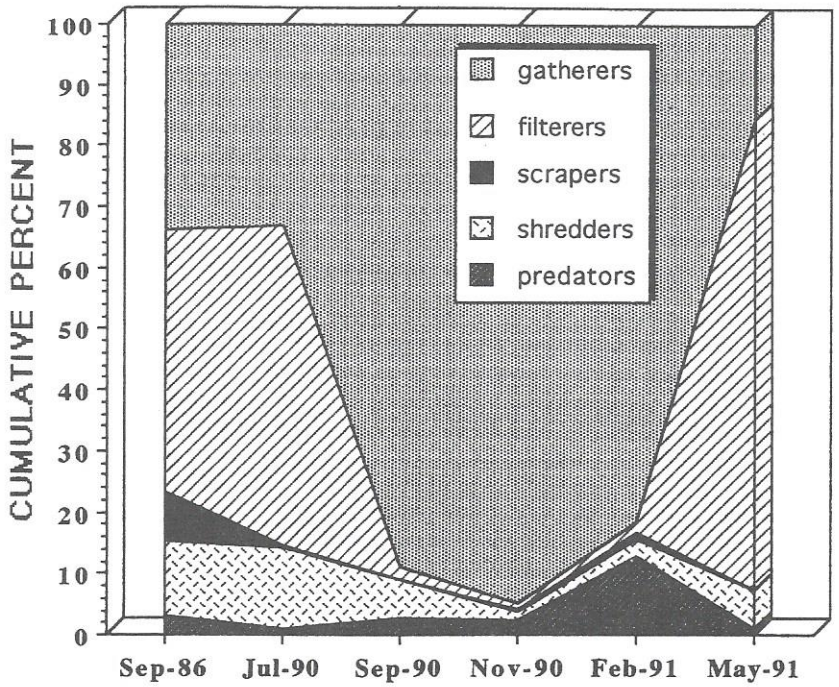


Fig. 2. Relative contributions (individuals $m^{-2}$) of macroinvertebrate functional feeding groups before (1986) and after (1990-1991) the creation of Valparaíso Reservoir.

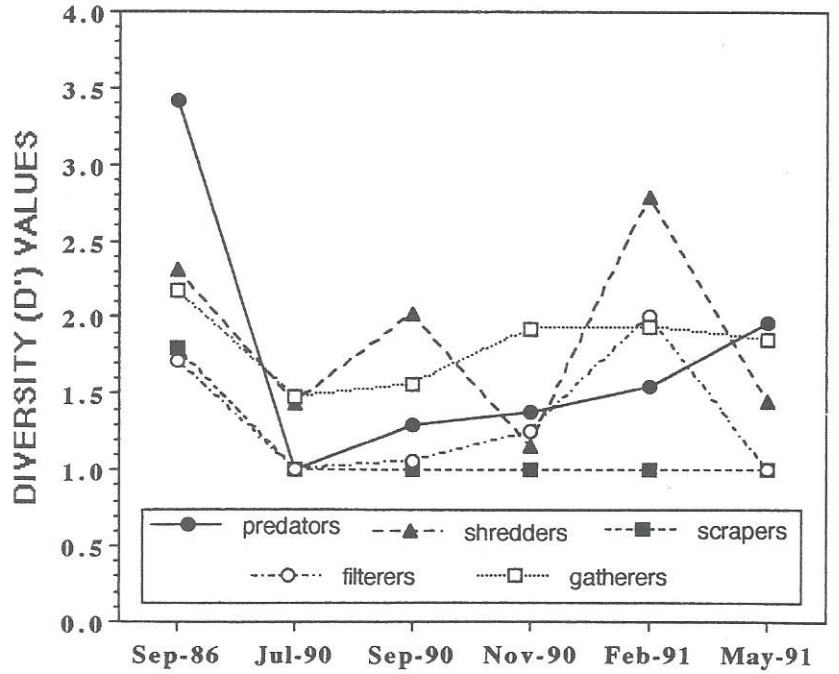


Fig. 3. Diversity (D') values for each macroinvertebrate functional feeding group before (1986) and after (1990-1991) the creation of Valparaíso Reservoir.

## ACKNOWLEDGMENTS

The authors thank M. Gonzalez del Tanago and M. Mayo for their comments on an early draft of this manuscript. The Department of Forestry Engineering (E.T.S.I. de Montes, Universidad Politécnica de Madrid, Spain) provided logistical support during this investigation.

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Received: 11 April 1995

Accepted: 12 August 1995