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The impact of an industrial effluent on the water quality, submersed macrophytes and benthic macroinvertebrates in a dammed river of Central Spain

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HIGHLIGHTS

- Fluoride and turbidity levels significantly increased downstream from the effluent.
- Macrophytes exhibited slighter ecological responses than macroinvertebrates.
- Fluoride was significantly bioaccumulated in macrophytes and macroinvertebrates.
- The amphipod *Echinogammarus calvus* was very sensitive to fluoride toxicity.
- This sensitivity would be due to its great capacity to take up and retain fluoride.

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ABSTRACT

This research was conducted in the middle Duratón River (Central Spain), in the vicinity of Burgomillodo Reservoir. An industrial effluent enters the river 300 m downstream from the dam. Fluoride and turbidity levels significantly increased downstream from the effluent, these levels being to some extent affected by differential water releases from the dam. The community of submersed macrophytes exhibited slighter responses and, accordingly, lower discriminatory power than the community of benthic macroinvertebrates, this indicating that metrics and indices based on macroinvertebrates may be more suitable for the biological monitoring of water pollution and habitat degradation in dammed rivers receiving industrial effluents. However, in relation to fluoride bioaccumulation at the organism level, macrophytes (*Fontinalis antipyretica* and *Potamogeton pectinatus*) were as suitable bioindicators of fluoride pollution as macroinvertebrates (*Ancylus fluviatilis* and *Pacifastacus leniusculus*). Fluoride bioaccumulation in both hard and soft tissues of these aquatic organisms could be used as suitable bioindicator of fluoride pollution (even lower than 1 mg $F^- L^{-1}$) in freshwater ecosystems. *Echinogammarus calvus* exhibited a great sensitivity to the toxicity of fluoride ions, with a 96 h LC_{50} of 7.5 mg $F^- L^{-1}$ and an estimated safe concentration of 0.56 mg $F^- L^{-1}$. The great capacity of *E. calvus* to take up and retain fluoride during exposures to fluoride ions would be a major cause of its great sensitivity to fluoride toxicity. It is concluded that the observed fluoride pollution might be partly responsible for the absence of this native amphipod downstream from the industrial effluent.

1. Introduction

Water pollution is one of the most important anthropogenic causes of global change in freshwater ecosystems. In the case of fluoride (F^-), certain human activities are unfortunately leading to increased fluoride levels in surface waters, causing acute and chronic toxicity to aquatic organisms (World Health Organization, 2002; Camargo, 2003). For example, aluminum smelters, phosphate fertilizer plants, plants producing fluoride chemicals, plants manufacturing brick, ceramics and glass, the use of fluoride containing pesticides, and discharges of fluoridated municipal waters can increase the natural background fluoride levels of fresh waters (usually ranging from 0.01 to 0.3 mg $F^- L^{-1}$) in more than 100 times (World Health Organization, 2002; Camargo, 2003). Besides, suspended solids and turbidity levels (expressed as Nephelometric Turbidity Units, NTU) in surface waters can increase because of surface runoff, mine drainage, sewage discharges and industrial effluents, causing significant impacts on aquatic organisms owing to mechanical damage, reduction of light transmission, and sedimentation (Henley et al., 2000; Rowe et al., 2002). In this regard, Henley et al. (2000) indicated that the use of turbidity levels as surrogate mea-

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surements of suspended solids and their sedimentation to predict biotic effects within watersheds is dubious since similar NTU measurements from different watersheds may be correlated with different concentrations of suspended sediment. And Rowe et al. (2002), after conducting laboratory experiments, concluded that freshwater invertebrates can be relatively tolerant to the potential toxicity of high turbidity levels (up to 20000 NTU).

On the other hand, dams can cause significant adverse effects on the structure of freshwater communities by modifying physicochemical conditions downstream from impoundments. Particular problems can arise when hydroelectric power generation induces short-term flow fluctuations, low concentrations of dissolved oxygen, and changes in temperature regimes (Ward and Stanford, 1979; Petts, 1984; Camargo and Voelz, 1998). Moreover, when river regulation and pollution sources (e.g., industrial effluents) act together, freshwater organisms can be exposed to significant changes in the concentration of toxic pollutants as a direct consequence of differential water releases from dams (Camargo, 1996).

Given that anthropogenic stressors (e.g., water pollution and dams) usually alters the biotic and abiotic components of freshwater ecosystems, the use of biological methods to assess their impacts on these ecological systems has been promoted over the last decades as a useful and complementary technique to water physicochemical analyzes (Hellawell, 1986; Ziglio et al., 2006). This biomonitoring is based on the numerical value of several metrics and indices that integrate the ecological responses of freshwater organisms to pollutants and other stressors. McKnight et al. (2012) have recently emphasized the combined use of field indicator methods (e.g., biotic indices), laboratory/microcosm studies (e.g., toxicity bioassays) and simulation techniques (e.g., process-based ecological models) for integrated assessments of the impacts of anthropogenic stressors on surface water ecosystems. In addition, the accumulation of pollutants in the body of living organisms is considered to be one of the best bioindicators for the assessment of water pollution in aquatic ecosystems (Rand, 1995; Gonzalo and Camargo, 2012).

The main goal of this research was to examine the ecological responses of submersed macrophytes and benthic macroinvertebrates to fluoride pollution and increased turbidity in a Spanish dammed river that receives an industrial effluent, comparing the suitability of biological metrics and indices based on these two aquatic communities to assess the impact of environmental stressors detected along the study area. Additionally, we determined the fluoride content in some submersed macrophytes and benthic macroinvertebrates, evaluating the suitability of fluoride bioaccumulation in these aquatic organisms to assess fluoride pollution in freshwater ecosystems. Lastly, we carried out a laboratory toxicity bioassay with the native amphipod *Echinogammarus calvus* (Margalef, 1956) to examine the sensitivity of this gammarid species to fluoride ions in order to evaluate if the observed fluoride pollution might be partly responsible for its absence downstream from the industrial effluent. The initial hypothesis was that *E. calvus* is a sensitive species to the toxicity of fluoride ions since previous laboratory studies had shown that the amphipods *Hyalella azteca* and *Dikerogammarus villosus* were sensitive species to fluoride toxicity (Metcalfe-Smith et al., 2003; Gonzalo et al., 2010).

2. Materials and methods

2.1. The study area and sampling sites

Field sampling surveys were carried out in the middle Duratón River (Central Spain, Duero River Basin), in the vicinity of Burgomillodo Reservoir (Fig. 1), a deep-release hydropower impoundment with a capacity of 15 hm^3 and a maximum depth of 40 m. A

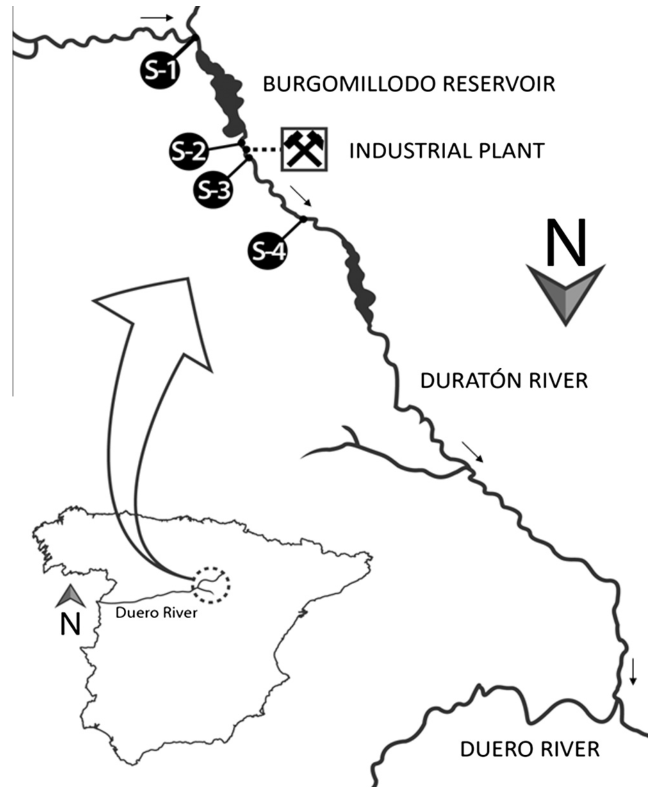

Fig. 1. General diagram of the middle Duratón River (Central Spain, Duero River Basin) showing the location of sampling sites (S-1, S-2, S-3 and S-4) along the study area. Arrows indicate the river flow direction.

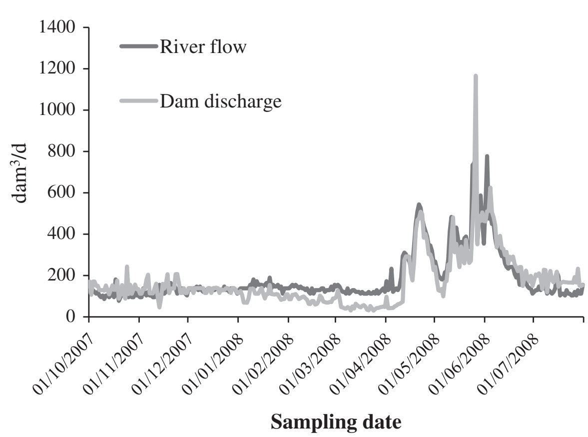

Fig. 2. Daily flow ($dam^3\,d^{-1}$) entering Burgomillodo Reservoir and daily flow ($dam^3\,d^{-1}$) released by the dam throughout the whole sampling period (from October 2007 to July 2008). Data of daily flows were obtained from Centro de Control Integrado de Bolarque, in Spain (personal communication).

comparison between the daily flow ($dam^3\,d^{-1}$) entering Burgomillodo Reservoir and the daily flow ($dam^3\,d^{-1}$) released by the dam throughout the whole sampling period (from October 2007 to July 2008) is showed in Fig. 2. Two major differences were detected between both water flows: (1) whilst the daily flow entering the reservoir was clearly higher than the daily flow released by the dam during the winter, the daily flow released by the dam was clearly higher than the daily flow entering the reservoir during the summer; and (2) flow variability throughout the whole sampling period was higher for the daily flow released by the dam (CV = 74.4%) than for the daily flow entering the reservoir (CV = 65.6%).