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Multimetric assessment of macroinvertebrate responses to mitigation measures in a dammed and polluted river of Central Spain

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A B S T R A C T

In this research, structural and functional responses of benthic macroinvertebrates to mitigation measures (carried out in the dammed and polluted Duraton River, Central Spain, during the 1990s and 2000s) were examined by comparing physicochemical and biological data from the summer of 1987 with data from the summer of 2014. Mitigation measures resulted in significant increases in dissolved oxygen concentrations, as well as in significant reductions of fluoride (F^-) pollution and short-term flow fluctuations. The macrobenthic community responded positively to improvements in river environmental conditions, exhibiting significant increases in abundance (total density, total biomass and EPT density) and diversity (total family richness and EPT richness) at impacted sampling sites. Furthermore, the presence of relatively sensitive benthic macroinvertebrates after mitigation measures (as indicated by increased values of BMWQ biotic indices) also was the main cause for observed reductions in the environmental impact caused by disturbance points (as indicated by decreased values of the EI index), and for the observed recovering of the trophic structure of the macrobenthic community, with macroinvertebrate scrapers as the functional feeding group most favored. These macroinvertebrate responses to mitigation measures were more marked at sampling sites that initially were more impacted (i.e., nearest to disturbance points), and less apparent at the sampling site that initially was less impacted (i.e., farthest to disturbance points). Within the hydropsychid assemblage, improvements in river environmental conditions clearly favored the presence of *Hydropsyche pellucidula* and *Cheumatopsyche lepida* at the expense of the other hydropsychid species. In spite of all monitored environmental improvements and macroinvertebrate positive responses, the need for additional mitigation measures was evident, particularly to reduce high turbidity levels and sedimentation of fine inorganic matter negatively affecting benthic macroinvertebrates downstream from the industrial effluent. Overall, it is concluded that the multimetric approach is an effective technique to assess macroinvertebrate responses to mitigation measures in river ecosystems.

1. Introduction

There seems little doubt that man's activities are seriously threatening the ecological integrity of most terrestrial and aquatic ecosystems on Earth. Within this tragic and real scenario, water pollution and its ensuing habitat degradation are among the most important anthropogenic causes of global change in river ecosystems. For example, surface runoff (from agriculture, primarily), wastewaters from livestock farming and inland aquaculture, and municipal sewage discharges (including effluents from sewage treatment plants without performing tertiary treatments) have significantly increased natural N and P fluxes into freshwater ecosystems around the world, this resulting in the widespread cultural eutrophication of surface waters (Harper, 1992; Smith et al., 1999; Räike et al., 2003; Camargo and Alonso, 2006; Schindler and Vallentyne, 2008; Ansari et al., 2011; Blaas and Kroeze, 2016). Likewise, excessive deposition of fine inorganic matter (particularly derived from agricultural catchments, road and channel constructions, mining operations, gravel pits, and industrial effluents) is becoming an anthropogenic environmental problem of increasing concern for river ecosystems worldwide (Wood and Armitage, 1997; Henley et al., 2000; Walling and Fang, 2003; Bilotta and Brazier, 2008; Bryce et al., 2010; Jones et al., 2012; Chapman et al., 2014; Naden et al., 2016). Additionally, numerous water chemical pollutants (e.g., acidification, cyanide, fluoride, detergents, heavy metals, insecticides and herbicides, PCBs, petroleum, pharmaceuticals, salinization) can cause significant adverse effects on aquatic organisms, this resulting in impaired populations and communities of freshwater ecosystems (Green and Trett, 1989; Rand, 1995; Camargo, 2003; Camargo and Alonso, 2006; Brain et al., 2008; Debenest et al., 2010; Cañedo-Argüelles et al., 2013; Stehle and Schulz, 2015; Berger et al., 2016; Della Rossa et al., 2017).

The construction and operation of dams represent other important

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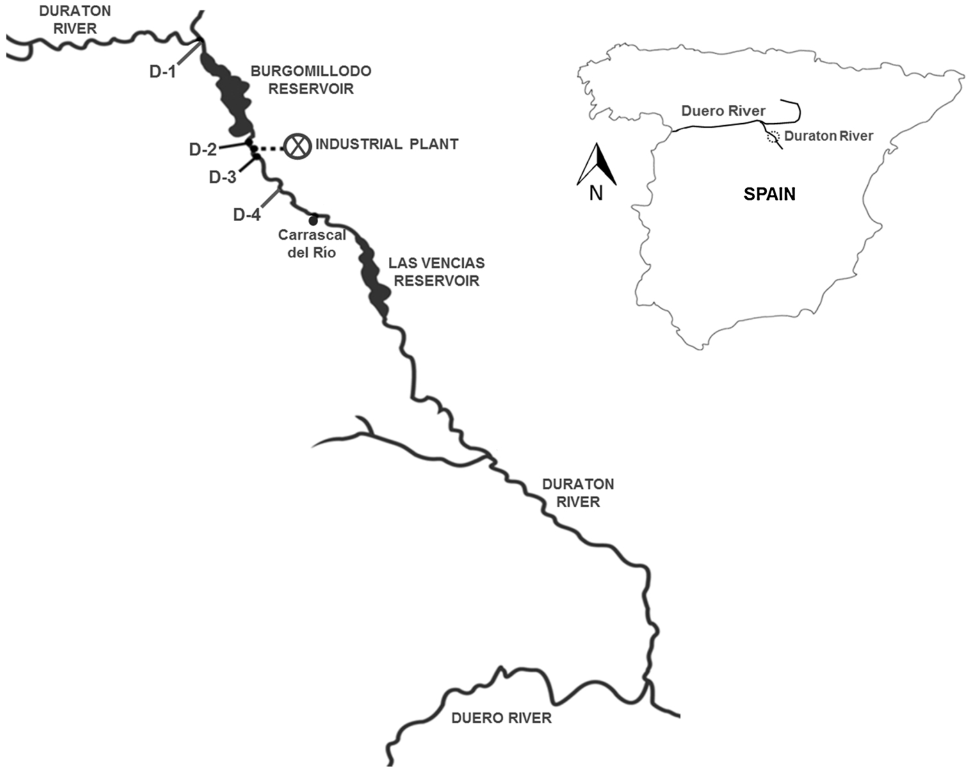

Fig. 1. General diagram of the study area in the middle Duraton River (Duero River Basin), showing the location of Burgomillodo Reservoir, the industrial plant, and sampling sites (D-1, D-2, D-3 and D-4).

anthropogenic cause of global change in river ecosystems. At the end of the twentieth century, there were about 40,000 large dams ($>$ 15 m in height) and more than 800,000 smaller dams worldwide, with nearly 75% of the world's large rivers being fragmented by dams (Bednarek, 2001; Nilsson et al., 2005). In addition to river fragmentation, dam construction and operation can cause important adverse effects on the abundance and diversity of fluvial communities by modifying physicochemical conditions along river ecosystems. For example, reductions in river flow and matter transport, changes in water temperature and dissolved oxygen, and alterations in nutrient concentrations have been generally observed downstream from impoundments (Ward and Stanford, 1979; Petts, 1984; Camargo and Voelz, 1998; Lessard and Hayes, 2003; Camargo et al., 2005; Beck et al., 2012; Benitez-Mora and Camargo, 2014). Further environmental problems can arise when hydroelectric power generation induces short-term flow fluctuations (with extreme hydropeaking) downstream from dams (Moog, 1993; Lauters et al., 1996; Céréghino et al., 2002; Rehn, 2009; Bruder et al., 2016; Hauer et al., 2017).

To reverse the impacts caused by human activities on natural populations and communities of river ecosystems, several mitigation and rehabilitation measures (e.g., improvements in sewage and wastewater treatments, recoveries of riparian zones, implementation of constructed riffles and small waterfalls, provision of adequate fish passages, establishment of downstream ecological flows, removal of dams and other man-made barriers) have been accomplished in rivers and streams around the world, but in general with limited success in restoring the ecological integrity of these aquatic ecosystems (Adams et al., 2002; Bednarek and Hart, 2005; Casper et al., 2006; Walther and Whiles, 2008; Lüderitz et al., 2011; Lorenz et al., 2012; Mueller et al., 2014; Kail et al., 2015; Muhar et al., 2016; Pan et al., 2016). Furthermore, field studies indicate that a deficient restoration of complex environmental factors, such as water quality and microhabitat heterogeneity, would be the primary cause for observed poor responses of benthic macroinvertebrates to mitigation and rehabilitation measures (Palmer et al., 2010; Verberk et al., 2010; Louhi et al., 2011; Sundermann et al., 2011; Ernst et al., 2012; Verdonschot et al., 2016).

The use of biological methods to assess water pollution and habitat degradation in river ecosystems has been traditionally recognized as an important complementary technique to conventional physicochemical surveys. This biomonitoring is usually based on the numerical value of several metrics and indices that integrate the ecological responses of aquatic organisms to environmental conditions, benthic macroinvertebrates being often regarded as the best indicators (Cairns and Dickson, 1973; Armitage et al., 1983; Washington, 1984; Hellawell, 1986; Extence et al., 1987; Rosenberg and Resh, 1993; Camargo, 1994; Hauer and Lamberti, 1996; Camargo et al., 2004; Bonada et al., 2006; Ziglio et al., 2006; Odume et al., 2012; Turley et al., 2016). In addition, a multimetric approach for practical biomonitoring with benthic macroinvertebrates is recommended since it can provide an integrated analysis of structural and functional attributes of the macrobenthic community, also pondering tolerances/sensitivities of benthic macroinvertebrates to water pollution and habitat degradation (Rosenberg and Resh, 1993; Camargo, 1994; Fore et al., 1996; Barbour and Yoder, 2000; Klemm et al., 2002; Camargo et al., 2004; Bonada et al., 2006; Ziglio et al., 2006; Odume et al., 2012; Seidel and Lüderitz, 2015; Serrano Balderas et al., 2016).

In this investigation, a multimetric assessment of structural and functional responses of benthic macroinvertebrates to mitigation measures in the dammed and polluted Duraton River (Central Spain) was carried out by comparing physicochemical and biological data from the summer of 1987 (Camargo, 1989) with data from the summer of 2014. More specifically, four different categories of metrics and indices were estimated: (1) metrics of taxonomic composition and richness (including an index of environmental impact); (2) metrics of abundance (density and biomass); (3) metrics of trophic structure (contributions of functional feeding groups); and (4) metrics of environmental quality (biotic indices).