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Effects of invasive fish and quality of water and sediment on macrophytes biomass, and their consequences for the waterbird community of a Mediterranean floodplain

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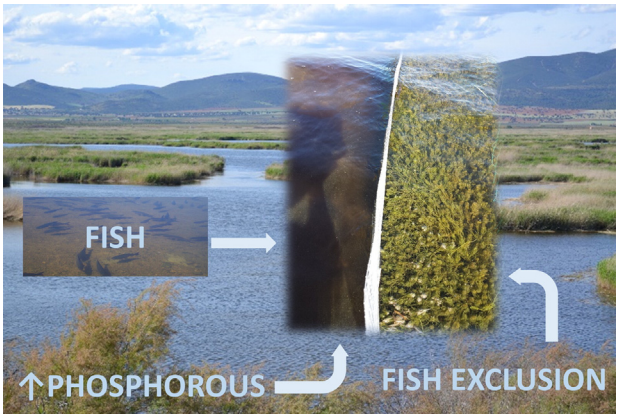
HIGHLIGHTS

- Waterbird community under flooding shifted from herbivorous to piscivorous.
- Submerged macrophytes developed much better in fish exclusion areas.
- Some sites did not develop macrophytes despite of fish exclusion.
- *Chara* spp. growth was associated with low values of phosphorus in sediment.
- Conservation efforts must focus on fish control and phosphorus inflow reduction.

GRAPHICAL ABSTRACT



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ABSTRACT

Floodplains are among the most threatened ecosystems world-wide because of multiple stressors, i.e., invasive species, pollution and aquifer overexploitation; the Tablas de Daimiel National Park (Spain) is a clear example of these kinds of impact. This work aims to test whether invasive fish and/or the water and sediment quality are significant drivers of the decline of stonewort (*Chara* spp.) meadows in the Tablas de Daimiel, investigating how this could explain changes observed in the waterbird community. Bird surveys performed monthly between June 2010 and April 2014 have shown that herbivorous species like the red-crested pochard (*Netta rufina*) reached historical records between September 2010 and June 2011, but have decreased since then. Piscivorous waterbirds like the great cormorant (*Phalacrocorax carbo*) and herons increased in population after 2011, however. These changes may be due to the decline of *Chara* spp. meadows, connected to overexploitation by herbivores, or to changes in water and sediment quality. To test this hypothesis, we studied the growth of *Chara* spp. biomass in ten sites of the Tablas de Daimiel, where experimental exclosures were set up to exclude herbivory by birds, and bioturbation and herbivory by fish. Our results have shown that the absence of *Chara* spp. in the Tablas de Daimiel is mostly explained by presence of invasive fish (i.e. common carp). Moreover, the

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physicochemical characteristics of the water (lower values of conductivity and higher values of inorganic carbon and organic nitrogen), as well as of the sediment (lower values of inorganic and organic phosphorus), favour the increase of *Chara* spp., in the absence of the fish effect. These results led the National Park managers to begin the control of invasive fish as an urgent measure to assure the ecological conservation of this Mediterranean wetland.

1. Introduction

River floodplains have been shaped for centuries by interactions between fluvial dynamics, groundwater and man-made processes (Maltby et al., 1994; Álvarez-Cobelas et al., 2001). Nowadays they are severely altered by multiple stressors of a very broad nature, such as intensive agriculture, groundwater extraction for irrigation, an overall decrease in surface and groundwater quality and invasive engineer species, all of which have worked together to generate effects on wetland biodiversity (Mitsch and Gosselink, 1993; Tockner and Stanford, 2002).

Globally, riverine floodplains cover more than 2×10^6 km^2 (Tockner and Stanford, 2002). Floodplains provide human society with many important ecosystem services; it is no coincidence that early human civilizations sprang from river valleys and floodplains (Postel and Carpenter, 1997). In Europe and North America, up to 90% of floodplains are functionally extinct (Tockner and Stanford, 2002). The situation of Mediterranean floodplains is similar, or perhaps worse (Brinson and Malvárez, 2002). In Spain, floodplains present the worst conservation situation among all wetlands, with more than 79% of the surface they possessed in the 19th century lost by draining for cultivation (Casado et al., 1992).

Herbivorous waterfowl such as the red-crested pochard (*Netta rufina*) may have been severely affected by the degradation of these floodplains because of the decline of charophytes, which make up an important part of their diet. Submerged vegetation is essential in supporting waterbird communities, and this is true not only for herbivorous species (Hansson et al., 2010; Milberg et al., 2002). Few studies have been conducted, however, to test the relationship between macrophyte abundance and waterbird communities in Mediterranean wetlands (Sandsten et al., 2002; Rodríguez-Pérez and Green, 2006; Rodriguez-Villafañe et al., 2007; Rodrigo et al., 2013). These macrophyte stands also stabilize the sediment, reduce wind-driven sediment resuspension, and compete with phytoplankton for nutrients, so the impact of their conservation goes beyond the support of herbivorous species (Scheffer et al., 1993; Weber and Brown, 2009; Álvarez-Cobelas et al., 2005).

Multiple stressors can affect submerged macrophyte stands, especially in semiarid Mediterranean regions (Britton and Crivelli, 1993; Rea and Ganf, 1994). A decrease in water quality because of high phosphorus concentrations, eutrophication and turbidity, all of which are sometimes associated with water scarcity, have, moreover, been shown to affect the development of charophyte meadows (Skubinna et al., 1995; Cirujano and Medina, 2002); this is one of the groups that are most sensitive to nutrient enrichment (Blindow, 1992). Some authors have studied the thresholds that may affect the growth of submerged vegetation in shallow temperate lakes (Gonzalez-Sagrario et al., 2005; Beklioglu and Tan, 2008). In addition to the stressors mentioned above, invasive freshwater fish, such as the common carp (*Cyprinus carpio*), may affect aquatic vegetation directly, by consuming macrophytes. Indirectly, they may do so by changing water quality (Dorenbosch and Bakker, 2012). The *C. carpio* dislodges aquatic macrophyte roots from the sediment (Crivelli, 1983; Parkos et al., 2003), suspends solids (Lammens, 1991) and increases sediment turbidity (Parkos et al., 2003; Chumchal et al., 2005), nutrient release, and algal biomass, attenuating light needed for aquatic macrophyte growth (Sidorkewicj et al., 1999). According to Weber and Brown (2009), 96% of the literature surveyed showed that aquatic macrophytes are generally reduced in the presence of *C. carpio*. Apart from the damage caused by fish, it has been shown by several studies that large concentrations of herbivorous waterfowl may have an effect on submerged macrophytes, although these have been restricted to wildfowl (ducks, swans and coots) and have concentrated largely on temperate areas of North America, Europe and New Zealand (Marklund et al., 2002; Rodríguez-Pérez and Green, 2006; Hansson et al., 2010).

Many studies on north temperate shallow lakes have contributed greatly to a general understanding of the impact of different stressors on aquatic ecosystems (Scheffer et al., 1993; Moss et al., 1996; Moss, 1998; Jeppesen et al., 1998), but comparable information on semiarid Mediterranean lakes is limited (Beklioglu et al., 2003, 2006; Romo et al., 2004, 2005). In this work, we have studied the different drivers that can affect submerged macrophytes in a representative Mediterranean floodplain in Central Spain, investigating their consequences for waterbird communities. Our study was conducted in the Tablas de Daimiel National Park (TDNP), which has been severely affected by many of the stressors mentioned above. After a long period of drought, TDNP has recovered its hydrological regime, due to the increase in the groundwater level. However, this has not been translated into a recovery of the herbivorous waterbird population, probably because of the scarce development of macrophyte stands. In this study, we aim to provide insight into the main causes of the degradation of *Chara* spp. meadows, insight which could help when deciding on implementation of management measures. To that end, the specific objectives are: (i) to determine the contribution of water and sediment quality on submerged aquatic macrophyte growth, (ii) to test the effects of freshwater fish (and birds) on macrophyte stands by means of exclosures and (iii) to discuss the consequences that invasive fish and macrophyte decline may have on the waterbird community of a Mediterranean floodplain.

2. Material and methods

2.1. Study area

TDNP is situated in the SW corner of the Mancha Húmeda Biosphere Reserve (MAB program, UNESCO), within the province of Ciudad Real (Fig. 1a). It is a Wetland Site of International Importance included in the Ramsar Convention, and a Special Protection Area for Birds under the European Union Directive 79/409/CEE. The Park covers an area of 3030 ha, of which almost 2000 ha consists of a fluctuating Mediterranean floodplain, which is fed by water from the Guadiana and Gigüela rivers and the underlying aquifer. This region has a semiarid continental Mediterranean climate, with an extremely irregular rainfall regime, the average annual rainfall being between 400 and 500 mm, and having an average temperature of 14 °C (Álvarez-Cobelas and Cirujano, 1996; Cirujano et al., 1996). Its many valuable features come from a structure of submerged vegetation communities, i.e. a mosaic of *Cladium mariscus* sawgrass-dominated emergent stands and open water habitats ("tablas"), which are dominated by several species of genus *Chara*, i.e. *Chara hispida* var. *major* and *Chara vulgaris*, accompanied by *Chara aspera*, *Chara connivens*, *Chara canescens* and *Chara fragilis* (Cirujano et al., 1996; Cirujano and Medina, 2002). Their presence relies on the quality and stability of calcium carbonate in fresh groundwater discharges coming from a series of sinkholes in the Guadiana River. At the same time, floodplain dynamics are controlled by fluctuating river pulses of hyposaline water coming from the Gigüela River. Both types of water promote huge biological diversity (Cirujano et al., 1996). In 1987, the aquifer was declared overexploited and the flow of the Guadiana River completely disappeared; this altered the hydrological and ecological functioning of TDNP, due to the decrease in groundwater input that had maintained the area's characteristics and its extensive