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Soil moisture prediction to support management in semiarid wetlands during drying episodes

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ABSTRACT

Wetlands supported by groundwater in semiarid regions are extremely vulnerable to the impacts of droughts, particularly anthropized systems. During drying periods, soil water content arises as the controlling factor for environmental and ecological disturbances such as the spread of invasive plant species, the combustibility of organic soils, nutrient redistribution or soil physical disruption. The presented management tool for semiarid wetlands is supported by the Soil-Water-Atmosphere-Plant (SWAP) model for soil moisture modeling and simulation. Main input data are experimental values of soil physical and hydraulic characteristics, soil moisture measurements, vegetation growth parameters and climatic records. Decision-makers can use the calibrated datasets to predict the evolution of soil moisture under different drying scenarios in order to choose the most efficient management options for preventing soil moisture to reach critical values. The approach has been tested in the anthropized Mediterranean semiarid wetland area of Las Tablas de Daimiel National Park in central Spain. Ten vadose zone water models were successfully calibrated and validated for different soil units. Critical soil moisture conditions for invasive reed overgrowth and peat combustibility have been estimated. Simulations of a typical 2-year drought scenario indicated that critical soil moisture conditions for reed overgrowth are attained 9–10 months after flooding ceased and that peat areas colonized by reed plants become combustible (even 50% probability chance) by the end of the simulated period.

1. Introduction

Wetland areas, besides constituting biodiversity reserves, perform a fundamental ecological-economical function as natural water filters and buffers, by storing nutrients and carbon in their sediments (Mitsch and Gosselink, 2000; Phillips, 1989; Reddy and DeLaune, 2008), and decreasing surface runoff peaks during storm events (Kazezyilmaz-Alhan et al., 2007). However, wetland systems, particularly those wetland areas linked to groundwater dynamics, are highly complex and show a fragile equilibrium and high sensibility and vulnerability. Also, the impacts they are subjected to are not always obvious and reversible (Boswell and Olyphant, 2007; Johnston, 1994; Rodríguez-Rodríguez and Benavente, 2008), causing their progressive disappearance to be a problem of major concern worldwide (Kingsford, 2000; Moiwo et al., 2010; Zedler and Kercher, 2005).

In Mediterranean semiarid climates, water scarcity, usually induced by droughts and high demands, becomes an essential political-socioeconomic issue which is worsen by climate change scenarios predicting increased aridity (Abouabdillah et al., 2010; Gao and Giorgi, 2008; MED WS&D WG, 2007). In this context, although often less attention is paid to wetlands, risks and impacts on them increase as water becomes a limited resource, unequally distributed in space and time and widely exploited. Eutrophication, biodiversity loss, accelerated oxidation of soil organic matter, solute mobilization to groundwater, expansion of invasive species and smoldering peat fires constitute strong degradation processes that take place as wetlands dry out. Wetlands lose their ecological function and the negative consequences of these processes are extrapolated to other natural and socioeconomic systems (Costanza et al., 1997; Zedler and Kercher, 2005). However, the usual lack of knowledge of their complexity and heterogeneity makes unsuitable management of Mediterranean wetlands more the rule rather than the exception (Amezaga and Santamaría, 2000; Kingsford, 2000; Melendez-Pastor et al., 2010). Therefore, the development of appropriate management tools to help sustain these vital natural systems plays a key role for present and future decision making (Trepel et al., 2000; Lefebvre et al., 2015).

Modeling approaches using soil moisture conditions as wetland health indicators may be useful as prediction tools. As noted by Jolly et al. (2008), simulation of processes in the unsaturated zone within and around wetlands is very important in terms of ecological responses related to vegetation growth or nutrient release. However, modeling approaches in Europe have mostly focused on temperate wetlands so far. In general, these approaches need to be site-specific to account for

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highly complex surface water – groundwater interactions in semiarid wetlands (Aguilera et al., 2013; Jolly et al., 2008; Sophocleous, 2002).

The main objective of this paper is to propose a management tool for wetland managers to predict critical soil moisture conditions resulting from system drying out. The presented case study is the anthropized wetland area of Las Tablas de Daimiel National Park in semiarid central Spain. The management support tool is based on the one-dimensional field scale Soil-Water-Atmosphere-Plant (SWAP) model, which simulates the evolution of soil moisture movement in the vadose zone (VZ) in interaction with vegetation development in shallow systems, where transport processes are predominantly vertical (Kroes et al., 2008). The input data for the model are soil physical properties, vegetation growth parameters and daily meteorological conditions, which can be based on climate change scenarios or historical observed records. Furthermore, the model allows preferential flow through macropores such as shrinking cracks in peat or clay. SWAP has already been successfully applied to assess management options with respect to different field scale problems (Bonfante et al., 2010; Diek et al., 2014; Droogers et al., 2008; van Schaik et al., 2010).

2. Case study

The Biosphere Reserve of Las Tablas de Daimiel National Park (TDNP) in central Spain (Fig. 1) is a good example of a highly sensitive wetland in a Mediterranean semiarid region, which has experienced the degradation processes mentioned above due to water scarcity and inappropriate management. Prior to 1970, under natural conditions, the surface flooded area reached over 150 km^2 due to groundwater discharge and river overflowing (Álvarez-Cobelas et al., 2001). The peculiar mix of water qualities and geographical location conferred TDNP a special relevance among European wetland areas as an ecological refuge for singular waterfowl and plant species. However, following degradation and human intervention the maximum flooding area has gone down to less than 19 km^2. The main reasons for water unavailability are the depletion of groundwater levels, due to recurrent droughts (Fig. 2) and increased groundwater-based irrigation, leading to hydraulic gradient inversion (vertical downward) turning TDNP into a recharge area (Castaño et al., 2008; Llamas, 1988).

Particularly relevant degradation processes for Park managers are common reed (*Phragmites australis*) expanding and smoldering peat fires. Both processes depend on soil moisture conditions. Under decreased flooding conditions and increased water pollution, reed shows rapid growth and high competitiveness and invasiveness against other macrophytes such as cut-sedge (*Cladium mariscus*). Cut-sedge communities constitute primal areas for waterfowl nesting and feeding. Management actions such as reed mowing with heavy farm machinery have become usual measures affecting by soil compacting both the structure and physical-chemical properties of soils at TDNP. Smoldering peat fires in TDNP and its surroundings have become a recurrent phenomenon since 1977 in the absence of flooding and with low soil moisture conditions during dry periods (García Rodríguez, 1996). Peat shrinkage and alteration processes in TDNP induced by drainage lead to the development of cracks and hollows which favors the occurrence of fires (Moreno et al., 2010). Smoldering fires completely disrupt the ecosystem's soil matrix causing irreversible alterations on the soil physical-chemical structure and massive killing of soil biota and vegetation. Therefore, if the ecological, environmental and landscape functions of TDNP are to be maintained, prevention and control of new fires are essential.

As water availability is a major limitation in the region, partial solutions have always been undertaken to overcome the water shortage emergency: water transfers and/or flooding with groundwater pumped from boreholes located next to the Park limits. However, these measures have never been based on technical-scientific criteria and have had limited effect. Water transfers, for example, have an average yield (percentage of volume of water arriving to TDNP) of approximately 50% since 1988, with a minimum of 3.8% in the transfer of 2009 (*data provided by TDNP Managing Authorities*). Flooding with pumped groundwater from an emergency well field aims to keep a minimum flooded area inside TDNP. However, it is an expensive contradictory measure

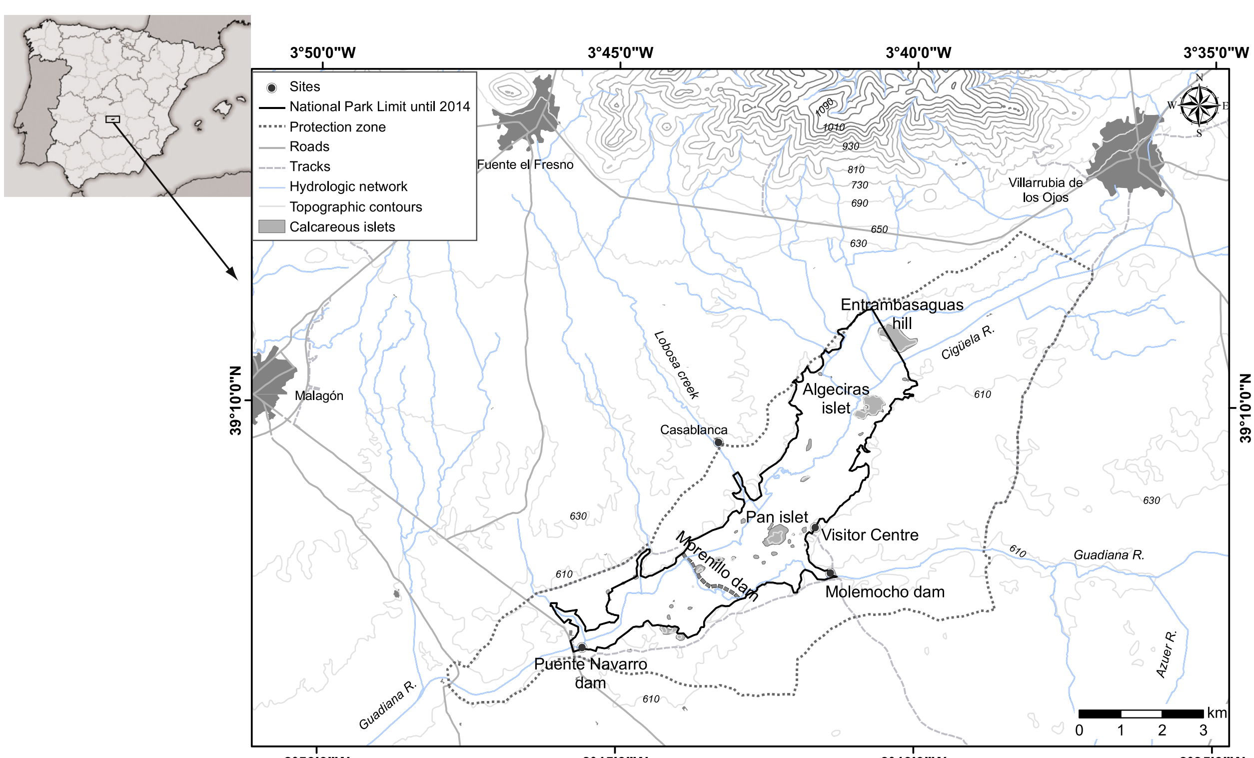

Fig. 1. Geographical setting of Las Tablas de Daimiel National Park (TDNP) in central Spain. TDNP representative sites, main surrounding urban areas as well as hydrologic and road networks are shown. Topographic elevations are expressed in meters above sea level (masl).