Agricultural Water Management 204 (2018) 301–313

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Assessing zebra mussel colonization of collective pressurized irrigation networks through pressure measurements and simulations

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ARTICLE INFO

Keywords:
Dreissena polymorpha
Hydraulic simulation
Irrigation piping network monitoring
Normalized pressure

ABSTRACT

Zebra mussel (*Dreissena polymorpha*) colonies are becoming a real problem in pressurized irrigation networks. The zebra mussel infestation of the 45 Water Users Associations (WUAs) of the *Riegos del Alto Aragón* (RAA) irrigation project (121 thousand hectares located in northeastern Spain) was assessed during the period of 2013–2017. Maps of WUA infestation stages were produced. A survey of the WUAs made it possible to assess the relevance of certain structural and management practices in the control of zebra mussels. A method to monitor zebra mussel colonization of pressurized collective irrigation networks was presented. The method is based on the combination of pressure measurements at network hydrants and hydraulic simulations. Normalized pressure, estimated as the difference between simulated and observed pressure, should approach zero in all hydrants in a properly characterized, non-infested network. A positive normalized pressure can indicate the presence of zebra mussel colonies. The methodology was validated using two different test cases located in two RAA WUAs: the first case involved a discrete chemical treatment, while the second case was based on the analysis of three years of telemetry pressure data and remote operation of network hydrants. The existence of an infested reservoir upstream of the WUAs was the most likely source of zebra mussel colonization of the WUA pressurized networks in the RAA project. The desiccation and chemical treatment of the small WUA reservoirs was associated with pest control. The hybrid (measurement-simulation) methodology is able to characterize the presence of zebra mussel colonies in specific reaches of pressurized irrigation networks.

1. Introduction

The zebra mussel (*Dreissena polymorpha*) has been classified as one of the 100 of the world's worst invasive alien species, together with eight other aquatic invertebrates (Lowe et al., 2004). In the beginning of the 19th century, the species started to spread from its area of origin in the Caspian and Black seas, reaching Britain in 1824 (Aldridge et al., 2004). It took quite a long time for zebra mussels to appear in North America in the mid-1980s (Herbert et al., 1989) and in Spain in 2001 (Araujo and Álvarez, 2001). Although natural vectors can play a role in the dispersal of the species, human activity (transportation, recreation and fishing) seems to be the key factor (Banha et al., 2016).

The species was characterized by Naddafi et al. (2011) as a successful invader since it has very high reproduction and growth rates, and it can develop in a wide range of physical and chemical conditions. However, its colonization potential is very low when water temperature is lower than 15 °C or higher than 27 °C, when water velocity exceeds 2.0 m/s, and when dissolved oxygen is lower than 4 ppm (ZMR, 1993).

Females can lay between forty thousand and a million eggs a year (CHE, 2007). Larvae first move freely in the water. At an age of 18–90 days, larvae adhere to hard substrates (i.e., concrete, plastic materials) using up to 200 filaments, known as byssal threads (Roberts, 1990). Only about 2% of larvae successfully adhere and develop. During the rest of their life, zebra mussels continue to adhere to the substrate. Adults start reproduction when they reach a size of 6 mm, and can live for 3–5 years (CHE, 2007). The size of a one-year adult is about 1 cm, growing about 1 cm a year.

Zebra mussels have created very important worldwide economic damage by blocking pipelines and other infrastructure, and by modifying river and lake hydrology (Aldridge et al., 2004). In the United States, yearly damage has been estimated at 5 G$/yr (Khalanski, 1997). In the recently infested Ebro Valley of Spain damage is still quite low: the total cost was estimated as 14 M€ for the period of 2001–2009 (CHE, unpublished internal report, 2009).

Shortly after the detection of the species in an area, zebra mussels start creating problems in different types of infrastructure. Zebra

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https://doi.org/10.1016/j.agwat.2018.04.025
Received 15 January 2018; Received in revised form 12 April 2018; Accepted 18 April 2018

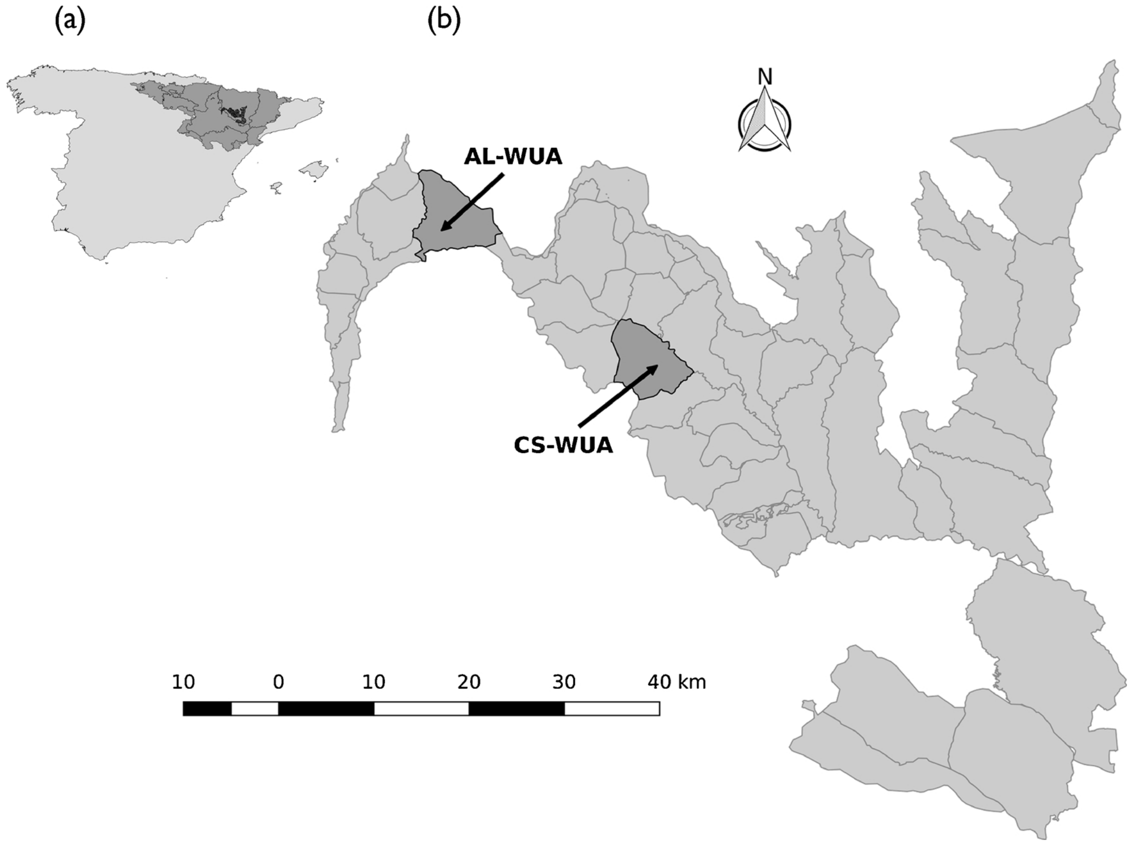

Fig. 1. Location of the Ebro river basin, its provinces and the RAA project (in black) in the Iberian Peninsula (a). Map of the RAA project and its WUAs, highlighting the WUAs analyzed in this paper: *Collarada Segunda* (CS-WUA) and *Almudévar* (AL-WUA) (b).

mussels latch to bridge abutments, water intake pipes, metal grids and screens, forming a dense mat of shells (Roberts, 1990). Regarding irrigation infrastructures, reservoirs and canals of all sizes can be colonized by the species. In general, this does not seriously compromise water delivery, except in screens used to filter debris. Mussels latch to concrete lining much better than they latch to the polyethylene film used for irrigation reservoir lining (Ackerman et al., 1996). Large, low-pressure pipelines used for reservoir intake can be strongly colonized by zebra mussels, severely reducing water passage by forming layers of adults completely covering pipeline walls. The most severe damage to irrigation infrastructure is associated with pressurized networks connected to colonized reservoirs and canals. In these systems, larvae are transported with flowing water from these reservoirs and canals into the pressurized systems, colonizing pipelines, filters and occasionally on-farm irrigation systems (sprinkler or drip). Adults grow and reproduce inside these system elements, reducing the conveyance capacity and blocking water passage.

The control of zebra mussels in irrigation infrastructure follows several strategies. Desiccation and exposure to extreme temperatures are commonly applied in irrigation reservoirs. Chemical substances (i.e., chlorine or hydrogen peroxide) are added to the water to control growth inside irrigation pipelines (Klerks and Fraleigh, 1991; Waller and Fisher, 1998; Seral et al., 2012). Chemicals are injected in the network in shock treatments, retained inside the pipelines for a few hours or days, and then flushed away. Alternatively, chemicals can be continuously added to irrigation water. Chemical treatments kill all development stages of the zebra mussel, including adults. When killed by the chemicals, the byssal threads let go and the shells freely move inside the pipelines. In the absence of adequate pipeline drains, shells can accumulate in filters and block pipeline sections, often producing more nuisance to farmers than latched adults do. In large irrigation projects of Spain, benefiting from economies of scale and including experienced technical staff, the yearly cost of chemical treatments rarely exceeds 10 €/ha.

Reports have been found in literature documenting and forecasting zebra mussel expansion. Bossenbroek et al. (2007) considered aspects such as the overland movement of recreational boaters or the chemical properties of reservoirs to model the expansion of the species in the United States. Bosso et al. (2017) used a maximum entropy algorithm to model the expansion in Italian rivers, lakes, watersheds and dams. These works led to observed or projected expansion maps.

In Spain, a very large irrigation modernization programme has been implemented since 2000, commonly leading to the replacement of canals and surface irrigation systems by collective pressurized networks and sprinkler or drip on-farm irrigation systems. MAPAMA (2015) estimated that irrigation modernization policies had been applied to 1.5 M ha since 2000. Consequently, drip and sprinkler irrigation currently represent 50% and 26% of the national irrigated area (respectively), estimated as 3.7 M ha (MAPAMA, 2016). The importance of pressurized irrigation and the prevalence of overland water *vs.* groundwater represent a relevant vulnerability of Spanish irrigation systems to zebra mussels. Farmers have always volunteered to participate in irrigation modernization programmes. Persistent zebra mussel infestation is the only reason why farmers have occasionally (in the middle of a crisis) expressed that they would be better off with their old surface irrigation systems.

Farmers' problems with zebra mussels have not yet received relevant scientific interest. In fact, scientific databases only contain information about the development and control of the species in industrial, urban and environmental infrastructure, including multipurpose reservoirs and canals. As an exception, Seral et al. (2012) addressed zebra mussels in collective pressurized irrigation networks from the perspective of optimizing chlorine application.

Hydraulic modeling has been commonly used to generate flow-