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Experimental study on control of *Limnoperna fortunei* biofouling in water transfer tunnels

Q4 Q1 Mengzhen Xu [a], Gustavo Darrigran [b], Zhaoyin Wang [a,*], Na Zhao [a], Cheng Chieh Lin [c]

[a] *State Key Laboratory of Hydroscience and Engineering, Tsinghua University, P.O. Box 10008, Beijing, China*
[b] *CONICET, División Zoología Invertebrados, Museo de La Plata, Paseo del Bosque s/n, 1900 La Plata, Argentina*
[c] *Program in Civil and Hydraulic Engineering, Feng Chia University, Taiwan, China*

Abstract

The golden mussel (*Limnoperna fortunei*) is a filter-collector macroinvertebrate species originating from southern China. It easily invades water transfer tunnels and attaches onto tunnel walls and structures with extremely high density, resulting in biofouling, pipe clogging, structure corrosion, a decrease in water transfer efficiency, and water pollution. It has become a prevalent problem and has caused concern all over the world. However, an effective and environment friendly method of controlling golden mussel invasion has not yet been approved. This study is aimed to propose measures for preventing golden mussel invasion and biofouling in the water transfer tunnels of the East River Water Source Project (ERWSP), which transfers water from the East River to Shenzhen, southern China for 10 million people. Long-term samplings and observations of the East River water were performed to study the golden mussel's invading pattern. Flume experiments were done to study the golden mussel's attachment on 14 different materials and performance in turbulent flows. An integrated ecological prevention pool was designed and constructed based on the flume experimental results for preventing the golden mussel invasion in the scale model tunnels of the ERWSP. The major technology of the ecological pool was preventing the golden mussel from entering the tunnels by attracting veligers to attach on geotextile cloth, attracting mussels to attach on bamboo, and killing veligers with high-frequency turbulence. An eight-month application experiment showed that the ecological pool successfully controlled the golden mussel invasion and biofouling in the scale model tunnels. The mussel density on the attachment materials decreased sharply as the distance of the materials from the pool entrance increased; the turbulence was effective in killing veligers that escaped from the attachment materials. No mussel was found on the model tunnels. Thus, the integrated ecological prevention pool is recommended as a successful measure for controlling the golden mussel invasion and biofouling in water transfer tunnels.

Keywords: Water transfer tunnels; Golden mussel invasion; Biofouling; Attachment attracting; Ecological prevention

1. Introduction

Q3 *Limnoperna fortunei* (Dunker, 1857) or the golden mussel, is a freshwater invading bivalve belonging in the family Mytilidae. It is a filter-collector macroinvertebrate species originating from southern China. This species colonizes widespread habitats with water temperature among 0–35 °C, flow velocity among 0.1–2 m/s, water depth among 0.1–40 m, dissolved oxygen among 0.2–11.33 mg/L, pH among 6.0–7.8, and Calcium concentration to 3.96 mg/L (Morton, 1982; Márcia, 2006; Darrigran et al., 2011, 2012). The golden mussel shows characteristics similar to those of the marine members of the family, i.e. an epibyssate habit and a planktonic larvae measuring only a few microns (Darrigran et al., 2007). It should be noted that until now, the golden mussel planktonic larvae have never been found in the waters of China. In China, it is revealed that the golden mussel becomes sexually mature when its shell length reaches 6–8 mm (Group of Pipeline Study (1973)). However, in a temperate

* Corresponding author. Tel.: +86 1062773448.
E-mail addresses: xumz07@gmail.com (M. Xu), zywang@tsinghua.edu.cn (Z. Wang).

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climate of Argentina, the golden mussel is found sexually mature at the shell length of 5 mm (Darrigran et al., 1999).

Inter-basin water transfer projects have been widely used to solve uneven distribution of water resources and water shortages in China. Along with diversion of water resources, the golden mussel has also been inadvertently transferred to new aquatic environments, resulting in a quick and uncontrolled spread of the species. For instance, the water transferred from East River to Hong Kong introduced the golden mussel into the aquatic ecosystem of Hong Kong and has disrupted the native aquatic community (Morton, 1977). In the water cooling system of the Wuhan Iron and Steel Company in Hubei, central China the golden mussel clogged the water-supply pipes and caused great economic loss (Group of Pipeline Study (1973)). In the past, the golden mussel was found only in southern China with the Yangtze River as its north boundary (Liu et al., 1979). However, the species was found in the Yellow River basin in the 1980s, and recently it has been found in the waters in Beijing (Ye et al., 2011).

The golden mussel has also invaded the aquatic ecosystems and hydraulic structures in South America and other Asian countries (Darrigran, 2002; Boltovskoy et al., 2006). It is a very effective ecosystem engineer, altering both ecosystem structure and function, and causes great ecological and economic impacts (Darrigran and Damborenea, 2011). The clogging of cooling water pipes caused by dead mussels stopped raw water pumping to a water purification plant and caused the shutdown of a turbine dynamo-electric generator in a hydraulic power plant in Japan (Magara et al., 2001). At the beginning of 1994, *Limnoperna* caused the first known case of freshwater industrial macrofouling in South America (Darrigran, 2010). This event occurred at the intake for the drinking water plant of the city of La Plata, Argentine. Since, *Limnoperna fortunei* infests all types of man-made facilities: treatment plants, irrigation channels, reservoirs, fisheries and several most important nuclear, hydroelectric and thermal power plants of the Plata Basin (Darrigran et al., 2007; Darrigran, 2010; Pereyra et al., 2012) and the golden mussel has also created significant problems for the city of Córdoba, one of the most important tourist city of Argentina. This city has a population of 1,400,000, which has one of the highest living standards in the country. In February 2008, the golden mussel shells accumulate in the cooling system from downtown San Roque, causing the plant to disconnect. This loss of power in turn closes distribution facilities and water treatment throughout the city, leaving the city of Cordoba, in the summer, no water for 24 h (Darrigran, 2010).

The golden mussel invasion and biofouling in water transfer systems has drawn attention because it has resulted in a high resistance to water flow in tunnels, corrosion of pipe walls and even clogging of tunnels. Additionally, the invasion has caused water pollution and ecological imbalance in the regions that receive water infested with the golden mussel (Darrigran, 2002). Therefore, quite a few researches have been done to study the golden mussel's biological and ecological features. It is found that it shares several biological and ecological features with the North American invasive pest zebra mussel (*Dreissena polymorpha*), like size, growth speed, and colonization on hard substrata by means of strong byssuses (Morton, 1979; Ricciardi, 1998; Karatayev et al., 2007). Both species are invasive by nature and endowed with a strong byssus for attaching onto their habitats, allowing them to easily invade natural and artificial aquatic systems, resulting in high-density attachment that causes serious biofouling. Invasion of the golden mussel in a new habitat results in changes in the feeding habits of fish and, consequently, the composition of the macroinvertebrate community (Darrigran and Ezcurra, 2000; Darrigran and Damborenea, 2005; Penchaszadeh et al., 2000).

Finding strategies to reduce biofouling caused by the golden mussel invasion has been studied for decades all over the world. Various chemical and physical measures of getting rid of the golden mussel's attachment, such as coating pipe walls (Luo, 2006), poisoning with pesticide (Darrigran and Damborenea, 2006; Pereyra et al., 2011, 2012), spraying with hot water (Morton, 1982), trapping with filters (Darrigran, 2002), using ultraviolet irradiation, washing with high velocity flow, removing artificially with scrapers (Xu et al., 2009) have been employed. However, such measures can themselves contribute to water pollution, damage water transfer tunnels, or cost too much to be of practical use. Preventing the golden mussel's invasion into water transfer tunnels is the most effective strategy to mitigate biofouling (Simberloff, 2001). Therefore, it is essential to understand the ways of dispersion (Belz et al., 2012) and invasion of the golden mussel. Ecological methods of preventing the golden mussel invasion in water transfer tunnels were applied in the East River Water Source Project (ERWSP) in this study.

2. Study area and methods

2.1. East River Water Source Project

As shown in Fig. 1, the East River Water Source Project (ERWSP) transfers water from the East River and its tributary Xizhijiang River to Shenzhen, southern China for 10 million people's use. The ERWSP consists of 17 km long double steel pipes (2.6 m in diameter), an 80 km long concrete tunnel (3.2 m in width and 4.0 m in height), several sections of culverts, and numerous valves. The tunnel entrance is located at the intake of the Dongjiang Pump Station (East River intake). The intake of the Xizhijiang Pump Station (Xizhijiang River intake) is located 17 km downstream from the tunnel entrance. This project has suffered from the golden mussel biofouling since it started operation in 2001. Attachment density of the mussels is 10,000 ind./m^2 on average and as high as 50,000 ind./m^2 on some sections. Thickness of the golden mussel clusters exceeds 10 cm on pipe walls, valves, gates, and other structures, resulting in concrete wall corrosion and high resistance for water transferring (Fig. 2a). Additionally, fungi species growing on dead mussels results in water pollution (Fig. 2b). Artificial clearance of the mussels has being conducted year after year. However, the biofouling became more and more severe after each clearance.