Landscape and Urban Planning 157 (2017) 45–55

Contents lists available at ScienceDirect

Landscape and Urban Planning

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

Research paper

Effects of local and landscape factors on exotic vegetation in the riparian zone of a regulated river: Implications for reservoir conservation

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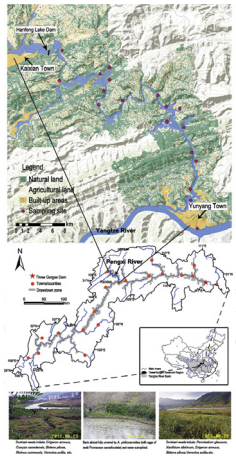
HIGHLIGHTS

- Partitioning methods provided insights into reservoir exotic species distribution.
- Reservoir flooding has a high independent effect on exotic species richness.
- Exotic invasion was significantly associated with landscape variables.
- A landscape approach to conservation of regulated riparian ecosystems is needed.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 13 November 2015
Received in revised form 8 June 2016
Accepted 9 June 2016

Keywords:
Biodiversity
Human impacts
Large dam
Water fluctuation

ABSTRACT

Riparian zones of regulated rivers are susceptible to species invasion due to a variety of anthropogenic disturbances. Adjacent land use and landscape patterns may be significant drivers in this process in conjunction with direct effects of flow regulation. Understanding different influences on invasion is necessary for regional landscape management. Here we explored the effects of local and adjacent landscape factors on exotic vegetation distribution along the Pengxi River controlled by the Three Gorges Dam. Vegetation data were collected in 5 × 1 m quadrats along transect lines perpendicular to the riverbank between 172 m and 178 m elevation. A total of 21 exotic herbs were found, accounting for 11.3% of all identified taxa. There was greater exotic species richness below 175 m zone directly affected by reservoir flooding. Variation partitioning indicated that landscape structure played a more important role in explaining the degree of invasion than did local variables. As expected, the landscape subgroup

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http://dx.doi.org/10.1016/j.landurbplan.2016.06.003

Plant invasion
Yangtze river

"landscape composition" appeared to be more influential than "landscape configuration". Hierarchical partitioning showed that overall invasion increased with increasing adjacent agricultural land uses and flooding presence, but decreased with greater distance to human impacts. Given that re-regulation of the reservoir flow regime is unlikely at this time, we support a landscape approach to riparian vegetation management, where the nature and impacts of the surrounding landscape matrix, and the particular composition and forms of land use and human activity should be considered. Suggestions include establishing buffer reserves, reclaiming abandoned agricultural land, and stricter urban greening regulations.

1. Introduction

Riparian zones are aquatic-terrestrial ecotones with complex, dynamic biophysical processes that support many ecological functions both for aquatic and whole watershed ecosystems (Naiman & Decamps, 1997). However, they are consistently affected and changed by human activities, such as dam construction and urbanisation, where they have been called "constructed ecologies" (Grose, 2014). Due to complex gradients of disturbance, especially human-caused flow alteration (Mortenson & Weisberg, 2010), riparian land becomes periodically exposed when water recedes and thus are prone to colonisation by exotic species which are tolerant of disturbance and have rapid recovery strategies (Hood & Naiman, 2000; Magee, Ringold, & Bollman, 2008; Nilsson, Reidy, Dynesius, & Revenga, 2005; Rood, Braatne, & Goater, 2010).

Most studies of riparian vegetation have focused on the stand scale where local physico-chemical conditions of soil and water, and interspecies competition are the main concerns (Ehrenfeld, 2008; Stohlgren et al., 2006). Especially in studies of regulated river systems, hydrological disturbance is regarded as the primary driver (Nilsson et al., 2005; Zając, Tokarska-Guzik, & Zając, 2011). Recent research has also highlighted the influence of historical land use on plant assemblages, with exotic or invasive species more prevalent in human altered environments (Kuhman, Pearson, & Turner, 2013; Malavasi, Carboni, Cutini, Carranza, & Acosta, 2014), such as agricultural land (Kulmatiski, Beard, & Stark, 2006), and managed forests (Kuhman, Pearson, & Turner, 2010; Lee & Thompson, 2012).

With the advent of landscape ecology and associated analytical tools, more recent studies have explored the relationships between socio-ecological processes and landscape spatial patterns. Attention has been drawn to the effects of landscape composition and configuration on biodiversity, vegetation structure and species invasion patterns (González-Moreno et al., 2013; Malavasi et al., 2014; Ohlemüller, Walker, & Wilson, 2006). It appears that biological community patterns are determined by multiple filters operating at a hierarchy of spatial scales from continental, regional, basin, to local microhabitat (Sandin & Johnson, 2004). According to this hierarchy theory, the fine-scale patterns observed at sites are constrained by macroscale geomorphic patterns (Sydenham, Moe, Totland, & Eldegard, 2014). So compositional changes, including spread of adapted exotic species, have to negotiate this series of filters.

Although such theories have been tested across various landscape settings (González-Moreno et al., 2013; Pino, Font, Carbo, Jové, & Pallares, 2005; Tscharntke et al., 2012), little of this has been applied specifically to reservoir ecosystems; and yet worldwide, there are more than 45,000 large reservoirs with water level fluctuations greater than 15 m (Nilsson et al., 2005). Although the dam building era ended in developed countries after the 1980s (Graf, 1999), it is still booming in developing countries (Grumbine & Pandit, 2013; Millikan, 2010). China alone has massive and rapid development, with 98,000 reservoirs built up to 2013 (Yang & Lu, 2014). Urban sprawl, population explosion and extreme weather events associated with climate change, have led to increased building of reservoirs in urban regions for water supply and flood control. Such environments are especially threatened by nearby disruptive or extractive activities, such as urban and road construction, agriculture, and even mismanaged ecological projects. Comprehending the responses of invasive species to human impacts is critical to conservation of diverse urban and regional ecosystems from both theoretical and practical standpoints.

The Pengxi River, an arm of the giant Three Gorges Reservoir (TGR) (Fig. 1), is an ideal case study for analysing the impacts of both local environments and wider landscape features on reservoir ecosystems. It passes through the urban areas of Kaixian and Yunyang towns, adjacent to intertwined environmental and anthropogenic impacts. Within the TGR's general operating regime of "145 m elevation during summer and 175 m during winter" since 2010, the Pengxi River fluctuates between 152 to 175 m and encompasses seasonally open water fluctuation zones of 55.47 km^2, accounting for 16% of the total in the whole TGR region and ranking as the largest among all the tributaries of TGR (Yuan et al., 2013). Since 70% of it is gently sloping (<15°) with fertile soil conditions, 52% of this land was previously used for agriculture and 20.4% were built on (Zhang & Zhu, 2005). Only 26.6% was in natural state of secondary forestry and grassland. To make way for TGR, this land was cleared and a new riparian ecosystem is forming.

Since the Three Gorges Dam (TGD) construction, the region has suffered ongoing biodiversity decline (Wu et al., 2004). Various potential causes have been described primarily focusing on local environmental changes directly associated with reservoir construction and management. However no research has specifically addressed exotic species' spread, nor distinguished the influences of surrounding anthropogenic disturbance on the vulnerability and invasibility of reservoir riparian habitats.

This study therefore investigates and compares the relative importance and interactive effects of local variables and adjacent landscapes on patterns of fine-scale plant invasion in a representative reservoir riparian zone. The concerned variables belonged to five subgroups: plant community structure, physical habitat, hydrology, landscape composition, and landscape configuration. The first three subgroups forms a local group and the left as a landscape group. Of particular interest is whether the reservoir flooding is the most influential factor in explaining plant invasion patterns. The exploration of these variables offers new understanding of the drivers determining structural and functional attributes of riparian vegetation. This should inform conservation policymaking, monitoring and management of altered environments by dams and other large infrastructure projects in China and elsewhere.

1.1. Study area

The Pengxi River catchment (107°42′ ~ 108°54′E, 30°41′ ~ 31°42′N) is located in the heart of the TGR region. It covers an area of 5276 km^2, and characterised by diverse topography of low-elevation river valleys, foothills, and mountain ranges. The catchment has a northern subtropical humid monsoonal climate with an average annual precipitation of 1200 mm, 60–80%