Title
Riparian vegetated buffer in Chinese urban wetlands: a case study of Xixi wetland, Hangzhou

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Abstract

Vegetated buffers are a widely recognized method for protecting aquatic resources such as rivers and wetlands from human activities. However, constructing vegetated buffers for aquatic resources is particularly challenging in urbanized areas due to many constraints associated with urban development. In this study, we investigated the buffer conditions around an important urban wetland, Xixi wetland, in Hangzhou, Zhejiang, with the goal to identify problems and areas for improvement in the current buffer design by considering physical, hydrological and land use factors. We identified opportunities for improving accessibility and social value of the riparian buffer and highlighted environmental concerns associated with overdevelopment in the wetland park. Insights learned from Xixi, the first national wetland park in China, can inform the design and management of other wetland parks in China.

Introduction

Rapid industrial development in China in the last few decades has witnessed significant retreat and degradation of wetlands and streams in highly urbanized areas. Research shows that China has lost 23.0% of its freshwater marshes, 16.1% of its lakes and 15.3% of its rivers to rapid economic development in the last 50 years (An et al., 2007). In an effort to protect and restore the urban wetlands which provide numerous social and ecological benefits to the society, the Ministry of Housing and Construction (MHC) initiated a series of policy reforms and government-led programs including wetland park construction and a recent policy of total wetland area control (i.e. no net loss) in 2016 (Xu et al., 2019). In this project, we studied a major urban wetland restoration project in Hangzhou, Zhejiang and the first national wetland park in China - Xixi wetland. While there were a total of 46 national wetland parks approved by MHC by the end of 2013 (Li et al., 2015), research on effective wetland restoration and management is still at a developing stage. Therefore, as one of the pioneering wetland park projects, Xixi wetland presents a good opportunity to study the merits and shortcomings in current wetland restoration and management, which will inform future wetland restoration design in other parts of China.

Xixi Wetland is a secondary urban wetland located in the west part of Hangzhou, separated from another major water basin - the West Lake basin by a hilly forest belt (Figure 1). Historically a lowland area, Xixi wetland was formed about 5000 years ago, due to seasonal flooding from a nearby mountain in the west (Mt. Tianmushan). About 3000 years ago during the Song Dynasty, the government established official township in the Xixi area, which marked the start of the fishing and farming culture in the region (Lin et al., 2008). Since then, Xixi wetland has gradually shrunken in size due to intensifying human activities which only worsened during the industrial revolution period in recent Chinese history. It was not until 2003 that the city government finally started to pay attention to the deteriorating environmental conditions at Xixi wetland.

Figure 1: Map of Xixi wetland and the surrounding landscape

Starting in 2005 when Xixi wetland was nominated as the first national wetland park by the National Forestry Bureau, a series of restoration programs including dredging and water quality improvement were carried out to restore ecological conditions in the wetland (He and Li, 2009). The Xixi wetland recognized by most local people in Hangzhou now is the core protection area of the national wetland park which is also our study site. It is bounded by Zijingang Road in the east, Tianmushan Road in the south, the green belt of the Ring Road in the west, and the West Wen'er Road in the north. The core protection zone covers an area of 10.07 km^2 (Gao et al., 2006), which is only about a fifth of the wetland's historical range but still an unusually large urban wetland in China (Zhang et al., 2020).

The streams and rivers in Xixi wetland are highly interconnected. Water bodies including river ports, ponds, lakes and swamps account for about 70% of the total area (Gao et al., 2006). The major river flowing past Xixi wetland is Xixi River, which passes through the southern edge of the wetland before making a turn to the north and joining Yuhangtang River (Figure 2). Yuhangtang River drains to the Grand Canal, which is part of the famous Beijing-Hangzhou Grand Canal. The water in the Grand Canal eventually drains into Taihu, one of the largest freshwater lakes in China, in Jiangsu Province. Xixi wetland is located in the transition zone of hills in the south and highly urbanized plain areas in the north, and provides many valuable ecosystem services including flood regulation and providing habitats for endangered wildlife.

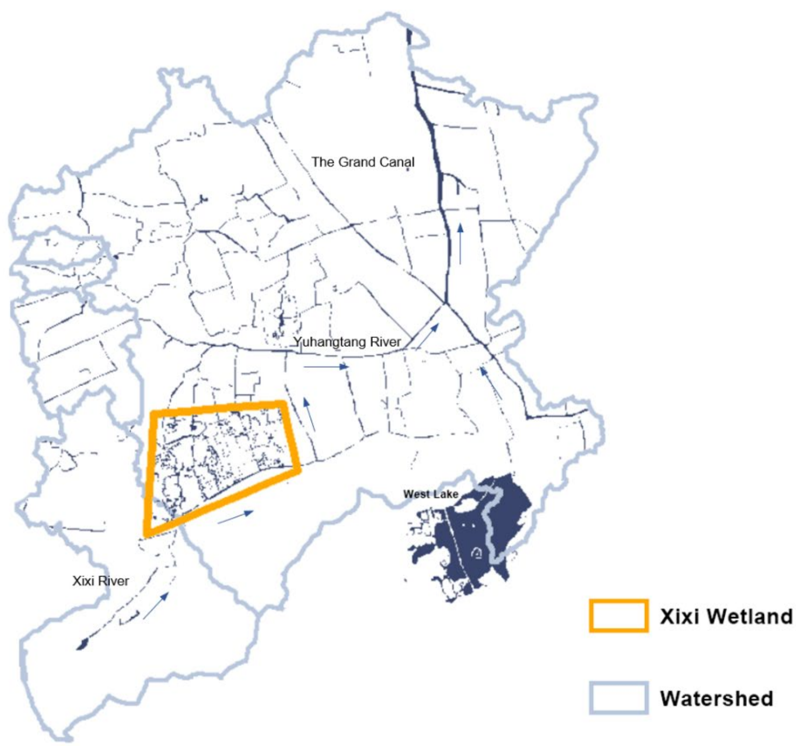


Figure 2: Watershed map containing Xixi wetland and the major rivers related (arrows show the directions of the river flows)

Through preliminary literature review, we found that one major problem with the current management of Xixi wetland is the insufficiency of buffer areas along the edge of the wetland to protect it from encroaching urban development. One GIS-based study used a functional landscape metric to show that the landscape health deteriorates from the center of the wetland park to its edges which suggests the need for enhanced ecological protection measures along the edge of the wetland (Figure 3) (Li et al., 2015).

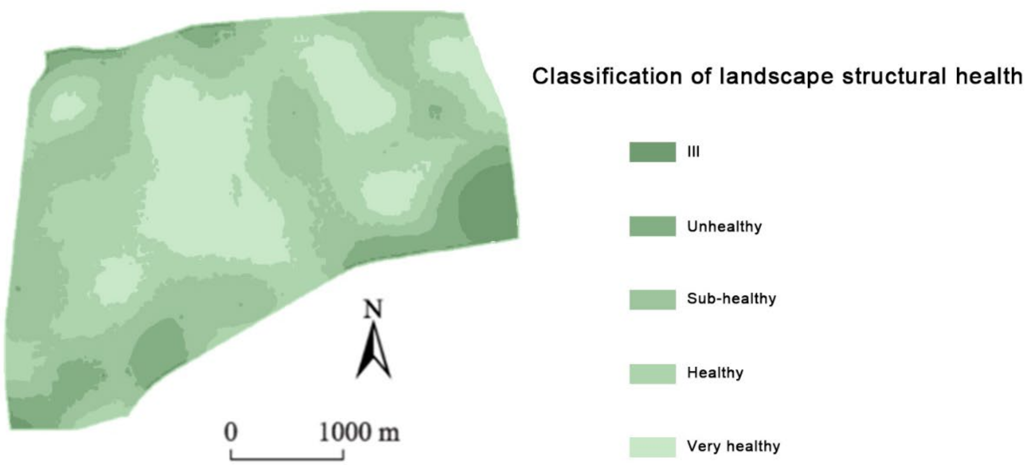


Figure 3: Spatial differences of landscape structural health in Xixi wetland (adapted from Li et al., 2015)

Constructing vegetated buffers is a widely recognized method for protecting rivers and wetlands from adjacent land use subject to human activities (Castelle et al., 1994). A wealth of literature has demonstrated the benefits of vegetated buffers including sediment removal, erosion control, excess nutrient removal and wildlife habitat values (Castelle et al., 1994; Liu et al., 2008; Khatavkar and Mays et al., 2017). Furthermore, a number of studies have shown that small buffers are often effective enough to achieve goals such as sediment and nutrient removal; for example, vegetated buffers approximately 4-9m wide are reported to have a nutrient trapping efficiency of 90-99%. Additionally, a meta-study by Liu et al., (2008) showed that the buffer width and slope for achieving the optimal sediment trapping efficiency is about 10m and 9.2%. Because vegetated buffers can protect aquatic resources with relatively small spatial requirement, we consider vegetated buffers a promising measure to improve the edge conditions of Xixi Wetland, given that it is located in a highly constrained urban area.

In this study, our goal is to evaluate current buffer conditions along the edge of Xixi wetland by considering hydrological, land use and spatial factors and to identify problems and areas for improvement in the current buffer design. Specifically, we identified the locations of potential drainage paths and examined buffer conditions at those sites by conducting a preliminary survey of the riparian vegetation, taking notes of the water quality and analyzing the spatial characteristics of the vegetated buffers.

Methods

We conducted a literature review to identify the problems in Xixi wetland, gather information about the site history and determine the focus of our study. The main approaches to achieve our objective are as follows:

Site selection

To select representative sites along the edge for field study, we first identified locations where adjacent urban rivers and streams intersect with the hydrological network in the wetland through examining google earth imagery. We drew a 500x500m block at each intersection for land use analysis later (Figure 4).

Figure 4: Nine intersections where adjacent rivers intersect with the wetland

To determine whether these intersection points are inflows or outflows, we calculated flow direction within the boundary of the wetland in ArcGIS using the 30m-resolution ASTER Global Digital Elevation Map (GDEM) data developed by NASA. We selected the geographical range which contains Xixi Wetland and downloaded the data from Geospatial Data Cloud (gscloud.cn). From the flow direction map (Figure 5), we can see that a large portion of the water body within the wetland flows to the north (green arrows) as well as on the northern edge. On the southern edge, the flow directions are mainly to the northwest (pink arrows) or west (yellow arrows). Therefore, we concluded that the four intersections in the southwest and southeast corners are inflows whereas the five intersections on the northern edge are outflows (Figure 6). Because riparian buffers are more effective at inflows for reducing runoff and trapping sediment from overland flow, we narrowed down the 9 intersection sites to the 4 inflow points.

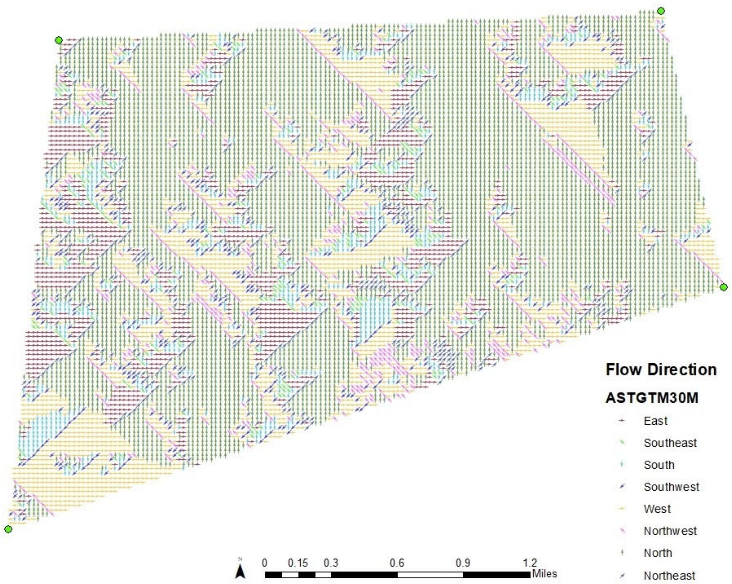


Figure 5: Flow direction within the wetland boundary

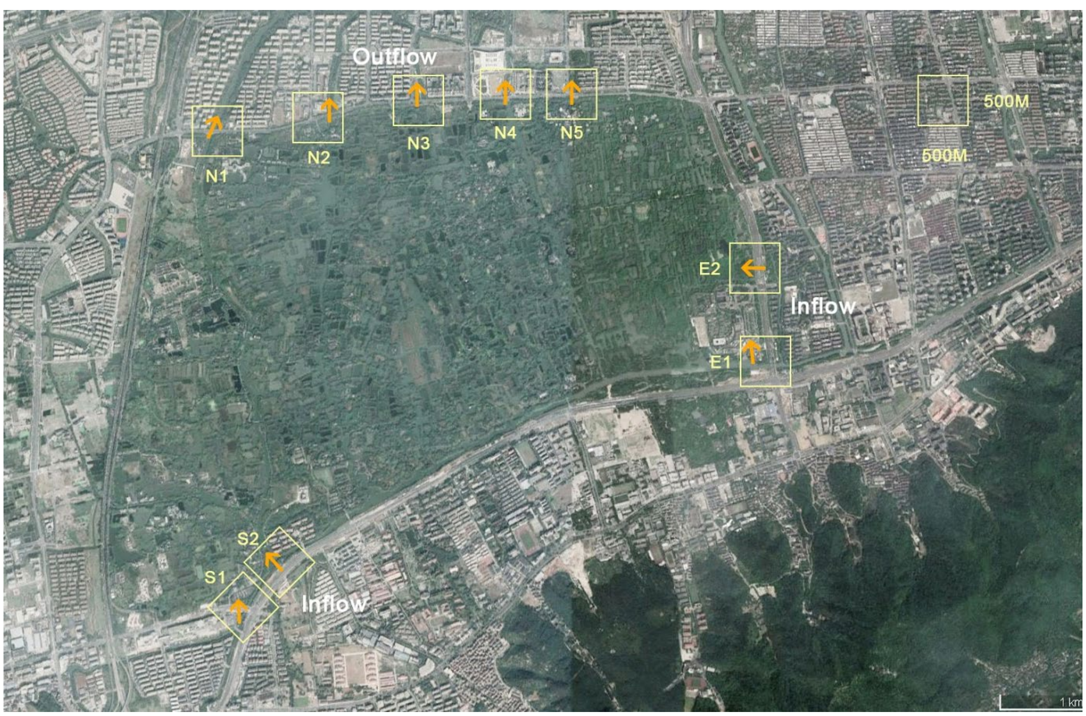


Figure 6: Flow directions at the intersections

We classified the transects based on spatial patterns of roads, green space and buildings. We classified the land use type of the buffer zones into two categories based on whether there are commercial or residential development in each transect (Table 1). Most of the transects are dominated by commercial and residential development and therefore highly constrained for potential buffer construction, except for transect S2 which is not occupied by existing development and therefore presents opportunities for potential buffer zone construction. Additionally, because the landscape structural health has been classified as “ill” on the eastern edge in an earlier study (Li et al., 2015) largely due to the development of a commercial center which invaded the southeast corner of the wetland, we also wanted to select a site on the eastern edge to see whether opportunities for buffer zones exist to improve the ecological conditions on the eastern edge. As a result, we chose S2 and E2 as our field study sites because both contain river inflows and have different surrounding land use which can be used for comparison.

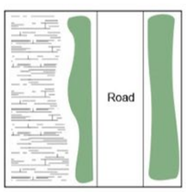
Land Use Pattern	Elements	Transect
	Green space Road	
	Green space Road Residential area (or Commercial area)	

Table 1: Land use classification (S2 and E2 are selected as field sites)

Physical and vegetation survey of riparian buffers

According to the literature, slope, width and vegetation compositions are the three main factors effecting vegetated buffers in terms of sediment trapping and nutrient removal. To evaluate the design of the current riparian buffers, we estimated the average buffer width and slope using a combination of footstep measurement and visual inspection. To get a preliminary understanding of the riparian vegetation composition at each site, we conducted a plant survey by documenting the major tree and shrub species we saw across a ~100m transect along the bank (Figure 7).

Figure 7: Plant survey and water sampling locations at site S2 (left) and E2 (right)

Hydrological conditions

Initially, we planned to measure the total suspended solids to get a rough estimate of the sediment load in the rivers flowing into and out of the wetland after a storm event. However, because fall is the dry season in Hangzhou, we were not able to conduct our field study on a rainy day and get accurate measurements of suspended solids. Instead, we recorded the hydrological conditions of the rivers along the edge of the wetland and inside the park by collecting water samples and taking notes of the water quality characteristics such as color and transparency.

Results

Physical characteristics and vegetation composition of riparian buffers

The average riparian buffer width at transect S2 was about 15m with a slope about 30%. The width of the channel was about 40m. We noticed that wooden stakes were used for bank protection on the side closer to the road, whereas the gravel bar closer to the wetland was left unprotected (Figure 8). There is an ongoing metro line construction project on Tianmushan Road, parallel to the river.

Figure 8: River channel at transect S2: aerial view (left) and bank protection measures (right)

Major tree species planted along the bank include *Metasequoia glyptostroboides (*dawn redwood*)*, *Sapindus mukorossi* (soapberry), *Salix babylonica* (willow), *Sapium sebiferum* (Chinese tallow) and others (Figure 9). The major herbaceous plants we observed were *Humulus scandens* (Japanese hop) and *Phragmites communis* (reed). The vegetated buffer is composed of a grassy vegetated filter strip (VFS) on the outer edge and large woody plants near the channel.

Figure 9: common woody and herbaceous plants at transect S2

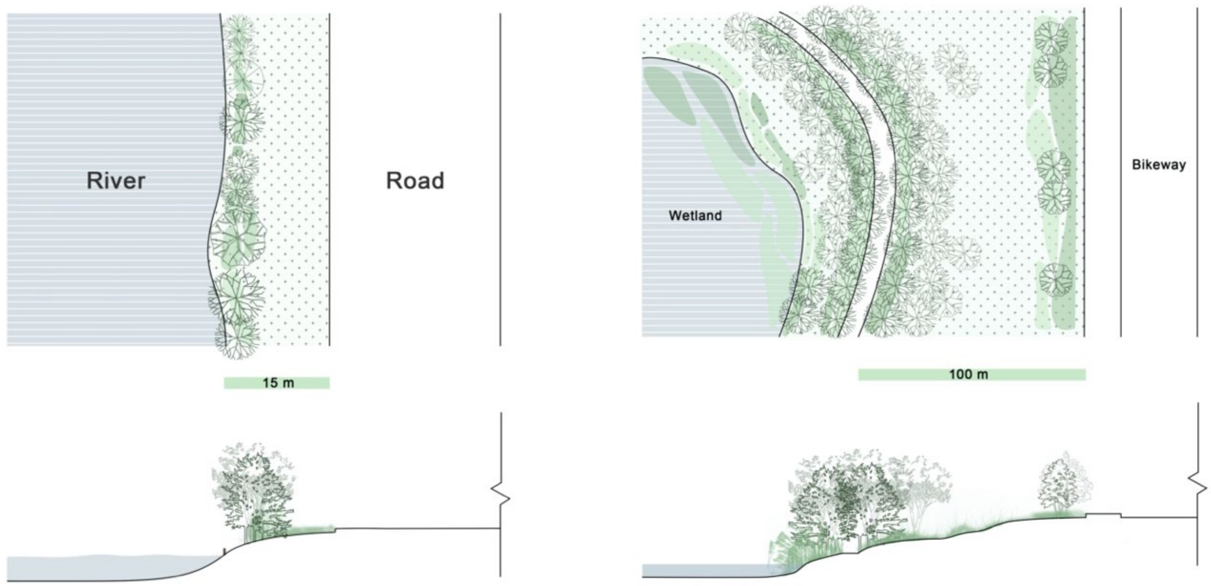
The average buffer width was about 100m at transect E2 with a slope of about 10%. The river channel is perpendicular to a major road (Zijinggang Rd.) nearby and extends to residential areas in the neighborhood. The channel immediately adjacent to the road was much narrower (about 15m on average) compared to the portion in the inner area of the park (Figure 10). We did not observe any bank protection measures in the channel at our transect. We observed aquatic plants including some species of water milfoil which was not found at transect S2.

Figure 10: River channel at transect E2: aerial view (left) and intersection at major road (right)

We found similar tree species (i.e. *Metasequoia glyptostroboides*, *Sapindus mukorossi* and *Salix babylonica*) in the riparian buffer at transect E2 as at transect S2, with the exception of *Ginkgo biloba* which was only found at transect E2. We also observed small shrubs including *Nandina domestica* (scared bamboo), *Ligustrum lucidum* (grossy privet), *Mahonia fortunei* (barberry) and *Buxus sinica* (Korean boxwood) (Figure 11). Common herbaceous plants we found include *Ophiopogon bodinieri* (Chinese lilyurf) and *Phragmites communis* (reed).

Figure 11: Common woody plants, shrubs and herbaceous plants at transect E2

Two plan and sectional drawings comparing the spatial arrangement of the riparian buffers at transect S2 versus E2 are shown below in Figure 9.



S2 E2

Figure 9: Plan and sectional views of riparian buffer at site S2 and E2

Water qualities in the riparian buffer zones

We did not observe any suspended solids greater than 0.1cm which could be filtered by our mesh. The water samples at both transect looked approximately equally transparent, with a slight brownish color and small suspended particles not large enough to be filtered but visible by eye (Figure 10). At transect E2, we noticed oily substance floating on top of the water near a building with unknown functions in the buffer zone, but we did not observe similar pollution problems at S2. Water samples collected inside the park did not look very different visually from those collected in the river buffers in our transects, but we did observe polluted standing water at some locations inside the park as observed at transect E2 (Appendix A).

Figure 10: Water samples at transect S2 (left) and transect E2 (right)

Discussion

While the channel in the buffer zone at transect S2 was on average wider (~40m) than the channel in the buffer zone at transect E2 (15~25m), the riparian vegetated buffer was on average much wider at transect E2 (~100m) compared to at transect S2 (~15m). We observed bank protection measures on the channel at transect S2 but not in transect E2. We speculate that it may be that the channel at transect S2 was wider and had a larger portion directly adjacent to the road, therefore exposed to higher risks of erosion problems. Overall, the buffers at both transects were wide enough and with slopes steep enough for effective sediment trapping and nutrient removal according to previous studies on riparian buffers (Liu et al., 2008).

The general spatial arrangements of the vegetation were similar at the two riparian buffers, with a grassy VFS on the outer edge and large woody plants near the channel. One difference was that woody plants were also planted on the outer edge near the road at transect S2, likely because the buffer was wider and therefore had more space for planting. Similar major tree species were found at both transects including species well-adapted to riparian environment and tolerant of high water levels such as dawn redwood and willow. Other tree species included those commonly used in traditional Chinese gardens such as soapberry, Chinese tallow and ginko, which have high aesthetic values in addition to ecological values. While the buffers at both transect included a grassy VFS on the outer edge, the grassy area at transect S2 looked less maintained with wild grasses and weeds such Japanese hop, whereas the grassy area at transect E2 had recognizable artificially planted grasses such as Chinese lilyurf. Similarly, shrubs commonly used in Chinese gardens such as sacred bamboo, grossy privet and Korean boxwood were also found along the boardwalk at transect E2, suggesting that the buffer at transect E2 had a higher level of artificial intervention compared to the buffer at transect S2. Overall, the buffers at both transect had similar plant composition and spatial arrangement and although we were unable to measure directly the effectiveness of the vegetated buffers due to limitations in equipment and training, we did observe signs of best management practices (BMPs) for sediment trapping and nutrient removal in the buffer design at both transects such as the incorporation of grassy VFSs (Castelle et al., 1994; Liu et al., 2008).

As for surrounding land use, S2 was mainly composed of green/open space and roads with little commercial or residential development. However, with predicted urbanization such as the construction of a major metro line nearby, the southern edge is likely to be confronted by urban encroachment, which may bring negative ecological impacts such as the decline of fish populations in the rivers as some studies have shown (Wang et al., 2006). On the other hand, while the current buffer design generally satisfies the physical requirements (i.e. slope and width) of a riparian buffer in terms of effective sediment trapping and nutrient removal, it was nevertheless relatively simple with less aesthetic value and accessibility. For example, to increase the social and ecological status of Xixi wetland, Qu et al. (2015) suggested that the wetland should be "separate and visible" from the city. However, the current single planting mode likely due to the fact that it is located right next to a road reduces its ornamental and recreational values. In this regard, the buffer at transect E2 had an easily accessible boardwalk with a complex planting scheme, therefore having higher aesthetic and reactional values (Appendix B). However, in accordance with the higher level of development in the buffer zone as well as on the eastern edge as a whole, we also observed some concerning trends. While the visual appearance of the water samples collected at both buffers did not differ very much, we observed a few locations with apparent water pollution problems in site E2, which were often next to commercial buildings or major roads. Although some studies showed that water quality in Xixi wetland has seen considerable improvement from poor (grade V) to acceptable as drinking water source and fish habitat (grade II-VI) due to restoration efforts led by the government since 2003 (Li et al., 2016), advancing development both inside the park and in the buffer zone poses a serious concern to the water quality in the wetland, as we have noticed during our field trip. Overall, we found that the buffer zone on the eastern edge is better planned as it is in fact part of the master planning of an "outer protection zone" for Xixi wetland with specific stipulations of floor area ratio and construction density (Qu et al., 2015). In a way, we think the buffer zone on the southern edge may learn from the buffer design on the eastern edge through incorporating structures with low environmental impacts such as boardwalks, with the caveat of avoiding overdevelopment, to enhance the functions of the buffer both as an ecological buffering zone and as a connection between the wetland and the city.

Conclusion

For this project, we mainly used field observation and literature summary to compile information about the current edge condition of Xixi wetland and research on the wetland's ecological restoration. Due to time constraint and difficulty to access the topographical and hydrological data, our study is limited to wetland area. While we managed to create a watershed map and identify inflows and outflows through spatial modelling in ArcGIS using digital elevation and hydrological network data, to better understand the water circulation and areas contributing to runoff pollution in the wetland, we think it will be beneficial to expand the analysis to the whole watershed in future studies.

The buffer areas we investigated in this study each had their own unique site conditions in terms of the hydrological condition and adjacent land use. Both buffers generally satisfied the physical requirements (i.e. slope and width) of riparian buffers for buffer functions such as sediment trapping and nutrient removal. Additionally, both had similar composition and spatial arrangement of vegetation, except that the buffer on the east edge showed a higher level of artificial intervention and planning. We think the buffer zone on the south edge may learn from the buffer design on the east edge by incorporating structures with low environmental impacts such as boardwalks to increase accessibility and social values of the riparian buffer. However, the higher level of artificial intervention on the east edge also has significant drawbacks as overdevelopment encroaches the natural habitats in the wetland and brings extra environmental concerns such as water pollution. Ultimately, it is important to find the balance between conservation and development for constructing effective riparian buffer in an urban wetland.

Appendices

Appendix A: Water samples collected from rivers and streams inside the wetland park

Appendix B: Boardwalk at transect E2

References

Liu et al. (2008). Major Factors Influencing the Efficacy of Vegetated Buffers on Sediment Trapping: A Review and Analysis. J. Environ. Qual. 37:1667–1674 (2008). doi:10.2134/jeq2007.0437

Castelle, A. J., Johnson, A. W., & Conolly, C. (1994). Wetland and Stream Buffer Size Requirements-A Review. *Journal of Environmental Quality*, *23*(5), 878–882. https://doi.org/10.2134/jeq1994.00472425002300050004x

Li et al. (2015). Study on Landscape Health of Urban Wetland Based on Landscape Structure and Water Environment: a Case Study of Xixi Wetland("基于结构和水环境的城市湿地景观健康研究——以西溪湿地公园为例")

Li et al. (2016). Water Quality Evaluation and Trend Analysis in Hangzhou Xixi Wetland ("杭州西溪湿地水质评价及变化趋势分析")

He and Li (2009). Community Structure of Phytoplankton and its relation with water quality in Xixi Wetland For The First Project Area, Hangzhou ("杭州西溪湿地首期工程区浮游植物群落结构及水质关系").

Xu et al. (2019). Hidden Loss of Wetlands in China. Current Biology. 29(18): 3065-3071 (2019). https://doi.org/10.1016/j.cub.2019.07.053

An et al. (2007). China's Natural Wetlands: Past Problems, Current Status and Future Challenges. AMBIO: A J. of the Human Environment, 36(4):335-342 (2007). https://doi.org/10.1579/0044-7447(2007)36[335:CNWPPC]2.0.CO;2

Lin et al. (2008). Research on recreational value evaluation of urban wetland in Hangzhou: cases study of Westlake and Xixi Wetland. ("杭州城市湿地游憩价值评价研究——以西湖和西溪湿地为例")

Gao et al. (2006). The Practices and Improvements of the Xixi National Wetland Park Model, Hangzhou [J]. *Wetland Science & Management*, 06(2): 56.

Zhang et al. (2020). Ecological Revetment Reconstruction Scheme of the Xixi National Wetland Park [J]. *Wetland Science & Management*, 16(1): 14.

Wang et al. (2006). Fish Resources in Xixi Wetland and Conservation Strategy [J]. *Wetland Science & Management*, 14(1): 22-23.

Qu et al. (2015). Effectiveness Study on the Spatial Morphology Built Pattern of the East Wing of the Peripheral Protection Zone of Xixi Wetland. ("西溪湿地外围保护带东翼的空间形态建成格局的效应研究")