*Eco Cities* (2022) Volume 3 Issue 1, *10 pages*.
doi: 10.54517/ec.v3i1.1857

ORIGINAL RESEARCH ARTICLE

# The return of river life—Urban river ecosystem restoration based on biodiversity enhancement

***Xingzhong Yuan[1*], Enrui Jia[2], Yangjing Liu[3], Song Chen[4]***

*[*1] School of Architecture and Urban Planning, Chongqing University, Chongqing 400000, China. E-mail: 1072000659@qq.com*
*[2] Wetland Protection Technology Research Institute of Tianze, Beijing 100000, China.*
*[3] Qianzhou Ecological Research Institute of Chongqing, Chongqing 400000, China.*
*[4] Haikou Wetland Protection Management Center, Haikou 570100, Hainan, China.*

## ABSTRACT

Biodiversity is the immune system of river ecological health. Restoration and improvement of urban river biodiversity and the return of life to rivers are the main goals and important tasks of river ecosystem restoration. Taking the Wuyuan River located in Xiuying District, Haikou City, as the research object, based on the ecological environment and biodiversity background before river restoration, the design technology and practice of Wuyuan River ecosystem restoration were discussed, and four strategies of ecological restoration were put forward: 1) River ecological restoration—three-dimensional ecological space reconstruction. 2) Riparian ecological restoration—flexible ecological riparian design. 3) River-wetland synergy—River-wetland complex construction. 4) Multi-functional habitat restoration—life landscape river reconstruction. Based on the goal of biodiversity improvement, the innovative path and mode of urban river ecosystem restoration were explored from the perspective of life-landscape river restoration. Finally, the biodiversity of the Wuyuan River after restoration was evaluated. The results showed that the habitat types of the Wuyuan River after restoration were diverse, the habitat quality was good, and the improvement effect of biodiversity was obvious. The practice of ecological restoration shows that urban river ecological restoration aimed at the improvement of biodiversity is more conducive to the overall protection of urban river ecosystems and the optimization and improvement of river landscape quality.

***Keywords:*** landscape architecture; urban rivers; river ecosystem restoration; river habitat; biodiversity; Wuyuan River; Haikou city

## 1. Introduction

Due to unreasonable utilization of water resources, construction of water conservancy and hydropower projects, water pollution, and changes in urban land use patterns, many rivers have been damaged[1]. River restoration is an important means to improve the physical and ecological conditions of degraded urban rivers[2]. In recent decades, Germany has vigorously carried out river ecological restoration guided by comprehensive objectives such as repairing the structure and function of the river ecosystem and improving the quality of the river landscape[3,4]. Japan carried out a series of multi-natural river governance practices in the 1980s[5]. In

**ARTICLE INFO**
Received: December 28, 2021 | Accepted: January 20, 2022 | Available online: February 14, 2022

**CITATION**
Yuan X, Jia E, Liu Y, et al. The return of river life—Urban river ecosystem restoration based on biodiversity enhancement. Eco Cities 2022; 3(1): 10 pages.

China, river ecological restoration has been paid more and more attention.

From the application of eco-hydraulic principles in river ecological restoration to river ecological restoration by letting nature do the work[6], there has been a transformation from engineering governance to ecological restoration in recent years. However, as an important support for river ecosystem health, biodiversity has been neglected in river ecological restoration. Due to insufficient understanding of river biodiversity, how to effectively improve biodiversity in river ecological restoration lacks scientific guidance, and research on relevant design methods and technical systems is also weak[7,8].

The author took the Wuyuan River, which is located in the Xiuying district of Haikou City, as the object to study the river's ecological restoration. Since April 2017, the author's team has started the practice of ecological restoration of the Wuyuan River on the basis of completing the ecological restoration design of the Wuyuan River. Before the author, based on the analysis of Wuyuan River restoration ecological environment and biodiversity, on the basis of background, target based on biological diversity, from the perspective of life landscape river restoration, explore the innovation of the urban river ecosystem restoration path and mode, so as to provide river ecosystem restoration and biodiversity to provide a scientific basis and technical reference to ascend.

# 2. Overview of the study area

## 2.1. Geographical location and environment

The Wuyuan River is a river flowing into the sea in Haikou City, Hainan Province. It originates from Dongcheng Village, Yongxing Town, Xiuying District, western Haikou City, and flows into Haikou Bay from the north side of Binhai Road, Houhai Village, and Xinhai Township. It is between the Yangshan volcanic lava wetland area in the south of Haikou city and the important ecological corridors. The watershed area is 84 $km^2$, the main stream is 27.29 km long, and the downstream reaches are affected by ocean tides. The Wuyuan River basin is a hilly plain landform; the terrain is high in the southeast and low in the northwest. The river is 5–20 m wide, with an average gradient of 3.63‰ and an annual runoff of 1.12 $m^3/s$. In the past, due to the requirements of flood control and drainage, 3.2 km of five from the outlet of Yongzhuang Reservoir to Yehai Avenue was hardened. The middle and lower reaches of the river invaded the channel seriously. In 2016, Haikou City carried out water environment control construction in cooperation with the Nantu River diversion project. As of February 2017, it had completed the construction of 3.3 km of downstream main sewage pipe, river dredging, and stone cage net bank protection, which made the downstream river banks straight and stiff, the river habitat type single, and the landscape quality poor. Before the implementation of ecological restoration, the overall water quality of the Wuyuan River was V-class, and water pollution was serious.

## 2.2. Background status of biodiversity

In 2016, the vegetation type of Wuyuan River before restoration was single, and the riparian vegetation in the middle and upper reaches was dominated by sparse shrub. The riparian vegetation in the downstream and estuarine sections is dominated by sparse semi-mangrove plants. There were 427 species of wild vascular plants in Wuyuan River before restoration, including 10 species of ferns and 417 species of angiosperm. Pistia Stratiotes and Eichhornia Crassipes caused oxygen hypoxia in many sections of stratiotes' rivers. Due to river pollution and unitary habitat, wetland plant species are few. Before restoration, there were 154 species of wild terrestrial vertebrates in the Wuyuan River, including 11 species of mammals, 82 species of birds, 8 species of reptiles and 9 species of amphibians.

# 3. Repair the target and policy

The objective vision of ecological restoration of the Wuyuan River is to restore the degraded river habitat, ensure the natural sinuous nature of the river

longitudinal space and the gradient structure of the natural habitat in the lateral space, and increase the diversity of the river habitat types in terms of overall spatial form control. Increase the biodiversity of the river, realize the return of river life, build the Wuyuan River into a model of an urban landscape river, and make it truly the source of life and the source of ecology.

Focusing on the goal of "river life regression—improving river biodiversity", an SMFIM strategy for ecological restoration was proposed (**Figure 1**).

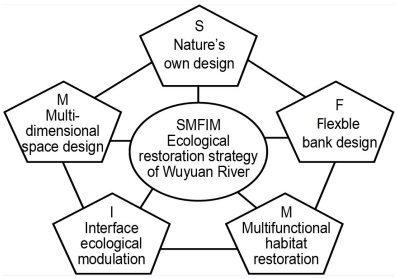


**Figure 1.** SMFIM strategy framework for ecological restoration of Wuyuan River.

Self-design of Nature: Attach importance to the self-design ability of river ecosystems dominated by natural forces such as flood processes, tides, wind, and biological transmission, and follow the principle that "nature is mother and time is father"[9].

Multidimensional Space Design: Emphasizing the vertical spatial dimension of ecological connectivity from upstream to downstream[10], following the process from river deep water to shallow water, the change of ecological gradient in the lateral space of riparian zone, transition highland and highland can strengthen the vertical ecological exchange from water surface to bed bottom to undercurrent layer, and rebuild the river landscape with meandering and changeable multi-landscape levels and multi-ecological sequences.

Flexible Riparian Design: For the hardening and channelization of the current riverbank and to cope with the tropics, the flexible design method and technology are used to rebuild the flexible river bank with resilience to the typhoon.

Interface ecological control regulation: Interface is an important ecological ecotone[11]. The theory and technology of interface ecological regulation are applied to ecological restoration of riparian interfaces, and the design of crossing interfaces—the construction of multi-zone and multi-function buffer systems—is proposed.

Multifunctional habitat restoration: Habitat restoration is very important for the improvement of river biodiversity[12], especially the restoration of habitats with multiple functions such as habitation, shelter, and foraging, which is an important strategy for river ecological restoration.

# 4. Design and practice of river ecosystem restoration

## 4.1. River ecological restoration—Reconstruction of three-dimensional ecological space

Vertical dimension: restoration of meandering rivers with ecological connectivity. At the scale of the Wuyuan River basin and the whole reach, ecological conservation is the priority of the water source and species pool in the source reach in order to ensure ecological connectivity and integrity of the river longitudinal dimension. On the premise of retaining the original landform in the upper reaches, the riverbank multi-pond system is designed to purify the non-point source pollution in the upper reaches and provide habitats for amphibians and birds. In the middle reaches, the wide floodplain and alternating shoal-pool river habitat pattern should be retained to restore continuous riparian vegetation. In the lower reaches, the straight channelized reach is restored to the longitudinal natural meander, and the shoal-deep pool longitudinal habitat pattern on the mesoscale is reconstructed. Sandbars in the river center are restored to ensure the diversity of river habitats along the longitudinal gradient and provide habitat and shelter for fish, birds, and aquatic plants[13]. River connectivity in the vertical dimension. In addition, the tidal dynamics of the ocean can be maintained, and aquatic organisms that need brackish water

habitat can live in the brackish water mixed reach of the lower reaches.

Lateral dimension-habitat gradient reconstruction from water to land. In the riparian zone with a width of 15 m on both sides of the Wuyuan River, an ecological buffer zone was constructed for the interception and purification of surface runoff and the improvement of biodiversity in the riparian zone. In order to guarantee leisure, recreation, and natural education space, a 15-meter-wide space is planned for the riparian plateau above the riparian zone. In order to ensure the riverside ecological space is 30 m wide on both sides, design and implement the multi-functional ecological buffer zone from the shallow water area to the riverbank zone to transition from highland to highland. The vegetation in shallow water mainly recovered naturally. Cyperus malaccensis, Typha orientalis, and other emergent species of Cyperus malaccensis were sparsely planted in the water line and low-riparian areas. Create volcanic stone pore spaces that allow water ferns (Ceratopteris thalictroides) to recover naturally. The upper part of the riparian belt is dominated by sparse forest meadows and forms a riparian ecological protection belt with the forest belt of transition highland. In the lateral dimension, the hard bank structure is removed, which ensures the ecological effect of periodic flood pulses.

Vertical dimension—maintenance of vertical and vertical ecological exchange. In order to ensure the vertical ecological connectivity of the river, the planning avoids the hard bedding of the river bed, ensures the gravel and gravel bottom of the river bed in the upper reaches, restores the sandy substrate of the riverbed in the middle and lower reaches,in the middle and lower reaches, maintains the hydrologic flow along the vertical gradient, realizes the vertical exchange of benthic organisms and nutrients, and provides the necessary conditions for the survival of fish and other aquatic organisms.

## 4.2. Riparian ecological restoration—Flexible ecological riparian design

Digestion of hard river banks—design and ecological treatment of flexible river banks Multi-hole flexible river bank reconstruction is an important means to conserve and enhance biodiversity. To break the hard cement steep bank and downstream straight flat artificial slope, flexible ecological technologies, such as flexible landscape space construction, flexible material application, and flexible construction technology, are used to reconstruct the flexible space of the river bank. From the water line, riparian zone, and transition highland, the multi-zone and multi-layer composite mixed vegetation forms the flexible landscape space of the river bank. Flexible materials such as volcanic stone and wooden remains are used to form a multi-cavity space, which serves as a habitat and shelter for aquatic insects, shrimp, crabs, and fish.

Design and cross-interface construction of a multi-belt and multi-function buffer system. Based on the surface runoff, nutrient flow, and species flow across the interface, a comprehensive design and restoration were carried out from the aspects of interface substrate, width, biological community composition, and ecological structure, and the design and construction of a multi-zone and multi-functional buffer system across the riparian interface was proposed[14] (**Figure 2**). Design interface width is 15 m, through the submerged plant along the elevation gradient belt-quite wet meadow vegetation zone-banks of the river water, river bank scrub meadow, riparian woodlands shrubland-take of riparian forest community structure design, implement river bank protection, intercept surface runoff and solid purification, biodiversity conservation, landscaping, leisure, recreation, etc.

Multi-functional interface thinking restoration of life complex in floodplain. A floodplain, located on one side or both sides of the main channel of the riverbed, is an exposed beach that is inundated during floods and exposed during dry periods. It is one of the types of riparian ecological interface and often forms diversified small and micro hydrographic geomorphic structures and small and micro habitat types, supporting a variety of river organisms[15].

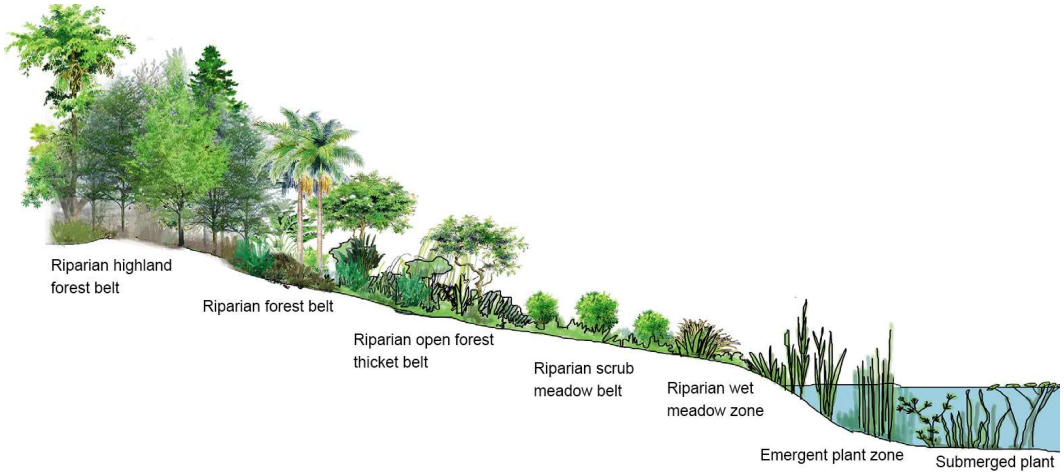


**Figure 2.** Model diagram of riparian multi-stripe, multi-functional buffer system.

The design of the "complex of life in floodplain" proposed by the author combines the growth needs of wetland plants as well as aquatic invertebrates, fish, and waterbirds foraging and spawning habitat requirements. According to the hydrological changes, through the terrain and plant design, flood land depressions, flood land ponds, flood land pebble beaches, and back swamp habitat types organic inlay, wet meadows, dry grass, and bushes flood land vegetation types organic combination, forming rich biodiversity, "mosaic" flood land life full of vitality.

## 4.3. River-wetland synergy-river-wetland complex construction

There are various types of river wetlands, which are associated with the hydrological and ecological functions of the main river, constituting the "river-wetland complex"[16]. A river-wetland complex is formed by river flooding. The river wetland of the Wuyuan River extends downstream until it is connected with the estuarine coastal wetland to form a complete river wetland system. Based on the collaborative symbiosis of rivers and wetlands, the design and construction of the river-wetland complex (**Figure 3**) were completed. Reserve, repair, and rebuild sandbanks, floodplain depressions, floodplain ponds, and lagoons in the Wuyuan River. Restoration and reconstruction of riparian reservoirs and riparian upland marshes in riparian areas. The reconstruction of the wetland pond group and sand-forest pond complex wetland system was done by using abandoned sites left by sand mining on both sides of Binhai Road. A series of small and micro wetlands were built on both sides of the middle and lower reaches of the river, including a rainwater garden, a rainwater retention wetland, a biological ditch, a biological pond (frog pond, dragonfly pond), a biological depression, a tree pond depression, etc[17]. These wetlands not only absorb the river flood but also purify the land surface runoff and provide a good habitat for diverse species.

## 4.4. Multifunctional habitat restoration—Life landscape river reconstruction

Multi-hydrologic form and multi-hole structure—multi-functional habitat design for aquatic organisms. According to the design objectives of river hydrology, flood, bed sediment, and multifunctional habitat, the river passage, water level regulation, and biogenesis were constructed in the lower reaches of the Wuyuan River. The multi-hydrographic and multi-pore structure of the volcanic stone snake bridge (**Figure 4**) is integrated with a total length of about 25.0 m, including the extension on both sides. A 2.0-meter-wide water passage is designed on 1/3 of the right bank of the Snake Bridge. The upstream of Snake Bridge forms a standing water and shallow water environment, which can provide a growth environment for Ottelia cordata, water fern, and other plants.

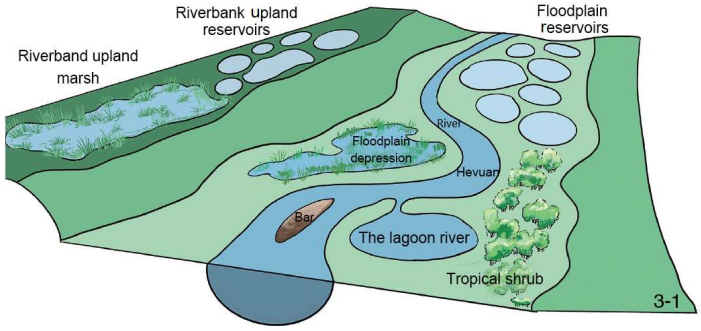


**Figure 3-1.** River-wetland complex model diagram of Wuyuan River.


**Figure 3-2.** Real picture after restoration.

**Figurre 4-1**. Volcanic stone snake bridge after completion.


**Figure 4-2.** Ottelia cordata, a national second class protected plant growing in the upstream of the volcanic stone snake bridge.

Habitat gradient reconstruction from water to land: symbiosis between plants and birds[18]. In the long-term co-evolution of plants and birds in river ecosystems, plants provide habitat, shelter, and food sources for birds, while birds serve as propagators of riparian plants. According to the habitat gradient from water to land, the birds in the river ecosystem can be divided into: waterbirds (including deep water birds and shallow water birds), water birds, riparian grassland birds and scrub birds, and riparian forest birds. Based on the background survey of birds in the Wuyuan River before restoration, the plant-bird complex ecosystem was designed (**Table 1**, **Figure 5**). In the habitat gradient from water to land, waterbirds (peribirds, waders), parparian birds, riparian grassland birds, shrub birds, forest birds, and corresponding plants formed complex patterns. In this complex system, the cooperative symbiosis between plants and birds not only improves bird diversity but also maintains plant diversity. After the ecological restoration of the Wuyuan River, the diversity of riparian plant species increased, which was related to the spread of birds to plant propagands. It's one of nature's self-designing mechanisms.

**Table 1.** Plant-bird complex pattern along the gradient from water to land in Wuyuan River

| Habitat gradient space | Group patterns of plant-bird | Main plants of each species group | Main birds of each species group |
|---|---|---|---|
| The deepwater area | Submerged and floating plants-swimming birds | Water Cauliflower, Ottelia alismoides, Ludwigia peploides | Tachybaptus ruficollis, Gallinula chloropus, Dendrocygna javanica, Cygnus columbianus, et al. |
| Bank front | Emergent plants-parching birds | Water Cauliflower, Water fern, Waterwheel front, Equisetum ramosissimum | Egretta garzetta, Ardeola bacchus, Amaurornis phoenicurus, Gallirallus striatus, Gallicrex cinerea, Charadrius mongolus, C. leschenaultia, et al. |
| Riparian scrub meadow | Herbs, shrubs-grass birds, scrub birds | Polygonum orientale, Lythrum salicaria, Rotala rotundifolia, Cyperus malaccensis, Typha angustifolia, Scirpus validus, Heleocharis plantagineiformis, Eclipta prostrata, Enydra fluctuans, Lindernia antipoda, Hygrophila ringens, Acrostichum aureum, et al. | Motacilla alba, M. flava, Alcedo atthis, Halcyon smyrnensis, H. pileata, Ceryle rudis, Phoenicurus auroreus |

**Table 1.** Continued.

| Habitat gradient space | Group patterns of plant-bird | Main plants of each species group | Main birds of each species group |
|---|---|---|---|
| Riparian scrub grass meadow | Herbaceous plants, shrubs-grasslands birds, scrub birds | Cyperus rotundus, Cynodon dactylon, Miscanthus sinensis, Oplismenus compositus, Ipomoea pes-caprae, Alocasia macrorrhiza, Cephalanthus tetrandrus, Rosa chinensis, Bougainvillea spectabilis, Senna tora, Caesalpinia decapetala, Paliurus ramosissimus, Buddleja lindleyana, Gonostegia hirta, Pandanus tectorius | Centropus sinensis, C. bengalensis, Eudynamys scolopaceus, Lanius cristatus, L. schach, Cisticola juncidis, Alauda gulgula, Pycnonotus sinensis, Zosterops japonicus, Lonchura striata, Passer montanus, Anthus richardi |
| Riparian and transitional upland forest belts | Forests-songbirds, raptors | Syzygium hainanense, Pongamia pinnata, Bombax ceiba, Hibiscus tiliaceus, Triadica sebifera, Ficus hispida, Melia azedarach, Plumeria rubra, Cerbera manghas, Radermachera hainanensis, Cocos nucifera | Parus major, Urocissa erythrorhyncha, Phylloscopus proregulus, Dark green embroidered-eye bird, Turdus merula, Spilopelia chinensis, Elanus caeruleus, Buteo buteo, Otus lettia, Gallus gallu, Francolinus pintadeanus |

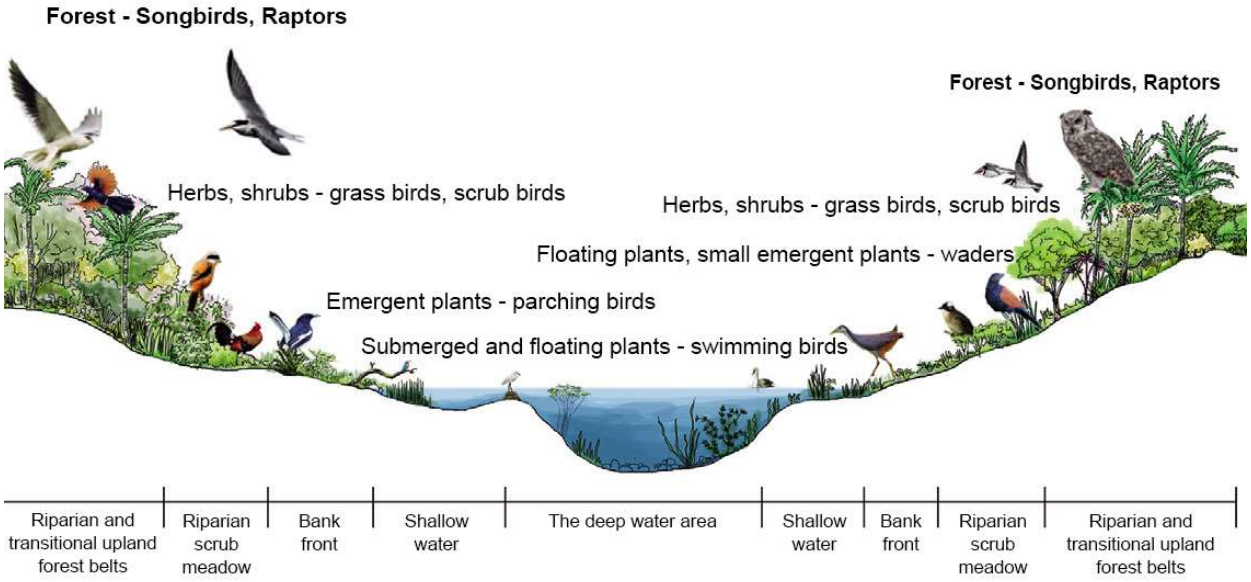


**Figure 5.** Habitat gradient reconstruction from water to land: Design model of plant-bird complex ecosystem in Wuyuan River.

# 5. Assessment of restoration effect of river ecosystem

## 5.1. Comparison of river habitat quality before and after restoration

From river habitat type diversity, habitat heterogeneity, and riparian habitat quality, river landscape quality, etc., after the implementation of ecological restoration evaluation, the results showed that (**Table 2**), Wuyuan River increased diversity of habitat types (**Figure 6**), river environment heterogeneity, river and riparian habitat quality optimization, waterfront space habitat quality, and river landscape quality are good. The restored Wuyuan River presents good landscape characteristics of a "life landscape river".

## 5.2. Restoration effect of river biodiversity

The ecological restoration of the Wuyuan River began in early 2017. Three years after the restoration, the improvement of biodiversity was obvious, and the species of animals and plants increased significantly (**Table 3**).

The author mainly analyzes and evaluates the wildlife in the Wuyuan River. The change in plant diversity was reflected in the increase in vegetation types, including the reappearance of submerged plants such as cauliflower and lianas such as thick rattan, which resulted in a significant increase in community types and a continuous increase in

riparian vegetation. After restoration, 21 species of higher vascular plants were added, mainly aquatic plants and riparian plants. Before restoration, water ferns were present only in the headwaters of the upstream star distribution. After restoration, five sites were found in the upper and lower reaches of the Wuyuan River. Recent investigations indicated that the distribution of water fern was further spreading to the small and micro wetlands on both sides of the river bank. After more than two years of restoration,

**Table 2.** Changes of river habitat before and after ecological restoration of the Wuyuan River

| Repair period | Diversity of biological types | Habitat heterogeneity | Habitat Heterogeneity | Riparian habitat quality | The quality of waterfront spatial habitat | The landscape quality of river habitat |
|---|---|---|---|---|---|---|
| Before the repair | Poor | Lower. The river channel is straight, with straight banks, rigid bank protection and a few artificial plantings, both horizontal space and vertical space are low in heterogeneity. | Poorer. River channel is canalizated, and the water quality pollution is more serious. | Poorer. Bank hardening, or stone cage net shore led to straight river bank, river plant species poor, poor birds. | Poorer. Dirty, messy, poor, low vegetation coverage. | Poorer. Poor visual viewing and sound quality. |
| After the repair | Diverse | High. The river channel is meandering and varied, the riverbank topography is rich, and the multi layer composite mixed communities form the high environmental heterogeneity of a horizontal and vertical space. | Better. The river channel is natural in form, complete in structure, with obvious water quality improved, excellent ecological function. | Better. Riparian habitat quality is good. All hardened banks are softened and ecologic, and the coverage of riparian vegetation is high and continuous, and the riparian plant species and birds are abundant. | Better. Waterfront space habitat quality is good. The waterfront ecological space is effectively controlled and managed, and the micro-wetland and vegetation cover in the waterfront space greatly improve the quality of its habitat. | Better. The landscape quality of river habitat is good. The landscape is well arranged, and the ecological sequence is complete. The visual viewing effect is good and the sound quality is better. |


**Figure 6.** Various types of river habitat after restoration of the Wuyuan River.

**Table 3.** Comparison of biodiversity before and after ecological restoration of Wuyuan River

| Year of repair | Higher vascular plant species | Bird species | Rare and endangered endemic plants | Rare and endangered endemic animals |
|---|---|---|---|---|
| 2016 (Before the repair) | 427 | 82 | One kind of national second-class protected plant is Water fern. Four kinds of Hainan provincial protected plants are Antiaris toxicaria, Halogen fern, Taxillus sutchuenensis, Bischofia Javanica. | Ten species of wild animals under state class II key protection are red prairie chicken, brown wing Rhododendron, little Rhododendron, Pernis ptilorhynchus, black-winged kite, Accipiter badius, common buzzard, Falco tinnunculus, F. peregrinus, Hoplobatrachus rugulosus. |
| 2019 (After the repair) | 448 | 115 | There are three kinds of national second-class protected plants, including Water fern, Water cauliflower and Oryza Rufipogon. Four species of Hainan provincial protected plants are Antiaris toxicaria, Halogen fern, Taxillus sutchuenensis, Bischofia Javanica. | Fourteen species of wild animals under state class II key protection are little swan, red prairie chicken, brown wings Rhododendron, little Rhododendron, Pernis ptilorhynchus, black-winged kite, Accipiter badius, common buzzard, Falco tinnunculus, F. peregrinus, Pandion haliaetus, screech-owl, tiger frog, Anguilla marmorata. |

in the summer of 2019, a number of wild plants—Common wild rice communities were found near Changming Village in the middle reaches of Wuyuan River, covering an area of about 600 $m^2$, which is the largest known wild rice species group in Haikou city and the closest distribution point of wild rice to the

city center. Wild rice grows high in the floodplain of Wuyuan River and symbiosis with wetland plants such as Leersia Hexandra and wild water chestnuts. The increase of these plant species depends on the original soil seed bank or the spread of water power, wind power and animals. For example, the water cauliflower is spread from the upper Yangshan region to the middle and lower reaches by water power. Thick vines typically rely on the original soil seed bank for restoration.

After restoration, 33 species of birds were added, including 12 wetland birds. These include chestnut duck, small grebe, Mongolian sand plover, iron-billed sand plover, blue-breasted crake, Dong Chicken, Oriental Charadrius Veredus, Numenius Minutus, Glareola Maldivarum, Chlidonias Hybridus, Butorides Striata, and Ardea Purpurea, among which 10 species of birds were waders, indicating that the restoration and reconstruction of the shoal-deep pool habitat pattern, the sandbank in the river center, and the river-wetland complex had an obvious effect on the habitat of waders. Forest bird species also increased significantly, indicating riparian thickets. The restoration and reconstruction of meadows and riparian forest belts produced good results. The species of forest birds increased obviously, indicating that the restoration of riparian thicket meadows and riparian forest belts produced good results. In the lower reaches of the Wuyuan River, the sand-forest complex wetland system was reconstructed by using abandoned pits and sand piles left by sand mining. In the spring of 2018, Merops viridis and Chestnut viridis were restored. Philippinus recreated the Wuyuan River, and the cliff of sand dunes became an excellent nesting and breeding habitat for the bee-tiger population in 2019. This has increased to more than 100. The sand-forest pond complex system can not only meet the needs of some herons and two species of bee-tigers for nesting and habitat but also become the habitat of forest birds and raptors. After the restoration, three species of rare and endangered birds were added, namely osprey, collared owl, and cygnet, as well as amphibians and fish. After the restoration, there are 14 species of national Class II key protected wild animals in the Wuyuan River, which is very rare in urban rivers in China.

The improvement of aquatic habitat, the restoration of natural flood processes, flood pulse processes, and tidal dynamics make the living environment of fish better. Because Wuyuan River is a sea-flowing river, the ocean tidal influence is in the estuary and downstream reaches of Wuyuan River. As one of the regulatory factors of the ecosystem, there is no water blocking structure in the Wuyuan River after restoration, which enables the daily ebb and flow of the ocean tidal dynamic influence to be realized. Mudfish and migratory fish, including eel anguilliform, a national class II protected animal, appear in the lower reaches of the Wuyuan River.

# 6. Conclusions and prospects

The author mainly carried out the design and practice of biodiversity improvement in the Wuyuan River through four aspects of ecological restoration: 1) River ecological restoration—reconstruction of three-dimensional ecological space. 2) The river Ecological restoration: flexible ecological river bank design. 3) River-wetland synergy-river-wetland complex construction. 4) Multi-functional habitat restoration-life landscape river reconstruction. At macro, meso, and micro scales, the restoration design and practice of rivers and their habitats are aimed at restoring and enhancing river biodiversity. In the past three years, through the implementation of a series of ecological restoration projects, the river form of the Wuyuan River has become natural, the number of animal and plant species and population has increased, and the biodiversity has been significantly improved. The practice of ecological restoration in the Wuyuan River shows that, compared with rigid river management, ecological restoration based on the goal of biodiversity improvement is more conducive to the overall protection of the river ecosystem and the optimization and improvement of river landscape quality.

After restoration, the improvement of biodiversity in the Wuyuan River is related to the

increase of river habitat types and quality improvement at different spatial scales and environmental gradients, as well as the symbiosis among various biological groups such as plants, birds, fish, and insects' relationship building, which goes hand in hand. River ecological restoration should not only pay attention to the reconstruction of form and structure but also realize the restoration of function and process and establish the cooperative symbiotic relationship of the river life system so as to truly realize the regression of river life.

River restoration in China is still in the process of transforming from pollution control to ecosystem restoration. Scientific guidance and technical support are urgently needed for improving river biodiversity and optimizing ecosystem services. In the future, we also need to further understand the formation and maintenance mechanisms of river biodiversity and study how to effectively improve urban river biodiversity through the design and reconstruction of multi-functional habitats at different spatial scales.

## Conflict of interest

The authors declare no conflict of interest.

## References

1. Ni J, Liu Y. Ecological rehabilitation of damaged river system. Journal of Hydraulic Engineering 2006; 37(9): 1029–1037, 1043.
2. Bernhardt ES, Palmer MA. Restoring streams in an urbanizing world. Freshwater Biology 2007; 52: 738–751.
3. Dong Z, Sun D, Zhao J. Progress and prospect of eco-hydraulic engineering. Journal of Hydraulic Engineering 2014; 45(14): 1419–1426.
4. Xie Y, Lin Y. The re-naturalized restoration of urban river landscape—A case study of Isar-plan, Munich, Germany. Chinese Landscape Architecture 2015; 31(1): 55–59.
5. The Japan Foundation River Improvement Center. Construction method and key points of multi-natural type river construction. Zhou H, Du X, Li Y, et al. (translators). Beijing: China Water&Power Press; 2003.
6. Huang J, Zhang J. River eco-restoration with nature acting—Huhhot black river eco-landscape conceptual planning. Landscape Architecture 2018; 25(10): 86–91.
7. Van Der Velde G, Leuven RSEW, Ragas AMJ, et al. Living rivers: Trends and challenges in science and management. Hydrobiologia 2006; 565(1): 359–367.
8. Palmer M, Ruhi A. Linkages between flow regime, biota, and ecosystem processes: Implications for river restoration. Science 2019; 365(6459): 1–13.
9. Mitsch WJ, Wu X, Nairn RW, et al. Creating and restoring wetlands: A whole-ecosystem experiment inself-design. BioScience 1998; 48(12): 1019–1030.
10. Vannote RL, Minshall GW, Cummins KW, et al. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 1980; 37(1): 130–137.
11. Yuan X, Yuan J, Gao L, et al. Demonstration study on ecological restoration and landscape optimization of urban riverside littoral zone in the Three Gorges Reservoir area. Shanghai Urban Planning Review 2018; (6): 132–136.
12. Steven EG, Larsen EW. Ecological design of multifunctional open channels for flood control and conservation planning. Landscape and Urban Planning 2014; 131: 14–26.
13. Naiman RJ, Bilby RE. River ecology and management: Lessons from the pacific coastal ecoregion. New York: Springer-Verlag; 1998.
14. Ma G. Technical guidelines for wetland restoration in national wetland parks. Beijing: China Environmental Press; 2017.
15. Bisson PA, Montgomery DR, Buffington JM. Valley segments, stream reaches, and channel units. In: Hauer FR, Lamberti GA (editors). Methods in stream ecology. Oxford, UK: Academic Press; 2007.
16. Bornette G, Amoros C, Piégay H, et al. Ecological complexity of wetlands within a river landscape. Biological Conservation 1998; 85(1–2): 35–45.
17. Yuan X, Jia E, Chen S, et al. Wetland restoration analysis: Example of Wuyuan River in Haikou, Hainan province. Landscape Architecture Academic Journal 2019; (11): 2–6.
18. García D. Birds in ecological networks: Insights from bird-plant mutualistic interactions. Ardeola 2016; 63(1): 151–180.