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Landscape Ecological Restoration As A Strategy For Achieving Carbon Neutrality Target: A Critical Review From Yellow River Floodplain

Ma Yali, Adam Aruldewan S. Muthuveeran, Mohd Johari Mohd Yusof, Gao Yuxuan, Ma Lulu

Department of Landscape Architecture, Faculty of Design and Architecture, Universiti Putra Malaysia, Serdang, 43400, MALAYSIA

Corresponding Author Email: aruldewan@upm.edu.my

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Abstract

Floodplains are valuable natural resources for humankind, serving to regulate the ecology and environment of the region and providing irreplaceable direct and indirect services to humankind. However, in recent years, the ecological environment of the floodplains has been seriously disturbed and damaged by the combined effects of global climate change and anthropogenic disturbance, and degradation has become a major challenge to the sustainable development of the ecological environment. This resulted in a low ecosystem function and difficulties in meeting the needs of economic development in the floodplain areas. Based on the theories of landscape ecology, landscape ecological planning, sponge city, elastic landscape, and carbon neutrality, this study combines the goal of carbon neutrality with the ecological restoration of the Yellow River floodplain and improves its carbon sink capacity by optimising ecological restoration strategies to increase the contribution rate and promote the early realisation of carbon neutrality.

Keyword: Landscape Ecological Restoration, Yellow River, Floodplain, Carbon Neutrality

Introduction

Floodplains and large rivers provide essential ecosystem services that support life and have enabled human civilisations to prosper in fertile alluvial soils (Postel and Carpenter 1997; Schindler et al. 2014). However, affected by natural factors (soil erosion, climate change, secondary overhang) and human factors (urbanisation, land use), there are many problems in the ecological environment of the Yellow River floodplain, such as: significant increase in forest cover but low quality; predominantly arable land with low carbon sink efficiency; and reduction in floodplain wetlands after the completion of the Xiaolangdi reservoir. These existing problems will have a very large impact on the improvement of the climate environment. By optimising the ecological restoration strategy, not only these problems can be improved, but its carbon sink capacity and carbon cycle will also be significantly improved, thus promoting the realisation of the goal of carbon neutrality. The UN Climate Change Conference in Glasgow (COP26) identifies ecosystem conservation and restoration as an important strategy for achieving the objective. Over the past two decades, China has continued to restore the ecology of the Yellow River, which has a huge carbon sink potential and plays an important role in the carbon sink of terrestrial ecosystems and the process of carbon neutrality in Jinan.

However, few studies have been conducted on the ecological restoration of the Yellow River floodplain, and even fewer studies have been conducted to quantitatively monitor and optimise the restoration results. Second, while the carbon sink capacity and carbon sink value of forests and greenlands have become the focus of research in recent years, the carbon sink capacity of floodplain ecosystems has rarely been studied by scholars. Even fewer studies have analysed and optimised the ecological restoration strategy of the Yellow River floodplain based on quantification with the goal of carbon neutrality, as shown in *Figure 1.* Hence, this study focuses on optimising landscape ecological restoration strategies for the Yellow River floodplain in Jinan, based on the carbon neutrality target.

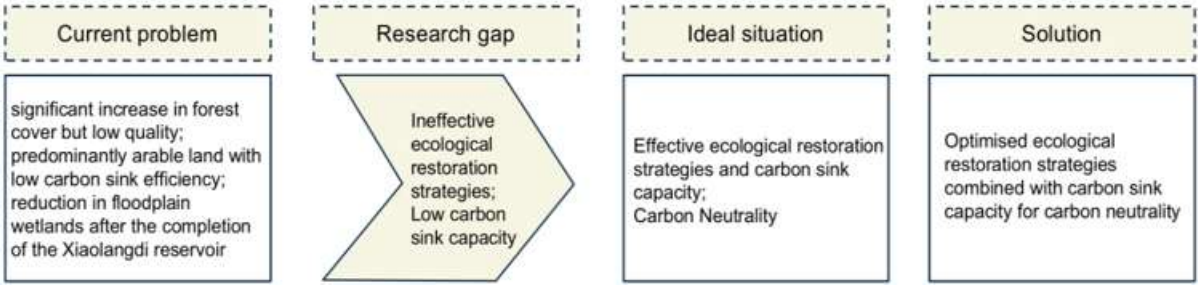


Figure 1.1: Study gap

Literature Review

Yellow River Floodplain

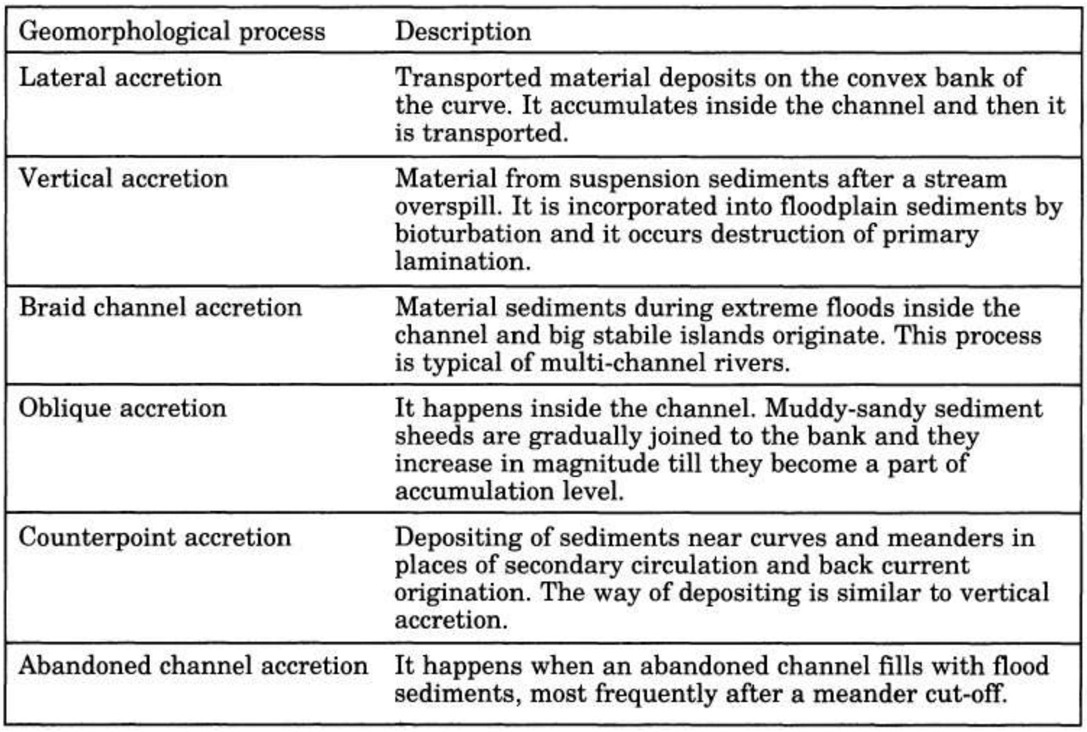
Floodplain

The floodplain is a typical community transition zone in the ecological structure of the river. It has the function of connecting the water area with the land area and is an important place for the survival of the animal and plant communities and the energy conversion of the river. In the context of landscape, the floodplain is a specific area typical of great dynamics of natural, especially fluvial, processes (Krizek et al., 2006).

The construction of an extensive floodplain requires large supplies of water and sediment; basin boundaries that supply these large quantities of material and provide the accommodation space necessary for extensive sediment storage; and long periods of time for accumulation and storage change of the large masses of sediment incorporated into floodplains, as detailed in *Table 2.1.*

Table 2.1

Natural Processes Forming the Floodplain According to Brierley, Fryirs (2005 modified)



Geomorphological process	Description
Lateral accretion	Transported material deposits on the convex bank of the curve. It accumulates inside the channel and then it is transported.
Vertical accretion	Material from suspension sediments after a stream overspill. It is incorporated into floodplain sediments by bioturbation and it occurs destruction of primary lamination.
Braid channel accretion	Material sediments during extreme floods inside the channel and big stabile islands originate. This process is typical of multi-channel rivers.
Oblique accretion	It happens inside the channel. Muddy-sandy sediment sheeds are gradually joined to the bank and they increase in magnitude till they become a part of accumulation level.
Counterpoint accretion	Depositing of sediments near curves and meanders in places of secondary circulation and back current origination. The way of depositing is similar to vertical accretion.
Abandoned channel accretion	It happens when an abandoned channel fills with flood sediments, most frequently after a meander cut-off.

Floodwaters bring large quantities of nutrients directly to the floodplain ecosystems and control the processes of floodplain sedimentation, influencing the evolution of hydrological and geomorphological patterns (*Table 2.2*).

Table 2.2

Floodplain Characteristics

Element	**Flood action**	**Characteristic**
Source of water	Ecological water source of wetlands, periodic flooding	The water system connecting the floodplain and the river can promote the water circulation of the wetland system and improve the water quality.
Soil	Sediment deposits are rich in nutrients	Through the leaching of water, the salinization of the soil is improved, and the physical and chemical environment of the Pushi soil is improved.
Landscape succession	Promoting the precious succession of wetlands	The time interval between two flood pulses controls the rate of landscape succession, maintaining wetland community diversity and high biomass.
Ecosystem	The degree of inundation has an impact on ecosystem diversity	Moderate flood biomes had the most types, the greatest diversity index and biomass.
Plant	Inundation makes the surface water layer thin and unstable	Swamp soil lacks oxygen, organic matter decomposes slowly and has few nutrients. Marsh plants have well-developed aerenchyma and adventitious roots

Generally, according to the geomorphological and hydrological characteristics, two types of floodplains may be defined (*Figure 2.3*): Hydrologic floodplain and Topographic floodplain (FISRWG, 1998).

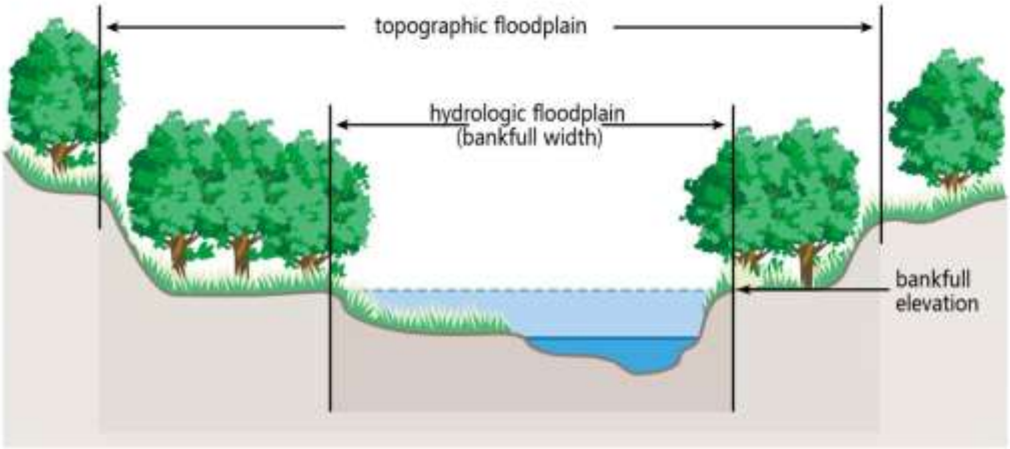


Figure 2.3: Hydrologic and Topographic Floodplain

Yellow River Floodplain

The floodplain of the lower Yellow River is 3154 km^2, accounting for 65% of the river channel area. There are more than 3.4 million acres of cultivated land in the floodplain, with a population of 1.9 million. The downstream floodplain is not only the place where the Yellow River flows through the flood, holds back flood, and settles sand, but also the home for the people in the beach to survive, and provide the unique ecological space of the North China Plain.

The floodplain in Shandong Province is an important part of the “two screens, three belts, and four areas” regional ecological security strategic pattern – “along the Yellow River protection zone”, and an important framework of the regional ecological barrier in Shandong Province. At present, there are two national and three provincial nature reserves in the lower floodplain of the Yellow River, and the floodplain provide unique natural ecological resources. There are more than 30 large and medium-sized cities such as Zhengzhou and Jinan on both sides of the river, with a population of more than 50 million, the urban ecological space is scarce, and there is an urgent need to get close to the Yellow River (Zhang, 2019).

Jinan is an important regional Centre city in the Yellow River basin and has an important strategic position in the whole ecosystem of the Yellow River. The total length of Yellow River in Jinan is 183.35 kilometres, including two floodplains in Changqing and Pingyin, involving seven counties (districts), namely, Pingyin, Changqing, Huaiyin, Tianqiao, Licheng, Zhangqiu and Jiyang. Among them, there is 51.28 km of the urban section (Huaiyin, Tianqiao, Licheng section), and the riverbed on both sides of the river is about 4~6 metres above the ground. There are cultivated land, forests, weeds and wetlands in the river floodplain, and the prominent feature is high trough and low diffusion, with depressions at the root of the dike and more depressions outside the dike, which is typical of a “secondary suspension river” (Yearbook, 2021).

The Yellow River floodplain in Jinan can be divided into three types: tender floodplain, lower floodplain, and higher floodplain, depending on the water cross section (Yu, 2020). As shown in *Figure 2.4*. Tender floodplain are very similar to wetlands and are more affected by seasonal inundation, while Lower floodplain and Higher floodplain are less affected.

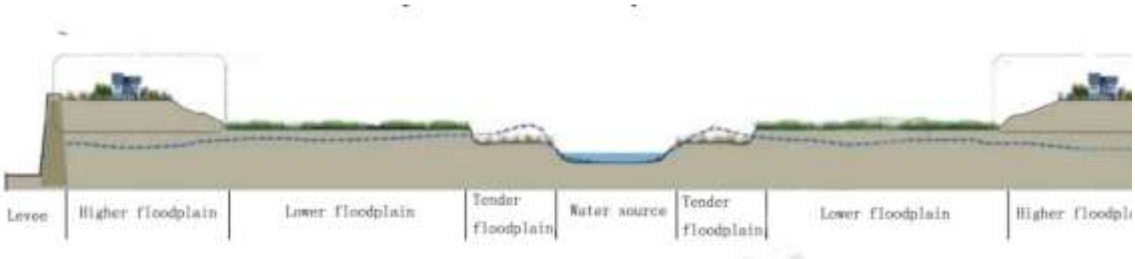


Figure 2.4: The Yellow River Floodplain

Landscape ecosystem of Yellow River Floodplain

The landscape ecosystem refers to a spatially distinct and interconnected area where ecological interactions occur among living organisms, including plants, animals, microorganisms, and their physical environment. It encompasses various ecological communities, habitats, and ecosystems within a defined geographical area, forming a complex and dynamic network of interactions and interdependencies.

In a landscape ecosystem, multiple ecological processes take place, such as nutrient cycling, energy flow, and ecological succession. These processes are influenced by the landscape's topography, climate, soil characteristics, and the presence of human activities and disturbances. The interactions between different ecosystems and habitats within the landscape contribute to the overall resilience and stability of the entire system.

Landscape ecosystems are essential for maintaining biodiversity, providing various ecosystem services such as water purification, pollination, and climate regulation, which support the well-being of human communities (Muthuveeran et. al., 2021). The concept of landscape ecosystem emphasises the importance of considering the broader landscape context when studying and managing ecological systems, recognising the interconnectedness of various components and the need for integrated conservation and management approaches.

The landscape ecosystem of the Yellow River Floodplain in Jinan is a diverse and ecologically significant area. It comprises components such as floodplains, wetlands, riparian vegetation, and aquatic ecosystems. The landscape ecosystem of the Yellow River Floodplain in Jinan serves vital functions and holds significant importance. Tender floodplain supports biodiversity, regulates floods, purifies water, and provides habitats for diverse wildlife. Lower floodplain and higher floodplain promote sustainable agriculture and offer recreational opportunities for ecotourism. Overall, the landscape ecosystem plays a crucial role in maintaining ecological balance, supporting livelihoods, and safeguarding China's cultural heritage.

The landscape ecosystem of the Yellow River Floodplain in Jinan faces various critical issues and challenges that pose threats to its ecological balance and long-term sustainability. These challenges arise from both human activities and environmental factors, and they require urgent attention and comprehensive solutions. Some of the key issues and challenges include habitat loss and fragmentation, soil erosion, conflicting land use, inadequate conservation efforts, and invasive species.

However, the current problems faced by the Yellow River floodplain ecosystem seriously limit its carbon sequestration capacity and high-quality development. In order to achieve high-quality development of the Yellow River Basin, China has issued a series of policy documents at different levels to lay the foundation and point out the direction for the ecological restoration of the Yellow River, as detailed in *Table 2.5.*

Table 2.5
Brief Description of Relevant Policy Document

Date	File Name	Related Content Description
29 July 2021	Shandong Province Land and Space Planning (2021-2035)	Adhere to the concept of a life community of mountains, rivers, forests, fields, lakes and grasses, coordinate and carry out major projects such as ecological restoration of land spaces such as the Yellow River Delta and along the Yellow River, and comprehensive improvement of important wetlands and shorelines to improve the connectivity and integrity of ecosystems and ensure the main functions of river and lake spaces. Promote the concentration of farmland, the concentration of construction land, and the efficient and intensive spatial form to create a healthy, attractive and high-quality land space.
22 August 2021	14th Five-Year" Ecological Environment Protection Plan of Shandong Province	Strengthen the comprehensive management of the water environment in the floodplain area and the main and tributary streams of the Yellow River. Coordinate the implementation of ecological restoration projects such as shelterbelts along the Yellow River, farmland shelterbelts, urban and rural green nets, and water and soil conservation management in the windy and sandy areas of the Yellow River. Build urban forest parks along the Yellow River and build Jinan-Dezhou, Liaocheng, Binzhou-Zibo-Dongying Hundred Mile Green Corridor. Focusing on Changqing District and Pingyin County, measures such as coastal sewage collection and treatment, comprehensive treatment of river environment, and water system connection have been taken to reduce the impact of tributaries such as Beidasha River and Jinshui River.
8 October 2021	Yellow River Basin Ecological Protection and High-quality Development Planning Outline	Build a green ecological corridor in the lower reaches of the Yellow River, increase efforts to protect and restore the wetland ecosystem in the Yellow River Delta, promote the improvement of the ecological functions of the lower reaches of the Yellow River and the ecological environment of the estuary, carry out comprehensive improvement of the ecological environment in floodplain areas, and promote the coordinated development of ecological protection and population economy.
14 December 2021	Jinan City Urban Renewal Special Plan (2021-2035)	Tell the "Yellow River Story" in the new era well and accelerate urban renewal in areas along the Yellow River. Carry out ecological restoration along the Yellow River, implement the comprehensive improvement project of the Jinan section of the Yellow River, and create an ecological protection belt for the Yellow River. Strengthen the protection of cultural heritage along the Yellow River and

		implement projects such as the protection and restoration of important cultural relics along the Yellow River, such as the ancient ferry at Luokou and the century-old railway bridge. Accelerate the construction of the Yellow River cultural and educational base and tell the story of the Yellow River in the new era. Continue to expand the Yellow River cultural tourism project, integrate natural ecological and cultural resources along the Yellow River, and show the charm of the Yellow River.
15 February 2022	Ecological Protection and High-quality Development Planning of the Yellow River Basin in Shandong Province	Carry out comprehensive improvement of the ecological environment in floodplain areas. Coordinate the ecological space and agricultural space in the floodplain area of the Yellow River, promote the adjustment of land use structure according to the new round of land space planning, and implement comprehensive land improvement and ecological protection and restoration projects. According to local conditions, promote the restoration of wetlands in floodplains, create a comprehensive ecological space of forests and grasses in floodplains, strengthen the management and control of water ecological spaces in floodplains, and improve the functions of flood discharge and flood detention and sediment deposition in downstream rivers.
14 March 2022	Key Points of Shandong Province's 2022 Work to Promote Ecological Protection and High-quality Development in the Yellow River Basin	Coordinate the protection and utilization of land space in the Yellow River Basin, promote the construction of ecological protection belts along the Yellow River, establish a 3D model of 60,000 square kilometers in the Yellow River Basin (Shandong section), and form a real three-dimensional "one map" of the Yellow River that integrates land and sea and presents it three-dimensionally.
30 June 2022	Eco-environmental Protection Planning for the Yellow River Basin	Promote the comprehensive management of the ecology of the downstream floodplain in an orderly manner. According to the use control policy of the floodplain in the lower reaches of the Yellow River, the shoreline space of the water area will be returned according to local conditions, and the land in the floodplain will be comprehensively improved to protect and restore the ecological environment of the floodplain. In accordance with the principle of applying policies, implement the relocation project of residents in the floodplain area. Strengthen the protection and restoration of water sources and high-quality land in floodplain areas, rationally utilize

		land resources in floodplain areas in accordance with the law, and crack down on illegal soil mining, illegal excavation of river sand, and illegal construction of private buildings. Strengthen ecological protection and restoration of floodplain wetlands, build a comprehensive ecological space for beach rivers, forests, fields and grass, and build a solid ecological barrier for downstream floodplains.
15 July 2022	New Urbanization Plan of Jinan City (2021-2035)	Strengthen the safety protection and ecological management of important water systems such as the Yellow River, Dawen River, Xiaoqing River, and Dongping Lake. Fully explore the rich connotations of the Yellow River culture, spring water culture, and historical culture, continue the historical context, incorporate modern elements, and strengthen the city's brand. Cultural genes are endless and passed down from generation to generation.
8 October 2022	Implementation Plan for Ecological Protection and High-quality Development of Scientific and Technological Innovation in the Yellow River Basin	Aiming at the problems of wide distribution, multiple types, easy degradation, difficult and slow restoration of ecologically fragile areas in the Yellow River Basin, focus on the upper reaches of the Qinghai-Tibet Plateau, the middle reaches of the Loess Plateau, and the lower reaches of rivers and deltas, and conduct research on key technologies for ecological restoration and improvement of ecological functions in the Yellow River Basin. Research on ecological function improvement technologies for downstream ecological corridors and delta wetlands.
30 October 2022	Yellow River Protection Law	The state formulates relevant legal provisions in terms of planning and control, ecological protection and restoration, economical and intensive use of water resources, water and sediment control and flood control safety, pollution prevention and control, and promotion of high-quality development to ensure that there are laws to abide by and violations must be prosecuted.
3 November 2022	Jinan City Land Space Ecological Restoration Plan (2021-2035)	Based on the natural ecological background, highlight the main functions and main ecological problems, delineate the ecological landscape improvement and restoration area of the Yellow River on the basis of watersheds and regions, and classify the protection and restoration of the ecological landscape belt of the Yellow River as a key area and a key project for the restoration and management of rivers and lakes.

The above policy document not only shows that the ecological restoration of the Yellow River is China's current top priority, but also points out the direction for the ecological restoration of the Yellow River.

Landscape Ecological Restoration of Yellow River Floodplain in Jinan

Landscape Ecological Restoration

Ecological restoration in the river is the process of recovering the degraded, damaged, and destroyed ecosystem of the river by restoring the ecological structure, function, and biotic integrity. Technologies were applied to recover water quality, habitat, biodiversity, and biotic integrity in the river, including engineering techniques or projects, methods, theories, management strategies and so on (Ustaoğlu et al., 2020; SER 2004; Feio et al., 2021; Zhen et al., 2020).

The theoretical basis of landscape ecological restoration draws upon the knowledge from various fields, including ecology, conservation biology, landscape ecology, and restoration ecology, to guide the design and implementation of restoration projects. Its core principles include ecological succession, biodiversity conservation, ecosystem services, habitat fragmentation and connectivity, disturbance ecology, landscape ecology, resilience theory, historical ecology, adaptive management, and social-ecological systems. By integrating these theoretical foundations, landscape ecological restoration aims to restore degraded landscapes, preserve biodiversity, enhance ecosystem services, and promote harmonious coexistence between human activities and the natural environment.

Drawing on the hierarchy of landscape ecology, Miseki and Takazawa (1993) studied riparian zones and watersheds at two scales, and proposed restoration measures at the level of community organisation and landscape organisation corresponding to the respective scales.

When considering the restoration of rivers and fluvial systems, ecological restoration should be seen as those efforts that help with the recovery of a degraded, damaged, or destroyed ecosystem (SER, 2021) and those that return the ecosystems to their original, undisturbed state (Bradshaw, 1996; Roni et al., 2005). This suggests that restoration is not simply the opposite of degradation (Moerke et al., 2004). Restoration reinstates essential key processes and improves the degraded state of a habitat. It aims at eliminating the causes of degradation (e.g., flow regulation, reduced habitat diversity, and reduced connectivity) rather than merely addressing the symptoms (e.g., reduced fish density) in an impaired system (Woolsey et al., 2005).

Review of Landscape Ecological Restoration Technologies

Ecological restoration technologies in rivers are effective measures for improving habitat and biodiversity, which have the advantage of recovering ecosystems and biodiversity while promoting the formation of healthy rivers.

Ecological restoration technologies include dam removal/retrofit, fish passage construction, ecological water transfer, floodplain reconnection, stormwater management, natural shoreline restoration, instream species management, bank stabilisation, revegetation, corridor restoration, channel reconfiguration, habitat improvement (Bohn et al., 2001; Kuo et al., 2021). Here is a proposal for the classification of different restoration technologies (*Figure 2.6*).

Over the past century or two, large-scale artificial "over-engineering" has been carried out, including embankment construction, damming, channelisation, river straightening, etc (Bombino et al., 2007 ; Havel et al., 2009 ; Hohensinner et al., 2018). The construction of dams or hydroelectric power stations hinders the connection between the upstream and downstream parts of the river, resulting in the obstruction of river habitats and unfavourable impacts on river biodiversity. The straightening of the river course reduces the surface area of the river and destroys the natural form of the river, which affect the ecological flow. Increased demand for agricultural irrigation through agricultural water pumping stations also reduced the river's flow. All of these resulted in the loss of biological habitats and affected the growth of animals, plants and microbes (Khaleghi et al., 2019 ; Nakamura et al., 2020). Ecological restoration projects in the Yellow River basin were carried out to enhance the vegetation coverage, but plant absorption and transpiration caused a lot of water loss from the sediment, exacerbated the water shortage, and resulted in the unsustainability of revegetation (Li et al., 2022).

To put it simply, ecological restoration strategies in the past have improved the ecological environment of the Yellow River and ensured the safety of flood discharge, but at the same time, they have also had a certain impact on the landscape ecosystem of the floodplain to a certain extent, thereby slowing down the progress towards the goal of carbon neutrality.

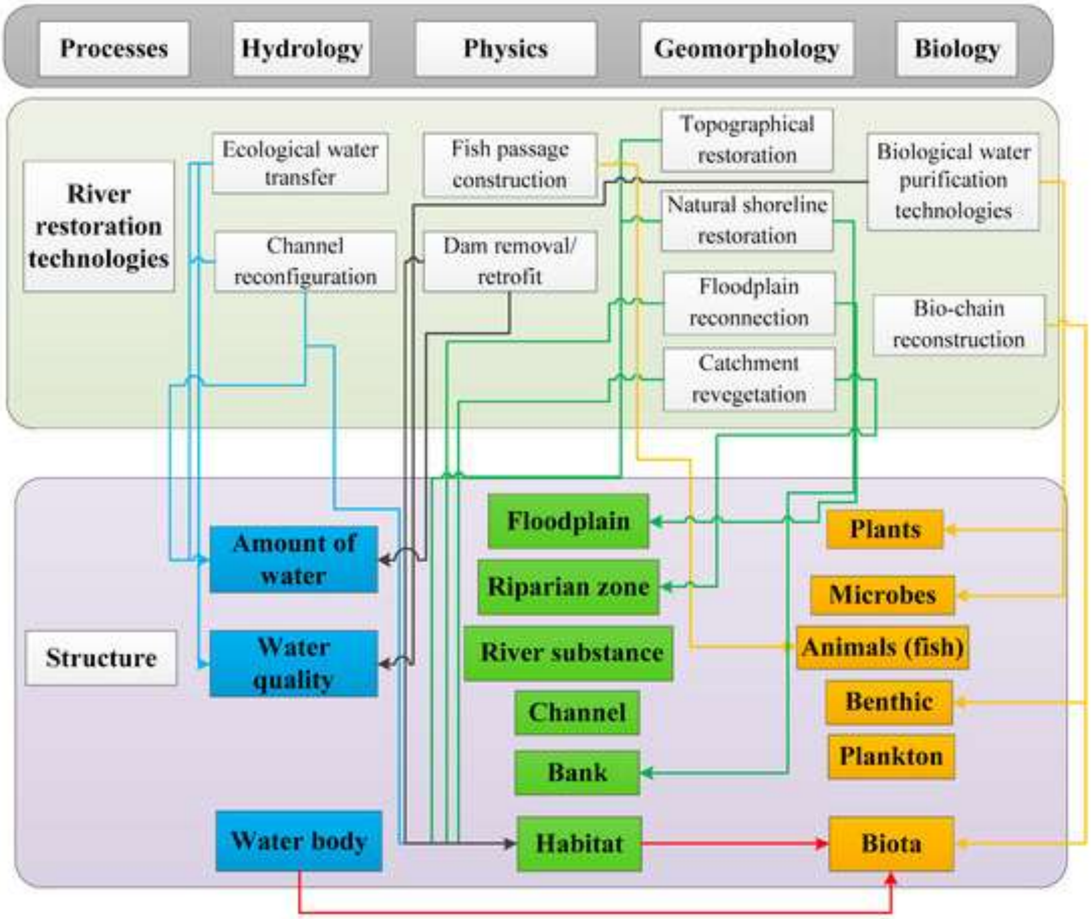


Figure 2.6: The Classification of Different Restoration Technologies

Landscape Ecological Restoration of Floodplain

Riparian areas are generally associated with wetlands, floodplains, and vegetation. Floodplains characterised by carbon storage, purification, and regulation, are an important component of the river. Some infrastructures, such as artificial dikes, canals, gravel dredging, and flow regulation systems, can easily cause the horizontal disconnection of river floodplains (Li et al., 2022). The reduction of floodplain hinders the connectivity of the river and also reduces floodplain productivity, nutrient exchange, and the spread of biota between rivers and floodplain wetlands (Gumiero et al., 2013).

Floodplain ecological restoration plays a key role in connecting the past and the future in urban river ecological restoration projects. On the one hand, the reconstruction of the floodplain system needs to take the restoration of the overall physical form of the urban river as the foundation and platform. After the completion of the project, on the other hand, reshaping the establishment of the floodplain system can create a variety of biological habitat types along the river, improve the landscape pattern of the urban matrix and river corridors, and create the edge zone effect at the boundary, which is to activate the river key for biological productivity.

Qiao et al (2006) have formulated a plan for the ecological reconstruction of the Zhengzhou Yellow River floodplain by rationally locating the reconstruction target, controlling the landscape structure, dividing the landscape into zoning areas, and using ecological economics methods to evaluate its effectiveness.

Li et al (2017), through the restoration of river ecosystems at the macro level, which is the restoration of the physical structure of the river at the meso level and the construction of specific habitat facilities at the micro level, have elaborated that the ecological restoration of floodplains is the key to ensuring the integrity of river ecosystems. Hu et al (2021) also found that ensuring continuous river flow is the key to restoring river vegetation during their study of the inland river network in northern China.

At present, the mainstream ecological restoration strategy for the Jinan Yellow River floodplain can be summarised as "three floodplains separate treatment". As showed in *Figure 2.7*.

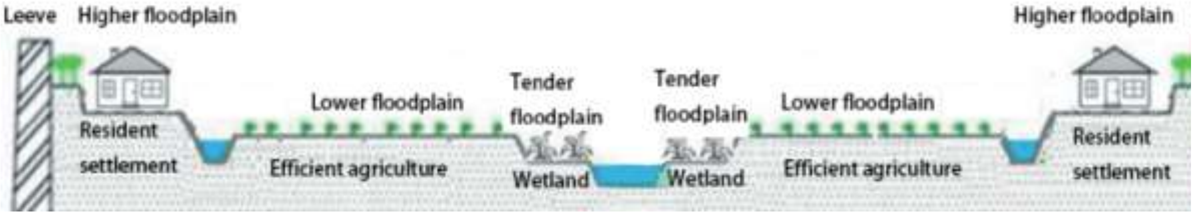


Figure 2.7: Three Floodplains Separate Treatment

Based on a full consideration of the national ecological development strategy and the requirements of the economic and social development along the Yellow River in the new era, Zhang (2018) had taken the Yellow River floodplain in Zhengzhou as an example, proposed five specific models and detailed implementation approaches for ecological management of the lower Yellow River floodplains based on the "three floodplains separate treatment" concept, as detailed in *Figure 2.8.*

Figure 2.8: Ecological Restoration of Yellow River Floodplain in Zhengzhou

Yu (2021) has also proposed a strategy for ecological restoration of the Yellow River floodplain from the perspective of the ecosystem services based on the implementation of the 'three floodplains separate treatment' (*Figure 2.9*). It is undoubtedly very desirable to adopt different restoration strategies according to the characteristics of different floodplains. However, both Zhang (2018); Yu (2021) did not analyse the landscape index to verify the effectiveness of the restoration strategies, nor did they quantify their impact on carbon sink capacity.

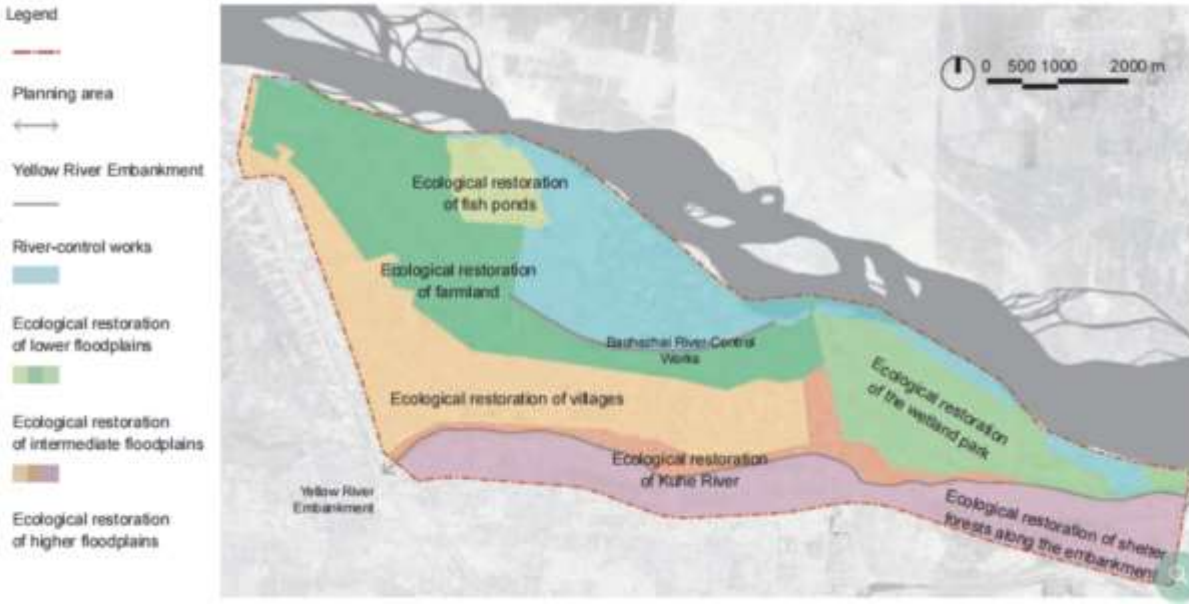


Figure 2.9: Yellow River Floodplain from the Perspective of Ecosystem Services

Landscape Ecological Restoration of Yellow River Floodplain in Jinan

The Yellow River in Jinan has been improved for a long time, focusing on Hujiaan to Gejiadian, while the section from Lokou Iron Bridge to Wangjia Lixing and the section above Beidianzi to Qinghemen have been improved successively (Xu et al., 2016).

The ecological restoration of the Yellow River floodplain is the key to realise the high-quality development of the Yellow River basin. The landscape ecological restoration provides an effective basis for the high-quality development of the Yellow River floodplains from two levels: ecological restoration and carbon sink. At present, studies related to the landscape ecological restoration of the Yellow River floodplains are relatively rare, and those around the Jinan section of the Yellow River floodplains are even fewer. The high importance at the national level provides an opportunity for this study and the research results in many related fields which provide a sufficient basis for this study and lay a good foundation for the development of this paper.

The focus of tender floodplain ecological restoration is to reduce human disturbance, implement ecological isolation, and improve the regulation and support functions of the ecosystem services (*Figure 2.10*).

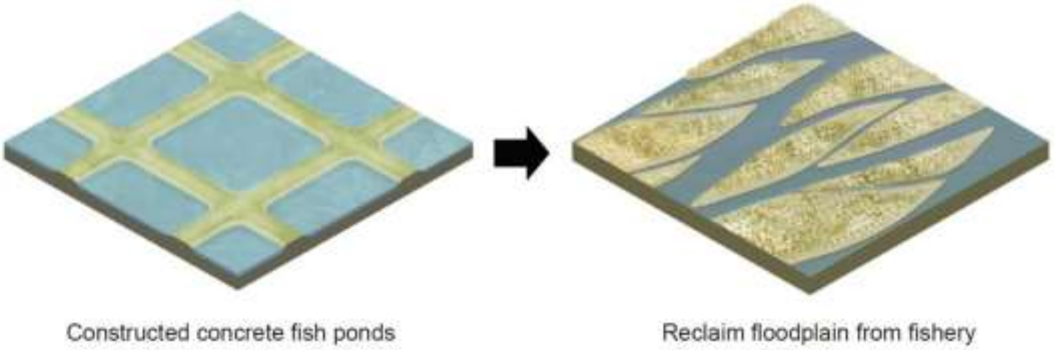


Figure 2.10: Tender Floodplain Ecological Restoration Model (Yu Kongjian)

The lower floodplain is vast, has a small probability of inundation and is subject to greater interference from human activities. Ecosystem services should be enhanced in all aspects to promote flood and disaster prevention, ecological protection and agricultural development in the floodplain area in parallel (*Figure 2.11*).

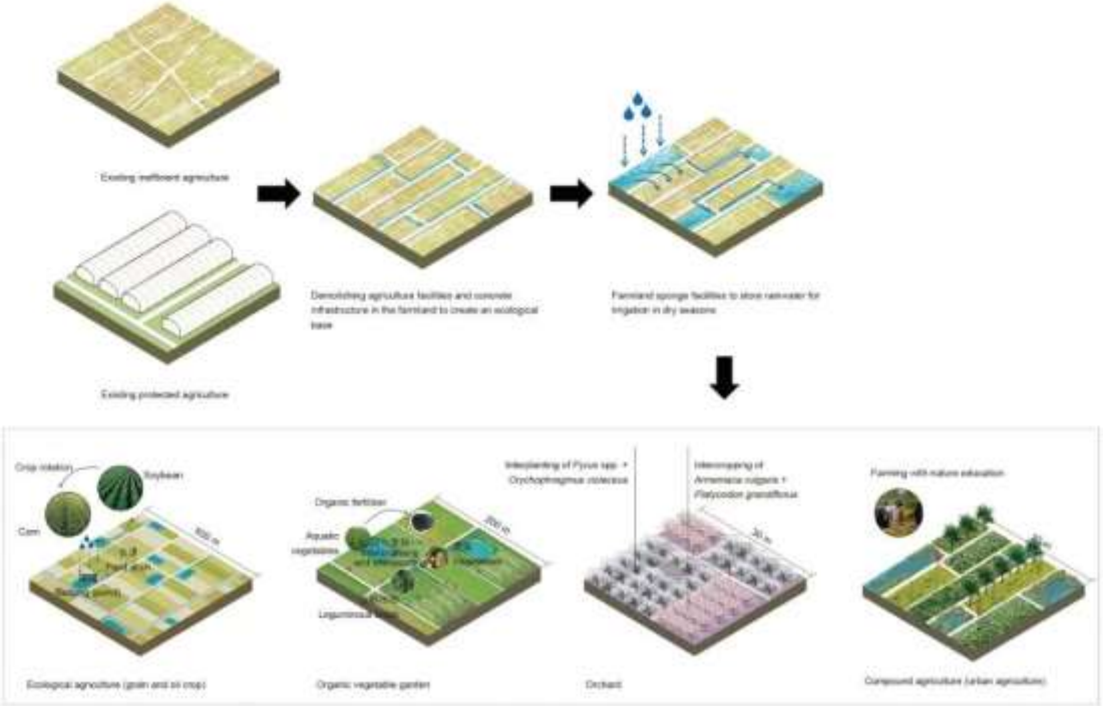


Figure 2.11: Lower Floodplain Ecological Restoration Model (Yu Kongjian)

According to Wu et al (2021), the ecological restoration of higher floodplain should focus on enhancing its regulating services, supporting services and cultural services. By increasing the native tree species and ground cover, biodiversity and community stability can be improved (*Figure 2.12)*.

Existing condition of Kuhe River

With narrow channel and steep slope, Kuhe River is unsuitable to develop waterfront activities

Wetlands and tree islands to enrich habitats

Site transformation with a gentler slope and longer shoreline, wetland bubbles created along banks, and ecological islands in the river can help purify water and construct habitats

Slow traffic for better waterfront recreational experience

The slow traffic system consisting of waterfront boardwalks and bicycle lanes can attract visitors to experience the diverse landscape along Kuhe River

Figure 2.12: Higher Floodplain Ecological Restoration Model (Yu Kongjian)

Landscape Ecological Restoration of Yellow River Floodplain in Jinan Based on Carbon Neutrality Target

Carbon Neutrality

Carbon neutrality means net-zero CO_2 emissions, not a complete absence of CO_2 emissions, but a long-term balance between emissions and absorption. Carbon neutrality is “anthropogenic carbon emissions = natural ecological carbon sequestration + ecological measures carbon sequestration + geoengineering carbon sequestration” to achieve a balance (Yu, 2022). Ding (2022) has said that achieving such a balance would require a "three-pronged approach": decarbonization of energy production, reduction of industrial consumption, and enhancement of ecological carbon sequestration. Achieving 'carbon neutrality' depends on two key processes: first, reducing carbon emissions from industry (including energy conservation, efficiency and the development and use of new energy sources) and second, increasing carbon sequestration (including ecosystem carbon sinks and industrial carbon sequestration, such as CCUS). The enhancement of terrestrial carbon sinks (also known as natural climate solutions (NCS)) is the most important (Griscom et al., 2017; Qin et al., 2021; Qin et al., 2021).

In 2060, China's terrestrial carbon sinks can offset between 2.8 and 18.7 per cent of carbon emissions under the no-policy scenario; under the 1.5°C limited scenario, terrestrial sinks can offset a higher proportion of carbon emissions (Yang et al., 2022). The above data suggest that enhancing the carbon sink capacity of ecosystems is the most feasible and cost-effective way to achieve carbon neutrality.

Landscape Ecology and Carbon Neutrality

Carbon sink in the landscape system refers to natural or artificial environments that absorb and store more carbon dioxide (CO_2) than they release, helping to mitigate climate change by reducing greenhouse gas concentrations in the atmosphere. The function of carbon sinks in landscape systems is closely related to several key concepts and mechanisms:

First, photosynthesis is the main carbon sink mechanism in the landscape systems. Through photosynthesis, plants absorb CO_2 from the atmosphere and convert it into organic compounds such as sucrose and starch in the process of photosynthesis. Carbon from these organic compounds is stored in plant tissues and roots.

Second, vegetation and forests play important roles in the landscape systems. Forests and other vegetation types such as grasslands and wetlands are important carbon sinks, with trees known for their large carbon storage potential. Large-scale intact forests contribute to carbon storage, serving as an important climate change mitigation measure.

Soil carbon storage is also an integral part of landscape systems. As plant matter decomposes, carbon is released into the soil where it is stored for longer periods of time. Factors such as soil type, land management practices and vegetation cover affect the amount of carbon stored in the soil, so scientific land management is essential to maintain and enhance carbon sinks.

Wetlands and coastal ecosystems are also important carbon sinks. Biomass and sediments in these environments can absorb and store large amounts of carbon and play an important role in mitigating climate change. Protecting wetlands and coastal ecosystems from encroachment and destruction is therefore crucial to maintaining the carbon sink function of landscape systems.

Landscape Ecological Restoration Based on Carbon Neutrality Target

In nature, the planting and maintenance of forests is a synergy between mitigation and adaptation strategies. The forests mitigate climate change by reducing and storing carbon. In addition, the forests adapt to climate change by offering protection to droughts, fires, floods, and heatwaves (Moomaw et al., 2019). Reducing forest conversion to agricultural land by promoting agroforestry, regenerative agriculture and polyculture contributes to climate change mitigation and adaptation in the agricultural sector (Montanaro et al., 2018). Reducing forest conversion contributes to climate change mitigation by reducing greenhouse gas emissions and increasing carbon storage. In addition, improving efficient agricultural practices supports climate change adaptation by increasing soil carbon and water efficiency, leading to resilient crops and food security.

Since the 1960s, Europe and the United States and other developed countries began to study the ecological restoration of rivers, so far, after half a century, the current situation of river ecological restoration research, scientific research, practice and other activities to carry out more research, research is more in-depth, based on a variety of objectives of the restoration of a variety of technologies have been developed (Nijland & Cals, 2000; Brinson & Malvarez, 2002; Malmqvist & Rundle, 2002). Along with the growing understanding of ecological restoration, scholars have gradually recognised the role of ecological restoration in ameliorating climate change.

According to Lu, et al (2018), ecological restoration makes a significant contribution to enhancing the carbon sink capacity of terrestrial ecosystems, and studies have shown that 56% of the carbon sink in restored areas is generated by the ecological restoration projects. Fu (2021) has pointed out that ecosystem management includes three main categories, namely conservation, improved management, and restoration, which have been extensively practiced in China with remarkable results. From 2000-2020, China sequestered 600 million tons of carbon per year through ecosystem management, offsetting 8 per cent of industrial carbon emissions over the same period. From 2020-2030, carbon sequestration is projected to reach 1.2 billion tons per year. By 2060, this figure will rise to 1.6 billion (Fu, 2021). According to China ‘s Third National Communication on Climate Change released in 2018 and related studies at home and abroad, 8 to 40 per cent of the country’s greenhouse gas emissions will be neutralised through terrestrial ecosystems (Xu & Wang, 2023).

Although China has implemented a number of major ecological protection and restoration projects, there are still a large number of middle-aged and young or near-mature forests, and the soil organic carbon content of agricultural ecosystems is relatively low compared to regions with similar climatic conditions in Europe and the United States (Lu, 2022). In order to better adapt to the background of carbon neutrality and vigorously promote the development of ecological restoration work in China, a new path must be constructed from the following four aspects for ecological restoration and carbon sequestration:

1. Expand the area of forest and grassland, consolidate and improve the ecological carbon sequestration capacity;
2. Improve the quality of forests and grasses to increase the increment of ecological carbon sequestration;
3. Comprehensively strengthen resource protection, adapt measures to local conditions, and reduce the loss of carbon pools;
4. Clarify carbon sequestration accounting indicators, increase publicity, and encourage the implementation of ecological restoration and carbon sequestration.

Landscape Ecological Restoration of floodplain and Carbon Neutrality

The Yellow River has a huge carbon sink potential and plays an important role in carbon sinks in terrestrial ecosystems and in the process of carbon neutralisation in Jinan. Over the past 20 years, China has continued to restore the ecology of the Yellow River and its carbon sink capacity has been significantly enhanced. However, China still needs to continuously optimise its ecological restoration strategy to tap its carbon sink potential and enhance its contribution to the carbon neutrality target.

Studies related to Yellow River Floodplain in Jinan have focused on river training, water and sand regulation, ground carrying capacity, and less on landscape related studies, mainly involving ecological management strategies, scape patterns and plant characteristics.

The Yellow River in Jinan has been improved for a long time, focusing on Hujiaan to Gejiadian, while the section from Lokou Iron Bridge to Wangjia Lixing and the section above Beidianzi to Qinghemen have been improved successively (Xu et al., 2016). SOM looks forwards to presenting the Yellow River in Jinan as a proven model for other river cities to follow, with the construction of the Yellow River National Wetland Park and providing a practical reference for the planning and design of the Yangtze River Basin and similar watersheds in other countries (Philip et al., 2019). As shown in *Figure 2.13.* Yin et al (2022) have systematically analysed the spatial and temporal dynamics of the landscape pattern and the gradient change characteristics of the Jinan section of the Yellow River, based on three phases of remote sensing image data in 2000, 2010 and 2020, using a combination of landscape pattern index and gradient analysis. Her study can provide a good reference for the landscape ecological restoration of the Jinan Yellow River floodplain.

There are few studies on the landscape ecological restoration of the Yellow River floodplain in Jinan based on the goal of carbon neutrality. However, by analysing its landscape structure, restoration strategies can be improved from the perspectives of increasing the area and quality of forests and vegetation, soil restoration, land use optimisation, and efficient agriculture. The main ways of ecological restoration based on Carbon Neutrality include forest, grass, soil, and wetland, which have remarkable carbon sequestration effects, huge carbon sequestration potential, and long-term and sustainable nature.

Take forest restoration as an example. Research results on terrestrial ecological carbon sequestration in the Carbon Special Project of the Chinese Academy of Sciences show that the amount of ecological carbon sequestration in China's land is 95.15±5.71Pg, of which the forest ecosystem carbon storage accounts for 38.9%. Although China has implemented a number of major ecological protection and restoration projects, there are still a large number of middle-aged and young or near-mature forests, and the soil organic carbon content of agricultural ecosystems is relatively low compared to regions with similar climatic conditions in Europe and the United States (Lu, 2022). Floodplain forests are part of dynamic systems, and their conservation and restoration must consider the hydrogeomorphic processes that structure the catchment and the landscape evolution (Dufour et al., 2005). To put it simply, by increasing forest coverage, rational plant allocation, optimising landscape structure, and grasping the timing of planting, etc., the carbon sink capacity of forests can be significantly improved and the contribution rate to carbon neutrality can be increased.

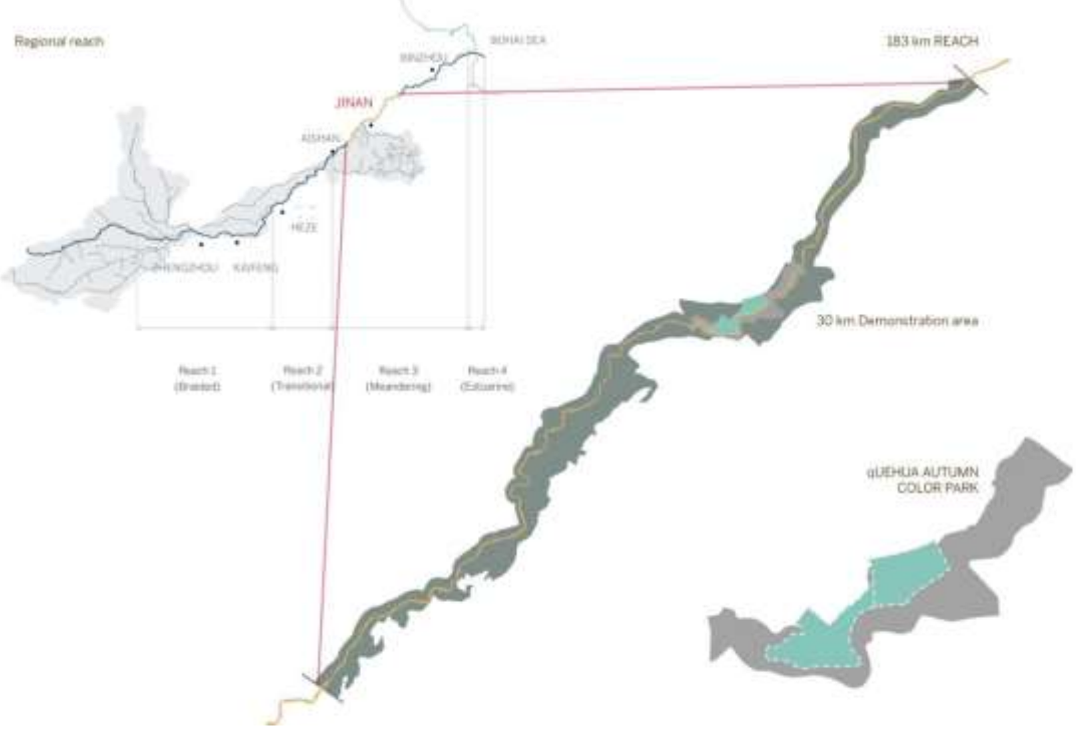


*Figure 2.13:The Planning of Jinan Yellow River (*Philip*)*

Conceptual Framework

The conceptual framework highlights follow the steps of carbon sink capacity prediction under ecological scenarios - landscape pattern analysis - optimisation of landscape ecological restoration strategies - validation of optimised carbon neutral contribution.

First, using GFPLAIN to determine the boundaries, distribution, and area characteristics of the Jinan Yellow River alluvial plain. Second, using the PLUS model to predict the changes in land use types in 2030 and 2060 under different ecological scenarios. Then, monitoring the changes in carbon storage from 2000 to 2020 using InVest, predicting the carbon storage in 2030 and 2060 under the current ecological restoration strategies, and estimating the impact and contribution of carbon. Third, importing the raster files divided by landscape types into Fragstats software, calculating landscape pattern indices, and analyzing the advantages and disadvantages of ecological restoration strategies. Fourth, proposing optimized landscape ecological restoration strategies based on the advantages and disadvantages. Finally, verifying whether the optimized ecological restoration strategies can increase the contribution to carbon neutralization and the degree of contribution. As detailed in *Figure 3.1.*

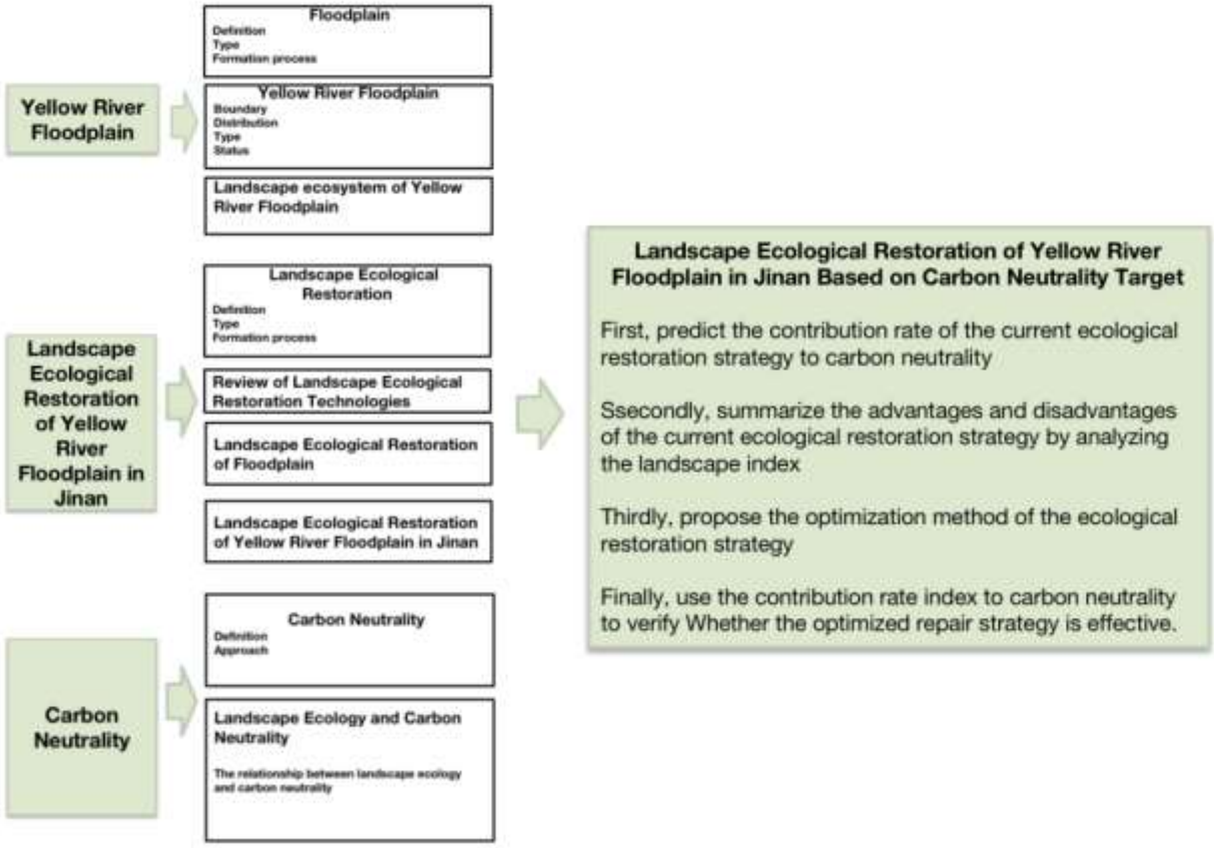


Figure 3.1: Conceptual Framework

The future landscape carbon sink should comprehensively consider above-ground plant carbon sequestration, below-ground soil carbon sequestration, and wetland and riparian carbon sequestration. At the same time, the important role of landscape and land use in the carbon cycle of the whole aquatic and terrestrial ecosystem should be considered, and the carbon sequestration efficiency of future landscape projects should be comprehensively improved.

These factors are interdependent and interact with each other to enhance the carbon sink capacity of the floodplain. Therefore, the inadequacies of the current ecological restoration strategies should be analysed from a systematic perspective. By quantifying the change and distribution characteristics of carbon storage in the floodplain and combining the needs of ecological/economic development, the landscape ecological restoration strategy should be optimised to accomplish carbon neutrality as soon as possible.

Conclusion

With the improvement of ecological restoration technology and the analysis of the advantages and disadvantages of previous restoration technologies, the ecological restoration technology of the Yellow River has been continuously adjusted. The strong carbon sink capacity of the ecosystem and its contribution to carbon neutrality have gradually become the focus of research. How much carbon emissions can be offset by past ecological restoration projects and how to optimise ecological restoration strategies are critical and well worth studying in the context of carbon neutrality.

This study is important not only because 56% of the carbon sink in restored areas is generated by ecological restoration projects (Lu et al., 2018), but also because more carbon emissions can be offset by optimising the ecological restoration technology ecosystem. This can promote the early realisation of the goal of carbon neutrality while improving the ecological environment.

To improve greater carbon sequestration and achieve Carbon Neutrality target, it is necessary to seek new breakthroughs in ecological restoration, promote the improvement of the quality and efficiency of ecosystems, comprehensively strengthen resource protection, continue to explore the potential for ecological carbon sequestration and growth, and further promote ecological restoration and management projects and construction.

Improving or restoring the structure and function of existing ecosystems, optimising the spatial layout of regional ecosystems, and effectively exerting the carbon sequestration role of forests, grasslands, wetlands, and soils is an important way to achieve the goal of carbon peaking and carbon neutrality, which is currently the most economical, safest, and most effective means of carbon sequestration.

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