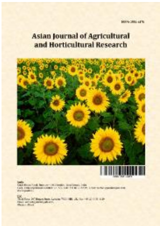

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Analysis of the Ecological Value of Pioneer Plants in the Yellow River Basin

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Pioneer plants are plant species that appear early in the community succession or show strong adaptability, which can improve the local ecological environment and create conditions for the succession and recovery of other plants and animals. After analyzing the general situation in the Yellow River Basin, this paper explores the main ecological values of pioneer plants, such as treatment of salt-alkali land, soil and water conservation, improvement of soil quality, community succession and biodiversity promotion. Also, typical cases of pioneer plants used for treatment and restoration in ecologically fragile areas such as Shanxi-Shaanxi-Inner Mongolia Pisha sandstone area, coastal saline-alkali land, abandoned mine pits in Yellow River Basin are introduced and analyzed to provide a theoretical basis for further embodying the ecological function of pioneer plants in the Yellow River Basin.

Keywords: Yellow River Basin; pioneer plant; ecological value.

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1. INTRODUCTION

The Yellow River originates in mountainous western China and flows through nine provinces and autonomous regions, namely Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan and Shandong, before finally discharging into the Bohai Sea at Dongying, Shandong. The Yellow River traverses four major geomorphic units, namely the Qinghai-Tibet Plateau, the Inner Mongolia Plateau, the Loess Plateau, and the Huang-Huai-Hai Plain, in a west-to-east direction. The basin exhibits significant variation in altitude differences, as well as longitudinal and latitudinal spans. The origin is perpetually obscured by ice and snow; the central part consists primarily of plateaus and loess formations, experiencing severe soil erosion due to the high cement sand content from the Yellow River; the eastern part, however, mainly consists of Yellow River alluvial plains and is characterized by flat terrain.

The source region of the Yellow River is high-altitude, rugged, cold, with frozen soil and glacial landforms, low precipitation and low vegetation coverage, making the ecological environment fragile. The middle reaches of the Yellow River flow through the Loess Plateau, which has a loess topography, sparse vegetation, frequent and concentrated summer storms, and severe soil erosion. The lower reaches of the Yellow River, due to their own soil erosion, combined with sediment brought from the middle and upper reaches, have resulted in significant development of the overland flow.

The Yellow River Basin is home to a diverse range of pioneer plants that play a crucial ecological role in various areas along the upper, middle and lower reaches of the river due to their exceptional adaptability to different vegetation conditions.

2. OVERVIEW OF PIONEER PLANTS AND MAJOR TYPES OF PIONEER PLANTS IN THE YELLOW RIVER BASIN

Pioneer plants are those that appear earliest in the succession of communities. They can survive in areas where soil nutrients and water are severely lacking, such as deserts, polar regions, and other harsh environments. Pioneer plants are not only able to withstand drought and barrenness, but also grow quickly, produce large seeds, and have a strong ability to spread. Pioneer plants have the ability to fix nutrients in the soil, enhance soil quality, attract fauna, and gradually enhance the ecological environment of the area. They play a crucial role in the initial stages of community succession.

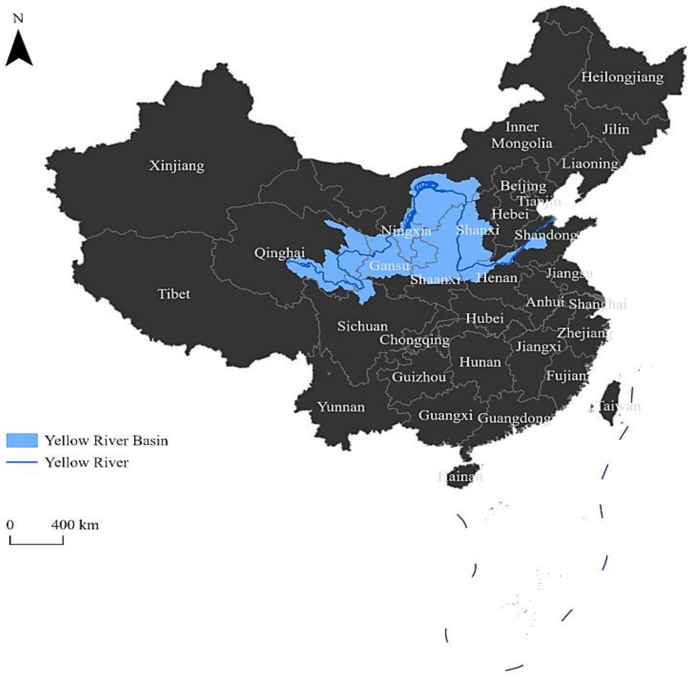

Fig. 1. Location of the Yellow River Basin

Table 1. Common pioneer plants of the Yellow River Basin

Name	Family	Genus	Life type	Main distribution area
Apocynum venetum L.	Apocynaceae	Apocynum	Perennial herb	Qinghai, Gansu, Inner Mongolia, Shaanxi, Shanxi, Henan
Artemisia scoparia Waldst.	Compositae	Artemisia	Perennial herbs or herbs of the last one or two years	Qinghai, Gansu, Shaanxi, Shanxi, Henan, Shandong
Artemisia ordosica	Compositae	Artemisia	Perennial semi-shrub	Inner Mongolia, Shaanxi (North), Shanxi (North), Ningxia, Gansu (Central and western)
Cynodon dactylon (L.) Persoon	Gramineae	Cynodon	Perennial herb	Qinghai, Sichuan, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Gansu, Shandong, Henan
Conyza canadensis	Compositae	Conyza	Annual herb	Distribution in each province
Eucommia ulmoides Oliv.	Eucommiaceae	Eucommia	Deciduous trees	Henan, Shaanxi, Gansu, Sichuan
Hippophae rhamnoides	Elaeagnaceae	Hippophae	Deciduous shrubs or trees	Inner Mongolia, Shaanxi, Shaanxi, Qinghai
Nitraria tangutorum Bobrov	Zygophyllaceae	Nitraria	Deciduous shrubs	Inner Mongolia (West), Ningxia, Gansu, Qinghai, Shaanxi (North)
Phragmites australis	Gramineae	Phragmites	Perennial herb	Qinghai, Gansu, Ningxia, Sichuan, Inner Mongolia, Shanxi, Shaanxi, Henan, Shandong
Populus simonii Carrière	Salicaceae	Populus	Deciduous trees	Gansu, Shaanxi, Shanxi, Henan, Shandong
Psammochloa villosa (Trin.) Bor	Gramineae	Psammochloa	Perennial herb	Qinghai, Gansu, Ningxia, Inner Mongolia, Shaanxi
Robinia pseudoacacia Linn.	Leguminosae	Robinia	Deciduous trees	Qinghai, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, Shandong, Sichuan
Salix matsudana Koidz.	Salicaceae	Salix	Deciduous trees	Qinghai, Gansu, Ningxia, Sichuan, Inner Mongolia, Shanxi, Shaanxi, Henan, Shandong
Suaeda salsa	Amaranthaceae	Suaeda	Annual herb	Henan, Shandong, Shanxi, Shaanxi, Ningxia, Gansu，Qinghai
Tamarix chinensis Lour.	Tamaricaceae	Tamarix	Deciduous shrubs or trees	Henan, Shandong

Pioneer plants include not only lichens, algae and mosses, but also many herbs, shrubs and trees such as *Suaeda salsa*, *Tamarix chinensis* Lour. and *Eucommia ulmoides* Oliv. Fig. 1 shows the location of Yellow River Basin. The common pioneer plant species distributed in the Yellow River Basin are presented in Table 1.

3. ECOLOGICAL EFFECTS OF PIONEER PLANT

3.1 Treatment of Saline-Alkali Land

Many pioneer plants are salt-tolerant and salt-resistant, and can be divided into salt-accumulating plants and salt-secreting plants.

Salt-accumulating plants exhibit robust salt resistance and can efficiently accumulate salt within their tissues without sustaining damage. As a representative example of such plants, *Suaeda salsa* demonstrates the ability to significantly reduce soil salinity levels, enhance microbial species diversity and abundance, as well as improve the structural complexity of microbial communities [1]. Furthermore, its root, stem, and leaf tissues harbor numerous halophilic microorganisms that actively contribute to the restoration process of saline-alkali soils [2].

Saline-secreting plants have the ability to excrete salt from their bodies, allowing them to survive in high-salt soils. Examples of these plants include *Tamarix chinensis* Lour, a typical salt-secreting plant that can absorb and accumulate soil salts and then secrete them through salt glands in the form of crystals from leaves and branches to regulate internal salt balance, maintain osmotic pressure, and grow in high-salt environments. Therefore, in the treatment of saline-alkali land, the leaves of *Tamarix chinensis* Lour. can be transferred by defoliation and manual removal, so as to realize the transfer of soil salinity. At the same time, plant growth can increase surface cover by forming mulch or increasing the canopy to protect the soil surface and reduce evaporation and wind erosion [3,4].

3.2 Windproof Sand Fixation, Soil Erosion Improvement

The root system of plants is a polymeric organism, and its cellulose molecular bonds give it a certain tensile resistance in the axial direction, and when applied it exhibits a certain elastic or viscoelasticity to accommodate the axial tension. When plants are attacked by strong external forces, such as strong winds or heavy rain, their roots and the soil form a root-soil complex, which has strong adhesion and friction and is better able to resist disturbance than pure soil [5]. The roots of pioneer plants are generally longer, faster growing, more numerous, and produce greater traction on the soil than those of common plants. As a result, pioneer plants have excellent soil consolidation, preventing water erosion from carrying away the soil and improving soil erosion to a certain extent. *Robinia pseudoacacia* Linn., for example, has strong roots, excellent soil fixation properties, wide adaptability, rapid growth rate and high survival rate, and can grow normally and thrive on hills, barren mountains, sunny slopes and sandy waste lands. The roots of *Robinia pseudoacacia* are interwoven in a network structure, with lateral and fibrous roots closely connected to the soil, effectively preventing surface soil loss [6,7].

3.3 Improvement of Soil Quality

When plants root in the soil, they loosen the soil, promote aeration and permeability, and improve soil structure. The roots have the ability to absorb nutrients while secreting root material, and are symbiotic with rhizospheric microorganisms that can activate and fix various nutrients, thereby increasing the soil nutrient content [8]. Pioneer plants, which normally have faster growth rates and more developed roots, are excellent at absorbing water and nutrients deep into the soil layer, helping to improve soil structure, improve aeration and permeability [9], and reduce ionic concentration and salinity vulnerability, thus enhancing soil fertility [10]. For example, *Hippophae rhamnoides* has shown greater ability than other legumes in nitrogen fixation by forming nodules through symbiosis with actinobacteria and mycobacterium, which can significantly increase the amount of organic matter and nitrogen in the soil, thereby increasing soil strength and water storage capacity and enhancing soil fertility [11-13].

3.4 Promoting Biodiversity and Community Succession

Pioneer plants play an important role in community succession. With their rapid growth and well-developed roots, pioneer plants can effectively improve the soil environment, which increases the survival chances of more plants, attracts animals, increases biodiversity, and promotes the improvement of the local ecological environment and community succession. In arid and semi-arid areas, pioneer plants are often the leading species in the restoration of vegetation, providing the necessary ecological conditions for other plants during their growth [14]. For example, plants such as *Psammochloa villosa* (Trin.) Bor and *Artemisia ordosica* can stabilize dunes and provide soil and water for subsequent vegetation.

4. ANALYSIS OF TYPICAL CASES OF ECOLOGICAL VALUE OF PIONEER PLANTS IN THE YELLOW RIVER BASIN

4.1 *Hippophae rhamnoides* Ecological Sand Reduction Project in Shanxi-Shaanxi-Inner Mongolia Pisha Sandstone Area

In the northern part of the Loess Plateau, bordering Shanxi, Shaanxi, and Inner Mongolia, there are large patches of Pisha sandstone area, a species peculiar to China. The structure of the Pisha sandstone is loose, shrinking slowly in water and turning to sand in the wind. Once there is a heavy rain, the crops growing on it are washed away by the roots, resulting in a crop-less harvest. Moreover, the Yellow River, which flows through the Pisha sandstone area, carries away a large amount of Pisha sandstone, which are deposited when the river flows through the middle and lower reaches, forming overland river water and endangering other areas [15].

Hippophae rhamnoides can tolerate barrenness and has a strong nitrogen fixation ability, which allows it to grow naturally on sandstone. Its strong roots and numerous fibrous roots can grow rapidly along the weathered layers of sandstone, forming underground root networks. With strong root neural forces, it can quickly form groups [16]. Each plant has an area of 70 - 80 m^2 for sand and soil consolidation. First-order lateral root nodules are abundant and can fix up to 180 kg of nitrogen per square kilometre of *Hippophae rhamnoides* woodland. In addition, a canopy forest can be formed in 3-5 years with low time cost [17].

In 1998, an ecological project in Shanxi-Shaanxi-Inner Mongolia Pisha sandstone area was officially launched. As a "pioneer tree", after more than 20 years of ecological construction of *Hippophae rhamnoides*, soil erosion has been effectively curbed, and the effect of sand retention is outstanding. Biodiversity has been gradually restored in the once-barren Pisa sandstone area, which displays contiguous gully slopes and green heathland. Large-scale contiguous *Hippophae rhamnoides* forest closure ditches can improve vegetation coverage by more than 70%, water storage efficiency by 75 - 85%, and erosion reduction efficiency by 80 - 90% [16]. The pioneer plant *Hippophae rhamnoides* has had a significant effect in controlling soil erosion, conserving water and improving the ecological environment, and has achieved good ecological, economic and social benefits in Shanxi-Shaanxi-Inner Mongolia Pisha sandstone area.

4.2 Saline Alkali Land Management in the Yellow River Basin

Saline-alkali land is a type of soil where the accumulated salt content exceeds the level of normal cultivated soil, affecting the normal growth of crops. According to incomplete statistics from UNESCO and FAO, the total area of saline-alkali land in China amounts to $9.9*10^5 km^2$ [18]. The distribution of saline-alkali land is found in the upper, middle and lower reaches of the Yellow River Basin. The Hetao region in Ningxia and Inner Mongolia, the river valley plains in Shaanxi and Shanxi, and the Huang-Huai-Hai plains in Shandong are all very well-known saline-alkali land distribution areas. However, saline-alkali land is an important reserve land resource with great potential for development.

The properties and degree of salinization of different types of saline-alkali soils in the Yellow River Basin vary widely. In the treatment of saline-alkali lands, the principles of specific analysis should be followed. Salt-alkali land in coastal Shandong Province has high groundwater levels, high soil salt content, hard soil structure, poor ventilation and permeability, low vegetation coverage and a relatively fragile ecological environment. In the long process of species selection, salt-tolerant plants such as *Tamarix Chinensis* Lour., *Salix matsudana*, *Nitraria tangutorum* Bobr., *Phragmites australis*, *Apocynum venetum* Linn. and *Cynodon dactylon* (L.) Pers. have been naturally selected to survive here. *Tamarix Chinensis* Lour. is an excellent tree species for windbreak and sand fixation and salt-alkali matrix [19-21]. In coastal saline-alkali land in Dongying, *Tamarix Chinensis* Lour. and its communities can increase the water content and water storage of the surface soil, decrease salinity, and pH, improve the pore structure of the surface soil, and increase the organic carbon, nitrate, nitrogen, ammonia, and available phosphorus content [21]. Its distribution also has ecological functions such as resisting coastal erosion, preventing soil erosion and maintaining water, and can enhance ecosystem productivity, nutrient cycling, soil and water conservation, and soil carbon sequestration [22-26].

4.3 Ecological Restoration of Abandoned Mine

Abandoned Mine refers to serious damage such as surface collapse and pollution caused by land excavation and mineral waste stacking during mineral extraction, which has deprived the land of its original use value [27]. As a result of the large amount of ore residues, waste and pollutants, soil, water and air quality are severely polluted, and the ecological environment is usually severely damaged.

In vegetation restoration in abandoned mines, it is necessary to achieve vegetation coverage as soon as possible and play a role in soil consolidation, so pioneer plants that grow quickly should be selected in the initial stages of restoration. Based on criteria such as barrenness tolerance, salinity tolerance, ability to enrich heavy metals, and resistance, *Cynodon dactylon* (L.) Pers., *Artemisia scopara, Conyza canadensis* were used for ecological restoration of waste mining areas enriched with heavy metals such as Cu, Cd, Cr,Pn, Ni, Mn [28,29]. For example, *Cynodon dactylon* (L.) Pers. grown in soil with a high Pn content can improve tolerance to high concentrations of Pn stress by increasing the activity of peroxidase and by enriching the upper parts of the plant and the roots with lead [29].

In addition, vegetation litter has good water absorption rate and water retention capacity, and is good at intercepting precipitation, conserving water and reducing soil erosion [30,31]. For example, *Robinia pseudoacacia* has strong roots, strong soil and water retention, and is highly adaptable to soil. *Robinia pseudoacacia* not only survives in acidic, alkaline, sandy soils, but also plays a good role in ecological restoration [32,33]. In the pit restoration work at the Antaibao open-pit coal mine in Shanxi province, the water filters of *Populus simonii* and *Robinia pseudoacacia* can effectively retain water and play a positive role in water conservation in the reclamation area of the open-pit coal mine [30].

5. CONCLUSION

Based on an analysis of the ecological characteristics of pioneer plants in the Yellow River Basin, this paper summarizes the many ecological values of pioneer plants, such as salt-alkali land management, protection from wind and sand, reduction of soil erosion, and promotion of community succession, and some typical cases are analyzed. The Yellow River Basin covers a wide area and includes harsh cold, arid, barren, saline, and other adverse environments, so there are many pioneer plant species with widespread distribution. Due to its many characteristics, the pioneer plant has demonstrated excellent ecological value in various environmental conditions distributed in the Yellow River Basin. For example, in various ecologically fragile areas such as Shanxi-Shaanxi-Inner Mongolia Pisha sandstone area, coastal saline-alkali land, abandoned mine pits, pioneer plant has carried out excellent ecological restoration in these areas by using its characteristics of rapid growth, strong soil fixation ability, strong resistance, strong heavy metal enrichment ability, strong nitrogen fixation ability and water retention and storage of litters. In light of this, it is necessary to strengthen research and analysis of the ecological value of pioneer plants and make rational use of them so that they can play a greater role in community succession, ecological restoration and other aspects of the Yellow River Basin and provide more ecological value.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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