Distribution and Regeneration Characteristics of Natural Populus euphratica Forests in the Hexi Corridor and Their Relationship with Soil Factors: Postprint

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Abstract

Through investigations on site types, distribution, growth, regeneration characteristics, and soil factors of natural Populus euphratica forests in the Hexi Corridor, this study analyzes the distribution and regeneration characteristics of natural Populus euphratica and their relationships with soil factors. The results show that: (1) The distribution of natural Populus euphratica forests in the Hexi Corridor is mainly concentrated on river terraces, paleochannel terraces of the three major watersheds (Shule River, Heihe River, and Shiyang River), and at the edges of oasis farmland in the lower reaches of each watershed. Based on current land use status and site conditions, existing natural Populus euphratica forests are classified into four types: abandoned farmland forestland, forestland around farmland and irrigation canals, current riverbank forestland, and paleochannel and Gobi lowland forestland. (2) The growth, age-class composition, and seedling regeneration of Populus euphratica in forestland around farmland and irrigation canals and current riverbank forestland are superior to those in abandoned farmland forestland and paleochannel and Gobi lowland forestland; in terms of the number of regenerated seedlings per unit area only, forestland around farmland and irrigation canals has the highest mean value of 22.13, followed by abandoned farmland forestland at 20.92, current riverbank forestland at 10.50, and paleochannel and Gobi lowland forestland has the lowest at 1.33. (3) Soil factors vary among different types of Populus euphratica forests. In the 0–20 cm and 20–40 cm soil layers, soil water content in forestland around farmland and irrigation canals and current riverbank forestland is significantly higher than that in abandoned farmland forestland and paleochannel and Gobi lowland forestland ($P < 0.05$); in the 0–20 cm soil layer, soil available P shows the following pattern: current riverbank forestland < paleochannel and Gobi lowland forestland < abandoned farmland forestland and forestland around farmland and irrigation canals, while in the 20–40 cm soil layer, soil available P in current riverbank forestland is significantly lower than in the other three forestland types ($P < 0.05$); total N and organic matter content show no significant differences among different forestland types ($P > 0.05$); soil electrical conductivity in the 0–20 cm and 20–40 cm soil layers is significantly lower in abandoned farmland forestland than in the other three forestland types ($P < 0.05$), particularly in the 40–60 cm soil layer, where paleochannel and Gobi lowland forestland is significantly higher than the other three forestland types ($P < 0.05$); among different forestland types, except for coarse sand particles in the 0–20 cm soil layer, the proportions of soil clay, silt, and coarse sand particles in forestland around farmland and irrigation canals are higher than those in the other three forestland types across all soil layers ($P < 0.05$). (4) Soil water content and available P content are positively correlated with the numbers of middle-aged, young, and seedling Populus euphratica trees ($P < 0.05$). Strengthening forestland management and protection, timely thinning and pruning, removal of dead branches, selective cutting, and irrigation water supplementation can promote the sustainable development of Populus euphratica forests.

Full Text

Preamble

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Distribution and Regeneration Characteristics of Natural Populus euphratica Forests in the Hexi Corridor and Their Relationship with Soil Factors

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Abstract

Through systematic investigation of site types, distribution, growth, regeneration characteristics, and soil factors of natural Populus euphratica forests in the Hexi Corridor, this study analyzed the distribution and regeneration patterns of these forests and their relationship with soil factors. The results indicated that: (1) Natural P. euphratica forests in the Hexi Corridor were primarily distributed along riparian terraces, ancient river terraces, and the edges of oasis farmland in the lower reaches of the Shule River, Black River, and Shiyang River basins.

Based on current land use and site conditions, existing natural P. euphratica forests can be classified into four types: abandoned farmland forestland, forestland around cultivated land and irrigation canals, forestland along current river courses, and forestland in ancient river courses and Gobi low-lying areas. (2) The growth status, age structure, and seedling regeneration of P. euphratica in forestland around cultivated land and irrigation canals and along current river courses were superior to those in abandoned farmland and ancient river course/Gobi low-lying areas. In terms of regenerated seedlings per unit area, forestland around cultivated land and irrigation canals had the highest mean value (22.13 plants), followed by abandoned farmland (20.92 plants), current river course forestland (10.50 plants), and ancient river course/Gobi low-lying land (1.33 plants). (3) Soil factors varied significantly among different forest types. In the 0–20 cm soil layer, soil available phosphorus showed the pattern: current river course forestland $<$ ancient river course/Gobi low-lying land $<$ abandoned farmland and forestland around cultivated land/irrigation canals. In the 20–40 cm layer, available phosphorus in current river course forestland was significantly lower than in the other three types ($P < 0.05$). Soil moisture content in forestland around cultivated land/irrigation canals and current river course forestland was higher than in abandoned farmland and ancient river course/Gobi low-lying land, with significant differences observed ($P < 0.05$). Soil electrical conductivity in the 0–20 cm and 20–40 cm layers was significantly lower in abandoned farmland than in the other three types ($P < 0.05$). No significant differences were found in total nitrogen or organic matter content among forest types ($P > 0.05$). Except for coarse sand particles in the 0–20 cm layer, the proportions of soil clay, silt, and coarse sand particles in forestland around cultivated land and irrigation canals were significantly higher than in other forest types ($P < 0.05$). (4) Soil moisture and available phosphorus content were positively correlated with the number of middle-aged, young, and seedling P. euphratica plants ($P < 0.05$). (5) Strengthening forest management and protection through timely pruning, removal of dead branches, thinning, and irrigation can promote sustainable development of P. euphratica forests.

Keywords: Hexi Corridor; natural Populus euphratica; distribution and regeneration; soil factors

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Introduction

Populus euphratica, a species in the Salicaceae family, is a deciduous tree uniquely adapted to extreme environments, with remarkable tolerance to salinity, drought, and wind erosion. In China, it is primarily distributed in the arid inland river basins of northwestern China, serving as the only natural constructive tree species in these regions and forming a critical ecological barrier for desert oases. This species plays an irreplaceable role in maintaining ecological balance in northwestern China. In recent decades, climate change, population growth, and agricultural expansion have led to unsustainable water resource development in the Hexi inland river basins. Consequently, water availability has decreased, regional ecosystems have deteriorated, and P. euphratica forests in the Shule River, Black River, and Shiyang River basins have exhibited decline patterns, with large-scale forest mortality, reduced distribution area, degraded stands, and hindered regeneration, weakening their ecological barrier functions.

However, with increased national ecological restoration efforts, comprehensive management projects in the three major inland river basins of the Hexi Corridor have been implemented, enabling integrated water resource utilization and improved hydrological conditions in P. euphratica distribution areas downstream, providing favorable conditions for population recovery. Due to its unique ornamental value, P. euphratica is becoming a popular species for urban landscaping and ecotourism in the region. The restoration of P. euphratica forests has emerged as an important measure for regional ecological construction and local economic development, making scientific and rational restoration and development of these forests a critical issue requiring urgent solutions.

Previous studies have investigated the reproductive and regeneration characteristics of P. euphratica under different environmental conditions in other regions, but research on natural P. euphratica reproduction and regeneration in Gansu' s Hexi area remains limited. Based on investigations of natural P. euphratica distribution, growth, regeneration, and site environmental characteristics in the Hexi Corridor, this study aims to elucidate the distribution and regeneration patterns of natural P. euphratica forests, analyze the causes of forest degradation and limiting factors for natural regeneration, and provide scientific basis and rational strategies for forest restoration and reconstruction.

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1. Study Area Overview

The Hexi Corridor is located in Gansu Province, extending from Wushaoling in the east to Xingxingxia in the west, bordered by the Qilian Mountains to the south and the Longshou, Heli, and Mazong mountains to the north. Spanning approximately 1,000 km with a total area of 27.11$\times10^{4}$ km^2 (60% of Gansu' s total area), the corridor lies between 37°17 –42°48 N and 93°23 –104°12 E, administratively comprising five cities: Zhangye, Jiuquan, Wuwei, Jinchang, and Jiayuguan. The terrain slopes from high in the south to low in the north, with most areas in the southern Qilian Mountains exceeding 3,000–3,500 m in elevation, while the piedmont plains generally range from 1,300–2,500 m. The Heishan and Kuantaishan mountains, along with the Dahuangshan mountain, divide the corridor into three major inland river basins: the Shiyang River, Black River, and Shule River.

Situated deep in the Eurasian continent, far from the ocean, and influenced by topography and altitude, the Hexi Corridor features an arid climate with unevenly distributed water and heat resources and significant regional precipitation variation. Annual precipitation is below 200 mm in most areas, while annual evaporation reaches 2,000–3,000 mm, representing a typical continental arid climate and forming a sensitive zone for climate change and ecologically fragile region.

Vegetation in P. euphratica distribution areas consists primarily of artificially planted species and native xerophytic and super-xerophytic shrubs and herbs. Artificially planted species include *Populus gansuensis* (Erba poplar), *Populus alba* var. *pyramidalis* (Xinjiang poplar), *Ulmus pumila* (elm), *Elaeagnus angustifolia* (Russian olive), and *Haloxylon ammodendron* (saxaul). Natural shrubs include *Tamarix ramosissima* (tamarisk), *Nitraria tangutorum* (nitrogen-fixing shrub), *Lycium barbarum* (goji berry), *Lycium ruthenicum* (black goji), *Calligonum mongolicum* (Mongolian calligonum), and *Kalidium foliatum* (saltwort). Semi-shrubs include *Alhagi sparsifolia* (camelthorn), *Salsola passerina* (pearl salsola), *Artemisia desertorum* (desert wormwood), *Sympegma regelii* (jointed sympegma), and *Ajania fruticulosa* (shrubby ajania). Herbaceous plants include *Karelinia caspia* (karelinia), *Glycyrrhiza uralensis* (licorice), *Sophora alopecuroides* (fox-tail sophora), *Halogeton glomeratus* (halogeton), *Bassia dasyphylla* (bassia), *Salsola collina* (common salsola), *Corispermum patelliforme* (disk-seeded bugseed), *Zygophyllum fabago* (beancaper), *Peganum nigellastrum* (camel peganum), *Peganum harmala* (harmal peganum), *Limonium aureum* (golden sea lavender), *Achnatherum splendens* (feather grass), *Cynanchum chinense* (Chinese cynanchum), *Lepidium lotifolium* (broad-leaved pepperweed), *Mulgedium tataricum* (Tatarian mulgedium), *Apocynum pictum* (painted apocynum), *Agriophyllum arenarium* (sand rice), *Phragmites australis* (common reed), *Leymus secalinus* (ryegrass), *Clematis tangutica* (Tangut clematis), *Chenopodium glaucum* (glaucous goosefoot), *Convolvulus arvensis* (field bindweed), *Scorzonera mongolica* (Mongolian scorzonera), *Hexinia polydichotoma* (Hexinia), *Chloris virgata* (feather finger grass), *Setaria viridis* (green foxtail), and *Stipa capillata* (feather grass). Soil types in the western Hexi Corridor are primarily brown desert soil, gray-brown desert soil in the central region, and gray desert soil, light brown calcic soil, and gray calcic soil in the eastern region.

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2. Materials and Methods

2.1 Forest Type Classification and Plot Establishment

From June to September 2020, investigations of natural P. euphratica forests in the Hexi Corridor were conducted based on data provided by local forestry departments. To facilitate analysis, natural P. euphratica forest lands were classified into four types according to site conditions and current land use: (1) abandoned farmland forestland, (2) forestland around cultivated land and irrigation canals, (3) forestland along current river courses, and (4) forestland in ancient river courses and Gobi low-lying areas. A total of 24 sample plots were established across these types: 6 in abandoned farmland, 6 around cultivated land and irrigation canals, 6 along current river courses, and 6 in ancient river courses and Gobi low-lying areas. These plots were distributed across different river basins. Plot size was determined based on the actual area of each P. euphratica distribution point: for areas larger than 2,500 m^2, plots measured 50 m × 50 m; for smaller areas, plot size was adjusted to actual distribution area, with a minimum of 50 m × 20 m. Geographic coordinates were recorded for all surveyed P. euphratica distribution points.

2.2 Vegetation Survey and Soil Sampling

Vegetation Survey: In each plot, all P. euphratica individuals were surveyed, recording tree height, diameter at breast height (DBH), crown width, and growth condition. Age classes were determined using DBH as a proxy: seedlings (DBH $<$ 5.0 cm), young trees (5 cm $\leq$ DBH $<$ 12 cm), middle-aged trees (12 cm $\leq$ DBH $<$ 25 cm), mature trees (25 cm $\leq$ DBH $<$ 50 cm), and over-mature trees (DBH $\geq$ 50 cm). The number of individuals in each age class and seedling count were standardized per 1,000 m^2. Plant species composition and coverage within each plot were also recorded.

Soil Sampling: Using a five-point sampling method, soil cores were collected from the P. euphratica root zone (within 100 cm of the trunk) at depths of 0–20 cm, 20–40 cm, and 40–60 cm. Soils from the five points within each plot were mixed for each depth layer, then divided into two subsamples (~100 g each). One subsample was weighed fresh, oven-dried, and reweighed to determine soil moisture content. The other was transported to the laboratory for analysis of nutrients, electrical conductivity, and particle composition.

2.3 Soil Factor Determination

Soil organic matter was measured using the potassium dichromate oxidation external heating method. Total nitrogen was determined by Kjeldahl digestion and distillation. Available phosphorus was analyzed using the molybdenum-antimony anti-colorimetric method. Soil pH was measured with a pH meter in a 1:5 soil-water suspension. Electrical conductivity was determined with a conductivity meter. Soil particle composition was analyzed using a Malvern laser particle size analyzer. Soil water content was determined by the oven-drying method and expressed as weight percentage: [(fresh soil weight - dry soil weight) / dry soil weight] × 100%.

2.4 Statistical Analysis

Survey data were entered and organized in Excel 2016. SPSS 20 was used for one-way ANOVA to compare soil moisture, nutrients, particle composition, and electrical conductivity among different forest types. Pearson correlation analysis was performed to examine relationships between P. euphratica age class distributions, seedling numbers, and soil factors.

3. Results

3.1 Distribution of Natural Populus euphratica Forests in the Hexi Corridor

Natural P. euphratica forests in the Hexi Corridor were mainly distributed along riparian terraces, ancient river terraces, and the edges of oasis farmland in the lower reaches of the Shule River, Black River, and Shiyang River basins. According to the 2019 Gansu Provincial Forest Land Annual Change Survey, the total area of concentrated natural P. euphratica forests in the Hexi Corridor was 4,506.59 hm^2, with 1,629.95 hm^2 of plantations. The Shule River basin contained 2,196.48 hm^2 of natural forest and 28.12 hm^2 of plantations; the Black River basin had 1,700 hm^2 of natural forest and 220 hm^2 of plantations; and the Shiyang River basin comprised 610.11 hm^2 of natural forest and 196.48 hm^2 of plantations.

In the Shule River basin, natural P. euphratica was distributed sporadically from Xiaxihonghao in Yumen City to Akesaiduoba in Aksay County, primarily along riverbanks and at the edges of oasis farmland, with relatively normal growth.

In the Black River basin, natural P. euphratica was mainly distributed in Gaotai and Jinta counties, presenting four distinct patterns: (1) fragmented, banded distribution along both banks of the Black River with relatively good growth; (2) scattered, point-shaped sparse distribution in areas far from existing rivers with weaker growth; (3) sporadic, patchy distribution around farmland within oases with normal growth; and (4) in northern Jinta, severe wind erosion exposed main roots to depths exceeding 1 m, with most regeneration seedlings dead or reduced to residual roots, extensive dead branches, dieback, and mortality, severe degradation of native understory vegetation, stand decline, and sandy desertification.

In the Shiyang River basin, natural P. euphratica was sporadically distributed in the lower reaches of Minqin County, primarily along ancient river courses, current canal systems, and oasis farmland edges. Trees near farmland and canals grew normally, while those far from cultivated land or on long-abandoned farmland showed weak growth with severe dead branch and dieback phenomena.

3.2 Characteristics and Plant Composition of Different Natural Populus euphratica Forest Types

As shown in , P. euphratica distribution areas in the Hexi Corridor contained 7 artificially planted species and 37 native plant species. Characteristics of different forest types were as follows:

Abandoned Farmland Forestland: These are former cultivated lands within oases where P. euphratica existed around the periphery. Due to various factors, cultivation was abandoned, allowing natural regeneration. Growth was related to abandonment duration, with longer-abandoned sites showing more obvious dead branch and dieback phenomena. The community contained 6 artificially planted species and 13 native species, with total vegetation coverage of 31.67%.

Forestland Around Cultivated Land and Irrigation Canals: These are P. euphratica forests retained around current farmland and irrigation canals within oases. Trees generally grew well with minimal dead branch and dieback. The community contained 7 artificially planted species and 24 native species, with total coverage of 45.91%.

Current River Course Forestland: These are P. euphratica forests distributed along current water flow paths and runoff areas in each basin, including hillside lands, river terraces, and floodplains. Growth was generally normal, though some stands with larger diameter classes or higher density showed dead branch and dieback. No artificially planted species were present, but 27 native species occurred, with total coverage of 40.50%.

Ancient River Course and Gobi Low-lying Land Forestland: These are areas where water flow has ceased due to reduced water volume or river course changes from water conservancy projects, yet P. euphratica persists in old river channels, desert dune lands, and Gobi low-lying areas. Trees showed poor growth with severe dead branch and dieback, some appearing as stunted "old-man" trees. No artificially planted species were present, with only 12 native species and total coverage of 39.70%.

Native plants in different forest types were dominated by drought- and salt-tolerant shrubs, small shrubs, and herbs with simple community structure, mostly single-species stands. Forestland around cultivated land and irrigation canals had the highest species richness (31 species), followed by current river course forestland (27 species), abandoned farmland (13 species), and ancient river course/Gobi low-lying land (12 species). Total vegetation coverage was highest in forestland around cultivated land and irrigation canals (45.91%), followed by current river course forestland (40.50%), ancient river course/Gobi low-lying land (39.70%), and abandoned farmland (31.67%).

3.3 Age Structure and Seedling Regeneration in Different Forest Types

Age class structure and seedling numbers per unit area varied among forest types (). Young tree numbers followed the pattern: forestland around cultivated land and irrigation canals > abandoned farmland > current river course forestland > ancient river course/Gobi low-lying land, with ancient river course/Gobi low-lying land significantly lower than other types ($P < 0.05$). Middle-aged tree numbers were significantly higher in forestland around cultivated land and irrigation canals than in other types ($P < 0.05$). Mature tree numbers were higher in forestland around cultivated land/irrigation canals and current river course forestland than in ancient river course/Gobi low-lying land and abandoned farmland, but differences were not significant among types ($P > 0.05$).

Regenerated seedlings per unit area were most abundant in forestland around cultivated land and irrigation canals (mean: 22.13 plants), followed by abandoned farmland (20.92 plants), current river course forestland (10.50 plants), and ancient river course/Gobi low-lying land (1.33 plants). Significant differences existed between forestland around cultivated land/irrigation canals and abandoned farmland versus the other two types ($P < 0.05$).

Growth conditions also differed: most trees in forestland around cultivated land/irrigation canals and current river course forestland grew normally, with only mature trees showing dead branch and dieback. Growth in abandoned farmland was related to abandonment duration, with longer-abandoned sites showing weaker growth and more dead branches. Trees in ancient river course/Gobi low-lying land showed overall weak growth with severe dead branch and dieback phenomena.

3.4 Soil Factors in Different Forest Types

3.4.1 Soil Nutrients As shown in , available phosphorus content in P. euphratica distribution areas varied among forest types. In the 0–20 cm layer, available phosphorus was significantly higher in abandoned farmland and forestland around cultivated land/irrigation canals than in ancient river course/Gobi low-lying land and current river course forestland ($P < 0.05$). In the 20–40 cm layer, current river course forestland had significantly lower available phosphorus than other types ($P < 0.05$). No significant differences in total nitrogen or organic matter content were found among forest types ($P > 0.05$).

3.4.2 Soil Moisture and Electrical Conductivity Soil moisture content varied considerably among sample plots (). In the 0–20 cm layer, moisture ranged from 0.13% to 21.31%; in 20–40 cm, 0.17% to 35.14%; and in 40–60 cm, 0.25% to 28.23%. In both 0–20 cm and 20–40 cm layers, forestland around cultivated land/irrigation canals and current river course forestland had significantly higher moisture than abandoned farmland and ancient river course/Gobi low-lying land ($P < 0.05$), with no significant differences among types in the 40–60 cm layer ($P > 0.05$).

Soil electrical conductivity showed the pattern: ancient river course/Gobi low-lying land > forestland around cultivated land/irrigation canals > current river course forestland > abandoned farmland. In the 0–20 cm and 20–40 cm layers, abandoned farmland had significantly lower conductivity than other types ($P < 0.05$), while in the 40–60 cm layer, ancient river course/Gobi low-lying land had significantly higher conductivity ($P < 0.05$).

3.4.3 Soil Particle Composition Soil particle composition in P. euphratica distribution areas was characterized by the highest proportion of fine sand particles, followed by coarse sand, silt, and clay (). Fine sand accounted for 38.84%-54.65% of soil volume, coarse sand 36.19%-54.42%, silt 5.41%-9.92%, and clay 1.25%-2.08%. Except for forestland around cultivated land and irrigation canals where silt exceeded coarse sand, all other forest types showed the pattern: coarse sand > silt > clay.

Proportions of clay, silt, and coarse sand varied little with depth within the same forest type but differed among types. Except for coarse sand in the 0-20 cm layer, forestland around cultivated land and irrigation canals had significantly higher clay and silt proportions than other types across all layers ($P < 0.05$), while differences among the other three types were not significant ($P > 0.05$).

3.5 Relationship Between Seedling Regeneration and Soil Factors

Correlation analysis between P. euphratica age classes, seedling numbers, and soil factors () revealed that available phosphorus was positively correlated with middle-aged, young, and seedling numbers (middle-aged and young: $P < 0.05$; seedlings: $P < 0.01$). Soil moisture content was positively correlated with middle-aged, young, and seedling numbers ($P < 0.01$). Soil electrical conductivity was negatively correlated with middle-aged tree numbers ($P < 0.05$). No significant correlations were found between other soil factors and young tree or seedling numbers.

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4. Discussion

4.1 Distribution, Growth, and Stand Characteristics of Natural Populus euphratica in the Hexi Corridor

Natural P. euphratica in the Hexi Corridor is distributed along the three major inland rivers, primarily on river terraces, around river channels, and at oasis edges and farmland peripheries, forming four main forest types. The current distribution pattern results from reduced upstream water inflow, declining groundwater levels, and human activities, which also affect tree growth and regeneration.

Under current site conditions, forestland around cultivated land/irrigation canals and along current river courses shows normal growth, balanced age structure, and adequate regeneration seedlings, enabling sustainable development. Although abandoned farmland has the most regeneration seedlings, without subsequent water supplementation, seedlings will decline as abandonment duration increases. Forestland in ancient river courses and Gobi low-lying areas is deteriorating due to further soil moisture reduction and aggravated secondary salinization.

Soil moisture and available phosphorus are positively correlated with middle-aged, young, and seedling numbers, confirming their important roles in P. euphratica growth and regeneration. The study area's P. euphratica forests possess natural regeneration capacity. Rational water allocation, slowed groundwater decline, and appropriate soil moisture supplementation are effective approaches for maintaining healthy forest development in the Hexi Corridor.

4.2 Soil Factor Characteristics of Natural Populus euphratica Forestland

Soil moisture content varied significantly among forest types. Forestland around cultivated land/irrigation canals and along current river courses received direct or indirect water supplementation from irrigation and river flow, resulting in significantly higher soil moisture than in abandoned farmland and ancient river course/Gobi low-lying land ($P < 0.05$ in 0–20 cm and 20–40 cm layers). Ancient river course and Gobi low-lying land relied solely on natural precipitation, which is scarce in the study area, resulting in relatively low soil moisture.

Available phosphorus content was significantly higher in abandoned farmland and forestland around cultivated land/irrigation canals than in other types, particularly in the 0–20 cm and 20–40 cm layers ($P < 0.05$). This is related to fertilizer application during cultivation and richer understory vegetation with greater litter and humus accumulation that improved soil surface properties. Available phosphorus was positively correlated with middle-aged, young, and seedling numbers ($P < 0.05$ for middle-aged and young; $P < 0.01$ for seedlings), indicating it promotes P. euphratica regeneration.

Soil electrical conductivity was lowest in abandoned farmland, significantly lower than other types in 0–20 cm and 20–40 cm layers ($P < 0.05$). Although conductivity was not correlated with young tree or seedling numbers, the overall pattern showed that lower conductivity (less soil salinity) corresponded to more young trees and seedlings, suggesting that within the study range, lower salinity favors root sucker reproduction.

Soil particle composition analysis revealed that forestland around cultivated land and irrigation canals had significantly higher clay and silt proportions than other types ($P < 0.05$), indicating lower sand content and stronger water/nutrient retention capacity, which benefits P. euphratica growth and regeneration. However, differences among other forest types were not significant, and growth patterns didn' t consistently follow particle composition gradients, suggesting soil particles didn' t significantly affect P. euphratica growth and regeneration in this study.

4.3 Relationship Between Populus euphratica Regeneration and Soil Factors

Forest regeneration is crucial for forest restoration and community succession, forming the basis for population survival and reproduction, while soil serves as the medium for many ecological processes and plant growth. In arid and semi-arid regions, soil moisture is the primary limiting factor for plant growth and significantly influences population regeneration. P. euphratica regenerates naturally primarily through root suckering, with horizontal root extension reaching tens of meters. This process is closely related to soil moisture—higher autumn soil moisture typically results in more new shoots the following year, mainly dependent on flood irrigation.

Different forest types exhibited varying soil moisture and regeneration status. Forestland around cultivated land/irrigation canals and along current river courses, receiving water supplementation from irrigation and river flow, had significantly higher soil moisture and more regeneration seedlings. Abandoned farmland had low soil moisture but the most regeneration seedlings because extensive P. euphratica spreading roots existed in the soil before abandonment. Farmland cultivation affected root performance and soil texture, promoting root sucker germination. Once cultivation ceased, numerous seedlings emerged and survived, consistent with Wang Yuchen' s findings. However, high seedling density in abandoned farmland increased water consumption, and with increasing abandonment duration, vegetation composition and quantity increased, further accelerating soil moisture depletion. Without irrigation supplementation, young trees weakened and many seedlings died, further demonstrating the positive correlation between growth/regeneration and soil moisture ($P < 0.01$).

Soil electrical conductivity, an indicator of soil salinity, inhibits plant reproduction and growth at high levels. Although not correlated with young tree or seedling numbers, conductivity showed the pattern: ancient river course/Gobi low-lying land > forestland around cultivated land/irrigation canals > current river course forestland > abandoned farmland. Abandoned farmland had significantly lower conductivity ($P < 0.05$), while the ranking of young trees and seedlings per unit area was inverse—lower conductivity corresponded to more young trees and seedlings—indicating that within the study range, lower salinity favored root sucker reproduction.

Soil physical structure and particle composition determine water/nutrient retention capacity, with sandy loam or clay loam containing less sand being more conducive to P. euphratica root suckering. The study area' s soil was dominated by fine sand particles, with forestland around cultivated land/irrigation canals having significantly higher clay and silt proportions ($P < 0.05$). However, growth and regeneration patterns didn' t align with particle composition gradients, suggesting soil particles didn' t significantly impact P. euphratica regeneration in this study.

Root suckers primarily occur on spreading roots at 15–25 cm depth. The significantly higher available phosphorus in 0–20 cm and 20–40 cm layers of abandoned farmland and forestland around cultivated land/irrigation canals ($P < 0.05$), combined with their higher seedling numbers, suggests that available phosphorus promotes regeneration. Total nitrogen and organic matter showed no significant differences among forest types and weren' t correlated with age class distributions, indicating they didn' t significantly affect regeneration in this study.

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5. Conclusions

1. Natural P. euphratica forests in the Hexi Corridor are distributed in patches along the three major inland rivers, on river terraces, around river channels, and at oasis edges and farmland peripheries. Four main forest types exist: abandoned farmland, forestland around cultivated land and irrigation canals, forestland along current river courses, and forestland in ancient river courses and Gobi low-lying areas. Reduced upstream water inflow, declining groundwater levels, and human activities are primary causes of the current distribution pattern and major factors affecting growth and regeneration.
2. Under current site conditions, forestland around cultivated land/irrigation canals and along current river courses shows normal growth, balanced age structure, and adequate regeneration seedlings, enabling sustainable development. Although abandoned farmland has the most regeneration seedlings, without subsequent water supplementation, seedlings will decline as abandonment duration increases. Forestland in ancient river courses and Gobi low-lying areas is deteriorating due to further soil moisture reduction and aggravated secondary salinization.
3. Soil moisture and available phosphorus are positively correlated with middle-aged, young, and seedling numbers, confirming their important roles in P. euphratica growth and regeneration. The study area’ s P. euphratica forests possess natural regeneration capacity. Rational water allocation, slowed groundwater decline, and appropriate soil moisture supplementation are effective approaches for maintaining healthy forest development in the Hexi Corridor.

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