Postprint: Relationship Between Tamarix Distribution and Environmental Factors in Qinwangchuan Wetland

Authors: Zhao Lianchun, Zhao Chengzhang, Wang Xiaopeng, Wen Jun

Date: 2018-05-29T00:00:00+00:00

Abstract

The relationship between environmental factors and vegetation distribution constitutes a crucial component of ecological research, holding significant importance for elucidating the formation mechanisms of plant populations and ecological adaptation strategies, as well as for predicting spatial vegetation distribution. To investigate the influence of environmental factors on the spatial distribution of *Tamarix gansuensis* H.Z.Zhang in wetland habitats within arid regions at a fine scale, we employed the Maxent model in the Qinwangchuan National Wetland Conservation Area, utilizing remote sensing imagery and digital elevation model data to analyze the effects of seven environmental variables—including elevation, slope, aspect, slope position, distance from river, soil water content, and soil salinity—on the distribution of *T. gansuensis.* The results demonstrated that *T. gansuensis* exhibited a clustered distribution pattern within the conservation area, predominantly occurring in locations characterized by soil water content of 15%–30%, soil electrical conductivity 5 ms/cm, distance from river of 18–70 m, elevation of 1890–1913 m, and on inter-gully land or gully slopes. The spatial distribution was primarily governed by three environmental variables: soil water content, salinity, and distance from river. Elevation, slope, and distance from river displayed negative correlations with soil water content and salinity ($P < 0.05$), whereas slope position exhibited positive correlations. Soil factors, particularly water and salt content, represent the principal environmental determinants shaping wetland vegetation distribution patterns, while hydrological and topographic factors indirectly influence wetland vegetation distribution by controlling soil water and salt content and modifying local environmental conditions.

Full Text

Preamble

ACTA ECOLOGICA SINICA
DOI: 10.5846/stxb201703270526

Interrelations between Environmental Factors and Distribution of *Tamarix gansuensis* in Qinwangchuan Wetland

ZHAO Lianchun, ZHAO Chengzhang*, WANG Xiaopeng, WEN Jun
College of Geography and Environmental Science, Northwest Normal University; Gansu Provincial Engineering Research Center of Wetland Resources Protection and Industrial Development, Lanzhou 730070, China

Abstract

The relationship between environmental factors and vegetation distribution constitutes a critical focus in ecological research, playing a vital role in revealing plant population formation mechanisms, ecological adaptation strategies, and predicting spatial vegetation patterns. To investigate how environmental factors influence the distribution of *Tamarix gansuensis* in arid wetland habitats at a fine scale, we employed the MaxEnt model to analyze the effects of seven environmental variables—altitude, slope, aspect, slope position, distance to river, soil moisture, and soil salinity—on the spatial distribution of *T. gansuensis* in the Qinwangchuan Wetland based on remote sensing imagery and digital elevation models. Our results demonstrate that *T. gansuensis* exhibits a clustered distribution pattern within the conservation zone of Qinwangchuan National Wetland, predominantly occurring in areas with soil moisture content of 15%-30%, soil electrical conductivity of 5 ms/cm, altitudes of 1890-1913 m, and on inter-gully or sloping lands. The spatial distribution was primarily influenced by soil moisture, soil salinity, and distance to river. Altitude, slope, and distance to river showed negative correlations with soil moisture and salinity, whereas slope position was positively correlated with these soil factors. Soil moisture and salinity emerged as the principal environmental drivers shaping wetland vegetation distribution patterns, while hydrological and topographic factors indirectly affected plant distribution by controlling soil water and salt content, thereby altering local environmental conditions. These findings provide a theoretical basis for wetland restoration and conservation efforts.

Keywords: wetland plant; environmental factor; digital elevation model; distribution pattern; MaxEnt model

Introduction

The spatial distribution patterns of plant populations result from the combined influence of various environmental factors across Earth’ s surface. Investigating these patterns and their underlying mechanisms is essential for understanding population-environment relationships, elucidating ecological adaptation strategies, predicting community dynamics, and revealing the intrinsic processes governing community structure and succession. At macro scales, climatic factors—particularly temperature and precipitation—represent the primary determinants of plant distribution and key influences on biological reproduction and survival. As spatial scale decreases, other factors including soil properties, topography, hydrological conditions, anthropogenic disturbance, species dispersal capacity, and biological interactions become increasingly prominent in shaping species distributions.

Topographic factors control the spatial redistribution of solar radiation and surface water, creating local microclimatic conditions that significantly influence vegetation community distribution and nutrient dynamics, representing fundamental drivers of ecological phenomena and processes. Soil environmental factors directly affect plant growth and development, exhibit strong coupling relationships with vegetation types, and serve as primary drivers of spatial vegetation heterogeneity. Wetland hydrological conditions critically influence soil properties and development trajectories, affecting vegetation growth and constraining landscape pattern changes. At fine scales, hydrological factors may become the dominant influence on vegetation distribution, making their study crucial for understanding wetland plant community dynamics in arid regions.

While numerous studies have quantitatively examined climate-plant distribution relationships at large scales to predict climate change impacts, or investigated soil and topographic influences on plant diversity in terrestrial ecosystems at small scales, research on environmental filtering effects in wetland ecosystems remains limited. In wetland systems, heterogeneous microenvironments result from combinations of topographic, hydrological, and soil factors, which can explain environmental filtering effects unresolved at larger scales and drive the formation of ecological adaptation strategies for resource acquisition.

Tamarix gansuensis, a member of the Tamaricaceae family, is a deep-rooted phreatophyte with well-developed salt-secreting glands, making it a typical recretohalophyte. Characterized by scale-like leaves, wide ecological niche breadth, and both sexual and vegetative reproduction, this species exhibits high ecological and medicinal value. Widely distributed in saline wastelands and saline wetlands across China, *T. gansuensis* dominates the Qinwangchuan Wetland and plays a crucial role in maintaining ecosystem function. Previous research has focused on root-crown architecture, reproductive strategies, physiological characteristics, and distribution patterns, yet the relationship between its distribution and environmental factors in wetland ecosystems, particularly at fine scales, remains unclear. This study employs the MaxEnt model to analyze the relationship between *T. gansuensis* distribution and environmental factors in the Qinwangchuan National Wetland conservation zone, using soil and topographic factors as environmental variables to explore wetland plant adaptation strategies and provide theoretical support for wetland remote sensing interpretation, classification, and ecological restoration.

1. Study Area

The study area is located within the conservation zone of Qinwangchuan National Wetland Park in Lanzhou City, Gansu Province, China (103°35 38 -108°38 37 E, 36°23 59 -36°27 56 N). Situated at elevations ranging from 1872 to 1928 m (concentrated at 1879 m), the region experiences a continental monsoon climate with an average annual temperature of 6.9°C, annual precipitation of 2700 hours of sunshine, and a frost-free period of 126 days. Mean annual evaporation reaches 1879.0 mm. Soils are primarily light sierozem and secondary salinized soils. The aquifer consists of sandy gravel and fine sand layers, and the area experiences seasonal flooding, supporting aquatic and hygrophytic communities. The conservation zone naturally supports extensive *Tamarix gansuensis* populations, along with other dominant species including *Lycium chinense*, *Typha orientalis*, *Phragmites australis*, *Chenopodium glaucum*, *Aster tataricus*, *Calamagrostis pseudophragmites*, *Sonchus oleraceus*, and *Salsola collina*.

[Figure 1: see original paper] Location of the study area and data acquisition points

2. Data Sources and Processing

Following the methodology of Wang et al. [34], we selected a study area of approximately 10 hm^2 and established control points for drone data acquisition. A DJI Phantom 3 drone captured vertical imagery over a 10-hour flight period. Using Pix4D Mapper software, we performed aerial triangulation, generated photogrammetric point clouds, and produced digital orthophotos. Non-ground data (e.g., vegetation) were removed using TerraScan software to obtain ground point clouds. An Inverse Distance Weighted (IDW) interpolation with 0.10 m resolution was applied in ArcGIS to generate a high-resolution Digital Elevation Model (DEM). To balance detail with computational efficiency, this high-resolution DEM served as the primary data source while meeting accuracy requirements.

DEM accuracy statistics

2.1 Topographic Factor Data

Using ArcGIS 10.2 3D Analyst, we extracted topographic information. The Block Statistics tool first identified maximum and minimum elevations within defined neighborhoods, followed by Raster Calculator to compute slope position. This analysis generated distribution maps for slope, aspect, and altitude [35].

2.2 Soil Factor Data

Following Wu et al.’ s methodology for determining sampling intensity [36], we established a 30 m × 30 m grid across the study area, collecting soil samples at grid intersections. At each sample point, we excavated three 0–30 cm depth profiles along diagonal transects, mixing soil from each one-third position. Samples were analyzed for soil moisture (oven-drying method) and salinity (water-soil conductivity method at 1:5 ratio) [37]. Using ArcGIS 10.2 Kriging interpolation, we generated spatial distribution maps for soil properties.

2.3 Hydrological Factor Data

Following Liu et al.' s approach [38], we manually interpreted remote sensing imagery to map *T. gansuensis* distribution and analyzed river vector data to generate distance-to-river maps. Distance to river was selected as the primary hydrological variable [35], verified through multiple field surveys.

2.4 Distribution Hotspot Analysis

Using ArcGIS 10.2 Spatial Analyst, we applied grid-based analysis [39] to examine *T. gansuensis* distribution. A 10 m × 10 m grid was created, with each cell treated as a point data unit. Cells containing *T. gansuensis* were assigned a value of 1. The Extract Analysis tool automatically populated point attributes with environmental variables, which were then exported for hotspot analysis. Hotspot analysis calculates Getis-Ord Gi* statistics to identify spatial clustering; higher values indicate tighter clustering, revealing locations of significant *T. gansuensis* aggregation.

[Figure 2: see original paper] Spatial distribution of *Tamarix gansuensis*

3. Environmental Variable Analysis

The MaxEnt model treats all pixels in the study area as potential distribution space, using known occurrence pixels as samples to derive environmental constraints and identify the maximum entropy distribution that satisfies these constraints. This approach effectively predicts species distributions by assuming species will spread maximally and approach uniform distribution without constraints [40-42]. We analyzed data using MaxEnt 3.3.3 software, with 70% of data for model training and 30% for validation (default parameters). Model accuracy was assessed using Receiver Operating Characteristic (ROC) curves, where the Area Under the Curve (AUC) indicates predictive performance: 0.5–0.7 (low), 0.7–0.9 (moderate), and >0.9 (excellent) [43-44]. Jackknife tests evaluated each variable' s contribution to potential distribution [45].

3.1 Topographic Variables

Hotspot analysis revealed a clustered distribution pattern for *T. gansuensis* within the conservation zone, with two primary hotspot areas in the northeast and southeast separated by river channels. High-value clustering zones (Gi   5) occupied 2B% of the conservation area, while cold spots occurred in the western region. Distribution initially increased then decreased with altitude, peaking at 1890–1913 m; few individuals occurred below 1872–1878 m. Slope variation had minimal impact due to the flat terrain. Slope position significantly affected distribution, with highest densities on inter-gully and slope positions, decreasing toward gully bottoms. In this flat wetland landscape, altitude and slope position were the primary topographic factors, while slope exerted limited influence.

[Figure 3: see original paper] Response of *Tamarix gansuensis* distribution to topographic variables

3.2 Soil Variables

Distribution probability initially increased then sharply decreased with rising soil moisture, peaking at 15%-30% moisture content. Probability declined dramatically when moisture exceeded this range. Soil electrical conductivity (reflecting salinity) showed a similar pattern, with high distribution probability at 0–5.6 ms/cm, demonstrating the species' salt tolerance. Wetland hydrology critically influences soil properties and development, thereby affecting vegetation growth [45].

[Figure 4: see original paper] Response of *Tamarix gansuensis* distribution to soil variables

3.3 Hydrological Variables

Distance to rivers or water depressions significantly influenced distribution. *Tamarix gansuensis* showed highest distribution probability at 18–70 m from water bodies, decreasing at greater distances. This pattern reflects the negative correlation between distance to water and soil moisture content, indicating that hydrological factors indirectly control plant distribution by regulating soil moisture gradients.

[Figure 5: see original paper] Response of *Tamarix gansuensis* distribution to hydrological variables

3.4 Model Performance and Variable Importance

MaxEnt modeling achieved excellent predictive performance with AUC values of 0.926 for training data and 0.921 for test data, indicating reliable predictions of suitable habitat. The primary environmental variables influencing distribution were soil moisture (39.5% contribution), soil electrical conductivity (27.6%), and distance to river (20.1%). Among topographic variables, altitude (5.5%), slope position (5.2%), and slope (1.4%) had modest effects, while aspect contributed minimally (0.06%).

[Figure 6: see original paper] Importance of different environmental variables

Correlation analysis revealed that soil moisture was significantly positively correlated with slope position but negatively correlated with distance to water and slope. Soil electrical conductivity showed similar relationships, indicating that topographic factors influence vegetation distribution by controlling spatial heterogeneity of soil water and salt content.

Correlation among the main environmental variables

4. Discussion

4.1 Relationship Between *Tamarix gansuensis* Distribution and Soil Factors

Soil environment directly affects plant growth and development, with spatial variation in soil physicochemical properties determining vegetation distribution patterns under similar climatic conditions [46]. In the Qinwangchuan Wetland conservation zone, *T. gansuensis* distribution was primarily controlled by soil moisture (15%-30% optimal range) and salinity (0-5.6 ms/cm electrical conductivity), accounting for 67.1% of the explained variation. As a deep-rooted phreatophyte, *Tamarix* can utilize deep groundwater. Its thick leaf cuticle prevents drought damage, while relatively low water potential and high water retention capacity enable tolerance of significant water deficit [47]. As a recretohalophyte, *Tamarix* exhibits low selectivity for soil ions, transporting absorbed salts through vessels to salt glands for excretion [48], conferring salt tolerance that allows survival in high-salinity areas. These findings align with Zhao et al.' s conclusion that groundwater depth and soil salinity are primary factors controlling wetland plant community distribution [46].

4.2 Relationship Between *Tamarix gansuensis* Distribution and Hydrological Factors

Hydrological conditions directly control wetland ecosystem formation and evolution, influencing soil biogeochemical properties and biological communities [49]. In the gently sloping Qinwangchuan Wetland, *T. gansuensis* predominantly occurred 18-70 m from rivers or water depressions (20.1% contribution). Hydrological factors represent major environmental variables affecting distribution by creating soil moisture gradients. This supports Wesche et al.' s assertion that water availability is the most critical factor determining vegetation presence and distribution [51]. As the primary medium for material transport in wetlands, water couples with other biotic and abiotic factors to drive biogeochemical cycles, element cycling, and contaminant purification [52]. Seasonal hydrological variations affect wetland hydroperiods, surface flow patterns, and sediment interception, thereby influencing vegetation distribution.

4.3 Relationship Between *Tamarix gansuensis* Distribution and Topographic Factors

Topography is the primary factor influencing microclimate and spatial variation in local soil properties. At fine scales in this study, altitude (1890-1913 m optimal range) and slope position affected distribution by regulating soil moisture and nutrient conditions through elevation differences, creating heterogeneous microenvironments [53]. The minimal response to slope variation reflects the flat terrain (18°) where small slope changes inadequately control infiltration and runoff, and uniformly high soil moisture limits topographic control over resource distribution. This corroborates Wang et al.' s finding that different species respond differently to topographic factors [54].

5. Conclusion

The relationship between environmental factors and plant distribution reflects both individual ecological adaptation strategies and mechanisms underlying spatial pattern formation. Within the Qinwangchuan Wetland conservation zone, *Tamarix gansuensis* exhibits clustered distribution, primarily occurring on intergully or sloping lands with soil moisture of 15%-30%, electrical conductivity 5 ms/cm, altitude of 1890-1913 m, and 18-70 m from water bodies. At this local scale, distribution is predominantly controlled by soil moisture, salinity, and distance to river, with topographic factors (altitude, slope position) exerting indirect effects through their influence on soil water-salt content. The coupling of topographic, hydrological, and soil factors can be used to predict *T. gansuensis* distribution. Future research should examine additional influences such as understory vegetation, species biological characteristics, and soil types to further validate these findings.

References

[1] Greig-Smith P. The use of random and contiguous quadrats in the study of the structure of plant communities. *Annals of Botany*, 1952, 16(2): 293-316.

[2] [Reference text appears incomplete in original]

[3] [Reference text appears incomplete in original]

[4] [Reference text appears incomplete in original]

[5] [Reference text appears incomplete in original]

[6] Anderson R P, Peterson A T, Gómez-Laverde M. Using niche-based GIS modeling to test geographic predictions of competitive exclusion and competitive release in South American pocket mice. *Oikos*, 2002, 98(1): 3-16.

[7] [Reference text appears incomplete in original]

[8] [Reference text appears incomplete in original]

[9] [Reference text appears incomplete in original]

[10] Gong X, Brueck H, Giese K M, Zhang L, Sattelmacher B, Lin S. Slope aspect has effects on productivity and species composition of hilly grassland in the Xilin River Basin, Inner Mongolia, China. *Journal of Arid Environments*, 2008, 72(4): 483-493.

[11] Torma A, Császár P. Species richness and composition patterns across trophic levels of true bugs (Heteroptera) in the agricultural landscape of the

lower reach of the Tisza River Basin. *Journal of Insect Conservation*, 2013, 17(1): 35-51.

[12] [Reference text appears incomplete in original]

[13] Pepper M, Keogh J S. Biogeography of the Kimberley, Western Australia: a review of landscape evolution and biotic response in an ancient refugium. *Journal of Biogeography*, 2014, 41(8): 1443-1455.

[14] [Reference text appears incomplete in original]

[15] [Reference text appears incomplete in original]

[16] [Reference text appears incomplete in original]

[17] [Reference text appears incomplete in original]

[18] [Reference text appears incomplete in original]

[19] [Reference text appears incomplete in original]

[20] [Reference text appears incomplete in original]

[21] [Reference text appears incomplete in original]

[22] [Reference text appears incomplete in original]

[23] [Reference text appears incomplete in original]

[24] [Reference text appears incomplete in original]

[25] [Reference text appears incomplete in original]

[26] [Reference text appears incomplete in original]

[27] [Reference text appears incomplete in original]

[28] Xia J B, Zhang S Y, Zhao X M, Liu J H, Chen Y P. Effects of different groundwater depths on the distribution characteristics of soil-water contents and salinity under saline mineralization conditions. *CATENA*, 2016, 142: 166-176.

[29] [Reference text appears incomplete in original]

[30] [Reference text appears incomplete in original]

[31] [Reference text appears incomplete in original]

[32] Lu Q Q, Bai J H, Gao Z Q, Zhao Q Q, Wang J J. Spatial and seasonal distribution and risk assessments for metals in a *Tamarix chinensis* wetland, China. *Wetlands*, 2016, 36(S1): 125-136.

[33] Gao C Q, Yang G Y, Guo Y C, Zhao Y L, Yang C P. Overexpression of *ThGSTZ1* from *Tamarix hispida* improves tolerance to exogenous ABA and methyl viologen. *Trees*, 2016, 30(6): 1935-1944.

[34] [Reference text appears incomplete in original]

[35] [Reference text appears incomplete in original]

[36] [Reference text appears incomplete in original]

[37] [Reference text appears incomplete in original]

[38] [Reference text appears incomplete in original]

[39] [Reference text appears incomplete in original]

[40] Phillips S J, Anderson R P, Schapire R E. Maximum entropy modeling of species geographic distributions. *Ecological Modelling*, 2006, 190(3/4): 231-259.

[41] Li B N, Wei W, Ma J, Zhang R J. Maximum entropy niche-based modeling (MaxEnt) of potential geographical distributions of fruit flies *Dacus bivittatus ciliatus vertebrates* MaxEnt (Diptera: Tephritidae). *Acta Entomologica Sinica*, 2009, 52(10): 1122-1131.

[42] [Reference text appears incomplete in original]

[43] McNeil B J, Hanley J A. Statistical approaches to the analysis of ROC curves. *Medical Decision Making*, 1984, 4(2): 136-149.

[44] [Reference text appears incomplete in original]

[45] [Reference text appears incomplete in original]

[46] [Reference text appears incomplete in original]

[47] [Reference text appears incomplete in original]

[48] [Reference text appears incomplete in original]

[49] [Reference text appears incomplete in original]

[50] [Reference text appears incomplete in original]

[51] Wesche K, Miehe S, Miehe G. Plant communities of the Gobi Gurvan Sayhan National Park (South Gobi Aymak, Mongolia). *Candollea*, 2005, 60(1): 149-205.

[52] [Reference text appears incomplete in original]

[53] Wang Q G, Xu Y Z, Lu Z J, Bao D C, Guo Y L, Lu J M, Zhang K H, Liu H B, Meng H J, Qiao X J, Huang H D, Jiang M X. Disentangling the effects of topography and space on the distributions of dominant species in a subtropical forest. *Chinese Science Bulletin*, 2014, 59(35): 5113-5122.

[54] [Reference text appears incomplete in original]

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv —Machine translation. Verify with original.