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Autecology of the Euphrates poplar (*Populus euphratica Oliv.*) in the Sistan Plain, Iran

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ABSTRACT

Aims: There is no reliable published information about the Euphrates poplar's habitats in the Sistan Plain. The primary aim of the present study was to ascertain the ecological characteristics and biological requirements of this species, particularly regarding soil features, to inform rehabilitation activities in the region.

Materials & Methods: After identifying key natural habitats in the Sistan Plain, various factors, such as climatic conditions, soil characteristics, quantitative attributes of individual species, and species phenology, were investigated.

Findings: The findings revealed that Euphrates poplar is distributed on various soil textures from light to heavy. The measurements of tree growth parameters indicated that tree density falls between 280 and 520 trees per hectare, the mean diameter at breast height of the trees ranges from 9 to 12 cm, the mean height is between 3 and 5 m, and the canopy cover percentage varies from 28 to 58. The correlation analysis revealed a positive and statistically significant relationship between the rate of clay particles, soil EC, and tree height and density.

Conclusion: This species has shown excellent resistance to harsh climatic and edaphic conditions and successive regional droughts. The vegetative condition of Poplars Paris is better in habitats where the soil texture is medium to heavy and in habitats with higher soil saturation moisture and lower calcium carbonate percentages. Planting these species in such places can be helpful in the biological restoration of the Sistan Plain.

Keywords: Canopy Density; Dryland Forests; Euphrates Poplar; Phenology; Soil Properties.

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Introduction

Identifying habitats and suitable environmental conditions for various animal and plant species is one of the key issues in ecology [1, 2]. The presence of any plant is affected by environmental factors and inter-species relations; one or more environmental factors have the most significant effect in the presence of a particular plant species if the environmental factors affecting the distribution of any plant can be determined [3]. Any management plan to reform, rehabilitate, and exploit natural resources in the first step requires the identification of vegetation in the respective area [4, 5, 6, 7].

In arid regions, the presence of vegetation is inherently scarce. Effective and prudent management of renewable natural resources, particularly in arid and semi-arid zones, holds considerable significance. Strengthening appropriate vegetation cover and implementing efficient management practices for natural ecosystems within these regions are strategic measures to mitigate ecosystem degradation and combat desertification activities. A comprehensive understanding of the ecological characteristics of these areas is crucial for the conservation, rehabilitation, development, and sustainable use of these resources [8]. Because native resistant species have evolved to thrive in specific environmental conditions over centuries, knowledge of their habitat characteristics can facilitate their use in place of previously limited species. This enriches the country's genetic resources and inspires greater confidence in the success of biological desertification control efforts [9].

Regarding plant systematics, the Euphrates Poplar (*Populus euphratica* Oliv.) is a species of the *Populus* genus and belongs to the Salicaceae. The dioecious nature of this species, in conjunction with its geographical and climatic variations, has led to its morphological and genetic diversity. This deciduous tree exhibits a substantial, circular crown and bears bluish, grayish, leather-like leaves with heterophyllous characteristics [10]. Catkins typically emerge simultaneously with leaf unfolding. The trunk of the Euphrates poplar is often characterized by a crooked and sometimes twisted configuration, which branches into multiple stems. The wood of this species is dense and durable, with a dark brown hue. It can be easily dried and used [11].

The Euphrates poplar has an inherent affinity for warm regions, which naturally extends its presence across expansive areas in Asia, Africa, and Europe [12]. In Iran, the distribution of this species occurs in specific regions, particularly those characterized by arid and semi-arid conditions [8, 13, 14]. Noteworthy characteristics of the Euphrates poplar include its remarkable resilience to environmental stressors such as drought, soil salinity, and wind erosion in desert landscapes [9, 15, 16]. The habitat of the Euphrates poplar, whether in pure or mixed stands, is predominantly located along the banks of permanent or seasonal watercourses and rivers in arid and semi-arid regions. These areas, which are known for seasonal floods and soil submergence, provide favorable conditions for the proliferation of this tree [17, 18, 19, 20]. Although the Euphrates poplar typically favors alluvial sandy-loam soils, it also exhibits adaptability to sandy-loam and loam-clay soil types [11].

The Sistan area, known for its scanty annual rainfall of less than 65 mm and annual evaporation exceeding 4500 mm, is one of the driest places in the world [21]. The annual rainfall in this region is minimal, but its distribution is uneven and varies significantly throughout the year. In addition, there are noticeable fluctuations in the temperature. These climatic elements, combined with other factors affecting moisture levels, have led to the arid nature of these ecosystems, making these areas highly fragile and vulnerable in both natural and human terms. In addition to limiting vegetation growth in these environments, these conditions expose soil to erosion by water and wind. This erosion, in turn, disrupts soil biological processes, contributing to desertification. Recent occurrences like droughts and excessive grazing have significantly deteriorated several ecosystems in Sistan, resulting in severe soil erosion, desertification, and intense storms throughout the region [22].

In the Sistan Region, the Euphrates poplar species demonstrate resilience to soil salinity and various prevailing ecological conditions, including an arid climate, limited rainfall, hot summers, cold winters, strong winds, and intense solar radiation [16]. This species can also withstand the high evaporation rates, flooding, and drought cycles associated with the river. Within this context, Euphrates poplar communities play a pivotal role in the desert areas of Sistan. By establishing stable ecological communities along the river, the Euphrates poplar has significantly contributed to mitigating riverbank erosion and providing essential forage and fuel wood for rural residents in the desert regions of Sistan. In addition to safeguarding agricultural produce from damage caused by strong winds and windborne sediments, the Euphrates poplar serves as a protective barrier for villages and cities against sandstorms [13].

Given the prevailing challenges in the Sistan plain, encompassing issues such as vegetation degradation, desertification, and sandstorms, addressing and managing these conditions through biological interventions employing appropriate species is imperative. This endeavor requires scientific investigations and a well-suited species for the purpose. Despite the specific ecological prerequisites for development in the region and the acknowledged value and significance of the Euphrates poplar species, there is a shortage of studies in this domain are scarce. The primary aim of the current study is to ascertain the ecological characteristics and biological requirements of the Euphrates poplar, particularly concerning soil conditions, to inform rehabilitation activities in the Sistan Plain. This research seeks to answer the following questions: What are the ecological characteristics of the Euphrates poplar's habitats? What are the biometric properties of trees in different habitats? Finally, which locations do these species grow most?

Materials & Methods

Study Area

The Sistan Plain covers over 80,000 hectares north of Sistan and Baluchestan Province, Iran. It is centered in Zabol city, on the border with Afghanistan. The study areas are located at the geographical coordinates 60°36'18" to 61°48'24" E and 30°03'32" to 31°32'50" N. The geographical positioning of the study area is depicted in Figure 1 [23].

Zabol City records a mean precipitation of 60.8 mm. The lowest temperature documented at the Zahak and Zabol stations is -10°C, while the highest has reached 49°C. The mean annual temperature in the study area was 22.6°C. Zabol encounters a mean of 16 frost days per year. The yearly cumulative evaporation in Zabol was quantified as 3212.9 mm [22].

Geologically, the Sistan Region forms a vast, flat, and mostly uniform plain of the Hirmand River. Sistan's well-known and powerful 120-day winds, also called Levar winds, is a significant geomorphological element in the area. These winds dominate the warmer months and substantially impact soil erosion [24]. Despite its considerable size, the fine texture of alluvial sediments has impeded the formation of underground aquifers in this region. If groundwater exists, it is located more than 100 meters below the soil surface [25].

Methodology

This study outlined the species distribution range by thoroughly analyzing the available resources, local knowledge, satellite imagery,

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and field visits. Finally, three forest habitats—Jazinak, Nyatak, and Zahak—were identified as natural sites where the species thrive. The habitat of Jazinak is closer to the Hirmand River. Soil moisture is affected by the intensity of river flooding. The associated species in these habitats included *Tamarix stricta* Boiss., *T. hispia* Willd., *Haloxylon ammodendron* C.A.Mey., *Prosopis farcta* L., *Desmostachya bipinnata* L., *Phragmites australis* Cav., C*ynodon dactylon* L., *Lepidium latifolium* L., *Cressa cretica* L., *Suaeda fruticosa* L., and *Alhagi camelorum* Fisch. Plots were utilized to examine the growth characteristics of trees, with the plot size determined based on plant dimensions and distances between individual trees. Eventually, five circular plots, each covering an area of 1000 square meters, were randomly chosen in each habitat. The measurements involved assessing the crown surface of each tree, estimation of canopy cover percentage (using a light sensor device), determining tree height (using a Suunto clinometer), measuring DBH as trunk diameter at breast height (with

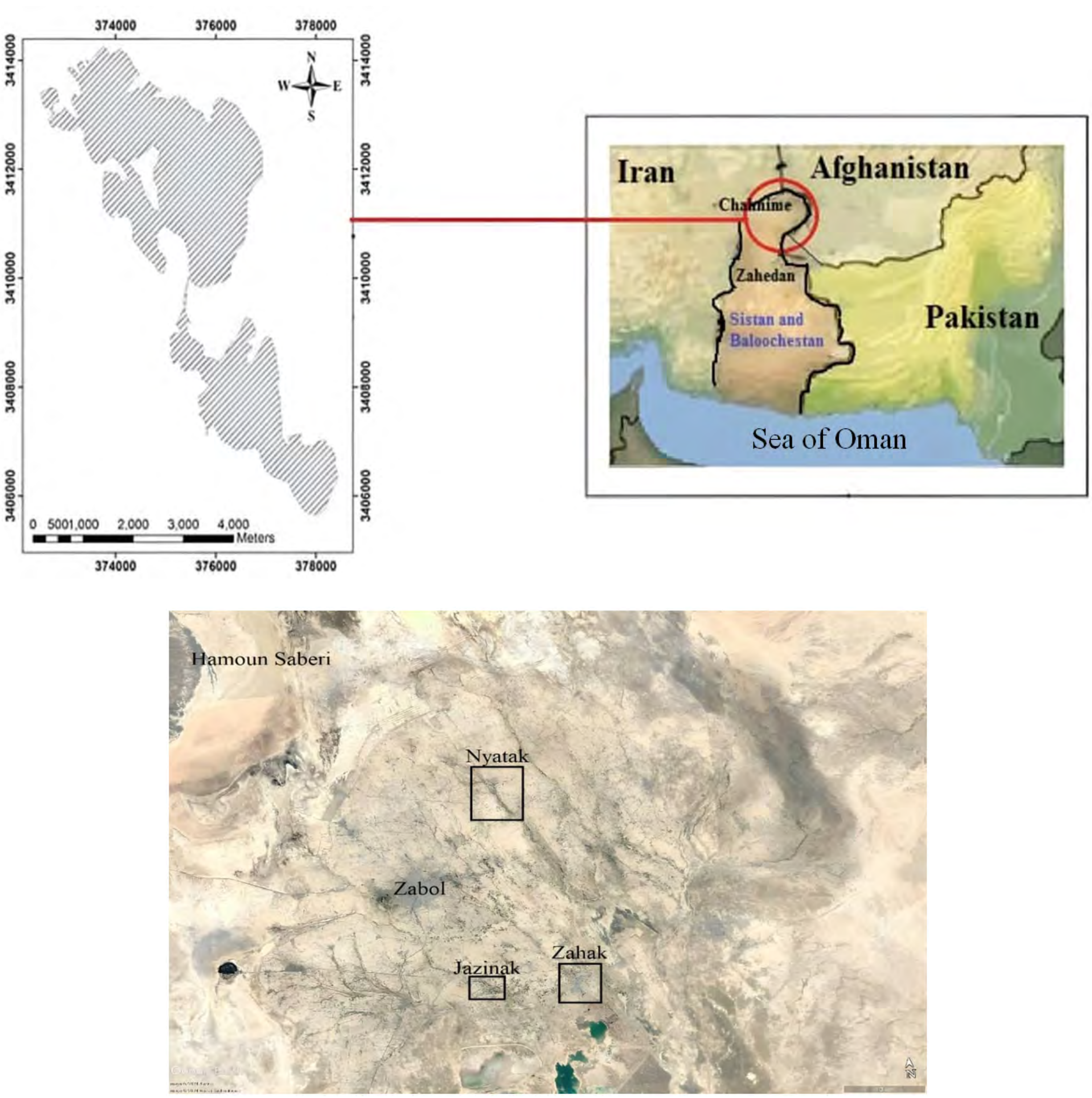

Figure 1) The location of the study area in southeastern Iran.

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a caliper), and calculating tree number per hectare (density).

To investigate the physical and chemical characteristics of the soil, three soil samples were taken between trees, approximately in the center of each plot, at a depth of 0-30 centimeters with a hand-driven corer. These composite samples underwent air-drying, and the soils were pulverized after eliminating impurities. The soil texture was obtained using the Bouyoucos hydrometer method. The pH was determined using an Orion Ionalyzer Model 901 pH meter in a 1:2.5 mixture of soil and deionized water. EC (electrical conductivity) was determined using an Orion Ionalyzer Model 901 EC meter in a 1:2.5 soil: water solution. Soil organic carbon was measured using the Walkley-Black test. Total nitrogen content was measured using the semi-micro-Kjeldahl method. The saturation percentage of the soil was directly obtained using a balance and by dividing the dry soil water by the dry soil mass. The $CaCO_3$ equivalent was determined by neutralizing with HCl and back titration with NaOH [27].

After one year of systematic phenological observations in the studied habitats, the timing of each life phenomenon, such as new leaf emergence, vegetative growth, flowering, seed ripening, and leaf fall, was thoroughly documented once every 15 days. In addition, the experiences of local experts were used. The collected data underwent analysis using the SPSS software. The normality of the data was assessed using the Kolmogorov-Smirnov test. A one-way ANOVA test was applied to discern differences across the three sites. Subsequently, the Tukey test was used to compare the mean growth and soil properties in the three examined habitats. Additionally, the Pearson correlation test was employed to determine the relationship between the growth characteristics of Euphrates poplar and the physical and chemical elements present in the soil of the habitat.

Findings

Significant differences were found in some growth characteristics of poplar trees among the habitats of the region (Table 1). There was a significant difference in tree heights at a 1% confidence level. The mean height of the Euphrates poplar trees peaked at 5.17 m in the Jazinak habitat and reached its lowest height at 3.74 m in the Zahak habitat. Although the mean diameter at breast height varied from 9.95 cm in Zahak to 12.19 cm in Jazinak, no statistically significant difference was observed among the habitats. Similarly, the mean crown surface per tree showed no significant statistical difference across habitats, ranging from 6.51 m^2 to 7.30 m^2. The Tukey test highlighted a considerable variation in the canopy cover percentage among the three habitats in the Sistan plain ($p<0.01$), with the highest percentage (58.56%) in Jazinak and the lowest (28.46%) in Zahak. Moreover, the mean number of trees per hectare showed a significant difference: the Jazinak habitat had the highest count at 520 compared with the Nyatak (360) and Zahak (280) habitats ($p<0.01$) (Figure 2).

Table 1) Variance ratio test of growth characteristics of trees for the whole habitats.

Growth Characteristics of Trees	F-Value
Total Height	16.27 **
Diameter at Breast Height	2.216 NS
Crown Area	0.439 NS
Canopy Density	9.792 **
Tree Density	13.176 **

NS –treatment effect not significant; ** P< 0. 0.01.

Significant differences were found in some soil properties of the Euphrates poplar habitats within the study area (Table 2). Habitat composition was determined using the soil texture triangle and was primarily categorized as loam and clay. According to the ANOVA tables,

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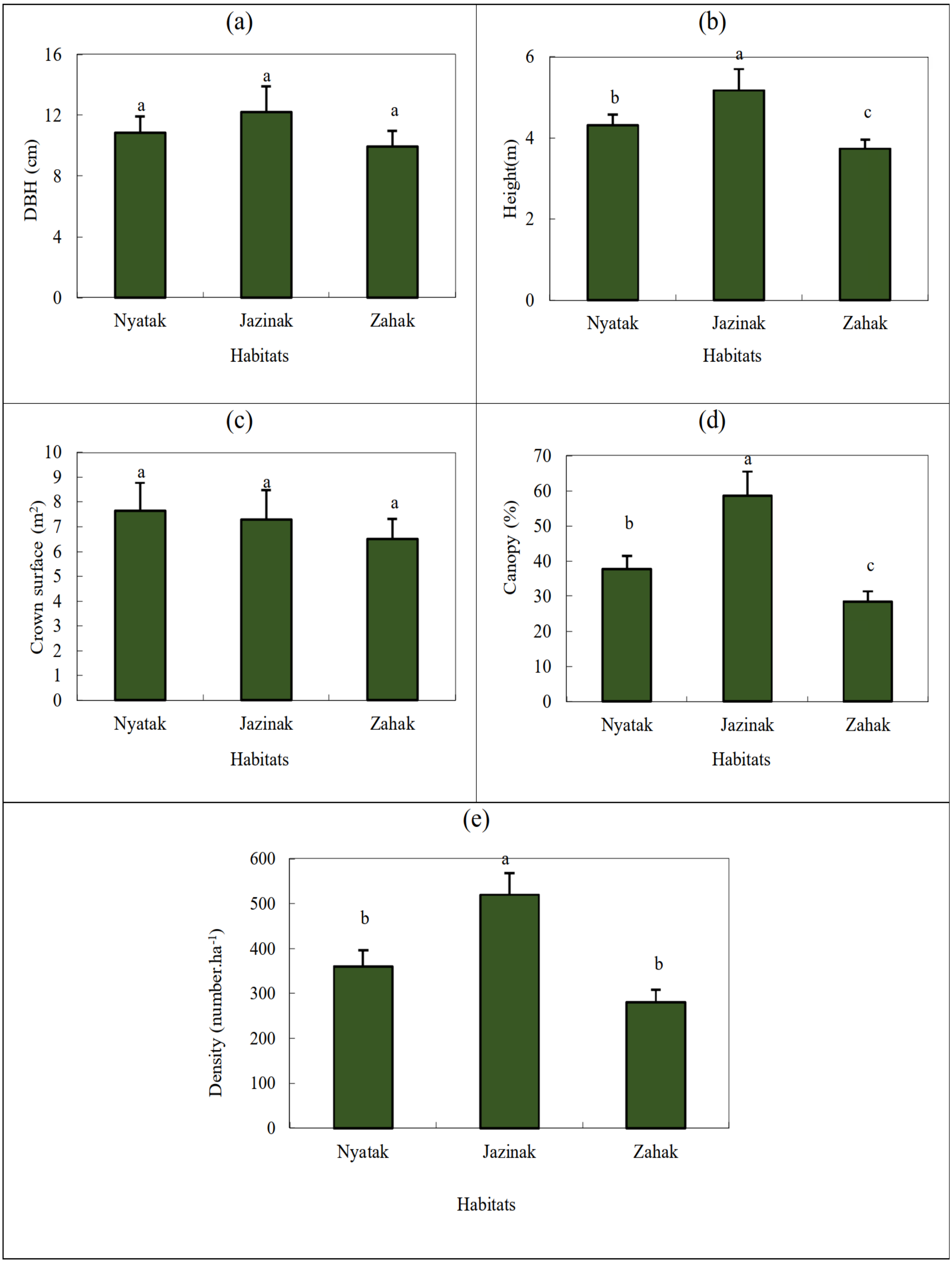

Figure 2) DBH (diameter at breast height) (a), Total height (b), Crown area (c), Canopy density (d), and Tree density (per ha) (e) of *P. euphratica* were compared in each habitat. Mean values with the same letter within a tree species do not differ significantly.

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specific soil properties showed no statistically significant differences among the habitats in the Sistan plain. These properties include mean organic carbon (ranging from 3.32% to 3.39%), nitrogen (0.34% to 0.41%), soil acidity (7.89 to 8.29), and EC values (18.66 to 30.80 $ds.m^{-1}$). However, noticeable differences were observed in the other soil properties. The total calcium carbonate content was significantly higher in the Nyatak habitat (38.5%) than in the Zahak (17.46%) and Jazinak (14.90%) habitats ($p<0.01$). Soil moisture saturation peaked in the Jazinak forest (38.48%) and was lowest in the Nyatak forest (21.22%) ($p<0.05$). The distribution of soil particles also varied among the habitats ($p<0.01$), with Nyatak forests exhibiting a higher mean sand percentage (89.0%) than Zahak (38.2%) and Jazinak (28.8%) forests. The Jazinak forest had the highest clay percentage (24.6%), while the Nyatak forest had the lowest (1.0%). Additionally, the mean silt percentage in the Nyatak forest (10.0%) was lower than that in the Zahak (51.2%) and Jazinak (46.6%) forests (Table 3). Generally, the soil in the Nyatak habitat is loam, the Jazinak habitat is loam, and the Zahak habitat is silty clay loam.

Table 2) Variance ratio test of soil properties for the whole habitats.

Soil Properties	F-Value
Clay (%)	13.40 **
Silt (%)	12.27 *
Sand (%)	11.86 **
pH (1:2.5 H_2O)	1.27 ^{NS}
EC ($ds.m^{-1}$)	3.20 ^{NS}
Organic Carbon (%)	2.06 ^{NS}
Total N (%)	0.21 ^{NS}
$CaCo_3$ (%)	16.87 **
Saturation Moisture Percentage (%)	18.02 *

^{NS} treatment effect not significant; * P < 0.05; ** P< 0. 0.01.

The results of the correlation analysis, as outlined in Table 4, demonstrate a positive and significant correlation between the soil electrical conductivity and the height and density of the Euphrates poplar habitats in the study area. Additional investigations revealed a positive and significant correlation between the clay percentage in the soil and the height and density of the Euphrates poplar trees. However, no substantial correlation was identified between other soil properties and the measured growth factors in the studied species.

The results concerning the phonological stages of the Euphrates poplar in the Sistan Region are summarized as follows: This species initiates new leaf emergence in March. The flowering stage, coinciding with leaf emergence in May, starts with catkins resembling cattails. The leaves begin to shed in December during autumn. The maturation of the seeds of this species begins in August and continues through September (Figure 3).

Discussion

The soil characteristics vary in different habitats of the Sistan Plain and affect the distribution and establishment of the Euphrates poplar species. Among the factors affecting the soil properties, acidity, electrical conductivity, and soil texture are essential. There was a notable difference in the calcium carbonate content in the soil. However, the correlation test results demonstrated no significant relationship between the calcium carbonate content in the habitat soil and the measured growth factors in Euphrates poplar trees. Consequently, alterations in the calcium carbonate content had no discernible impact on the growth of the Euphrates poplar. These findings align with the research conducted by Sepehri and Bozorgmehr [12], who, in their study on the natural habitats of the Euphrates poplar (along the Tajan River), asserted that salinity, alkalinity,

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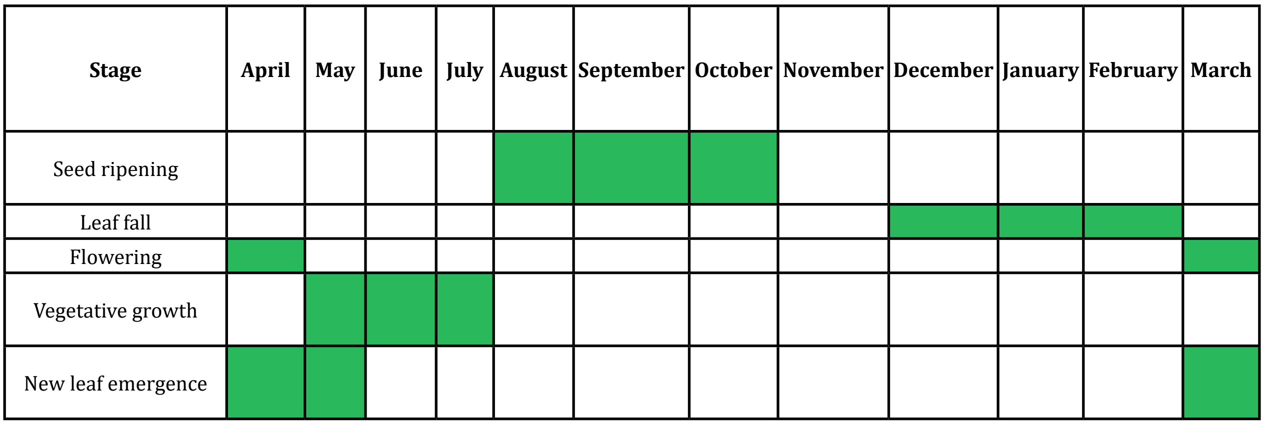

Figure 3) Phenology chart of the species in the study area.

Table 3) The mean physical and chemical soil properties of the study area, with standard errors in parentheses.

Habitat Soil Properties	Nyatak	Jazinak	Zahak	ANOVA
Clay (%)	1.0 [c] (0.03)	24.6 [a] (3.58)	10.6 [b] (1.53)	**
Silt (%)	10.0 [b] (2.89)	46.6 [a] (8.94)	51.2 [a] (9.44)	**
Sand (%)	89.9 [a] (13.29)	28.8 [b] (5.86)	38.2 [b] (b)	**
pH (1:2.5 H_2O)	7.89 (0.24)	8.29 (0.46)	8.02 (0.29)	NS
EC ($ds.m^{-1}$)	22.94 (4.86)	30.80 (4.88)	18.66 (3.66)	NS
Organic Carbon (%)	3.32 (0.32)	3.42 (0.36)	3.97 (0.37)	NS
Total N (%)	0.34 (0.11)	0.37 (0.08)	0.41 (0.08)	NS
$CaCo_3$ (%)	38.5 [a] (2.09)	14.9 b (1.10)	17.46 [b] (1.53)	**
Saturation Moisture Percentage (%)	21.22 [c] (4.54)	38.48 [a] (5.44)	27.76 [b] (4.59)	*

[NS] treatment effect not significant; * P< 0.05; ** P< 0. 0.01. Similar letters within a row indicate that means are similar (Tukey HSD).

and chlorine toxicity were the qualitative limiting factors the Euphrates poplar. At the same time, the $CaCo_3$ percentage exhibited no influence on the Euphrates poplar stands. This investigation determined that the Euphrates poplar species exhibits growth capability in areas with a mean salinity ranging from 18 to 30 $dS.m^{-1}$. The correlation analyses indicated a significant association between soil EC and the height and density of Euphrates poplar trees. Consequently, the salinity level directly influences the height and density of the Euphrates poplar trees, aligning with the findings of Calagari et al. [28]. Similar results were reported by Wang, Zhao et al., Daneshvar et al., Calagari and Tavakoli Neko et al. [29, 30, 31, 8, 15] affirming the high tolerance of this species to pH and elevated

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Table 4) The correlation coefficients between soil parameters and the growth characteristics of *P. euphratica* trees in the study area.

Study Factor	Trees Height	Trees DBH	Trees Crown Surface	Canopy Percent	Density
Clay (%)	**0.554** *	0.391	- 0.033	0.510	1.561 *
Silt (%)	- 0.230	- 0.294	- 0.354	- 0.003	0.128
Sand (%)	0.016	0.094	0.294	- 0.181	- 0.304
pH (1:2.5 H_2o)	0.066	0.064	0.023	0.324	0.297
EC ($ds.m^{-1}$)	**0.688** **	0.419	0.084	0.443	**0.568** *
Organic Carbon (%)	- 0.307	- 0.094	0.009	0.189	- 0.139
Total N (%)	- 0.303	- 0.125	0.077	0.156	0.241
$CaCo_3$ (%)	- 0.144	- 0.164	0.148	- 0.288	- 0.254
Saturation Moisture (%)	0.510	0.191	- 0.243	0.169	0.142

* $P < 0.05$; ** $P < 0.01$.

EC, allowing it to thrive in saline and alkaline soils. Several studies have indicated varying growth responses regarding diameter and height for Euphrates poplar seedlings under different salinity treatments in diverse habitats across the country [14, 32]. Eric et al. [33] proposed that, in response to salinity, the species reduces calcium and carbohydrates to balance the osmotic pressure within the leaves. Increased cell volume dilutes sodium, enhancing the species' resistance to adverse environmental conditions. Bosheng et al. [34] introduced microRNAs as contributors to saline stress tolerance in Euphrates poplar. Notably, the Jazinak Region exhibited the highest electrical conductivity, accompanied by taller trees and higher density in Euphrates poplar. However, some studies have suggested that the tolerance and performance of the Euphrates poplar diminish with increasing salinity concentration [15]. The Jazinak Region is closer to the Hirmand River, and its soil is more exposed to wetting. After the river water is cut off, the moisture in the soil evaporates. For this reason, its electrical conductivity increases.

P. euphratica demonstrates a notable tolerance to alkaline soils. Assessing soil acidity levels revealed that these species thrive in soils with a pH ranging from 7 to 8. These findings agree with the research of Sepehri and Bozorgmehr [13], which qualitatively identified soil salinity and alkalinity as the primary limiting factors for Euphrates poplar growth. However, the presence of these species in the Sistan shows that they tolerate saline and alkaline soils. The study results indicate that the Euphrates poplar can proliferate in soils ranging from sandy to clay textures. However, in regions where the soil texture leans toward medium to heavy and exhibits a higher clay percentage, the distribution, density, and height of these trees are notably broader. These findings align with the observations of Javanshir et al. [34], who emphasized that the Euphrates poplar, beyond thriving in desert sandy soils, also establishes itself in relatively heavy clay soils, particularly along riverbanks, and is intentionally planted by humans in light or sandy soils. The higher clay content in this region's soil contributes to increased moisture retention, enhancing its availability to the plant's roots.

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This study revealed a substantial disparity in the sand content among the soils in different habitats. Nevertheless, no significant correlation was found between the amount of sand and the growth parameters of the tree. These outcomes deviate from the conclusions drawn by Calagari [28] in their respective studies. In their research, they identified light soils as conducive to the growth of this species and asserted that Euphrates poplar exhibits enhanced growth and distribution in such light soils. However, as mentioned, this tree can sustain growth across diverse soil textures, ranging from light to heavy.

A significant difference exists in the soil moisture saturation among the three examined habitats. However, no significant correlation was discerned between this parameter and the growth parameters of the Euphrates poplar trees. Javanshir et al. acknowledged the rapid growth and substantial size of Euphrates poplar and trees and classified these species as suitable for cultivation in regions with moist soils. Assareh et al. and Ahmadi et al. [16, 19] highlighted the preservation of riverbanks, natural ecosystems, and wildlife as advantages associated with Euphrates poplar trees. The soil in the Jazinak Region exhibited the highest saturation moisture percentage due to its higher clay content, which contributes to the heightened growth of Euphrates poplar trees in this area. Clay's capacity to retain more interlayer water aids in providing adequate moisture to the roots of this tree. Conversely, in areas characterized by lighter textures, such as Nyatak, the saturation moisture percentage in the soil was lower, resulting in decreased density and the Euphrates poplar trees.

Considering the adverse climatic conditions, recent droughts, and the desiccation of the Hamoon wetland in the Sistan Region, the growth conditions for Euphrates poplar trees are unfavorable. Hesami et al. [9] also noted that in nursery cultivation, the seedlings from the Zabol provenance exhibited less height growth compared to those from other habitats in Iran.

Conclusion

In a comprehensive evaluation of growth parameters, the Jazinak forest exhibited more favorable conditions than other habitats, potentially due to its higher clay percentage and lower sand percentage in the soil texture. The superior condition can also be linked to increased soil moisture saturation and reduced calcium carbonate percentage. Therefore, planting these species in such locations will be more successful. Based on the findings of this investigation, it can be inferred that *Populus euphratica* exhibits a remarkable tolerance to the ecological conditions prevailing in the Sistan Region. Its high resistance to salinity, drought, alkaline soils, elevated temperatures, and the severe storms characteristic of the region enables it to endure the challenging environmental conditions effectively. The species has successfully adapted to the harsh environment over many years and demonstrates significant potential for growth and expansion within the region. Consequently, from a biological restoration perspective, it is deemed suitable for combating desertification in Sistan. Moreover, this species is very suitable for creating green spaces in the region due to its beautiful autumn color, late leaf fall, and broad crown. Considering that groundwater is very scarce in the Sistan Plain, the presence of Euphrates poplar forests depends on the seasonal floods.

Author's Contributions

Einollah Rouhi Moghaddam, Akbar Fakhireh, and Mozhgan Shoeibi conceived the work, performed the experiments and analyses,

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contributed analysis tools, wrote and revised the paper, and edited the English text. All authors approved the final paper.

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Competing Interests: This manuscript has not been published or presented elsewhere in part or entirety and is not under consideration by another journal. There are no conflicts of interest to declare.

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