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ROLE OF STAND CHARACTERISTICS, CLIMATE, SOIL PROPERTIES, AND TOPOGRAPHY IN PRODUCTIVITY OF *Pinus brutia* Ten. TREE IN TERMS OF CONES AND SEEDS IN SEMI-ARID AREA (DOHUK REGION)

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ABSTRACT

The natural regeneration process of forest stands begins with seed preparation, either from seeds that have fallen onto the soil or from the seed reserves present on trees, which represents the first stage in the natural regeneration process. The quantity, quality, viability, and preparation of seeds vary significantly over intermittent periods and across several years for most tree species. These variations are influenced by numerous factors. This study was conducted in Duhok Governorate, located in northern Iraq, a semi-arid region, to determine the effects of stand characteristics, climate, soil, and topography on the productivity of *Pinus brutia* Ten. trees in terms of cones and seeds. The results showed that several factors such as (Total number of trees for all species per unit area, number of mother trees and their diameter mean, crown surface area, spacing between trees per unit area, light percentage, soil pH, litter thickness, average annual temperature and relative humidity, total annual precipitation, and soil nitrogen content) were correlated with the productivity of mother Pinus brutia trees in terms of cones. Similarly, the number of seeds produced by mother trees was correlated with factors such as (number of cones produced per unit area, total number of trees for all species per unit area, crown surface area of mother trees, spacing between trees per unit area, soil pH, litter thickness, average annual temperature and relative humidity, total annual precipitation, elevation, and soil nitrogen content).

INTRODUCTION

Forests cover approximately 31% of the Earth's land surface, providing numerous environmental, economic, social, and aesthetic services. They play a crucial role in preventing soil erosion, preserving watersheds, and mitigating the impacts of climate change (Alday *et al.*, 2022, Al-Allaf *et al.*, 2023). Moreover, forests are essential natural habitats for biodiversity conservation (Hammond *et al.*, 2021, Salim & Ibrahim 2021a&b). Given the increasing threats posed by climate change, there is a pressing need to raise awareness and prioritize forest protection, restoration, and sustainable management (Ali *et al.*, 2024a&b, Younis *et al.*, 2024). Despite their importance, forests are under significant pressure worldwide. According to the FAO's latest assessment, global forest area decreased by about 3% between 1990 and 2015 (FAO, 2018). Forest degradation has become a global issue, with an annual loss of 10.6 million hectares of forest (FAO, 2015). This loss has direct implications for biodiversity, leading to its decline (Davidar *et al*., 2010). Human-induced disturbances and environmental conditions significantly influence forest ecosystem dynamics on both local and regional scales (Sapkota *et al*., 2009, Mohsen *et al*., 2022), directly affecting natural regeneration processes (Lawes *et al*., 2007). Natural regeneration is one of the most critical processes for sustaining forest growth, enhancing biodiversity stability, and enabling ecosystems to adapt to climate change (Hammond *et al*., 2021). However, it is often slow and complex, primarily due to the interplay between seedling establishment success and the environmental factors of the site where they grow (Pardos *et al*., 2005). Natural regeneration represents a cornerstone for forest sustainability and biodiversity conservation, highlighting the importance of understanding and addressing the factors influencing this process. Most tree species undergo natural regeneration through seeds that fall from mother trees to the ground and germinate when favorable conditions for germination are available (Serrada, 2003, Mohammed and Omar 2020).The natural regeneration process in forest stands begins with seed preparation, which is influenced by various factors related to mother trees, including their morphological characteristics, age, and the environment in which they grow. These factors significantly impact the natural regeneration process. Cendan *et al*. (2013) highlighted that seed production represents one of the initial stages of natural regeneration, with the quantity and quality of seeds being affected by several factors, including the characteristics of mother trees. Ayari *et al*. (2012) reported that *Pinus halepensis* trees with larger diameters produce more cones and seeds compared to smaller-diameter trees of the same age. Similarly, Moya *et al*. (2008) noted that cone size depends on tree size, with larger, intact cones yielding higher-quality, larger seeds. Annual variations in cone production are influenced by genetic factors, moisture availability, nutrient supply, pests, and diseases. Additionally, some factors that directly affect tree growth indirectly influence cone and seed production. Girard *et al*. (2012) found a relationship between tree phenotypic traits and cone formation, with higher cone densities observed at the tops and midsections of tree crowns. This has been observed in many conifer species, including *Pinus halepensis*, where growth in height, diameter, and crown development correlates positively with increased cone and seed production, as well as the size of cones and seeds (Sghaier & Ammari, 2012). Dominant trees with larger crowns tend to have higher cone and seed productivity than subdominant and suppressed trees (Ayari *et al*., 2011). Qian et al. (2014) observed that seed production varies between years and among trees of the same species. This variation is influenced by both biotic and abiotic factors, including natural resources. Many factors affecting cone and seed production must be identified to aid in natural regeneration efforts. The temporal and spatial variability in cone and seed production is influenced by differences in tree growth conditions (Ayari & Khouja, 2014). The variation in seed production within individual tree can result from the availability of natural resources, as trees growing in fertile, moist soils produce larger seeds than those in resource-limited soils. This variability can also be attributed to internal plant factors, such as the availability of nutrients involved in seed production (Greenberg, 2000). Identifying these factors is crucial for understanding and supporting natural regeneration processes. Matsumoto et al. (2005) emphasized that all physiological activities performed by trees, including stomatal exchange and photosynthesis, vary significantly among conifer species. These variations are influenced by factors such as the amount of light received, site quality, tree age, carbon dioxide concentration, vapor pressure deficit between leaves and the atmosphere, ozone levels, and hormones that regulate stomatal opening. Tree growth, development, and biomass production depend on the availability and accessibility of soil nutrients. A deficiency in any essential nutrient can negatively impact tree growth and physiological activity (Gallardo *et al*., 2003). Standovár and Kenderes (2003) noted a relationship between local climate, tree height, and tree positioning within a stand, all of which influence flowering and seed productivity. Furthermore, seed production within a stand can exhibit significant spatial variability. Ayari *et al*. (2012) reported a negative correlation between stand density and cone and seed productivity. Thinning operations that reduce stand density have been shown to enhance cone and seed production. High stand density increases competition among trees for natural resources, reducing the production and dispersal of pollen, these factors vary from year to year and even within the same tree (Goubitz *et al*., 2002). Tree productivity in terms of cones and seeds is strongly affected by the amount of light penetrating the canopy. Adequate light promotes cone and seed production (Everard, 1987). Sweet (1975) observed that the amount of light received by trees enhances the rate of photosynthesis, leading to a higher carbon-to-nitrogen ratio. This increased carbon availability results in greater cone and seed production. Light exposure also increases the number of male and female cones produced (Alan *et al.*, 2011). Rotenberg and Yakir (2011) highlighted that temperature plays a crucial role in cone and seed production in Pinus halepensis throughout its life cycle, provided that other conditions, such as moisture and nutrient availability, are met. Seasonal temperature fluctuations, such as relatively warm and dry winters, cold winters, or late spring temperature variations, can disrupt cone formation by causing cone mortality in early developmental stages. This negatively impacts cone formation and seed production for the following year (Owens & Blake, 1985). Water stress further exacerbates this issue by reducing transpiration, which in turn decreases photosynthesis. This leads to reduced growth and lower reserves of nutrients allocated for reproduction (Carevic *et al*., 2010). Additionally, soil properties, such as pH and nutrient availability, significantly influence seed productivity. Trees growing in fertile, slightly acidic soils produce higher seed quantities due to the sufficient availability of nutrients that support increased flower production and successful fertilization. This underscores the critical role of soil conditions in flowering, pollination, and fertilization processes (Sala et al., 2012). Climent *et al*. (2008) identified a positive correlation between cone production and annual precipitation. Adequate rainfall positively affects both the number and size of seeds, as supported by previous ecophysiological studies. These studies emphasized the role of sufficient moisture in promoting both vegetative and reproductive growth in Pinus halepensis, resulting in increased cone and seed production. This trend has also been observed in other conifer species. Sharma *et al*. (2009) emphasized that elevation above sea level is one of the most significant factors influencing seed production. Elevation correlates with various other factors, including rainfall, climate, and soil properties, which collectively affect plant habitats. Seed quantity is influenced by climatic conditions, which vary with elevation, latitude, and proximity to oceans and seas.

MATERIALS AND METHODS

The study was conducted in Duhok Governorate, located in the northern part of Iraq, which is classified as a semi-arid region. The study area is geographically bounded between latitudes (36°18′12.64″N - 37°20′33.55″N) and longitudes (42°20′25.36″E - 44°17′40.50″E), with elevations ranging between 430 and 2500 meters above sea level. The vegetative cover in Duhok spans an area of 3052 km², representing 27.58% of the governorate's total area (Applied Remote Sensing & GIS Center, 2015). Duhok is characterized by its mountainous terrain and relatively moderate climate. The soil composition varies, ranging from sandy soils in lowland areas to clayey soils in valleys and agricultural zones. According to Buringh (1960), the soil in the region is classified as non-saline based on its chemical composition. Study samples were identified through an initial survey conducted randomly across all sites. Each sample was in a square plot measuring 20 × 20 meters. A total of 28 samples were collected. Data collection for these samples began in October 2022 and included the following variables:

1- **Species count in the sample**

The identification of all species present in each sample was conducted. The species varied from one sample to another. The study samples included the following species (*Pinus brutia*, *Quercus aegilops*, *Quercus infectoria*, *Prunus microcarpa*, *Juniperus oxycedrus*, *Crataegus azarolus*, *Paliurus spina-christi*, *Salix acmophylla*, *Populus euphratica*, *Tamarix arceuthoides*)

2- Total Tree Height (meters) H

Tree height was defined as the vertical distance from the base of the tree at ground level to the highest point at the top of the tree. The height of cone- and seed-producing mother trees was measured using a Haga altimeter (DeYoung, 2024). Additionally, the mean height of trees within each sample was calculated for each species separately. The arithmetic mean of all recorded heights within the sample for each species was computed using the following formula (Al-Rawi, 1984):

$$\bar{h} = \frac{\sum_{i=1}^{n} h_i}{n}$$

Where: $\bar{h}$ = Mean height of the trees in the sample (meters), hi = Height of individual trees (meters), n = Total number of trees in the sample.

3- Crown Center Height (meters) CCH

Crown center height represents the vertical distance from the base of the tree at ground level to the start of the tree crown, defined as the point where the first three living branches are distributed in a circular pattern around the main trunk. The crown center height of mother trees was measured using a Haga altimeter (DeYoung, 2024).

4- Tree Diameter (Centimeters) d

Tree diameter is the straight-line distance connecting the opposite edges of the tree trunk, passing through its center. The diameter of mother trees was measured using a measuring tape at breast height (1.3 meters above ground level) (DeYoung, 2024). The mean diameter for trees within each sample was calculated by determining the arithmetic mean of all diameters recorded within the sample for each species, using the following formula (Al-Rawi, 1984):

$$\bar{d} = \frac{\sum_{i=1}^{n} d_i}{n}$$

Where: $\bar{d}$ = Mean tree diameter at breast height for the sample (cm), di = Individual tree diameter at breast height (cm), n = Total number of trees in the sample

5- Crown Diameter (Meters) CD

Crown diameter is the horizontal distance from one edge of the crown to the opposite edge. It is measured by projecting imaginary lines from the crown's edges onto the ground in multiple directions. The crown diameter of mother trees was measured using a measuring tape. Several readings of the crown's radii were taken, and the arithmetic mean of these measurements was calculated (West, 2015).The formula for calculating the average crown radius is as follows:

$$\bar{r} = \frac{\sum_{i=1}^{n} r_i}{n}$$

Where: $\bar{r}$ = Arithmetic mean of the tree's crown radius (meters), r_i = Individual crown radius measurement (meters), n = Number of observations

6- Number of Pinus brutia Cones (Cone.Tree^{-1})

The number of cones produced by each *Pinus brutia* tree within the sample was counted for the current year. This measurement included all *Pinus brutia* trees within each sample plot.

7- Litter Layer Thickness (cm)

Thickness of the litter layer was estimated for each sample plot by taking multiple measurements. These measurements included areas beneath large and small trees as well as tree-free zones within the sample. A ruler was placed vertically until it reached the mineral soil beneath the litter layer, and the reading was recorded at the top of the litter layer. The arithmetic mean of these measurements was then calculated to determine the average litter layer thickness for each sample.

8- Basal Area (m^2)

The basal area represents the cross-sectional area of a tree trunk at breast height (1.3 meters above ground level). The basal area for individual trees was calculated using the following formula (West, 2015):

$$BA = 0.00007354 * d_i^2$$

The total basal area per unit area (G) was computed as the sum of the basal areas of all trees in the plot using the formula:

$$G = 0.00007854 * \sum_{i=1}^{n} d_i^2 * fi$$

Where: G = Total basal area per unit area (m^2), di = Diameter of the tree at breast height (cm), fi = Number of trees within the plot.

9- Crown Length (meters)

Crown length is the vertical distance between the crown center height (CCH) and the top of the tree. The crown length for mother trees in all samples was calculated using the following formula (West, 2015):

$$CL = H - CCH$$

Where: CL = Crown length of the tree (meters), H = Total tree height (meters), CCH = Crown center height (meters).

10- Crown Projection Area (m^2) CPA

Crown projection area refers to the ground area covered by the tree crown's projection, which corresponds to the area directly beneath the tree's canopy when viewed from above. The crown projection area was estimated using field data measurements and calculated using the following formula (West, 2015):

$$C\rho A = \left(\frac{CD}{2}\right)^2 * \pi$$

Where: CρA = Crown projection area (m^2), CD = Crown Diameter (m), π = Constant value (3.1416).

11- Crown Volume (m^3) CV

Crown volume refers to the three-dimensional space occupied by the tree's leaves, branches, and twigs. The crown volume of *Pinus brutia* mother trees was calculated using the method described by Franceschi *et al*. (2022) and determined with the following formula:

$$CV = \frac{cr^2 * CL * \pi}{3}$$

Where: CV = Crown Volume (m^3), CL = Crown Length (m), CR = Crown Radius (m), π =Constant Value (3.1416).

12- Crown Surface Area (m^2) CSA

Crown surface area represents the total external surface area of the tree crown, including both the sides and the top of the crown, which are exposed to light. The crown surface area of *Pinus brutia* mother trees were calculated using the method described by Franceschi *et al*. (2022) and determined with the following formula:

$$CSA = \pi * cr^2 + \pi * cr * \sqrt{cr^2 + CL^2}$$

Where: CSA = Crown Surface Area (m^2), CL = Crown length (m), CR = Crown radius (m), π =Constant value (3.1416).

13- Light Index LI

The Light Index (LI) measures the amount of light penetrating the tree canopy and reaching the lower layers of the forest floor. It was calculated for all trees in the samples using the formula proposed by Vanclay (1994):

$$LI = H - (0.24 * CL)$$

Where: LI = Light Index, H = Total tree height (m), CL = Crown length (m)

The total Light Index for all trees in a sample was summed and then divided by the sample area in hectares (10,000) m^2 to determine the light percentage for the sample. This provides a measure of canopy light penetration per unit area.

14- Spacing (meters) SP

The spacing between trees (SP) was calculated for all tree categories and species within each sample using the formula provided by Husch *et al*. (2002):

$$SP = \sqrt{\frac{10000}{N}}$$

Where: SP = Spacing between individuals (meters), N = Total number of individuals within the unit area (hectare).

15- Estimation of Total Seed Count

The total seed count for *Pinus brutia* trees in each sample was estimated using the cones collected during data collection, which ranged between 25–30 cones per sample. The volume of each cone was calculated for all samples using the geometric formula for cone volume. Subsequently, three cones of varying sizes (small, medium, and large) were selected from each sample. Their sizes were measured and fixed, and the cones were placed in the laboratory and exposed to a hot air stream from an air conditioner at a temperature of 25–30°C. This process aimed to accelerate the drying of the cones, allowing them to open and release their seeds. This procedure was also applied to all other cones from all samples, which were placed in perforated plastic baskets to facilitate seed extraction. After extracting the seeds from the three selected cones, the seed count for each cone was recorded along with its previously measured volume. The average seed count and cone volume were then calculated for these cones. Based on this average, a relationship between cone volume and seed count was established to estimate the seed numbers for all cones in the sample. The average seed count for all cones in the sample was also calculated. Finally, the total seed count for each sample was determined by multiplying the average seed count per cone by the total number of cones in the sample as recorded in the field measurements.

16- Estimation of Topography Factors

Topographic factors, including slope, aspect, and elevation, were estimated using a Digital Elevation Model (DEM) with a spatial resolution of 12.5 meters. The DEM was obtained from the Japanese satellite ALOS PALSAR through the ASF Data Search platform of the Alaska Satellite Facility. The topographic factors for each sample were calculated using ArcGIS version 10.8.1, following the method described by Al-Azzawi (2009).

17- Climate Factors

Climatic elements, including temperature, precipitation, and relative humidity, play a significant role in studying natural regeneration processes in forests. Each element influences flowering, fruit, cone, and seed formation, as well as their dispersion. Climatic data for the study area from 2000 to 2022 were obtained from the **Climatic Research Unit – Groups and Centers** website (http://cru.uea.ac.uk). Relative humidity values were calculated based on actual vapor pressure (ea / es) data, which were derived from the same source. Saturation vapor pressure (es / es) was extracted using specialized tables related to temperature available online:

https:/www.researchgate.net/publication/277403356
https://atoc.colorado.edu/~saraht/atoc1050/homework/svp.pdf

As in the following formula:

$$RH = \frac{ea}{es} * 100$$

Where: RH = Relative humidity (%), ea = Actual vapor pressure, es = Saturation vapor pressure determined as a function of temperature.

18 – Soil Properties

Soil samples were collected from each study plot by removing the litter layer on the soil surface, then extracting the mineral soil by digging to a depth of 30 cm. The samples were placed in tightly sealed plastic bags. The soil samples from all study plots were taken to the central laboratory of the College of Agriculture and Forestry for analysis. The analyses included the following parameters: Nitrogen content, Phosphorus content, Potassium content, Soil pH, Electrical conductivity, Organic matter percentage, and Soil texture.

Statistical Analysis

Several statistical methods were employed to analyze, interpret, and present the data based on the requirements to achieve the objectives of this study. These methods aimed to explore and understand the relationships between the variables under investigation. Among the techniques used were correlation and regression analysis. Correlation is a statistical method used to determine the strength and direction of the relationship between two independent variables. The relationship between any two variables can be assessed by estimating a statistical measure called the simple correlation coefficient, denoted by (r) for samples. This coefficient is an unbiased measure of the population correlation coefficient. Regression analysis is a highly useful statistical method to identify the true relationship and direction between two or more variables. In regression analysis, one variable is considered the dependent variable, while the other(s) are independent variable(s). The relationship is expressed in the form of a mathematical model called the regression equation, which can be used to estimate or predict the value of the dependent variable. Statistical metrics used in the analyses included:

- Coefficient of determination (R^2): Measures the proportion of variation in the dependent variable explained by the independent variable(s).
- Standard Error (S.E.): Indicates the accuracy of the regression model.
- Standardized Residual (e_S): Used to evaluate the residuals and identify any patterns or outliers.
- P-value: Determines the statistical significance of the results.

RESULTS AND DISCUSSION

The study of stand structure and the spatial distribution pattern of trees, including both horizontal and vertical distribution and the interaction between upper and lower canopy cover, plays a critical role in stand composition. Horizontal distribution determines the spacing between trees, which in turn influences stand density and affects tree characteristics such as diameter, height, and crown size (Carrer, 2013). Additionally, environmental factors such as climate—temperature, precipitation, and relative humidity—significantly impact tree growth within stands (Liang & Wei, 2020). Tree productivity, specifically cone and seed production, varies due to the interaction between climatic factors and the trees within the stand. These factors influence flowering periods, cone formation, and seed production. They also affect the characteristics of mother trees, including diameter, height, and spatial positioning within the stand (Standovár & Kenderes, 2003). Similarly, soil properties such as organic matter, nutrient content, and pH levels play an important role in stand composition and structure (Laughlin *et al*., 2007). These combined factors impact tree productivity, particularly in conifers, where cone and seed production represent the initial stage of the natural regeneration process (Liang & Wei, 2020). Given the importance of understanding the relationship between the first stage of natural regeneration—cone and seed productivity of *Pinus brutia* Ten. and the biotic and abiotic factors influencing it, we analyzed these interactions. Data were collected from 28 *Pinus brutia* samples in uneven-aged mixed stands in the forests of Duhok. Analyses were conducted using Microsoft Excel and the statistical analysis software Statgraphics Centurion 18 to examine the correlations between cone and seed productivity of *Pinus brutia* mother trees and the influencing factors. The strongest positive and negative correlations were identified from the correlation matrix and are presented in Table (1).

Table (1): Correlation values of factors affecting the productivity of cones and seeds in naturally grown brutia pine trees in uneven-aged mixed forests of Duhok

Biotic and Abiotic Factors	Number of cones		Number of seeds	
	Correlation value (r)	Type of relationship	Correlation value (r)	Type of relationship
Number of cones	-	-	0.87	Positive
Total number of trees for all species	-0.43	Negative	-0.42	Negative
Crown surface area of mother trees	0.47	Positive	0.26	Positive
Mean diameter of mother trees at breast height	0.43	Positive	-	-
Number of mother trees	0.4	Positive	-	-
Spacing between all trees per unit area	0.33	Positive	0.30	Positive
Light percentage	0.36	Positive	-	-
Soil pH	-0.60	Negative	-0.65	Negative
Litter layer thickness	0.61	Positive	0.49	Positive
Average annual temperature	-0.49	Negative	-0.55	Negative
Total annual precipitation	0.49	Positive	0.54	Positive
Average annual relative humidity	0.48	Positive	0.54	Positive
Altitude above sea level	-	-	0.47	Positive
Soil nitrogen content	0.34	Positive	0.41	Positive

From Table (1), it is evident that several factors are correlated with the production of cones and seeds in Brutia pine trees. These factors include the number of cones, total number of trees, canopy surface area of mother trees, average diameter of mother trees at breast height, number of mother trees, distances between trees, and light availability. These represent biotic factors related to the spatial distribution of trees within the forest. As for the abiotic factors correlated with cone and seed productivity, they include soil pH, litter layer thickness, average annual temperature, total annual precipitation, average annual relative humidity, altitude above sea level, and soil nitrogen content. It is also notable from Table (1) that there is a similarity in the influence of most factors on the productivity of both cones and seeds. This is because the production of cones and seeds requires the same conditions. Additionally, the number of seeds showed a strong positive correlation with the number of cones, with a correlation value of 0.87. These correlations can be either positive or negative, indicating annual variability in the production of cones and seeds due to the combined influence of these factors (Ayari and Khouja, 2014). Table (1) also shows that the total number of trees had a negative correlation with both the number of cones and seeds, with correlation values of -0.42 and -0.43, respectively. The total number of trees of all species reflects the horizontal spatial distribution and indicates forest density, available space for trees, and the level of competition among them for natural resources (Liang and Wei, 2020). Variations in cone and seed productivity and quality significantly depend on forest density and the level of competition among trees for natural resources. This competition influences the characteristics of mother trees, affecting their flowering rate, cone formation, and seed production. Consequently, there is variability in seed productivity among mother trees from one tree to another and from year to year, depending on their spatial distribution within the forest (Goubitz et al., 2002). Table (1) also shows a positive correlation between the canopy surface area of mother trees and the quantity of cones and seeds produced, with correlation values of 0.47 and 0.26, respectively. Similarly, the correlation values for the distances between trees and the productivity of cones and seeds were 0.33 and 0.30, respectively. Both the canopy surface area of mother trees and the distances between trees indicate forest density, which significantly affects tree vitality due to competition for natural resources. Trees growing in forests with low to medium densities exhibit higher productivity of cones and seeds compared to those in high-density forests. This is because trees in low and medium-density forests have larger canopies and experience less competition for natural resources such as light, water, and nutrients (Goubitz *et al*., 2004). Consequently, this enhances the growth of vegetative and reproductive parts, increasing cone and seed production. Moreover, lower forest densities facilitate wind pollination, which is more efficient in such environments (Bladé & Vallejo, 2008). Lower-density forests also encourage the development of both male and female cones, promoting pollination and subsequent cone and seed production (Arista & Talavera, 1997). Ayari *et al*. (2012) noted that thinned forests resulted in increased cone and seed production. Additionally, the increased canopy surface area enhances the efficiency of photosynthesis, thereby boosting the production of essential nutrients required for cone and seed production in terms of both quantity and quality (Alan *et al*., 2018). In low-density forests, the increased light penetration to tree canopies further improves photosynthesis, leading to higher storage of nutrients within trees, which serves as the primary source for cone and seed production (Spiecker, 2000). Table (1) of the correlation matrix shows that the productivity of Brutia pine trees in the uneven-aged mixed forests of Duhok was positively correlated with the average diameter at breast height (DBH) of mother trees, the number of mother trees, and light availability, with correlation values of 0.43, 0.4, and 0.36, respectively. The DBH is considered a critical variable in the production of cones and seeds in trees (Liang & Wei, 2020). Mother trees with larger diameters at breast height are generally dominant in the forest and have better access to natural resources required for growth (Qian *et al*., 2014). As a result, these trees are stronger, more vigorous, and exhibit higher productivity of cones and seeds, both in quantity and quality (Hébert *et al*., 2016). It has been observed in most coniferous trees that those with larger diameters tend to have well-developed canopies, leading to higher cone and seed productivity as well as an increase in cone size (Sghaier & Ammari, 2012). Additionally, increasing the number of mother trees in the forest, up to a certain extent, enhances the overall productivity of cones and seeds in the stand (Mao *et al*., 2014). Light patterns in forests also play a significant role in the growth and development of trees throughout their various life stages (Lieffers *et al*., 1999), including mother trees. Adequate light promotes the production of both male and female cones in these trees (Alan *et al*., 2011). Furthermore, the amount of light available increases the production of nutrients through enhanced photosynthesis. This increase in nutrients directly impacts the size and productivity of cones (Alan *et al*., 2011). As for the abiotic factors correlated with the productivity of Brutia pine trees in terms of cones and seeds, Table (1) shows that soil pH exhibited negative correlation values with cone and seed production, with correlation values of -0.60 and -0.65, respectively. Increased soil acidity reduces tree productivity as it negatively impacts the availability of essential nutrients. Trees growing in acidic soils struggle to absorb critical nutrients necessary for growth and reproduction, such as phosphorus, calcium, and magnesium, which are vital for cone formation and seed production. Moreover, acidic soils increase the solubility of toxic minerals like aluminum, which adversely affect root growth and development. This, in turn, reduces the absorption of nutrients essential for the trees' biological activities. High soil acidity also weakens the activity of soil microorganisms responsible for decomposing organic matter into simpler, more accessible forms. Furthermore, it impairs the activity of symbiotic organisms such as mycorrhizal fungi, which play a crucial role in nutrient absorption. Additionally, increased acidity limits the production and movement of plant hormones like auxins, cytokinins, and gibberellins, which are essential for regulating the growth and development of reproductive organs, thereby affecting cone formation and seed production (Brady & Weil, 2014). Table (1) also indicates a negative correlation between the average annual temperature and the productivity of cones and seeds, with correlation values of -0.49 and -0.55, respectively. The negative relationship between temperature and seed productivity in Brutia pine trees highlights that unfavorable temperatures induce physiological stresses that hinder tree growth, ultimately affecting flowering, its timing, cone formation, and seed production (Allen *et al*., 2010). Unfavorable temperatures adversely impact all stages of cone and seed productivity, causing environmental stress on trees. This stress leads to reduced flowering and pollination, as well as a decline in pollen production, which affects the timing of pollination and fertilization. High thermal stress can also cause cones to dry out prematurely before they fully mature, leading to a decrease in the number of seeds produced inside them. Additionally, thermal stress increases the respiration rates of trees, consuming more energy to support other vital functions required to resist these stresses. This energy consumption reduces the resources available for cone and seed production. Consequently, the size of cones and the number of seeds they contain are diminished due to the lack of sufficient energy and nutrients (Messaoud & Houle, 2006). Table

(1) also indicates a positive correlation between the productivity of Brutia pine trees in terms of cones and seeds and the total annual precipitation, with correlation values of 0.49 and 0.54, respectively. Similarly, there is a positive correlation with the average annual relative humidity, with correlation values of 0.48 and 0.54, respectively. Both factors, total annual precipitation and average relative humidity, are indicators of moisture availability—whether atmospheric or soil moisture—which play a crucial role in improving the environmental conditions for tree growth and vitality. Adequate moisture helps fulfill the water requirements of trees, enhancing photosynthesis and nutrient availability. This leads to better vegetative and root growth, ultimately improving growth and reproductive processes and increasing the trees' capacity to produce cones and seeds. Sufficient moisture is essential for flower and cone formation as well as for the processes of pollination and fertilization (Ayari & Khouja, 2014). By providing optimal conditions for these critical stages, moisture availability contributes significantly to the successful production of cones and seeds. Table (1) indicates a positive correlation between the thickness of the litter layer and the soil nitrogen content with the quantity of cones and seeds produced by Brutia pine trees. The correlation values for the thickness of the litter layer with cone and seed production were 0.61 and 0.49, respectively, while the correlation values for soil nitrogen content with cone and seed production were 0.34 and 0.41, respectively. This can be explained as follows: litter layer thickness, the litter layer plays a crucial role in nutrient cycling and soil properties within forest ecosystems (Facelli & Pickett, 1991). It enhances soil properties and nutrient availability (Augusto *et al*., 2002). The decomposition of the litter layer improves soil fertility by enhancing its physical and chemical properties, increasing nutrient availability, microbial activity, and the soil's moisture retention capacity. These improvements create better environmental conditions for root growth, which, in turn, enhance the biological activity and physiological efficiency of trees, leading to better flowering, cone formation, and seed production (Prescott & Vesterdal, 2021). On the other hand, soil nitrogen content where the positive relationship between soil nitrogen content and cone and seed production is attributed to the essential role of nitrogen in tree growth. Nitrogen is a critical element for forming many protein compounds, including chlorophyll, which drives photosynthesis. Enhanced nitrogen availability promotes vegetative growth, increases physiological activity, and boosts photosynthesis. This results in a higher production of the nutritional compounds required for flower development, cone formation, and seed production (Fenn *et al*., 2010). The correlation matrix in Table (1) shows that the seed productivity of Brutia pine trees in uneven-aged mixed forests in Duhok is positively correlated with altitude above sea level, with a correlation value of 0.47. This value indicates a positive relationship between seed production and increasing altitude. Altitude directly influences environmental conditions in areas affected by the Mediterranean climate, such as the forests in Duhok Governorate. As altitude increases in these regions, environmental conditions improve due to lower temperatures, higher precipitation, and increased humidity. These improved conditions enhance the growth environment for trees, positively impacting their seed productivity (Haag *et al*., 2019). To further illustrate the correlation values of the factors influencing the productivity of Brutia pine trees in terms of cones and seeds, Figures (1) and (2) have been prepared.

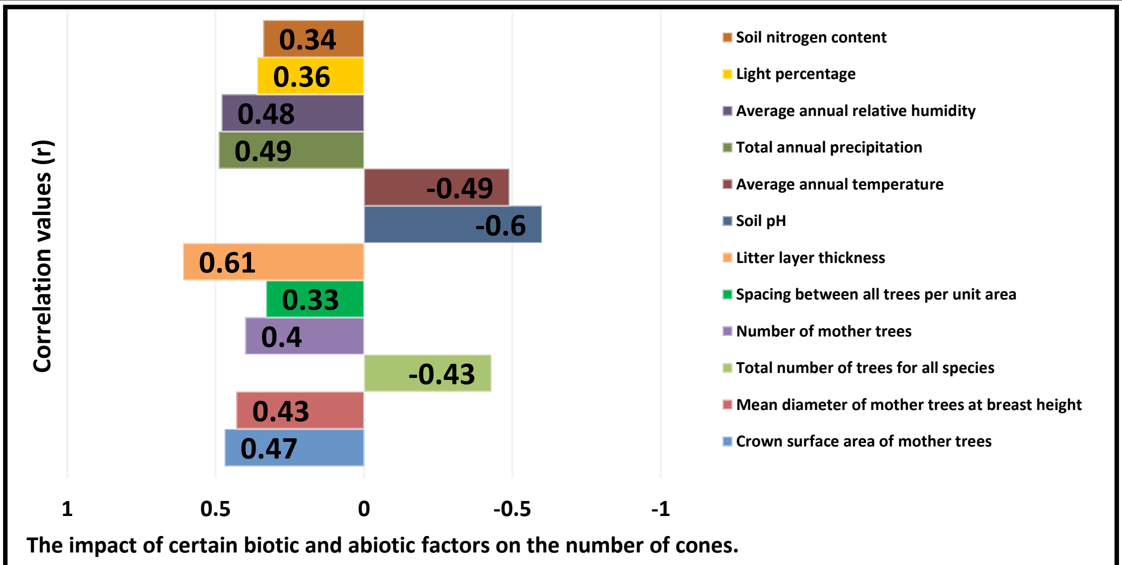

Figure (1): The mutual relationship between the number of cones of *Pinus brutia* Ten. trees and certain biotic and abiotic factors.

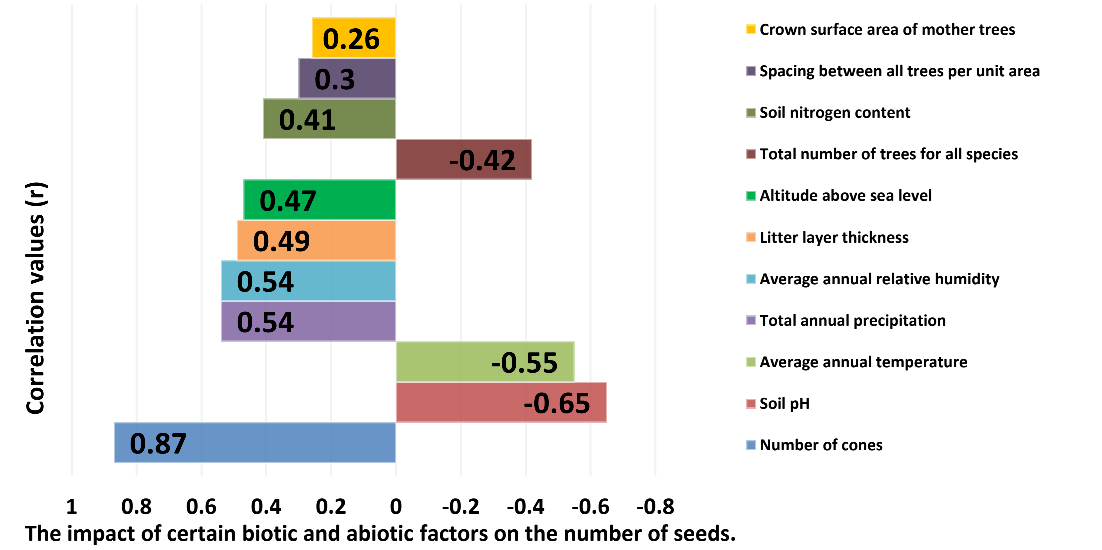

Figure (2): The mutual relationship between the number of seeds of *Pinus brutia* Ten. and certain biotic and abiotic factors.

From Figures (1) and (2), it is evident that the correlation values between the productivity of cones and seeds in Brutia pine trees and the biotic factors (representing forest stand characteristics) and abiotic factors (representing climate, soil, and topography characteristics) were varied. These correlations, whether positive or negative, showed both similarities and differences across factors. While certain factors influenced both cone and seed productivity similarly, others exhibited distinct effects on each.

Modeling the Number of Cones and Seeds for Brutia Pine Trees in Uneven-Aged Mixed Forests of Duhok. Estimating the number of cones and seeds produced by trees is a critical variable due to its significant role in the initial stages of natural forest regeneration. Several factors influence the productivity of trees in terms of cones and seeds (Moya *et al*., 2008). This is supported by the correlation matrix in

Table (1), which indicates that certain biotic and abiotic factors affect the cone and seed productivity of naturally grown Brutia pine trees in uneven-aged mixed forests of Duhok. The correlation matrix revealed that the number of mother trees and the average annual temperature play crucial roles in cone and seed productivity. Therefore, studying the variation in cone and seed productivity and identifying the influencing factors is essential for understanding the natural regeneration process occurring in forest stands. This process determines the initiation of forest regeneration and the establishment of future stands. For this reason, equations were developed to estimate the number of cones and seeds produced by Brutia pine trees. This was achieved through field data analysis from 28 randomly distributed samples in the forests of Duhok. Using the Statgraphics Centurion 18 statistical analysis software, which includes various regression methods, the following equations were formulated:

Annual Cone Number Estimation Equation (Cone.Year^{-1})

An equation was developed to estimate the number of cones produced by Brutia pine trees growing in uneven-aged mixed forests in Duhok. This equation was derived from the field data collected in the study and used the number of cones as the dependent variable, while the number of mother trees and the average annual temperature were the independent variables. The resulting equation is as follows:

$$No.CONE = 7879.08 + 8.22803 * (No.Mother\ Tree) - 311.534 * (Temperature\ average)$$

Table (2): Variables of the Equation for Estimating the Annual Number of Cones Produced by Brutia Pine Trees with Their Statistical Measures.

Parameter	*Estimate*	*Standard Error*	*T Statistic*	*P-Value*
CONSTANT	7879.08	880.905	8.94431	0.0000
NO. of mother tree	8.22803	1.30611	6.29964	0.0000
Temperature average	-311.534	51.7112	-6.0245	0.0000

R^2 = 0.73 S.E. = 683.50

From the statistical measures of the equation in Table (2), it is evident that both the number of mother trees and the average annual temperature had a significant impact on estimating the annual number of cones produced by Brutia pine trees. The coefficient of determination (R^2) was 0.73, indicating a strong correlation and a high explanatory power of the independent variables (number of mother trees and average annual temperature) in predicting cone production. Additionally, the P-Value was less than 0.05, signifying a highly significant relationship between the independent variables and the dependent variable at a confidence level exceeding 95%. To ensure the validity of the equation and to rule out the presence of autocorrelation among the residuals of the independent variables, a residual analysis was performed, as illustrated in Figure (3).

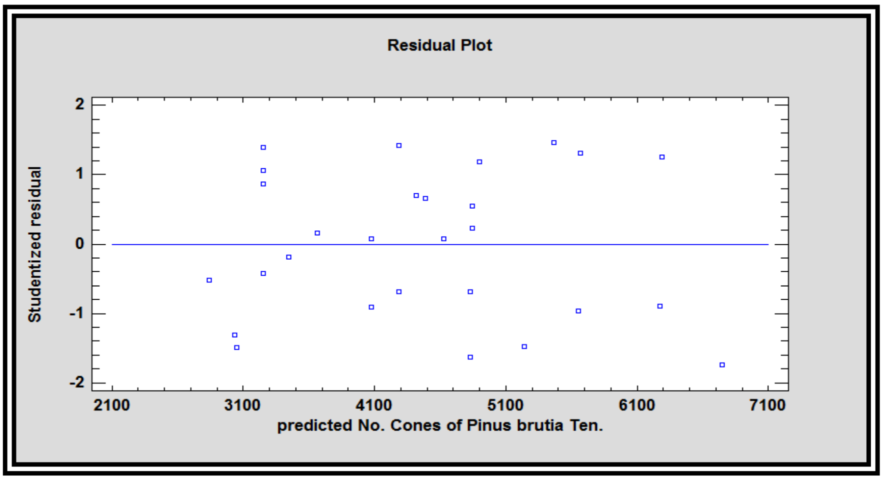

Figure (3): Distribution of Random Residuals Between Actual and Predicted Values for the Number of Cones Produced by *Pinus brutia* Trees

From Figure (3), it can be observed that the residuals are randomly distributed along the line representing zero. This indicates the absence of autocorrelation among the observations for the various variables in the equation. Therefore, the equation can be reliably used to estimate the annual number of cones produced per unit area.

Annual Seed Number Estimation Equation (Seeds.Year^{-1})

The formation of cones is one of the fundamental factors in the seed production process for trees. Seeds play a crucial role in the natural regeneration process when favorable environmental conditions for germination are present (Omar and Mohammed 2021). Without these seeds produced by the trees, natural regeneration would not occur, making seed production a cornerstone of forest sustainability (Dey *et al*., 2018). Therefore, estimating the number of seeds produced is essential information for forest developers and managers who plan and regulate developmental and administrative operations within forest stands. Given the relationship between the number of cones and the number of seeds produced from them, as shown in the correlation matrix in Table (1), we developed an equation to estimate the number of seeds produced per unit area for Brutia pine trees in uneven-aged mixed forests in Duhok. This equation was based on the number of cones produced by the trees, which can be estimated, and on field data collected from 28 randomly distributed samples in the forests of Duhok. Using Statgraphics Centurion 18, which includes various regression methods, we analyzed this data and derived the following equation:

$$No.Seeds = 25.0512 * (No.cones)1.07197$$

From the statistical measures in Table (4), it is evident that there is a correlation between the number of cones and the number of seeds produced from these forest stands. This relationship is non-linear, and the coefficient of determination (R^2) is relatively high at 0.90, indicating a strong correlation and a high predictive accuracy of the equation using the number of cones as the independent variable.

Table (4): Variables of the Equation for Estimating the Annual Number of Seeds Produced by Brutia Pine Trees with Their Statistical Measures

Parameter	*Estimate*	*Asymptotic Standard Error*	*Asymptotic Confidence Lower*	*Interval Upper 95.0%*
b0	25.0512	13.7533	-3.21915	53.3215
b1	1.07197	0.057511	0.953757	1.19019

$R^2 = 0.90$ MSE = 2.17

Additionally, the other statistical measures support the accuracy of this estimation equation. To validate its applicability, a residual analysis was performed to ensure the absence of autocorrelation among the random errors of the independent variable, as illustrated in Figure (4).

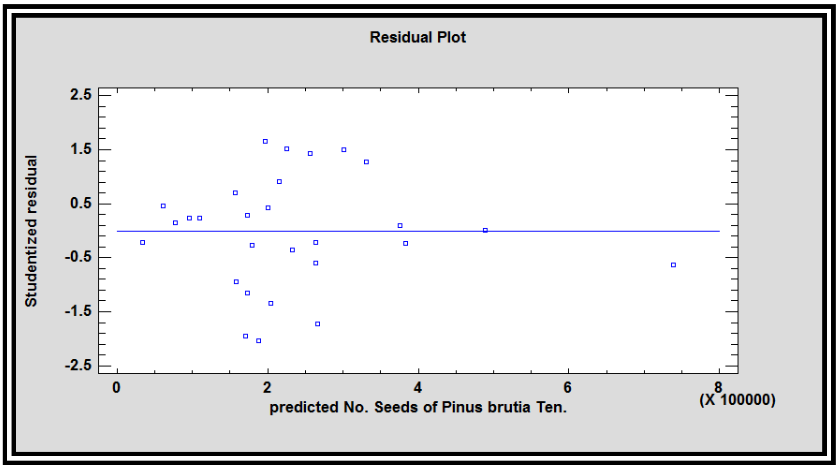

Figure (4): Distribution of Random Residuals Between Actual and Predicted Values for the Number of Seeds Produced by *Pinus brutia* Trees.

Figure (4) shows that the residuals are randomly distributed along the line representing zero, indicating no autocorrelation between the observations and the independent variable. Therefore, the equation can be reliably used to estimate the annual number of seeds produced per unit area for Brutia pine trees in uneven-aged mixed forests in the Duhok forests

CONCLUSIONS

The results of this research indicated that there are many factors, such as tree characteristics, climate, soil, and topography, that affect the process of producing cones and seeds in trees of unequal-aged mixed forests in Dohuk forests. This process is the first stage in which the natural regeneration process begins, which maintains the sustainability of forests.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

دور خصائص المشجر والمناخ وخواص التربة والطوبوغرافية في إنتاجية أشجار الصنوبر البروتي *Pinus brutia* Ten. من المخاريط والبذور في المناطق شبه الجافة (منطقة دهوك)

منذر يونس محمد [1]، مزاحم سعيد يونس [1]، عمار جاسم محمد [1]
قسم علوم الغابات / كلية الزراعة والغابات / جامعة الموصل / الموصل / العراق [1]

الخلاصة

ان عملية التجديد الطبيعي لمشاجر الغابات تبدأ مع تجهيز البذور اما من البذور الساقطة على التربة او من خزين البذور المتواجد على الأشجار وهذه الأخيرة متعلقة بمرحلة انتاج البذور التي تعد المرحلة الاولى التي تمر بها عملية التجديد الطبيعي حيث ان كمية ونوعية البذور وحيويتها وتجهيزها يتباين بشكل كبير عبر فترات متقطعة ولعدة سنين لمعظم انواع الأشجار، اذ تتأثر بالعديد من العوامل. ولذلك أجريت هذه الدراسة في محافظة دهوك الواقعة في شمال العراق والتي تعد من المناطق شبه الجافة لمعرفة تأثير خصائص المشجر والمناخ والتربة والطوبوغرافية في إنتاجية أشجار الصنوبر البروتي *Pinus brutia* Ten. من المخاريط والبذور، أظهرت النتائج ان (عدد الأشجار لوحدة المساحة، عدد الأشجار الأمهات ومتوسط قطرها والمساحة السطحية لتيجانها، المسافات بين الأشجار لوحدة المساحة، نسبة الإضاءة، درجة حامضية التربة، سمك طبقة اللتر، معدل درجة الحرارة والرطوبة النسبية السنوية، مجموع السواقط السنوية، محتوى التربة من النتروجين) كان لها ارتباطا مع إنتاجية أشجار الامهات للصنوبر البروتي من المخاريط ، اما بالنسبة لعدد البذور المنتجة من أشجار الأمهات فقد كان لها ارتباطا مع العوامل (عدد المخاريط المنتجة لوحدة المساحة، عدد الأشجار الكلية لوحدة المساحة، المساحة السطحية لتيجان الأشجار الأمهات، المسافات بين الأشجار لوحدة المساحة، درجة حامضية التربة، سمك طبقة اللتر، معدل درجة الحرارة والرطوبة النسبية السنوية، مجموع السواقط السنوية، الارتفاع عن مستوى سطح البحر، محتوى التربة من النتروجين).

الكلمات المفتاحية: صنوبر بروتي ، إنتاجية المخاريط و البذور ، خصائص المشجر ، المناخ ، خواص التربة.

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