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ESTIMATING GROWTH OF *POPULUS NIGRA* STAND USING STAND TABLE METHOD

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SUMMARY

In Northern Iraq, growing *Populus nigra* L. occurs in small areas and narrow plains among the mountains. The samples selected for temporal plotting assessed these strains' current and future growth. Thirty-five samples underwent random selection to cover an area of 0.1 ha. Measuring the DBH (diameter at mean height) and mean height of each sample comprised cutting two trees from the dominant and subdominant trees and taking the cross-sections at DBH. Statistical analysis established a nonlinear mathematical relationship between diameter growth and mean height diameter. Creating a tree table estimates the growth by listing diameter classes and frequencies for all samples. Populus volume per hectare's determination used the local *Populus nigra* volume database. Therefore, utilizing the stand table projection method helps determine the migration of tree diameter classes within the stand over the next two years. The prediction of the final stand volume and number of trees was also easy. Since these stands had intensive management, an assumption was the number of dead and felled trees was zero, with the number of mature trees implicitly measured by calculating the movement of the trees for the next two years. The difference between current and future volumes' evaluation revealed accurate growth.

Keywords: *Populus nigra* L., stand table, growth and yield, non-linear equations, present and future volume

Key findings: The tree table's development used diameter classes and frequencies for all samples aided in growth estimates. The stand table projection determined tree diameter migration inside the stand during the next two years. The dead and felled trees were considerably zero, and an implicit estimation of mature trees relied on tree movement.

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INTRODUCTION

Urgent and sound management decisions are necessary for forest management personnel to achieve sustainable forest development through accurate data on current and future growth. In planted stands, *Populus nigra* L. is one of the utilized main trees. Around 50 species comprised the family of Salicaceae, which also includes willows. It produces hybrids, including *P. nigra*, with a natural distribution in the Northern hemisphere (Dickmann and Kuzovkina, 2014). Various biometric studies have transpired on *P. nigra* to assess the volume and yield of the tree and stand (Molto *et al*., 2014). *P. nigra* is one of the fastest-growing species, and its wood is also superior for utilization in various wood industries (Mohammed and Younis, 2005; Yadav *et al.,* 2022).

One of the priorities of sustainable management is knowing the factors that affect the growth of individual trees, which are different from those that affect growth per unit area. However, the tree acquires influences from the spatial space occupied by the neighboring trees. Forest management focuses on the progress of trees per unit area to make managerial decisions for estimating production and making policy decisions toward sustainable production (Zhang *et al*., 2017).

Growth estimation is one of the essential requirements for successful management; however, estimating current and future growth can be challenging. Forests constantly vary in their horizontal and vertical spatial distribution due to development occurring in the forest and the cutting and death of trees (Gonzalez-Benecke *et al*. 2012). Forestry demands technical and administrative competence and skills for a guaranteed balance between environmental needs and the goods and services provided to society. As a result, achieving these objectives through forest management is enormously intricate (Bullard *et al*., 2014).

The procedure for measuring the growth of a tree involves the construction of a standing table that includes the various measurements, i.e., tree height, frequency, and diameter. The methodology is applicable across several forest plots and inventories, enabling the estimation of both present and future predictions about tree growth. The utilization of this approach had initial exploration in various forest measurements (Toillon *et al*., 2013). These scientists used models based on information gathered from the tree's basal and cross-sectional areas. Calculating the growth and yield of the trees can use mathematical models to get data on all the tree attributes***.***

The Weibull distribution function application gathered data on the diameter expansion to estimate the basal area per unit (Pienaar and Harrison, 1988; Nepal and Somers, 1992). In the relevant investigation, the transfer rate of a strain of *Populus nigra* reached estimation in northern Iraq. In particular, the study examined the strain's migration over two years from one diameter class to another. In estimating such transfer rates, a mathematical formula designed expressly for that purpose was helpful to that measurement. The current study's goal sought to evaluate *Populus nigra*'s current and potential growth. Moreover, the assessment and estimation of volume increase for the wood product's various diameter classes ensued.

MATERIALS AND METHODS

In Northern Iraq, *Populus nigra* L. populations are prevalent, particularly along river banks. These areas include the Duhok Governorate, District Zakho, District Batavia, and Bank village occurring southeast of Zakho, and the anthropogenic populations in Northwestern Iraq, located at an altitude of 433.8 masl. The mountainous areas and narrow plains among the mountains with trees are called irrigated areas. The area of these trees has an estimated 25 hectares, with the valley fed by springs from the surrounding mountains. Determining the study samples utilized various methods, which mainly depended on purpose (Yang *et al*., 2017). The total number of samples was 35, randomly selected to cover the site, and an estimated area of 0.1 ha for each sample (Vanclay, 2010). The measurements sought to calculate the volume and estimate the number of trees by size classes in each study sample (Rykiel, 1996).

The data recording included the following parameters: The tree height (m) measured using the (Haga) device; The diameter at breast height (cm) measured by a diameter tape; Two trees cut from each sample of dominant and semi-dominant trees, taking a disc of the cut trees for the basal space at breast height by an automatic saw; Measuring the thickness of the annual rings of the disc of 70 trees for the last two consecutive years through polishing one side of the disc with an electric wood polisher, then adding water to the polished side to make the annual growth rings appear clear; Measuring the thickness of the last two rings used a digital vernier from several sides, with the average readings taken to represent the growth that occurred for two years and all study samples (Jacquin *et al.,* 2019).

Office work

Preparing the standing table for 35 samples commenced (Table 1). Preparing a mathematical model will compute the relationship between the diameter growth for the last two years (Dg_2) and the diameter at breast height. The fundamental hypothesis on which the stand table projection method depends is the trees in each diameter class have an even distribution over all the classes. All trees growing in the stand in each diameter class grow in the same proportion. The growth occurring during the past two years is equivalent to the expected growth for the future two years within the same growth period. Developing the local volume table of *P. nigra* trees grown in the Zakho region was according to the following equation (Al-Ali, 2009):

$$V=0.00007\times D^{2.8433}$$

For the selection of biometric equations, the researchers utilized various criteria mentioned (Sheng and Harold, 2019).

Variance (S^2):

$$s^2 = \frac{\sum(X-\underline{X})^2}{n-1}$$

Where:
s^2 : sample variance
Σ : sum of ….
X : each value
$\underline{X}$: sample mean
n : number of values in the sample

Coefficient of determination (R^2):

$$R^2 = \frac{\sum \quad (Yi^{\wedge} - \underline{y})^2}{\sum \quad (Yi - \underline{y})^2}$$

Where:
$\underline{y}$ = the arithmetic mean of the observations of the dependent variable
Y = the true value of the dependent variable $Y^{\wedge}$ = the estimated value (the dependent variable after substituting the x-values into the regression model equation)

Estimate standard error of the mean (S.E):

$$S.E_{\underline{x}} = \frac{s}{\sqrt{n}}$$

Where:
$\bar{x}$ = mean values of independent observations
Xi = the observed value
S = the mean of the measurement deviation for the study sample
n = number of observation

Residuals analysis:

$$e_i = y_i - y^{\wedge}{}_i$$

RESULTS AND DISCUSSION

The results revealed that the trees' density effect had a clear role in its growth, and the more space available for trees, the faster the

Table 1. A table of the *Populus nigra* L. samples, sample No. 6.

No.	Diameter class	Frequencies
1	4-5.9	2
2	6-7.9	5
3	8-9.9	10
4	10-11.9	12
5	12- 13.9	18
6	14-15.9	14
7	16-17.9	11
8	18-19.9	7
9	20-21.9	4
10	22-24	1

Table 2. Statistical measures for each of the diameter at breast height, the diameter growth for the last two years, and the total height of trees for the study samples.

Item	Max.	Min.	Average	Var.
D.B.H (cm)	28.0	4.0	14.8	12.49
Dg2 (mm)	22.1	3.2	11.9	11.78
H (m)	12.7	3.6	10.9	5.442
N (trees/ha)	1245	643	865	2248.496

D.B.H = diameter at breast height, Dg2 = diameter growth, H = total height, and N = number of trees/ha.

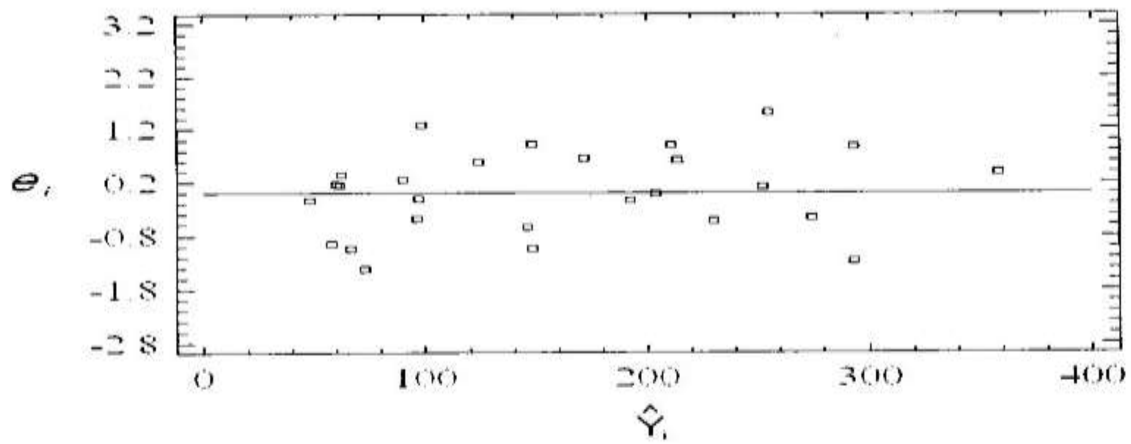

Figure 1. The relationship between (ei) and the independent variable does not take a specific form and the error is randomly distributed.

growth. This effect, then, reaches the point that there was variation in the growth function of trees of different densities (Amaro *et al*., 1998), which was visible in samples taken from *P. nigra* L. grown in the area of Zakho (Table 2).

The results also showed differences in tree variables, which appeared in the study sample 35 for DBH (diameter at breast height), diameter growth, total height, and number of trees per unit area (Table 2). It was due to the differences in densities that reflect the effects of these conditions on various tree characteristics, and differences in densities between sites were due to the environmental conditions at each site, soil quality, and organic matter content (Cao, 2006; Lin *et al*., 2013).

The data about the diameter growth that occurs in trees from one season to the next had a basis on field measurements that are easy to measure. The simplest was the chest-height diameter measurement. For this purpose, the statistical program Stratigraphic Centurion XV and various regression equations proceeded. All the regression equations with better statistical measures between growth in diameter as the dependent variable and diameter at breast height as the independent variable underwent analysis with the following equation (Figure 1):

$$Dg_2 = -2.57301 + 167.539 \times DBH^{-1.13106}$$

$$R^2 = 0.859, \text{ Standard Error of Est.} = 2.08247$$

Notably, the above formula gives the best values for the coefficient of determination and the measurement error due to the means. The value for the D-W test was 1.7483, and the scale also indicates no autocorrelation between the independent variables when the values were between 1.5 and 2.5. These findings concluded that this equation has a good relationship represented by an exponential relationship between the dependent and independent variables (Husch *et al*., 1982; Salih *et al*., 1989, 2021).

The residual analysis also ensured that the estimates of this equation were better and that the random errors were free of autocorrelation. Therefore, by knowing the diameter at the breast level, this equation can estimate the diameter growth of *P. nigra* L. The field data recorded for the various samples sustained conversion to a unit area per hectare, each of which had its diameter growth rate for two years, and prepared in each diameter class, the volume of the tree, and the classes to estimate its current volume (Table 3).

The gradual decrease in diameter growth with increasing diameter at the breast level (Table 3) was consistent with previously recorded findings (Tang *et al*., 1997; Dukenov *et al*., 2023). An explanation can also be that as the tree diameter increases, in addition to wood accumulation, the thickness of growth rings decreases due to the increase in tree circumference. As presented in Table 3, the growth in diameter was the highest possible value in the early stages of the trees' age; then, it soon declined with the trees' age. It was also evident that in the trees whose average diameter was 9 cm, the diameter growth was 1.14 cm; however when the diameter was 21 cm, the growth in diameter became 0.28 cm. Still, when the average diameter was 5 cm, the growth in diameter was 2.46 cm. From this, we can conclude the relationship between growth in diameter and average tree diameter was inverse.

The equation helped estimate the diameter growth for the future two years and a tree table for each sample, whether it was the sixth sample or not. The value of the midpoint of the diameter class had substitution in the previously created diameter growth equation. The estimated migration rate of trees from one diameter class to another was by dividing the diameter growth by the class length in the middle of the diameter class (Table 4).

In determining the percentage of transfer from one diameter class to another, divide the achieved diameter increase in that class by the length of the class (i.e., the diameter of the first class centered at 5, its rate of movement). Since (2.46/2) was equal to 1.23, different migration rate calculations for the remaining classes emerged, as shown in column 3 (Table 4). Calculating the number of future trees was done by adding the fields five, six, and seven. Following the names in the fields, column five represents the remaining trees that were not moved from one class to another during execution. The sixth column represents trees shifted by one diameter class, and the seventh column represents trees shifted by two diameter classes each. Their calculation was by multiplying the fractional part of the third column by the current number of trees to determine the number of trees to move corresponding to the integer plus the integer in the third field value, as seen in the eighth column of Table 4, showing the distribution of tree diameters after two years. Differences in tree diameter distribution within a stand were due to stand growth (Table 5).

By adding the current and future volumes and sizes of deadwood and felled trees and the established tree volume during the two estimated periods of migration of a

Table 3. Stand table, diameter growth, and volume classes/ha of the sixth sample.

No.	Mid-class diameter (cm)	Diameter growth (cm)	Number of trees	Vol. tree/m^3
1	5	2.46	20	0.0068
2	7	1.60	50	0.0177
3	9	1.14	100	0.036166
4	11	0.86	120	0.063987
5	13	0.66	180	0.10289
6	15	0.53	140	0.154553
7	17	0.42	110	0.220614
8	19	0.34	70	0.302676
9	21	0.28	40	0.402313
10	23	0.23	10	0.521073

Table 4. The relative movement of a stand from one diameter class to another during two years for the sixth sample in the future.

	1	2	3	4	5	6	7	8
No.	Mid-diameter class (cm)	Diameter Growth	Movement Ratio	Number of present trees	Number of movement trees			Number of future trees
					Class 2	Class 1	Class 0	
1	5	2.46	1.23	20	4.6	15.4	0	0
2	7	1.60	0.8	50	0	40	10	25.4
3	9	1.14	0.57	100	0	57	43	87.6
4	11	0.86	0.43	120	0	51.6	68.4	125.4
5	13	0.66	0.33	180	0	59.4	120.6	172.2
6	15	0.53	0.27	140	0	37.8	102.2	161.6
7	17	0.42	0.21	110	0	23.1	86.9	124.7
8	19	0.34	0.17	70	0	11.9	58.1	81.2
9	21	0.28	0.14	40	0	5.6	34.4	46.3
10	23	0.23	0.12	10	0	1.2	8. 8	14.4
11	24	-	-	-	0	-	-	1.2
Total	-	-	-	840	-	-	-	840

Table 5. Estimation of the expected volume growth for two years in the future for the sixth sample.

No.	Mid-diameter class (cm)	Vol. tree/m^3	Number of present trees	Number of future trees	Present stand vol. (m^3/ha)	Future stand vol. (m^3/ha)
1	5	0.0068	20	0	0.136	0
2	7	0.0177	50	25.4	0.885	0.44958
3	9	0.036166	100	87.6	3.6166	3.168142
4	11	0.063987	120	125.4	7.67844	8.02397
5	13	0.10289	180	172.2	18.5202	17.71766
6	15	0.154553	140	161.6	21.63742	24.97576
7	17	0.220614	110	124.7	24.26754	27.51057
8	19	0.302676	70	81.2	21.18732	24.57729
9	21	0.402313	40	46.3	16.09252	18.62709
10	23	0.521073	10	14.4	5.21073	7.503451
11	25	0.660482	0	1.2	0	0.792578
Total	-	-	840	840	119.2318	133.3461

single tree, the biennial forecast can be estimated for the periodic growth (Table 5). Convert the diameter class to another class with its volume implicitly calculated here. The amount of dead and felled trees was considerably minimal. Therefore, the total tree volume was negligible, especially in intensively managed plantations. The expected periodic growth estimation can result from the difference between current and future volumes:

$$\text{Expected period growth} = \text{future volume} - \text{current volume},$$

$$\text{Expected periodic growth} = (133.3461 - 119.2318) = 14.1143\ \text{m}^3/\text{ha},$$

$$\text{Periodic growth rate} = (14.1143/2) = 7.05715\ \text{m}^3\ /\ \text{hectare/year}.$$

This method relies primarily on the differences in diameter distribution resulting from tree diameter growth at mean height and, thus, smooth transitions between current and future periods. This hypothesis holds when the estimation period is short and when growth assessments occur at the same stage of the volume-age relationship and have an erroneous influence on other things. The accuracy of this method also depends on the stability over time of the relationship between the diameter at breast height and the total height.

CONCLUSIONS

The future growth of trees incurred estimation over two years using the tree diameter growth equation and stand table, and the migration rate from one diameter class to another succeeded estimation for each sample. By determining the current and future number of trees, we can approximate the current and future volume per unit area and growth rate.

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